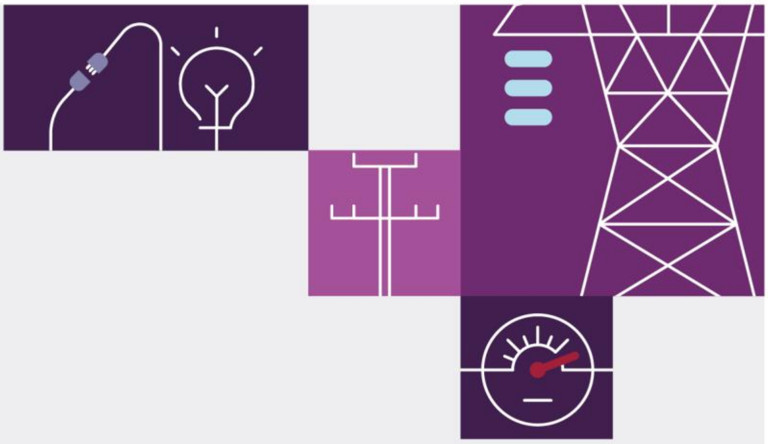
Power System Frequency Risk Review – Appendices

July 2022

Final Report

A report for the National Electricity Market



Important notice

Please refer to the notice at the front of the 2022 Power System Frequency Risk Review Final Report, which is published under clause 5.20A.3 of version 176 of the National Electricity Rules. The Appendices in this document form part of that Final Report and are subject to the same disclaimer.

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Version control

Version	Release date	Changes
1.0	26/07/2022	Publication of Final Report

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A1. Status of actions arising from recent major events

Table 1 presents a summary of the status of recommendations arising from major reviewable power system incidents. This table covers recommendations from major incidents that occurred from 2018-19 onwards.

Table 1 Status of actions arising from major reviewable incidents

Incident	Recommendation	Status	Details
25 August 2018 – Queensland and South Australia system separation	Primary frequency control in the NEM a) AEMO to work with the AEMC, AER and NEM participants to establish appropriate interim arrangements, through rule changes as required, to increase primary frequency control (PFC[1]) responses at both existing and new (synchronous and non-synchronous) generator connection points where feasible, by Q3 2019. b) AEMO to support work on a permanent mechanism to secure adequate PFC as contemplated in the AEMC's Frequency Control Framework Review, with the aim of identifying any required rule changes to be submitted to the AEMC by the end of Q3 2019 with a detailed solution and implementation process completed by mid-2020.	Open	a) AEMO submitted a rule change proposal for mandatory PFR in August 2019. b) Following the rule change, AEMO issued an Interim Primary Frequency Response document (IPFRR) in June 2020, including implementation processes[2].
	Automating secondary frequency control implementation after separation events AEMO to investigate the opportunity for automation of reconfiguring AEMO's systems, including AGC and NEMDE, after separation and large system events. AEMO to report on options to industry in Q2 2019.	Closed	AEMO decided not to proceed with this initiative after initial investigation.
	Circumstances for regional FCAS or frequency control AEMO to investigate whether a minimum regional FCAS requirement is feasible, or whether there is scope to manage frequency requirements arising from non-credible regional separation under the protected events framework in the NER after interim PFC outcomes at the end of Q3 2019.	Open	FCAS is only procured to cover credible events. Since the commencement of PFR implementation in 2020, a material improvement in frequency performance on the power system has been observed, lessening the impact of non-credible events. Following implementation of very fast FCAS[3], AEMO will consider regional FCAS requirements.
	Frequency response capability models	Open	AEMO continues to work with generators in monitoring their compliance obligations. AEMO plans greater collaboration with NSPs to ensure accuracy of generator models.

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[1] Now referred to as PFR, or primary frequency response.

[2] The latest update on PFR implementation can be found at https://aemo.com.au/en/initiatives/major-programs/primary-frequency-response.

[3] As required by the National Electricity Amendment (Fast frequency response market ancillary service) Rule 2021 No. 8, at https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service.

Incident	Recommendation	Status	Details
	Commencing in Q1 2019, AEMO to work with participants to obtain information required to fully and accurately model generator frequency response and all other active power controls.		As part of this collaboration AEMO wrote to all Generators with PFR-enabled synchronous generating units in September 2021, asking them to confirm that their OPDMS PSS®E models are up to date and reflects each generating unit's response to frequency events, or otherwise provide updates to the relevant NSP and AEMO.
	DPV inverter performance standards and analysis DPV – AEMO to work with industry and Standards Australia to: a) immediately assess technical requirements of inverters (AS 4777) and complete by Q2 2019 b) work with stakeholders to implement improved performance standards for inverters by end of 2019 c) establish solutions for obtaining data on the performance of distributed rooftop PV systems, and to develop the necessary simulation models and analysis tools to predict their response to system disturbances progressively up to the end of 2020.	Closed	AEMO has completed its assessment of AS/NZS4777. Improved inverter performance standards (AS/NZS4777.2:2020) have been implemented. AEMO is engaging with relevant industry bodies and regulators to improve compliance with the new standard.
	Protection and control schemes a) AEMO to immediately commence a review of the EAPT scheme to identify improvements by 1 July 2019. b) AEMO to also review other existing AC interconnector schemes with TNSPs to determine whether their performance remains fit for purpose in the NEM's changing environment and are properly co-ordinated, by Q1 2020.	Closed	Please see update on EAPT scheme review in Table 2. ElectraNet has reviewed the SIPS scheme and the WAPS scheme will be implemented to improve overall performance.
	Emergency frequency control schemes AEMO to continue implementation and investigate any further functional requirements of EFCS for each region, commencing with SA and QLD prior Q1 2020	Open	SA OFGS - AEMO has reviewed and suggested improvements to better manage the over-frequency risks. As a first step AEMO will be working with ElectraNet to implement the improvements. More details can be found in section 6.1 of the 2022 PSFRR report. QLD OFGS - This PSFRR considered the issue of over-frequency in QLD and recommends that AEMO and Powerlink collaborate to implement an OFGS for QLD to manage over-frequency during separation. Please see the executive summary and section 8.2 of the 2022 PSFRR report for more details.
16 November 2019 – South Australia and Victoria separation	Root cause of failure of comms multiplexer AusNet Services to confirm root cause of communications multiplexer failure at APD.	Closed	Following the incident, the two multiplexers were replaced as investigations could not conclusively identify which was faulty. Testing on the removed multiplexers was undertaken to diagnose the root cause of the failure. The first multiplexer powered up and performed as expected during testing. The other multiplexer could not be powered up for diagnostic testing and it remains unclear why it would not power up. Hence, the root cause of the multiplexer failure cannot be identified.
	Risk mitigation measures associated with comms multiplexer failure	Closed	AusNet have risk-assessed a number of 220 kV lines in their network and have updated the protection system associated with these lines (where

Incident	Recommendation	Status	Details
	AusNet Services to review the mitigation measures for NEM security pending determination of root cause of multiplexer failure.		required) to reduce the risk of multiplexer failure causing protection mal operations.
	Compliance of DPV systems AEMO to work on auditing and establishment of methods for monitoring and improving compliance of DPV systems	Open	Preliminary data indicates compliance rates could be as low as 10-20%. This requires a considerable and urgent work program to improve compliance rates. AEMO is currently launching this work program.
4 January 2020 – New South Wales and Victoria Separation Event	Transgrid review of procedures AEMO recommends Transgrid review its policies for splitting the Wagga–Yass 132 kV network under certain operational configurations.	Closed	Transgrid has updated its relevant Operating Manual to address this recommendation.
	Modify constraint formulation The power system was not in a secure operating state for up to 45 minutes after the islanding event due to a shortage of FCAS in the NSW/QLD island. AEMO will modify the constraint formulation to reduce the probability of reoccurrence	Closed	In May 2021 AEMO modified the relevant constraint sets to co-optimise the largest generators in NSW with the FCAS requirements. This co-optimisation was already in place for QLD and SA.
	Review unexpected frequency deviation There was an unexpected frequency deviation within the NOFB in the VIC/SA area shortly after the multiple contingency event. AEMO will conduct further analysis to determine the reason for this.	Closed	AEMO provided analysis of the event in the incident report[4] and is not undertaking further investigation.
	Review of PASA tools PASA did not correctly determine reserve levels in NSW after islanding due to the effective change in region boundaries.	Open	AEMO is currently reviewing its PASA tools with changes expected to be implemented by mid-2022.
	Review of AS/NZS4777.2.2015 DPV generation was observed to decrease output in NSW, VIC and SA in response to the fault that resulted in the separation of NSW and VIC. Approximately half of this response was related to disconnection of DPV. AEMO is working with stakeholders on a review of AS/NZS4777.2:2015 to implement requirements for improved disturbance ride-through capabilities and is investigating accelerated deployment of voltage ride-through testing in South Australia.	Complete	The AS/NZS4777.2 review is complete, and the revised Standard published on 18 December 2020. There was a one-year transition period for the Standard to be implemented.
	Identify sources on non-compliance in DPV systems 40-50% of DPV systems demonstrated behaviours that were not consistent with the relevant standards (AS/NZS4777.2:2015). This represents a growing power system security risk as more DPV continues to be installed. AEMO is working with stakeholders to identify and address sources of non-compliance	Open	Preliminary data indicates compliance rates could be as low as 10-20%. This requires a considerable and urgent work program to improve compliance rates. AEMO has engaged with industry bodies and regulators to achieve the necessary improvements.

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[4] At https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-nsw-and-victoria-separation-event-4-jan-2020.pdf?la=en.

Incident	Recommendation	Status	Details
	Visibility of DPV systems Visibility of DER is becoming increasingly important for assessment and management of power system security. AEMO (in collaboration with the Australian Renewable Energy Agency [ARENA], University of New South Wales [UNSW], Solar Analytics, WattWatchers, ElectraNet, TasNetworks and other stakeholders) is continuing work to improve data sources, analysis tools, and power system models to investigate and represent distributed energy resources accurately.	Open	AEMO has established Project MATCH (http://www.ceem.unsw.edu.au/project-match) with UNSW and ARENA funding to improve visibility of DPV system behaviour during disturbances. Work is in progress, with a present focus on data to assess compliance with standards.
31 January 2020 – Victoria and South Australia Separation Event	Risk assessment for extreme weather impacts Seven transmission towers either collapsed or were severely damaged in very high wind conditions, associated with a severe convective downdraft resulting from thunderstorm activity in the area. AusNet Services will conduct a risk assessment into the potential for similar extreme weather to impact its assets. AEMO will liaise with AusNet Services on any outcomes from this assessment.	Closed	AusNet Services has completed its risk analysis of towers in critical circuits (as identified by AEMO) within its network and has completed/approved projects to strengthen towers based on safety priority (focussing on towers where failures would impact road user safety, for example). AusNet shared details of its tower failure risk assessment with AEMO. AusNet control room will advise AEMO if it becomes aware of extreme weather risks.
	Alcoa Portland Pty Ltd (APD) review options to limit impacts of voltage disturbances The trip of the APD potlines was in response to the voltage disturbance caused by line faults. This is a known issue. APD has advised AEMO that it is reviewing options to minimise the impact to the plant during similar events, but has not determined a timeframe for this work.	Open	Last update received from APD on 10 August 2021, advising that the review of the tripping of the potlines is not expected to start until Q4 2022.
	Pre-contingent regional FCAS The frequency in VIC, NSW and QLD fell to a minimum of 49.66 Hz. The FOS in respect to containment and stabilisation was met but not in relation to recovery time. AEMO will continue to review frequency response in relation to future separation events and, if warranted, consider further options to facilitate pre-contingent FCAS enablement on a regional basis in appropriate conditions.	Closed	In addition to reviewing frequency performance as part of its review of reviewable incidents, AEMO issues quarterly reports on the frequency and time error performance, and will provide input to the next FOS review by the Reliability Panel. AEMO will continue to review frequency response in relation to future separation events and, if warranted, consider further options to facilitate pre-contingent FCAS enablement on a regional basis in appropriate conditions.
	Fast frequency response from transmission connected solar farms BESS and transmission-connected SFs responded as designed to the high frequency in SA. AEMO recommends that the potential for a fast response by transmission-connected SFs to frequency changes be investigated. This has the potential to reduce reliance on the inertial response from the steadily reducing amount of traditional thermal generation online in SA.	Closed	Investigation into the VIC-SA separation incident has demonstrated that Tailem Bend SF can provide some form of FFR. AEMO is continuing to engage with SF operators on their ability to provide FFR.

Incident	Recommendation	Status	Details
	Fault ride-through capability of distribution connected solar PV Larger DPV systems were observed to disconnect at a higher rate than smaller systems, particularly in north-west VIC. This could be related to protection systems required by DNSPs for larger PV systems. AEMO is collaborating with Powercor to explore possible explanations and mitigation mechanisms and is engaging with DNSPs across the NEM to align central protection requirements with the necessary disturbance ride-through capabilities.	Closed	Ride through has been made a requirement for inverters - this was published in AS/NZS4777.2 in December 2020 and required on all new inverters from 18 December 2021.
	Manufacturer issue with DPV systems DPV associated with one manufacturer has been identified as more likely to demonstrate behaviour not in accordance with the 2015 AS/NZS4777.2. AEMO is engaging with the relevant manufacturer to identify causes of this behaviour and explore mitigation mechanisms.	Closed	AEMO has worked with the manufacturer, who issued a firmware update correcting the undesired behaviour. This was rolled out in batches across regions throughout Q1 of 2021.
24 January 2021 – Total Loss of NEM SCADA Data	AEMO to implement real-time monitoring and alerting of the SCADA heartbeat delays. This will allow for proactive remediation of issues prior to broader system degradation. Targeted for implementation Q4 2021.	Closed	AEMO implemented real-time monitoring and alerting of the SCADA heartbeat delays during October 2021.
	AEMO to review and update its internal major incident management and escalation processes AEMO to review and update its internal major incident management and escalation processes and procedures and ensure they are used expediently during an incident. This review in in progress and is due to be completed by 31 October 2021.	Closed	AEMO completed the review of its internal major incident management and escalation processes during November 2021.
	Review communication processes for IT issues to market AEMO plans to review whether broader communication to the market relating to IT incidents could be issued in a timelier manner.	Closed	AEMO completed the review of its communications process for IT incidents during November 2021. Following recent SCADA outages in SA on 18/02/2022 and TAS on 01/03/2022, additional recommendations were made to improve market communications.
	AEMO to Work with GE to review best practice for SCADA availability AEMO to work with support vendor GE to review the best practice for maintaining high availability in the SCADA system. Review targeted for completion Q4 2021.	Implemented	AEMO reviewed best practice for maintain high availability SCADA with GE during October 2021.
12 March 2021 – Trip of Torrens Island A and B West 275 kV busbars	Identify root cause of Torrens CT failure ElectraNet is working with the CT manufacturer to identify the underlying cause of the failure. Once identified, ElectraNet should share this information with AEMO and undertake any additional remedial actions.	Open	ElectraNet’s investigation into the root cause of the CT failure is ongoing.
	AEMO to discuss key information about this incident with the Power System Security Working Group.	Closed	AEMO discussed this event at the Power System Security Working Group on 6 August 2021. The following points were considered by the TNSP operational representatives:

Incident	Recommendation	Status	Details
			- The requirement to advise AEMO before making protection changes. - The requirement to collaborate with AEMO on the impact that protection changes have on power system security. - The requirement to maintain protection knowledge across control rooms. No further action recommended.
14 March 2021 – Maintaining operational demand in South Australia	AEMO recommends the SA government consider an update to the Smarter Home framework to require separation of new DPV connections at the meter to enable aggregate near real-time visibility of DPV at statistically valid samples. AEMO also recommends other governments consider how DPV curtailment will be managed in their states during low operational demand conditions.	Closed	AEMO has shared the incident report with each participating jurisdiction for their consideration.
25 May 2021 – Trip of multiple generators and lines in Central Queensland and associated under-frequency load shedding	Power station operators to consider learnings from this incident Including implications for protection designs, operating procedures and communication protocols. AEMO to send letters advising power stations of the report and recommendations.	Closed	AEMO has shared the report and its findings with synchronous generators operating in the NEM and WEM for their consideration when reviewing their operating and maintenance procedures.
	AEMO to discuss with Generators the need to: - Provide advice to AEMO when protection schemes and associated direct current (DC) supplies are temporarily not fully duplicated due to maintenance outages or equipment failure, and - Establish agreed protocols for managing such risks similar to those already in place with TNSPs.	Open	AEMO has shared the findings of the final incident report with generators in the NEM and WEM, asking them to review the recommendations and how this incident might impact their own operations. The Power System Security Working Group has initiated a review of generator reclassification requirements. The outcome of this review will address this recommendation. This review is planned for completion in Q4 2022.
	AEMO, TNSPs and Generators to review the emergency communications protocols This review will include: - A clear procedure to support the identification of potential motoring of generators and appropriate responses. - Roles, responsibilities and communication channels to be used in emergency circumstances. - A process to assess apparent discrepancies between SCADA and site observations and to agree on action to be taken. This will include any necessary training programmes for operating staff.	Open	This is being progressed as part of the generator reclassification requirements review. This work is planned for completion by Q4 2022.
	AEMO to review Stanwell TTHL settings During review of this event, AEMO identified Trip to House Load (TTHL) settings implemented at Stanwell Power Station that impacted its ability to remain connected to the power system following voltage disturbances. The under-voltage trigger was removed in September 2021 to reduce the likelihood of Stanwell Power Station	Open	AEMO is targeting completion of this review in Q1 2023.

Incident	Recommendation	Status	Details
	disconnecting following network disturbances. AEMO will review with Stanwell whether to re-establish this trigger with revised settings.		
	AEMO to assess the impact on power system resilience of generator protection settings that led to loss of generation.	Open	AEMO is targeting completion of this review in Q4 2022.
	<u>Investigate and confirm Townsville GT behaviour</u> AEMO has requested further information on why Townsville Gas Turbine (GT) controller switched from 'load control' to speed control'. AGL's investigation into this behaviour is expected to conclude by the end of October 2021.	Closed	AGL has modified the Townsville GT plant to improve plant behaviour.
	<u>Confirm whether Yarwun performance was in line with expectations</u> AEMO is investigating whether the tripping of the Yarwun CCGT cogeneration unit was consistent with expected performance in response to conditions at its connection point.	Open	AEMO's Investigation is ongoing.
	AEMO to seek and review further information to identify the causes more conclusively for loss of load for reasons other than UFLS, to assess what risks this might pose in other circumstances.	Closed	AEMO will continue to improve its understanding of load behaviour during faults through: • Development of PSS®E and PSCAD load models; and • Collaboration with NSPs to improve load models.
	<u>AEMO to raise review of voltage control settings with TNSPs</u> Based on observations following this event associated with unusual operating conditions, AEMO recommends that TNSPs review appropriateness of current settings for voltage control schemes under low system strength conditions.	Open	At the May 2022 Power System Security Working Group AEMO requested that TNSPs review the appropriateness of wide area voltage control scheme settings.
	AEMO will Identify any practical changes to improve the accuracy of reserve forecasts following this type of event, including improved visibility, and forecasting of the response of controlled loads.	Open	AEMO is exploring a number of initiatives which it hopes will improve: • Visibility of embedded generators and virtual power plants. • The flow of relevant data from DNSPs to AEMO and TNSPs. • Visibility of controlled and price sensitive loads.
	CS Energy's independent investigation into the root cause of this incident is ongoing. Once CS Energy's independent investigation is concluded, the findings will be shared with AEMO. AEMO and CS Energy may identify additional recommendations based on the outcome of this independent investigation.	Open	CS Energy has confirmed that the investigation into the root cause of this incident is ongoing.

A2. Status of previous PSFRR recommendations

Table 2 contains the status of previous PSFRR recommendations and a brief update on actions taken to progress each recommendation.

Table 2 Summary of previous PSFRR recommendation status

Recommendation	Status	Update
The performance of the IECS should be reviewed by AEMO (in its role as Victorian transmission planner), including assessment of any necessary modifications. This review should be focused on the low probability operating conditions under which IECS operation might not be sufficient to prevent separation between VIC and NSW following non-credible contingency events. In these cases, the interaction and coordination between IECS and UFLS is critically important.	Closed	AEMO has recently reviewed the IECS[5] and recommended that more load blocks be included into the selected load groups to be tripped by IECS. This is done to offset the impact of increased rooftop PV and distributed generation by ensuring sufficient load is available to be tripped by the IECS. AEMO also found: • There is no adverse interaction between IECS and UFLS. • It is acceptable that IECS operation might be insufficient to prevent VIC and NSW separation during low probability operating conditions. This is aligned with the purpose of the IECS which is to reduce the risk of separation. • There is no plan to develop a new control scheme to manage non-credible contingency events as such a need has not been identified. AEMO will continuously assess the need for new control schemes and explore available options to minimise impact of contingencies on the Victorian transmission network performance.
Emergency Alcoa Portland Tripping (EAPT) tripping scheme review	Ongoing	AEMO recently completed several reviews of EAPT in response to a mal-operation in 2018[6] and also as part of an impact assessment of recent network changes. As a result, setting changes have been implemented to minimise the risk of future mal-operation, and recommendations made to further modify the scheme to improve its reliability. Other findings include: • It is inappropriate to modify the EAPT to address a frequency performance issue introduced by high generation along the HYTS to MLTS lines. AEMO's preferred solution to address this generation-driven issue is to trip or runback generation, not to trip APD load. It should be noted that all existing generation connected along the line, with the exception of Macarthur WF, would be tripped if separation from MLTS occurs, which could be sufficient in addressing any issue driven by renewable generation connected to South-West VIC; • The reliability of the EAPT scheme could be greatly improved by changing its contingency detection from a performance-based approach to a topology-based approach. This is in line with the Final Report – Queensland and South Australia System Separation on 25 August 2018[7] and the 2020 PSFRR recommendation to avoid mal-operation due to unexpected interaction with IECS; • With the use of the topology-based contingency detection, the response time of the scheme will be minimised, which will address the high RoCoF issue identified in the PSFRR, and also improve coordination between EAPT and UFLS as recommended by the 2020 PSFRR. • If necessary, AEMO will investigate, jointly with ElectraNet, possible new control schemes to address any high generation-driven issues. • AEMO will continue to monitor the latest changes in the area and will assess the need to further modify the EAPT accordingly.

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[5] See https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/vapr/2021/2021-victorian-annual-planning-report.pdf?la=en section 4.7 (IECS) for more details

[6] See 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?la=en&hash=49B5296CF683E6748DD8D05E012E901C

[7] See 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?la=en&hash=49B5296CF683E6748DD8D05E012E901C

Recommendation	Status	Update
ElectraNet in collaboration with AEMO to enhance the reliability of the SIPS by implementing a WAPS	Detailed design and site construction works are ongoing. WAPS is planned for completion in Q1 2023.	Stage 1 and Stage 2 of SIPS (the battery response and load shedding stages) will be replaced by a WAPS, which will dynamically calibrate load shedding and battery response to increase the effectiveness of the scheme at preventing Heywood separation following a trip of SA generation, while minimising the amount of load shed. Stage 3 of SIPS (loss of synchronism protection of the Heywood interconnector) will remain in place.
Protected event recommended for the non-credible synchronous separation of SA from the rest of the NEM be considered a protected event	In progress	AEMO is progressing the work required and is targeting a submission around Q3 of 2022.
Powerlink and Energy Queensland to review UFLS and implement measures to mitigate the impacts of DPV.	In progress	AEMO has provided advice to NSPs in QLD, VIC and NSW that UFLS load levels are now far below levels anticipated in the NER, and NSPs should immediately seek to identify and implement measures to restore it to as close as possible to the level of 60% of underlying load at all times. AEMO is actively working with NSPs in both QLD and VIC on the design of remediation measures. Actions in progress include: • Investigating the potential to add more load to UFLS, or remove circuits from UFLS that are frequently exporting active power to the transmission system. • Investigating dynamic UFLS arming (i.e blocking UFLS relay operation when a circuit is in reverse flows). • Exploring alternative UFLS configurations (for example, moving UFLS relays to lower voltage levels). • Exploring options for real-time monitoring of UFLS availability.
AEMO and ElectraNet to confirm if the Heywood Interconnector instability identified for SA separation at Moorabool can be improved by the SIPS-WAPS schemes.	Closed	AEMO has confirmed that the WAPS scheme does not respond to this event. AEMO has investigated whether modifications to the EAPT could improve the ability to manage SA separation events in the VIC 500 kV network. The analysis indicated this would have limited benefit.
Various recommendations to address the identified SA UFLS issues	In progress	Several initiatives are underway to address these issues: • SAPN and ElectraNet have now added additional load to UFLS. • SAPN is seeking approval to implement dynamic arming of UFLS relays (blocking relay operation when circuit is in reverse flows). • AEMO has provided recommendations to SAPN about adaptive arming (updating relay frequency settings in real-time depending on power system conditions), indicating this provides some benefit to minimise binding of Heywood constraints, although implementation may only be justified if costs are low. • AEMO is providing recommendations to SAPN about increasing the amount of load on delayed UFLS blocks to better assist frequency recovery. • SAPN is pursuing a tender process to procure Emergency Under Frequency response (EUFR) as a complement to traditional UFLS.
Review of SA minimum inertia level to manage RoCoF - post commissioning of synchronous condenser and new generating unit commitments	Closed	In December 2021 AEMO published its System Security Reports, which include the latest System Strength, Inertia and NSCAS requirements for SA. AEMO will review and update the inertia requirements and assessments as required.
AEMO, in consultation with ElectraNet, will review the effectiveness of the OFGS and modify it if required, to include additional generation in the scheme.	In progress	Review of SA's OFGS is in progress. AEMO is planning to complete its review by Q4 2022.
AEMO periodically conducts a review of UFLS and OFGS schemes. The current NEM mainland UFLS review will be completed by mid-2021. The adequacy of the UFLS and OFGS settings based on this review will be considered in the next PSFRR.	Closed	AEMO has recently completed a review of the mainland NEM UFLS scheme as configured during the period 1 January 2018 to 30 June 2020. The review assessed the ability of the UFLS scheme to prevent frequency dropping below 47 hertz (Hz) following an event during historical periods. The review included assessment of the NEM intact scenario and chosen separation scenarios, representing actual historical events and a selection of other non-credible events.

Recommendation	Status	Update
		For the historic NEM intact scenarios, there was sufficient UFLS at all times between 1 January 2018 and 30 June 2020 to cater for the following assessed non-credible contingency events: • AC separation of QLD and NSW followed by SA separation from VIC • AC separation of QLD and NSW followed by loss of Kogan Creek • Loss of Heywood interconnector and APD load in VIC • NEM split into two islands (VIC-SA and QLD-NSW) • SA-VIC separation at MLTS For the historic South Australian separation scenarios, there was sufficient UFLS performance for most scenarios. For historic Queensland separation scenarios, there was sufficient UFLS for most scenarios. For historic Victoria and New South Wales, there was sufficient UFLS for all assessed separation scenarios. Tasmanian UFLS adequacy was not studied by AEMO (TasNetworks has recently completed a review of UFLS adequacy within their network). **Forward UFLS projections** Forward projections considered during AEMO's review of historic UFLS adequacy indicated that all regions would be trending towards very low levels of UFLS availability, decreasing overall UFLS effectiveness. The 2022 PSFRR and other AEMO studies completed with recent UFLS and DPV availability data have identified a number of specific recommendations in this area, more details can be found in the executive summary of the 2022 PSFRR report. **OFGS review** AEMO is currently reviewing the SA / Western VIC OFGS scheme as noted above. Preliminary findings of AEMO's review of OFGS schemes indicate that changes might be needed to ensure these schemes remain adequate in the near future. AEMO is planning to complete its assessment in Q4 2022.
AEMO's studies indicate that managing the CQ-SQ flow and the amount of generation tripped under the SPS are the key variables for successful management of the non-credible loss of the Calvale – Halys double-circuit transmission line. Revisions to the SPS are required and underway. This confirms the urgent need for work being progressed by Powerlink in consultation with AEMO, to develop an enhanced CQ-SQ SPS.	In progress	WAMPAC stage 1 is now in service, and this increases power system security compared with the original SPS. Although, there might still be some cases where the scheme does not provide coverage compared to the current maximum N-1 secure power transfer limit of 2100MW, Powerlink has assessed that, due to prevailing market conditions and generation availability, the likelihood of CQ-SQ power transfers exceeding the reliable level afforded by WAMPAC stage 1 is very low. As such, Powerlink is prioritising other applications of WAMPAC that will provide positive benefits to customers as Powerlink rolls out a large program of reinvestment and maintenance activities in Central and North QLD.
It is possible that system strength between HYTS and MLTS is reduced after separation to lower levels which may are not adequate for WFs in the region to operate satisfactorily. This was not assessed in detail in the 2020 PSFRR report but is recommended for further analysis using EMT modelling tools.	Closed	AEMO has confirmed that there are suitable operational procedures in place to manage wind farms in the region after separation events. Further analysis using EMT modelling tool is therefore not required.
With reference to the existing protected event specified as the loss of multiple transmission elements causing generation disconnection in SA when destructive wind conditions are forecast by the Bureau of Meteorology, AEMO will review the continuation of the protected event, with consideration to the commitment status and timing of PEC.	Complete	Review included in this report including associated subsequent actions.

Recommendation	Status	Update
The success of the PSFRR depends on the quality of models and data used for the risk assessments. In order to deliver the 2020 PSFRR, several inadequacies in the power system models were identified and addressed.	Ongoing improvement process	AEMO has taken the following steps to improve data and model quality: • Contacted all Generators with PFR-enabled generation to check that AEMO has current and accurate model information. • Early engagement with TNSPs to ensure that SPSs are modelled accurately. • Improvement initiatives around data quality for OPDMS. • AEMO is continually working with NSPs to update data and modelling of DPV and UFLS in respective regions.
Recommendations to review and streamline the protected events process.	On hold	The AEMC considered this issue was not within the scope of other rule change processes (Implementing a GPSRR and Enhancing operational resilience in relation to indistinct events). Given ongoing significant regulatory reform workloads, AEMO is not currently proceeding with this recommendation.
Recommendations on managing the risks associated with the non-credible loss of QNI	Update included this report	AEMO has studied this contingency event. Based on the study findings to manage QLD over-frequency, an OFGS scheme has been recommended for QLD in this report.
The adequacy of the UFLS and OFGS settings based on AEMO's periodic review of these schemes will be included in the 2022 PSFRR report	Complete	An update on the adequacy of these schemes is included in the 2022 PSFRR report.

A3. Study approach

The PSS®E simulation program was used to carry out all contingency studies completed as part of the 2022 PSFRR. The full NEM model (as described in OPDMS) and simplified NEM models were used to study the network and its dynamic behaviour. This section covers the models and assumptions used for the study in more detail.

A3.1 Methodology – historic cases

Suitable historic PSS®E cases were selected from the OPDMS database for the period 2019 to 2021. Depending on the non-credible contingency considered, the historic operating conditions that would have a severe impact on the contingency were identified and selected. Some of the key parameters that AEMO considered when identifying suitable historic operating conditions to use for the studies include:

- Regional demand.
- Regional inertia.
- Flows on the impacted interconnectors and impacted lines.
- Generation mix (synchronous, wind and solar).
- DPV/DER generation.
- Availability of UFLS loads and OFGS generation.

Appropriate time stamps were selected based on the above parameters for the historic studies.

A3.2 Methodology – future cases

This PSFRR considered ISP 2027 *Step Change* scenarios for future studies. The following 2027 *Step Change* forecast data was considered by AEMO when setting up the future study cases:

- Maximum and minimum regional demands.
- Maximum and minimum IBR generation.
- Projected DPV generation.
- Projected UFLS availability.
- Decommissioning of synchronous generators.

The future scenario studies were undertaken using the following NEM network models:

- Full OPDMS NEM network model augmented with relevant network upgrades for studied contingencies[8].
- Simplified NEM network model considers QNI upgrades without PEC.

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[8] For studies of CQ-SQ contingencies, QNI upgrades were added to OPDMS models. For Victorian and South Australian contingencies, PEC, QNI, VNI and Western Renewables Link were added to OPDMS models.

The future studies using the full OPDMS NEM model also considered the following new interconnector projects/upgrades:

- PEC interconnector.
- QNI upgrade.
- VNI Upgrade.
- Western Renewables Link.

Assumptions and limitations of simplified NEM model

For the simplified NEM model, the following network configuration and modelling approaches were used:

- Each mainland region was represented by a common high voltage bus (New South Wales, Victoria and Queensland 330 kV and South Australia 275 kV buses). All the regional generators were assumed to be connected to these regional common buses through appropriate generator transformers.
- Regional generators were lumped as steam, gas, hydro, wind and solar with appropriate generic models such as alternator, voltage controller, governors and IBR controllers included to the lumped generators according to each generator type.
- UFLS and underlying DPV were grouped according to their frequency trip bands and connected at 33 kV distribution level buses. The number of regional trip bands modelled were:
  - New South Wales – 121.
  - Victoria – 32.
  - Queensland – 33.
  - South Australia – 30.
- The grouped UFLS and DPV feeders were also connected to common high voltage buses through appropriate transformers.
- Interconnectors were modelled as per OPDMS network with compensating devices, such as reactors, capacitors and static VAR compensators (SVCs).
- The high voltage (HV) network between South East Switching Station (SESS) and MLTS was modelled as per OPDMS network.
- South Australia generators and generators connected between HYTS and MLTS were modelled as per OPDMS including their dynamic models.
- APD network loads were modelled as per the OPDMS.
- The South Australian OFGS generators were modelled as per OPDMS generator models for the respective plants along with their OFGS trip settings.

Even though the simplified network can capture frequency variations with reasonable accuracy, it is impacted by the following limitations:

- The model excludes actual network impedances, therefore, it will not accurately predict power system voltages.

- The model cannot accurately reflect the fault ride-through characteristics of IBR plant.
- The power swings on interconnectors and their angular stability predictions will be less conservative when compared with the full NEM OPDMS model.
- The model cannot correctly predict the voltage-based tripping behaviour of DPV.

A3.3 Dynamic modelling

Governor models

AEMO has developed generic governor models that represent typical steam, gas and hydro turbine frequency responses. These models were used in the PSFRR studies for the following generating units:

- Where the generator supplied governor models with PFR settings are not available in the OPDMS model.
- Where AEMO does not have a governor model in the OPDMS model.

Generic IBR models

There are several legacy IBR plant in OPDMS without dynamic models and other IBR plant represented as negative loads. All these IBR were represented using PSS®E generic IBR library models with minimum PFR settings applied.

PFR settings

The following assumptions are made for full OPDMS study cases to account for recent PFR changes applied to generating units:

- For synchronous generating units where the generator provided PFR governor models, these models were included. Otherwise, generic governor models with applied PFR settings were used.
- For IBR plant, the controller models included in OPDMS were used. For those that are represented as negative loads in OPDMS, generic controller models were used with minimum PFR settings.

The following assumptions were made for simplified NEM model study cases to account for recent PFR changes applied to generating units:

- The generic governor and controller models were used for the lumped synchronous and IBR plant with minimum PFR settings. The generator’s maximum FCAS raise is limited to +5 % of Pmax and lower limited to -10 % of Pmax.

SPS models

The SPSs that are in operation on interconnectors and key transmission lines were included. The list of SPSs considered in the study are included in Table 3.

Table 3 List of SPSs used in the studies

Model	Region	Implementation	Remarks
EAPT	VIC	Fortran	Historic studies: Assumes performance-based operation Future studies: Assumes topology-based operation
IECS	VIC	Python	Historic studies: For Dederang – South Morang contingency
SIPS	SA	Fortran	Historic studies
WAMPAC Stage 1	QLD	Python	Historic and future studies
PEC SPS	SA-NSW	Python	Future studies: An approximate SPS action assumed since SPS design is not completed at this stage
South West 500 kV Special Control Schemes (SW500SCS)	VIC	Python	Future studies: SA separation Full NEM studies

UFLS and DPV models

Lumped representation of UFLS and DPV according to individual frequency trip blocks were used for full NEM and simplified NEM cases. The number of regional lumped blocks that were considered are detailed in Section A3.2. For full NEM model cases, the individual blocks were dispersed across the relevant region; for the simplified model, the lumped blocks were connected to a common regional bus. Dynamic models were included for DPV, and UFLS trip models were attached to the UFLS loads.

Tasmanian UFLS models were included for historic cases as per the data and models provided to AEMO by TasNetworks.

OFGS models

The OFGS models for South Australian generators were used in both OPDMS and simplified NEM models. Tasmanian OFGS models were included for historic cases as per the data and models provided by TasNetworks.

A4. Benchmarking of historical events

A4.1 25 May 2021 – Trip of multiple generator and lines in Central Queensland and associated under-frequency load shedding

The loss of primary and backup direct current (DC) supplies, which occurred during a switching sequence performed just prior to the incident at Callide C Power Station, together with the simultaneous loss of AC power supplies, resulted in Callide C4 unit losing the excitation system and steam supply to the turbine. As a result, at 1333 hrs on 25 May 2021 the Callide C4 unit stopped generating but remained connected to the power system since the generator circuit breaker (CB) did not open. Consequently, the generating unit began motoring asynchronously. At 1344 hrs, Callide C3 tripped from approximately 417 MW. At 1406 hrs, a series of events took place in quick succession. Further details of the event are provided in AEMO's published incident report[9].

The sequence of events that took place during this incident was simulated in PSS®E for benchmarking purposes. The sequence of events and timings are given in Figure 1**,** along with the corresponding simulation timings. These events were initiated in PSS®E rather than being an outcome of the modelling simulation, as there is inadequate detail in the model regarding protection models and settings to do so accurately.

The simulated and measured frequencies in Queensland for this event are shown in Figure 2**.** As shown, the simulated and the measured frequency are closely matched. Owing to the UFLS action, the measured frequency recovered back to 50 Hz, and this recovery phase also matches well with simulated frequency.

The simulated and measured frequencies in all regions except Queensland for the 25 May 2021 event are shown in Figure 3. The simulated frequency traces in all regions except Queensland match relatively well with the measured frequency. The error between the measured frequency nadir and the simulated frequency nadir is relatively small at 0.15 Hz.

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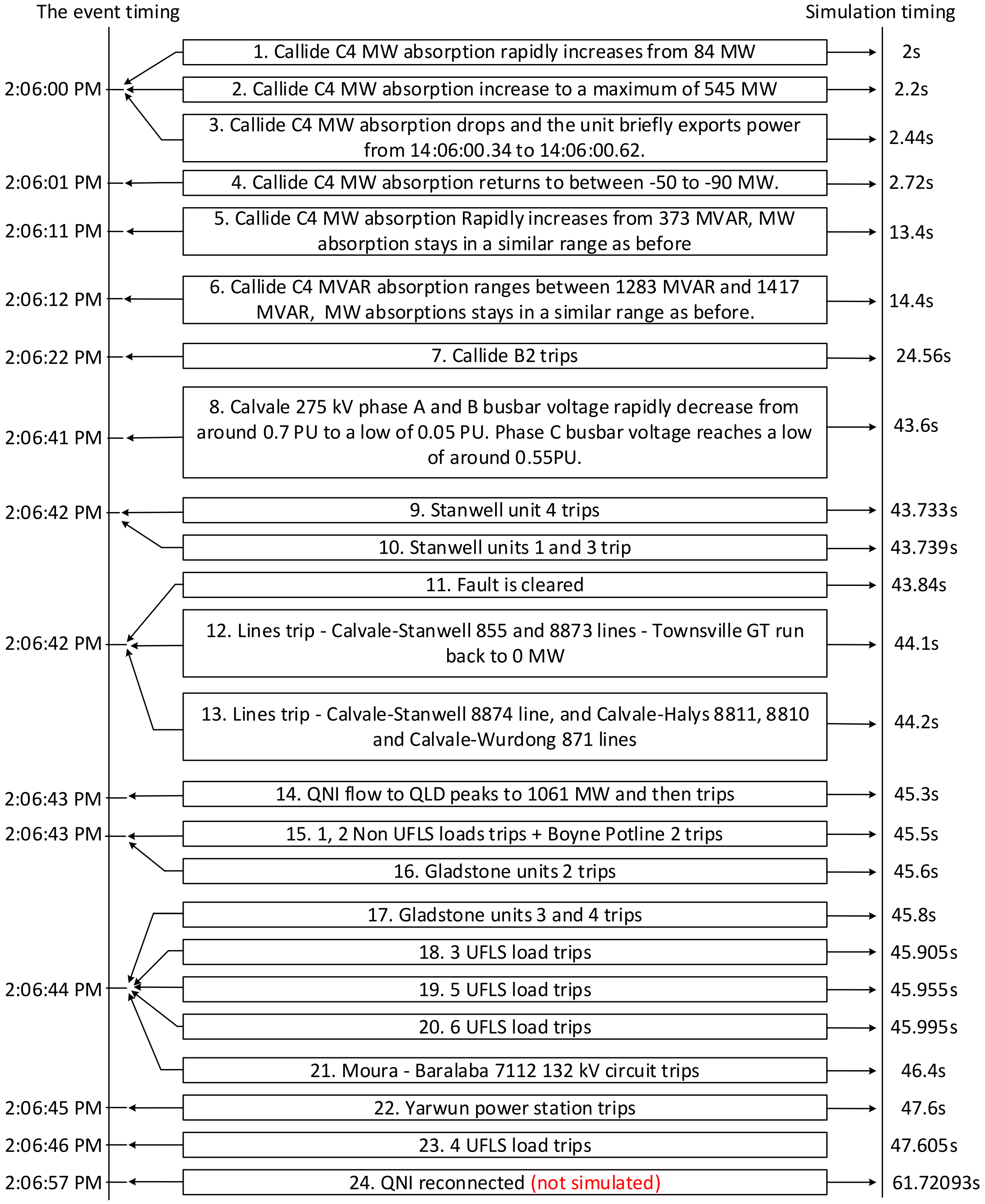
[9] AEMO (2021) *Trip of Multiple Generators and Lines in Queensland and Associated Under-Frequency Load Shedding*, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/final-report-trip-of-multiple-generators-and-lines-in-qld-and-under-frequency-load-shedding.pdf?la=en.

Figure 1 25 May 2021 Callide event sequence and timings, with corresponding simulation timings



The event timing		Simulation timing
2:06:00 PM	1. Callide C4 MW absorption rapidly increases from 84 MW	2s
	2. Callide C4 MW absorption increase to a maximum of 545 MW	2.2s
	3. Callide C4 MW absorption drops and the unit briefly exports power from 14:06:00.34 to 14:06:00.62.	2.44s
2:06:01 PM	4. Callide C4 MW absorption returns to between -50 to -90 MW.	2.72s
2:06:11 PM	5. Callide C4 MW absorption Rapidly increases from 373 MVAR, MW absorption stays in a similar range as before	13.4s
2:06:12 PM	6. Callide C4 MVAR absorption ranges between 1283 MVAR and 1417 MVAR, MW absorptions stays in a similar range as before.	14.4s
2:06:22 PM	7. Callide B2 trips	24.56s
2:06:41 PM	8. Calvale 275 kV phase A and B busbar voltage rapidly decrease from around 0.7 PU to a low of 0.05 PU. Phase C busbar voltage reaches a low of around 0.55PU.	43.6s
2:06:42 PM	9. Stanwell unit 4 trips	43.733s
	10. Stanwell units 1 and 3 trip	43.739s
2:06:42 PM	11. Fault is cleared	43.84s
	12. Lines trip - Calvale-Stanwell 855 and 8873 lines - Townsville GT run back to 0 MW	44.1s
	13. Lines trip - Calvale-Stanwell 8874 line, and Calvale-Halys 8811, 8810 and Calvale-Wurdong 871 lines	44.2s
2:06:43 PM	14. QNI flow to QLD peaks to 1061 MW and then trips	45.3s
2:06:43 PM	15. 1, 2 Non UFLS loads trips + Boyne Potline 2 trips	45.5s
	16. Gladstone units 2 trips	45.6s
2:06:44 PM	17. Gladstone units 3 and 4 trips	45.8s
	18. 3 UFLS load trips	45.905s
	19. 5 UFLS load trips	45.955s
	20. 6 UFLS load trips	45.995s
	21. Moura - Baralaba 7112 132 kV circuit trips	46.4s
2:06:45 PM	22. Yarwun power station trips	47.6s
2:06:46 PM	23. 4 UFLS load trips	47.605s
2:06:57 PM	24. QNI reconnected (not simulated)	61.72093s

Figure 2 Benchmarking of simulated and measured frequency in Queensland following 25 May 2021 event

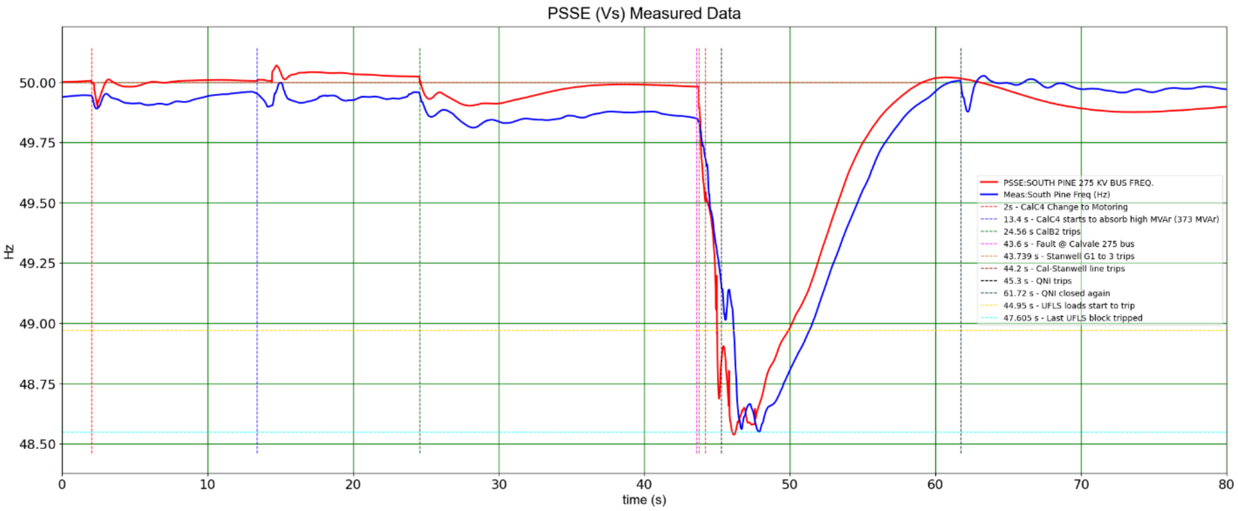
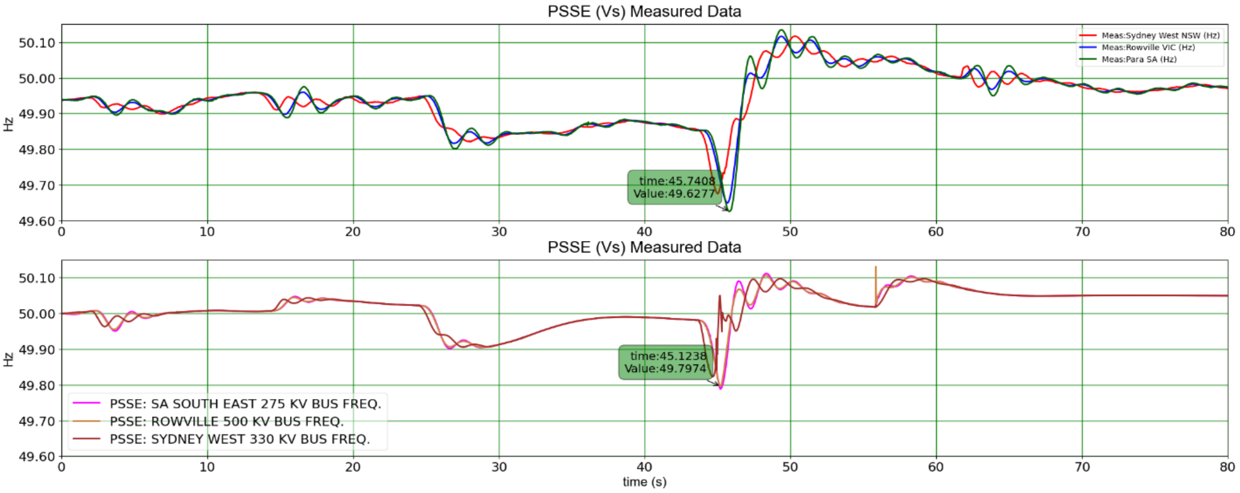


Figure 3 Benchmarking of simulated and measured frequency in all regions except Queensland following 25 May 2021 event

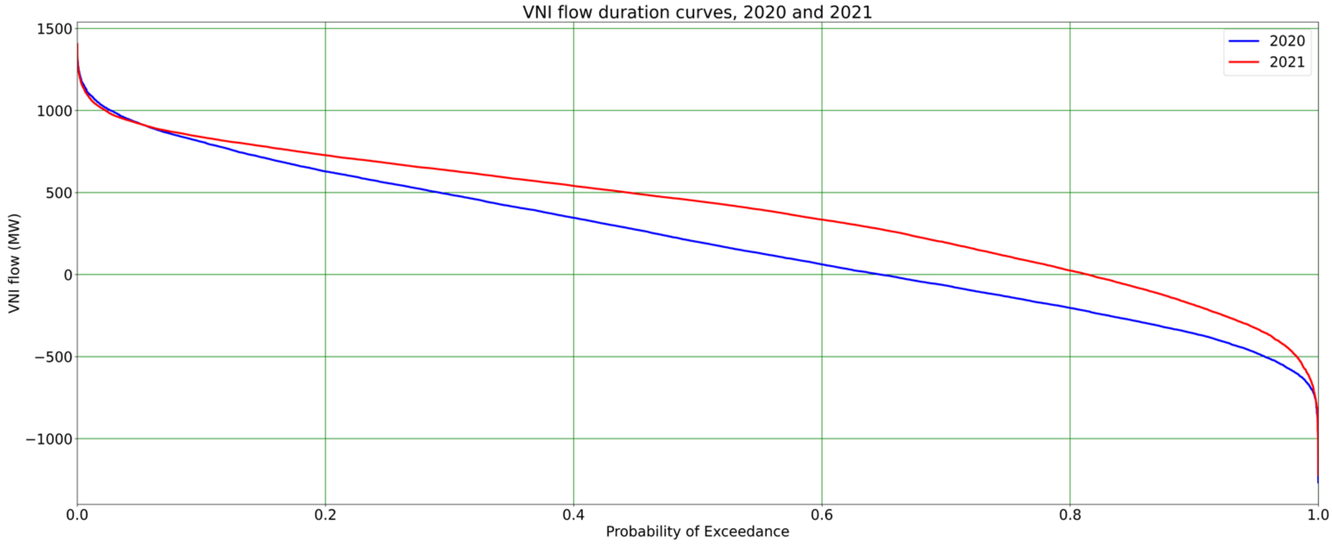


A5. Study results and observations (contd.)

A5.1 Contingency 5 – non-credible loss of VNI

Non-credible concurrent loss of all VNI circuits is remote and included in the review only for illustrative purposes. VNI is comprised of four transmission lines: three 330 kV transmission lines between Murray – Upper Tumut, Murray – Lower Tumut, and Jindera – Wodonga substations, and a 275 kV transmission line from Buronga to Red Cliffs. VNI's nominal capacity is 700-1,600 MW from Victoria to New South Wales and 400-1,350 MW from New South Wales to Victoria. Figure 4 shows the duration curves for the power flow from Victoria to New South Wales and New South Wales to Victoria across VNI from 1 January 2020 to 31 December 2021.

Figure 4 Duration curves for the VNI power flow for 2020 and 2021



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

The non-credible simultaneous loss of the four VNI lines (Murray – Lower Tumut, Murray – Upper Tumut and Jindera – Wodonga) was considered for Victorian import and Victorian export conditions. Both historical and future (2027) operating boundary conditions were included in the study.

A5.1.1 Victorian import – historical cases

Study scenarios

Eight cases were considered for the historical studies of the non-credible loss of VNI during Victorian import conditions. Historical cases were selected for study primarily based on maximum/high VNI import levels (as high VNI transfers during VNI loss are likely to cause the largest system frequency excursions). Coincident with historic high Victorian imports, Victorian inertia varied from 11,752 MWs to 16,303 MWs and underlying Victorian UFLS load ranged from 2,777 MW to 3,508 MW. In addition, coincident with historic high Victorian imports, maximum DPV and Victorian renewable generation were 1,272 MW and 955 MW respectively. The range of power system variables considered for the studies is given in Table 4. Detailed parameters of the selected cases are included in Table 42 in Appendix A6.15.1.

Table 4 System operating points for historical cases (Victorian import)

VIC operational load (MW)	VIC import (MW)	VIC inertia (MWs)	VIC underlying UFLS (MW)	Total VIC DPV (MW)	VIC renewables (MW)
4291 - 5356	660 - 1133	11752 - 16303	2777 - 3508	0 - 1272	307 - 955

Key findings

Historical studies showed that for VNI separation simulations failed to converge. The results indicate that the VNI contingency would result in the loss of various lines and lead to voltage instability.

Although the possibility of VNI loss is very remote, during bushfire conditions there may be a requirement to manually separate VNI, which has occurred in the past. In the past, such separations were managed by adopting measures necessary to ensure safe separation. At present, during an event in which an abnormal condition affecting the power system eventuates, AEMO can impose the power system reclassification framework, as defined in Chapter 4 of the NER. During some previous instances, bushfires have necessitated the reclassification of the VNI lines, from which the associated constraints result in reduced power transfer such that power system security can be maintained following the credible loss of the reclassified elements. For the most extreme scenario that occurred in January 2020 where these bushfires also impacted 330 kV substations, these substations were also de-energised until the threat had passed. The present measures must be continued to manage VNI separation.

A5.1.2 Victorian import – future cases (simplified NEM model)

VNI separation future scenario studies were undertaken using the simplified NEM model to establish the sufficiency of UFLS and OFGS in the event of a separation.

Study scenarios

A total of seven cases were considered for the future studies for VNI separation when Victoria is importing. For all regions except South Australia, three different generator dispatch scenarios (Scenario 1, Scenario 2, and Scenario 3), which are described in Section 5 of the main report, were considered. For South Australia, four synchronous condensers with no synchronous units were assumed. The range of power system variables considered for the studies is given in Table 5. Detailed parameters of the selected cases are included in Table 69 in Appendix A6.15.1.

Table 5 System operating points for the future cases (VNI separation: Victoria importing)

VIC operational load (MW)	NSW operational load (MW)	VIC import (MW)	VIC underlying UFLS load (MW)	Total VIC DPV (MW)	NSW underlying UFLS (MW)	Total NSW DPV (MW)
1134 - 8464	2292 - 8980	1150	1666 - 5217	0 - 4396	4839 - 6914	0 - 6077

The range of key power system variables observed during the simulations is summarised in Table 6, Table 7 and Table 8. Detailed results for each case are included in Table 70, 0, and Table 72 in Appendix A6.15.1.

Table 6 Simulation results of the future cases for generation dispatch Scenario 1 (VNI separation: Victoria importing)

Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped	% Total DPV tripped
NSW	50.67 - 50.85	0.23 - 0.61	0	0	0	0
QLD			0	0	0	0
VIC	48.05 - 48.7	1.24 - 1.57	2125 - 2654	42 - 74	0 - 1449	0 - 47
SA			409 - 1256	26 - 52	0 - 739	0 - 57

Table 7 Simulation results of the future cases for generation dispatch Scenario 2 (VNI separation: Victoria importing)

Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped	% Total DPV tripped
NSW	50.77 - 50.91	0.35 - 0.66	0	0	0 - 319	0 - 5
QLD			0	0	0 - 124	0 - 2
VIC	48.05 - 48.68	1.30 - 1.57	1695 - 2258	33 - 74	0 - 1627	0 - 50
SA			179 - 1289	14 - 52	0 - 794	0 - 58

Table 8 Simulation results of the future cases for generation dispatch Scenario 3 (VNI separation: Victoria importing)

Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped	% Total DPV tripped
NSW	50.76 - 51.03	0.44 - 0.70	0 - 838	0 - 16	0 - 1528	0 - 26
QLD			0 -1057	0 - 26	0 - 573	0 - 10
VIC	48.1 - 48.68	1.50 - 1.95	1695 - 2258	33 - 74	0 - 1625	0 - 50
SA			253 - 1321	19 - 54	0 - 803	0 - 59

Key findings

The VNI (Victorian import) simplified studies identified:

- The frequency in the New South Wales/Queensland island remained below 51 Hz for all cases.
- The steady state frequency in the Victoria/ South Australia island was regulated above 48 Hz in three cases through UFLS action. In Cases 1,2,6, and 7, however, the frequency in the Victoria/South Australia collapsed due to the UFLS inadequacy in Victoria and South Australia (see the results in Appendix A6.17.1). Sufficient Victorian and South Australian combined UFLS is required to manage the Victoria/South Australia frequency.

As the inertia is reduced (due to a reduction in synchronous generation availability) from Scenario 1 to Scenario 3, the maximum RoCoF in the Victoria/ South Australia island increased from 1.57 HZ/s to 1.95 Hz/s following VNI separation.

A5.1.3 Victorian export historical cases

Study scenarios

Nine cases were considered for the historical studies of the non-credible loss of VNI during Victorian export conditions. Historical cases were selected for study primarily based on maximum/high VNI export levels (as high VNI transfers during VNI loss are likely to cause the largest system frequency excursions). Coincident with historic high Victorian exports, Victorian inertia varied from 14,913 MWs to 19,252 MWs and underlying Victorian UFLS load ranged from 2,085 MW to 3,563 MW. In addition, coincident with historic high South Australian imports, maximum DPV and South Australian renewable generation were 1,423 MW and 5,039 MW respectively. The range of power system variables considered for the studies is given in Table 9. Detailed parameters of each of the cases are included in Table 43 in Appendix A6.15.3.

Table 9 System operating points for historical cases (Victorian export)

VIC operational load (MW)	VIC export (MW)	VIC inertia (MWs)	VIC underlying UFLS load (MW)	Total VIC DPV (MW)	VIC renewables (MW)
3588 - 4800	513 - 1423	14913 - 19252	2085 - 3563	0 - 1423	0 - 5039

Key findings

The historical VNI (Victorian export) studies identified:

- All considered cases were found to fail during simulations. The simulation results indicate that the VNI contingency would result in the loss of various lines and lead to voltage instability.
- Even though the possibility of VNI loss is very remote, during bushfires in the area there could be a requirement to separate VNI and this has happened in the past. At present, during an event in which an abnormal condition is affecting the power system, AEMO can impose the power system reclassification framework, as defined in Chapter 4 of the NER. In the past, during some previous instances, bushfires have necessitated the reclassification of the VNI lines, from which the associated constraints result in reduced power transfer such that power system security can be maintained following the credible loss of the reclassified elements. For the most extreme scenario that occurred in January 2020 where these bushfires also impacted 330 kV substations, these substations were also de-energised until the threat had passed. The present measures must be continued to manage VNI separation.

A5.1.4 Victorian export – future cases (simplified NEM model)

Study scenarios

A total of nine cases were considered for the future studies for the VNI contingency when Victoria is exporting. For all regions except South Australia, three different generator dispatch scenarios (Scenario 1, Scenario 2, and Scenario 3), which are described in Section 5.1.2 of the main report, were considered. For South Australia, four synchronous condensers with no synchronous units were assumed. The range of power system variables considered for the studies is given in Table 10. Detailed parameters of each case are included in Table 75 in Appendix A6.15.3.

Table 10 System operating points for future cases (VNI Sep: Victoria exporting)

VIC operational load (MW)	NSW operational load (MW)	VIC export (MW)	Underlying VIC UFLS load (MW)	Total VIC DPV (MW)	Underlying NSW UFLS load (MW)	Total NSW DPV (MW)
374 - 5196	2745 - 12300	1350	1105 - 3067	0 - 3155	3785 - 8015	0 - 6077

The range of key power system variables observed during the simulations is summarised in Table 11, Table 12, and Table 13. Detailed results for each case are included in 0, Table 77**,** and Table 78 in Appendix A6.15.3.

Table 11 Simulation results of future cases for generation dispatch Scenario 1 (VNI Sep: Victoria exporting)

Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped	% Total DPV tripped
NSW	47.92 - 48.89	0.64 - 0.88	505 - 2743	8 - 47	0.3 - 5283	11.3 - 77.3
QLD			1265 - 2669	24 - 53	0 - 1734	0 - 28.1
VIC	50.97 - 51.62	1.3 - 1.93	0	0	0.2 - 496	6.4 - 11.6
SA			0	0	6 - 188	5.9 - 9.4

Table 12 Simulation results of future cases for generation dispatch Scenario 2 (VNI Sep: Victoria exporting)

Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped	% Total DPV tripped
NSW	47.89 - 48.77	0.75 - 1.10	1090 - 2870	18 - 49	0.4 - 5691	15 - 93.6
QLD			661 - 2669	12 - 53	0 - 1734	0 - 30.8
VIC	50.98 - 51.62	1.43 - 2.15	0	0	0.2 - 496	6.4 - 17
SA			0	0	6 - 188	5.9 - 11.3

Table 13 Simulation results of future cases for generation dispatch Scenario 3 (VNI Sep: Victoria exporting)

Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped	% Total DPV tripped
NSW	47.89 - 48.74	0.70 - 1.9	1171 - 2906	19 - 49	0.4 - 2537	16 - 42
QLD			1488 - 2575	28 - 51	0 - 1652	0 - 29
VIC	50.97 - 51.70	1.79 - 2.46	0 - 659	0 - 21	0.2 - 1267	6.4 - 50.6
SA			0 - 120	0 - 7	6 - 379	5.9 - 22.8

Key findings

The VNI (Victorian export) simplified studies identified:

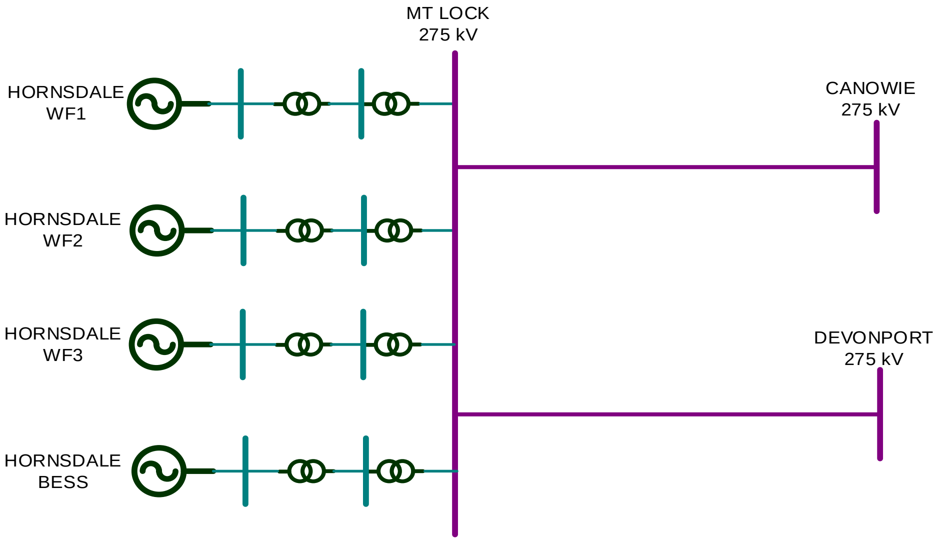
- Frequency in the New South Wales/Queensland island was regulated above 48 Hz due to UFLS action in all cases except Case 8.
- The frequency in the Victoria/South Australia island stabilises below 51 Hz for all stable cases. In Cases 6 and 7, where the OFGS operated in South Australia, the OFGS was sufficient to stabilise the frequency in the Victoria/South Australia island below 51 Hz.

- As the inertia is reduced from Scenario 1 to Scenario 3, the maximum RoCoF in the New South Wales/ Queensland island increases from 1.10 Hz/s to 1.90 Hz/s following VNI separation.
- QNI tends to become unstable as the power inflow from Victoria is lost following VNI separation. This is evident in cases where the Queensland export is high into New South Wales prior to the VNI separation.

A5.2 Contingency 6 – Mt Lock 275 kV bus bar failure – historic cases

The non-credible failure of the Mt Lock 275 kV busbar was considered. Mt Lock substation is connected to Canowie and Devonport substations through 275 kV lines. Hornsdale WFs and BESS are connected to the Mt Lock bus as shown in Figure 5. A non-credible fault at the Mt Lock busbar will result in the loss of generation from the Hornsdale WFs and BESS.

Figure 5 Mt Lock substation (simplified representation)



Study scenarios

Seven cases were considered for the historical studies of the non-credible loss of Mt Lock 275 kV busbar during South Australian import and export conditions. Historical cases were selected for study primarily based on maximum/high South Australian transfer levels and high Hornsdale WF and BESS generation output (as high South Australian transfers and Hornsdale generation output during Mt Lock busbar loss are likely to cause the largest system frequency excursions). Coincident with historic high South Australian transfers, South Australian inertia varied from 5,548 MWs to 16,155 MWs and Hornsdale generation ranged from 135 MW to 396 MW. In addition, coincident with historic high South Australian transfers, maximum South Australian operational demand was 2,528 MW. The range of power system variables considered for the studies is given in Table 14. Detailed parameters of each case are given in Table 44 in Appendix A6.6.

Table 14 Mt Lock 275 kV busbar failure: system operating points for the historical cases

SA operational demand (MW)	SA HIC import (MW)	SA inertia (MWs)	Hornsdale WFs (MW)	Hornsdale BESS (MW)	Hornsdale total output (MW)	SA renewables (MW)
1449 - 2528	-604 - +550	5548 - 16155	121 - 316	-27 - 80	135 - 396	211 - 812

The maximum values of key power system variables observed during the simulations are summarised in Table 15. Detailed results for each case are included in Table 45 in Appendix A6.6.

Table 15 Mt Lock 275 busbar failure: historical cases results

Region	Freq nadir range (Hz)	RoCoF (Hz/s)	UFLS load tripped (MW)	% UFLS load tripped	Total DPV tripped (MW)	Total DPV tripped on protection only (MW)	% DPV tripped
SA	49.- 49.94	0.07 - 0.27	0	0	0 - 16.2	0 - 16.2	0 - 4.8

Key findings

The historical Mt Lock 275 kV busbar failure studies identified:

- The minimum frequency nadir is 49.87 Hz and, hence, UFLS was not triggered.
- The maximum RoCoF was around 0.24 Hz/s.
- A maximum of 16.2 MW of DPV were found to have tripped due to operation of their own protection during the applied fault.
- For the cases studied, the SIPS operation was not triggered; however it should be noted the loss of Hornsdale BESS will reduce the effectiveness of SIPS during the contingency.

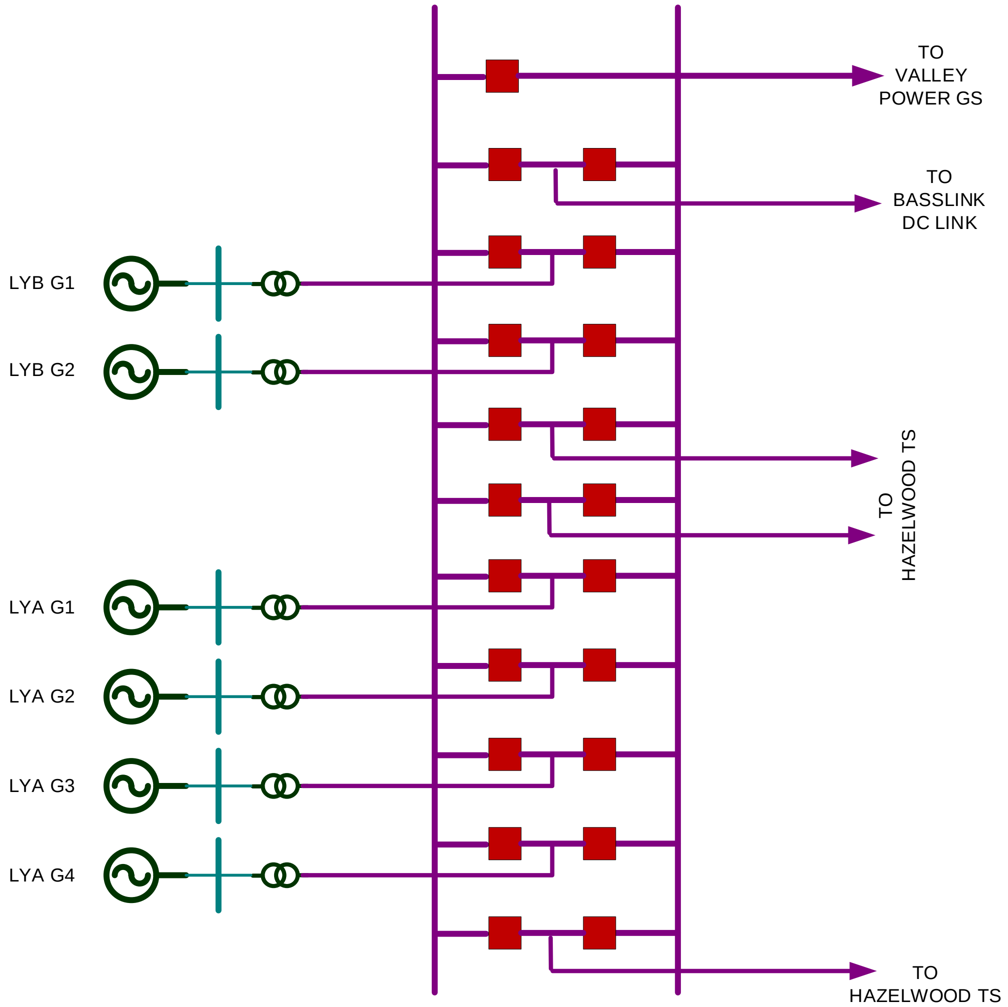
A5.3 Contingency 9 – simultaneous loss of multiple Loy Yang generating units – historic cases

The non-credible loss of various Loy Yang generator units was studied for a range of different historical scenarios.

At Loy Yang, there is Loy Yang A Power Station with four units with a total capacity of 2,210 MW and Loy Yang B Power Station with two units with a total capacity of 1,160 MW as shown in Figure 6.

Non-credible losses of Loy Yang A and Loy Yang B units were studied separately. As the system failed to remain stable after the loss of Loy Yang A in all cases considered due to significant loss in generation, the study results are not discussed below. The simulations were successfully completed for the loss of Loy Yang B units. Hence, only loss of Loy Yang B results are discussed in this report.

Figure 6 Loy Yang power station (simplified representation)



Study scenarios

Ten cases were considered for the historical studies of the non-credible loss of various Loy Yang A and Loy Yang B generators. Historical cases were selected for study primarily based on maximum/high Loy Yang generator output (as high Loy Yang generation output prior to Loy Yang unit trips is likely to cause the largest system frequency excursions). Coincident with historic high Loy Yang generation levels, Victorian inertia varied from 17,606 MWs to 37,097 MWs and Victorian operational demand ranged from 4,042 MW to 7,883 MW. The range of Loy Yang generation and the key power system variables considered are given in Table 16 and Table 17 respectively. More detailed information on each case is included in Appendix A6.9.

Table 16 Loy Yang generation dispatch range

	Loy Yang A unit 1 (MW)	Loy Yang A unit 2 (MW)	Loy Yang A unit 3 (MW)	Loy Yang A unit 4 (MW)	Loy Yang A total (MW)	Loy Yang B unit 1 (MW)	Loy Yang B unit 2 (MW)	Loy Yang B total (MW)
Generation range	502 - 563	506 - 534	532 - 563	484 - 564	2050 - 2223	464 - 538	486 - 577	950 - 1112

Table 17 Range of power system operating conditions for Loy Yang contingency

Region	Operational demand (MW)	Pgen (MW)	Inertia (MWs)	Underlying UFLS load (MW)	Total DPV (MW)	Renewables (MW)
NSW	6272 - 10865	6085 - 11349	30853 - 47134	4080 - 7644	0 - 1219	420 - 1102
VIC	4042 - 7883	4917 - 7647	17606 - 37097	2354 - 5637	0 - 982	37 - 981
QLD	5628 - 7368	6321 - 9743	31548 - 39753	2925 - 4362	0 - 1570	0 - 409
SA	934 - 1897	654 - 2580	11265 - 17068	761 - 1686	0 - 627	87 - 811
TAS	910 - 1293	526 - 1823	5480 - 10283	0 - 0	0 - 0	0 - 63

A high-level summary of the results is included in Table 18 and detailed simulation study results are included in Table 55 in Appendix A6.9.

Table 18 Loy Yang Group B trip simulation results

Region	Peak/Nadir range (Hz)	Max UFLS tripped (MW)	Max % UFLS tripped	Max total DPV tripped (MW)	Max % DPV tripped
NSW	48.78 - 50.4	2213	36.21	4223.18	27.64
VIC	48.78 - 50.4	878	15.58	512	52.97
QLD	49.46 - 51.93	0	0	105	12.74
SA	48.92 - 51	124	8.44	140	24.25
TAS	47.85 - 50.45	62.1	0	0	0

Key findings

The historical studies identified that for loss of both Loy Yang Power Station B units:

- The Victorian frequency nadir did not fall below 49 Hz, except in Cases 10 and 11, where QNI reached its stability limit of 1,200 MW.
- HIC was separated due to EAPT operation for Cases 5, 10 and 11 following the contingency. See Figure 24 in Appendix A6.9 for relevant interconnector flows.
- Frequency in the rest of the NEM was maintained above 48 Hz, except for Tasmania, where frequency dropped to below 48 Hz in Case 1 even following Tasmanian UFLS action.
- Following the loss of Loy Yang B units during high Queensland export conditions, studies showed that QNI could lose stability.
- Due to large power swings in HIC, EAPT operation could trip HIC leading to South Australia separation.

The historical studies of Loy Yang Group A or Group A and B trip identified:

- Loss of all Loy Yang A units or the loss of A and B units together can lead to voltage collapse and various lines losing stability leading to their disconnection.

A5.4 Contingency 10 – loss of Ballarat – Waubra 220 kV, Balranald – Darlington point 220 kV (x5) and Darlington Point – Wagga 330 kV (63) lines – historic cases

The non-credible loss of the Ballarat – Waubra 220 kV line followed by the loss of either the Balranald – Darlington Point 220 kV (X5) line or the Darlington Point – Wagga 330 kV (63) line was studied for a range of historical scenarios. For the simulation of this contingency, a fault was applied at Ballarat and the Ballarat – Waubra 220 kV line was tripped with a clearance time of 120 ms. Ten seconds later, a second fault was applied at either the Balranald or Darlington Point bus, and either the Balranald – Darlington Point 220 kV line or the Darlington Point – Wagga 330 kV line was tripped. Studies included modelling of the generation runback/tripping schemes that would operate following this contingency. The relevant protection schemes and their assumed operation times for the study are included below:

Ballarat – Waubra 220 kV line trip:

- Waubra WF Anti-Islanding Scheme – 120 ms.
- Crowlands WF Generation Fast Trip Scheme – 180 ms.
- Bulgana WF Generation Fast Trip Scheme – 180 ms.
- Ararat WF Generation Fast Trip Scheme – 180 ms.
- Murra Warra WF Generation Fast Trip Scheme 1 – 200 ms.

Balranald – Darlington Point 220 kV (X5) line or Darlington Point – Wagga 330 kV (63) line trips:

- Broken Hill SF and Silverton WF Transfer Trip Scheme – 120 ms.
- Limondale 1 and Sunraysia SFs Transfer Trip Scheme – 120 ms.

The Murraylink runback scheme operates for the trip of the Ballarat – Waubra 220 kV line when the power flow is in the Victoria to South Australia direction. For all cases studied, the Murraylink power flow was in the South Australia to Victoria direction, so the Murraylink runback scheme was not considered.

Study scenarios

Twelve cases were considered for this contingency. Historical cases were selected for study primarily based on high western Victoria renewable generation (as high western Victoria renewable generation will present more onerous conditions during the contingency). Times of high import into Victoria from New South Wales were selected for the study.

The range of power system variables considered for the studies is given in Table 19 and detailed parameters of each case are included in Table 56 in Appendix A6.10.

Table 19 Power system operating points for historical cases

Region	Operational demand (MW)	Import /Export (MW)	UFLS load (MW)	Renewables (MW)
VIC	3398 - 4260	665 - 1422 (VIC import from NSW)	1990 - 2550	1207 - 1629
NSW	5423 - 6971	880 - 1372 (NSW export to VIC)	3682 - 4658	713 - 1270

The range of values for key power system variables observed during the simulations is summarised in Table 20 and Table 21. More detailed results for each case are included in Table 56 in Appendix A6.10**.**

Table 20 Historical case results for the loss of the Ballarat – Waubra 220 kV line and the Balranald – Darlington Point 220 kV (X5) line

Region	Freq nadir range (Hz)	RoCoF (Hz)	UFLS load tripped (MW)	% UFLS load tripped	Total DPV tripped (MW)	% DPV tripped	Total DPV tripped on protection only (MW)
VIC	49.7 - 49.8	0.07 - 0.35	0	0	0	0	0
NSW			0	0	0	0	0

Table 21 Historical case results for the loss of the Ballarat – Waubra 220 kV line and the Darlington Point – Wagga 330 kV (63) line

Region	Freq nadir range (Hz)	RoCoF (Hz)	UFLS load tripped (MW)	% UFLS load tripped	Total DPV tripped (MW)	% DPV tripped	Total DPV tripped on protection only (MW)
VIC	49.70 - 49.85	0.218 - 0.326	0	0	0	0	0
NSW			0	0	0	0	0

Key findings

The historical loss of Ballarat – Waubra 220 kV line and Darlington Point – Wagga 220 kV line contingency studies identified:

- The NEM frequency nadir was maintained above 49 Hz. The NEM frequency RoCoF was also maintained below 1 Hz/s following fault clearance.
- Following the contingency and the generation trips by the relevant protection schemes, the transmission lines are de-loaded, leading to severe over-voltages above 1.15 p.u. at several West Murray transmission buses.
- High frequency, voltage and reactive power oscillations were observed in traces of IBR and SVCs in the Red Cliffs area for Case 11 following the loss of the Darlington Point – Wagga 330 kV (63) line. This could be due to insufficient fault levels around Red Cliffs during the 2019-20 period.
- The results indicate that, subject to the initial operational conditions, there is potential for transmission over-voltages to occur after fault clearance due to generator tripping associated with the generator runback scheme associated with this contingency.
- For this event, apart from generation disconnected due to operation of special protection schemes, additional generation could be constrained following the contingency events in order to resecure the system. To assess the maximum possible generation loss due to the contingency, the historical generation from the impacted SFs and WFs for the contingency for the period from 1 June 2021 to 19 July 2022 was considered. Based on the historical data the maximum generation that could be lost for this contingency is around 1460 MW, compared to approximately 1,190 MW if it were a single N-1 event rather than N-1-1 event. Loss of this volume of generation may have an adverse impact on system reserves and result in potential supply disruptions.

A6. Simulation of priority non-credible events

This chapter gives detailed references to study cases, results, and key result graphs to supplement the observations provided in Chapter 5.

A6.1 Contingency 1 – South Australia separation from HYTS

The non-credible separation of South Australia from HYTS was considered for import and export conditions. Both historical and future (2027) operating boundary conditions were included in the study.

A6.1.1 South Australian import condition

Study scenarios

Eleven historical cases were considered for South Australia separation from HYTS (South Australian import). Historical cases were selected for study primarily based on maximum/high HIC South Australian import levels (as high HIC transfers during South Australia separation are likely to cause the largest system frequency excursions). Coincident with historic high South Australian imports, South Australian inertia varied from 9,805 MWs to 20,870 MWs and underlying South Australian UFLS load ranged from 1,090 MW to 2,401 MW. In addition, coincident with historic high South Australian imports, maximum DPV and South Australian renewable generation were 956 MW and 583 MW respectively. Case details are given in Table 22.

Table 22 South Australia separation from HYTS: Historical cases considered – South Australia variables (South Australian import)

Case	SA operational demand (MW)	Total import (HIC + Murraylink) (MW)	HIC import (MW)	SA inertia (MWs)	SA underlying UFLS load (MW)	SA DPV (MW)	SA renewables (MW)
1	1146	693	678	9805	1180	535	140
2	2070	834	587	14157	2264	796	313
3	2279	853	556	17376	2231	603	178
4	2360	765	541	20787	2401	696	243
5	1663	754	538	12165	2014	953	548
6	1737	819	581	14034	2071	943	534
7	1594	651	474	12165	1971	956	583
8	2295	812	618	20870	2348	728	282
9	1889	690	549	14034	2220	854	419
10	2304	756	589	17862	2261	549	172
11	1112	672	575	9805	1090	465	228

Study results

The key results of the historical case simulation studies are given in Table 23.

Table 23 South Australia separation from HYTS: Historical cases results – South Australia variables (South Australian import)

Case	SA frequency nadir (Hz)	SA RoCoF (Hz/s)	SA underlying UFLS load tripped (MW)	SA % Total DPV tripped	Was the case stable? (Yes/No)
1	47.8	1.32	887	71	Yes
2	48.6	0.89	676	25	Yes
3	48.7	0.79	689	25	Yes
4	48.8	0.82	591	19	Yes
5	48.6	0.87	749	31	Yes
6	48.6	1.50	748	31	Yes
7	48.6	0.64	599	25	Yes
8	48.7	0.72	714	25	Yes
9	48.6	0.79	668	25	Yes
10	48.7	0.82	676	25	Yes
11	48.0	1.15	731	64	Yes

Representative results

The simulation results for Case 11 are shown in **Error! Reference source not found.**, where the frequency nadir was just below 48 Hz and settled at 49.4 Hz.

A6.1.2 South Australian export condition

Study scenarios

Twelve historical cases were considered for South Australia separation from HYTS (South Australian export). Historical cases were selected for study primarily based on maximum/high HIC South Australian export levels (as high HIC transfers during South Australia separation are likely to cause the largest system frequency excursions). Coincident with historic high South Australian exports, South Australian inertia varied from 9,527 MWs to 18,043 MWs and underlying South Australian UFLS load ranged from 967 MW to 1,777 MW. In addition, coincident with historic high South Australian exports, maximum DPV and South Australian renewable generation were 945 MW and 976 MW respectively. The case details are given in Table 24.

Table 24 South Australia separation from HYTS: Historical cases considered – South Australia variables (South Australian export)

Case	SA operational demand (MW)	Total export (HIC + Murraylink) (MW)	HIC export (MW)	SA inertia (MWs)	SA underlying UFLS load (MW)	SA available OFGS (MW)	SA DPV (MW)	SA renewables (MW)
1	504	585	459	9527	967	506	865	575
2	477	628	460	9805	1058	357	945	694
3	520	602	454	9805	1042	388	908	759
4	647	777	543	10705	1064	605	739	932
5	747	697	556	10893	969	661	540	948
6	652	725	580	10705	1040	585	716	884
7	723	691	581	9805	1094	571	788	829

Case	SA operational demand (MW)	Total export (HIC + Murraylink) (MW)	HIC export (MW)	SA inertia (MWs)	SA underlying UFLS load (MW)	SA available OFGS (MW)	SA DPV (MW)	SA renewables (MW)
9	1034	790	573	11674	1133	642	520	976
10	1562	766	648	18043	1726	723	680	875
11	1611	832	638	18043	1777	671	699	852
12	1306	672	558	15729	1307	687	580	915
13	1205	574	448	14829	1366	627	724	811

Study results

The key results of the historical case simulation studies are given in Table 25.

Table 25 South Australia separation from HYTS: Historical cases results – South Australia variables (South Australian export)

Case	SA frequency peak (Hz)	SA RoCoF (Hz/s)	SA OFGS generation tripped (MW)	Total DPV tripped on protection only (MW)	Was the case stable? (Yes/No)
1	51.0	0.78	13	98	Yes
2	51.0	0.77	9	94	Yes
3	51.0	0.77	8	83	Yes
4	51.2	0.83	15	76	Yes
5	51.1	0.86	20	55	Yes
6	51.2	0.87	15	93	Yes
7	51.2	0.90	14	96	Yes
9	51.1	0.82	16	56	Yes
10	51.1	0.69	22	67	Yes
11	51.2	0.67	21	69	Yes
12	51.0	0.65	15	59	Yes
13	51.0	0.57	0	67	Yes

Representative results

The simulation results for Case 11 are shown in Figure 7. Following South Australia separation, QNI loses stability, and this would lead to the separation of Queensland from the rest of the NEM resulting in three islands being formed (South Australia, Victoria/New South Wales, and Queensland).

HIC Export Case 11 was rerun with the tripping of QNI 150 ms after the loss of HIC. There was sufficient UFLS present to arrest the NEM frequency nadir to 48.8 Hz and limit the RoCoF to below 3 Hz/s.

The simulation results for Case 7 are shown in Figure 8. Following South Australia separation, South Australian frequency settles close to 51 Hz, which demonstrates the need for further frequency regulating services, like AGC, to reduce the frequency to 50 Hz.

Figure 7 **Case 11 South Australia separation from HYTS: HIC and QNI P flows**

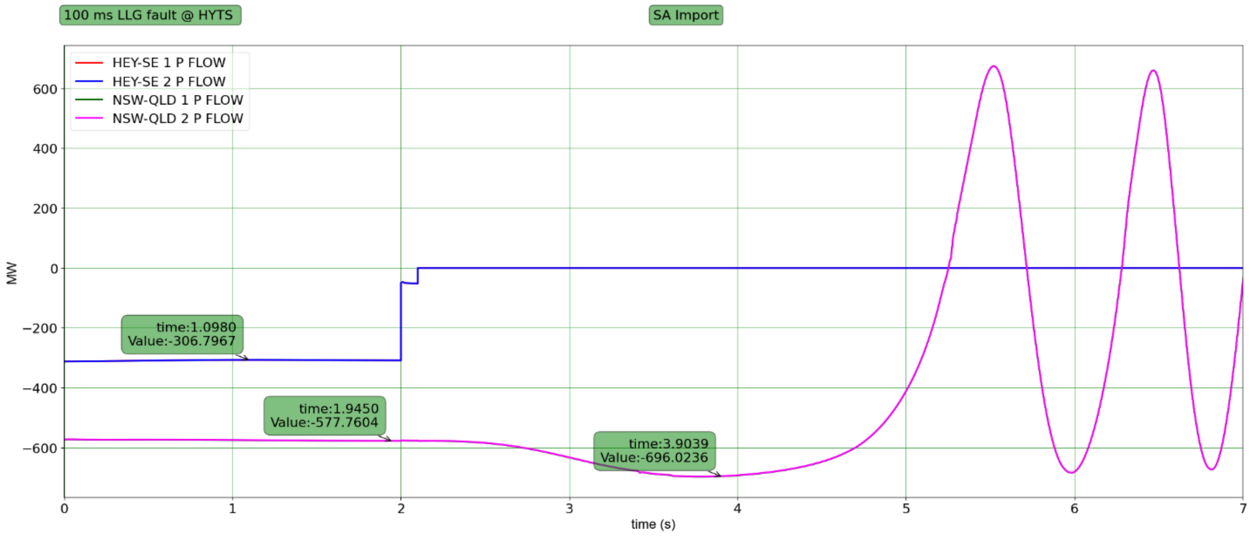
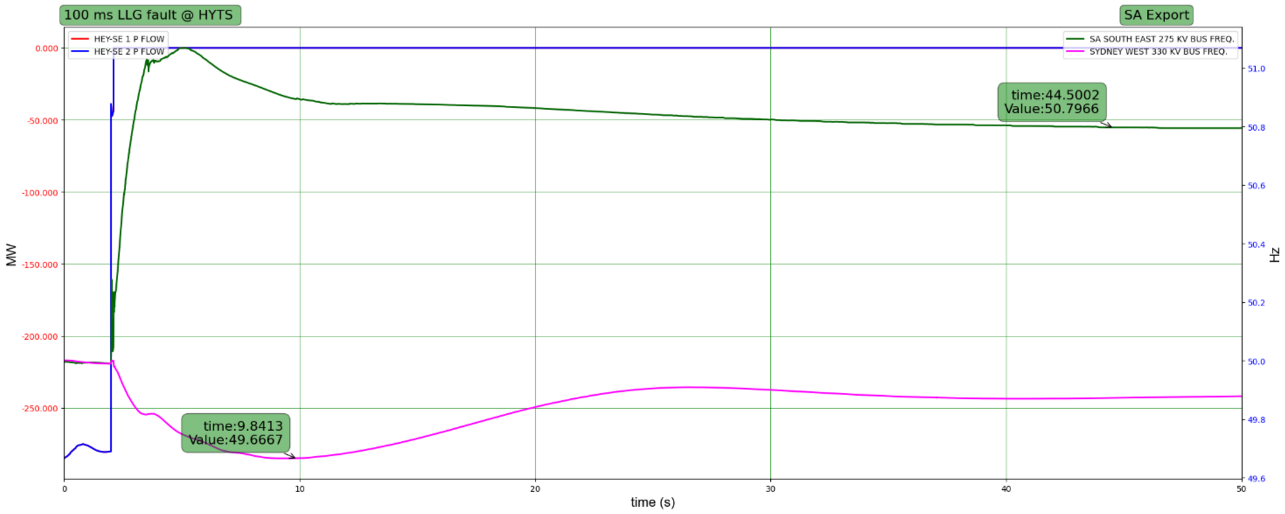


Figure 8 **Case 7 South Australia separation from HYTS (South Australian export): HIC P flows and South Australian and remaining mainland frequencies**



Impact of IBR frequency response

During the 2022 PSFRR consultation period, AEMO identified a need to undertake additional sensitivity studies with IBR frequency control disabled for historic studies where there is a risk of over-frequency.

AEMO understands that ahead of implementing and enabling PFR capabilities, many IBR generators disable frequency responsiveness, despite providing models to AEMO with these frequency controls enabled. Additional studies were therefore undertaken to assess the frequency outcomes with IBR over-frequency response disabled.

The specific contingencies that will be most impacted are:

- South Australia separation from HYTS and MLTS when South Australia is exporting (presented in Sections 5.2.3 and 5.3.3).
- Queensland synchronous separation for a non-credible loss of QNI when Queensland is exporting (presented in Section 5.4.3).

To confirm, the sensitivity study on the impact of disabling IBR frequency response for South Australia separation at HYTS showed only minimal peak frequency difference. This is because South Australian over-frequency is already managed by the South Australian OFGS scheme.

A6.2 Contingency 2 – South Australia separation from MLTS

The non-credible separation of South Australia from MLTS was considered for South Australian import and South Australian export conditions.

A6.2.1 South Australian import condition

Study scenarios

Ten historical cases were considered for the South Australia separation from MLTS (South Australian import). Historical cases were selected for study primarily based on maximum/high South Australia import levels (as high South Australian import transfers during South Australia separation are likely to cause the largest system frequency excursions). Coincident with historic high South Australian imports, South Australian inertia varied from 9805 to 21038 MWs and underlying South Australian UFLS load ranged from 651 MW to 2448 MW. In addition, coincident with historic high South Australian exports, maximum DPV and South Australian renewable generation were 648 MW and 365 MW respectively. Case details are given in Table 26.

Table 26 South Australia separation from MLTS: Historical cases considered – South Australia variables (South Australian import)

Case	SA operational demand (MW)	Total import (HIC + Murraylink) (MW)	HIC import (MW)	SA Inertia (MWs)	SA underlying UFLS load (MW)	SA DPV (MW)	SA renewables (MW)
1	1066	693	678	9805	1180	535	140
2	1255	846	587	9805	843	0	53
3	1122	858	589	9805	936	240	121
4	1180	850	585	9805	789	0	63
8	1028	835	552	9805	651	0	23
9	2476	551	615	20344	2106	215	175
10	2121	616	514	18182	1646	0	147
11	2338	566	472	21038	2405	648	321
12	2411	570	492	20602	2448	618	365
13	2355	529	437	20668	1943	0	160

Study results

The key results of historical case simulation studies are given in Table 27.

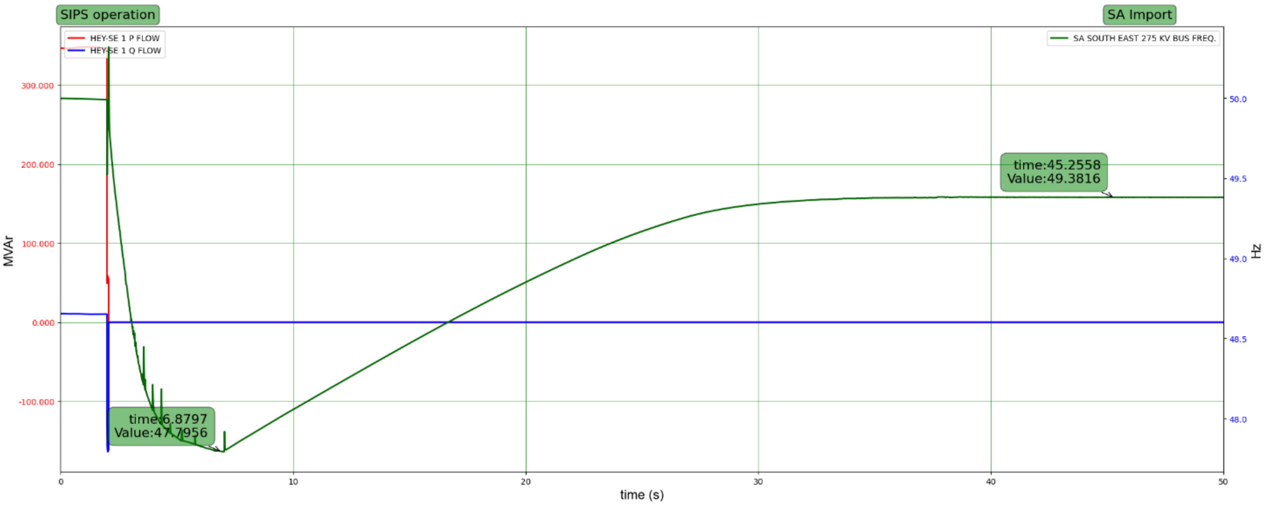
Table 27 South Australia separation from MLTS: Historical cases results – South Australia variables (South Australian import)

Case	SA freq nadir range (Hz)	SA RoCoF (Hz)	SA underlying UFLS load tripped (MW)	SA % total DPV tripped	EAPT/SIPS operation	Was the case stable? (Yes/No)
1	47.8	1.34	887	71	SIPS	Yes
2	48.2	1.53	413	0	EAPT	Yes
3	48.1	1.71	567	59	EAPT	Yes
4	48.2	1.51	398	0	EAPT	Yes
8	48.1	1.62	389	0	EAPT	Yes
9	48.9	0.46	182	6		Yes
10	49.0	0.55	97	0		Yes
11	49.0	0.32	140	4		Yes
12	48.9	0.34	144	4		Yes
13	49.7	0.20	0	0		Yes

Representative results

For MLTS Import Case 1, SIPS Stage 3 operated at 2.07s and tripped HIC. South Australian frequency fell below 48 Hz with a nadir of 47.8 Hz. HIC flows and South Australian frequency for Case 1 are included in Figure 9.

Figure 9 Case 1 South Australia separation from MLTS (South Australian import): HIC and South Australian frequency



A6.2.2 South Australian export condition

Study scenarios

Eleven historical cases were considered for South Australia separation from MLTS (South Australian export). Historical cases were selected for study primarily based on maximum/high South Australian export levels (as high South Australian export transfers during South Australia separation are likely to cause the largest system frequency excursions). Coincident with historic high South Australian exports, South Australian inertia varied from 13,134 MWs to 22,985 MWs and underlying South Australian UFLS load ranged from 938 MW to 1,897 MW. In addition, coincident with historic high South Australian exports, maximum DPV and South Australian renewable generation were 778 MW and 1,011 MW respectively. Case details are given in Table 28.

Table 28 South Australia separation from MLTS: Historical cases considered - South Australia variables (South Australian export)

Case	SA operational demand (MW)	Total export (HIC + Murraylink) (MW)	HIC export (MW)	SA inertia (MWs)	SA underlying UFLS load (MW)	SA available OFGS (MW)	SA DPV (MW)	SA renewables (MW)
1	1774	630	560	18043	1855	749	723	949
2	805	644	529	13220	1080	115	798	345
3	1989	631	558	18036	1897	778	480	1011
4	1132	642	560	13134	1475	648	900	907
5	1856	580	525	22985	1689	138	465	310
6	852	551	535	14934	1087	106	758	296
7	1380	606	507	13264	938	722	0	860
8	1447	562	501	15729	1119	634	163	775
9	777	503	512	15624	1044	21	798	258
11	825	516	506	13220	1052	76	743	298
12	1013	632	527	14934	1063	75	554	210

Study results

The key results of historical case simulation studies are given in Table 29.

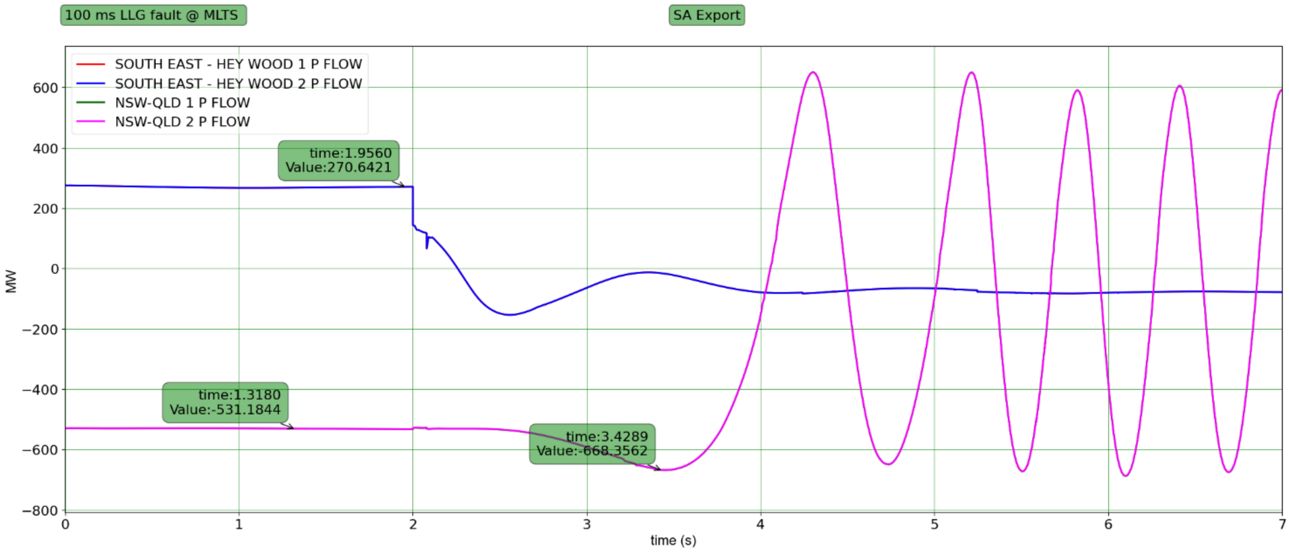
Table 29 South Australia separation from MLTS: Historical cases results - South Australia variables (South Australian export)

Case	SA freq peak range (Hz)	SA RoCoF (Hz)	SA OFGS generation tripped (MW)	SA total DPV tripped on protection only (MW)	Was the case stable? (Yes/No)
1	51.2	0.38	23	66	Yes
2	50.3	0.12	0	0	Yes
3	51.2	0.73	20	44	Yes
4	51.4	1.10	16	81	Yes
5	51.0	0.24	9	42	Yes
6	50.2	0.08	0	0	Yes
7	51.8	1.11	32	0	Yes
8	51.5	0.68	28	15	Yes
9	50.6	0.23	0	0	Yes
11	50.2	0.10	0	0	Yes
12	50.2	0.09	0	1	Yes

Representative results

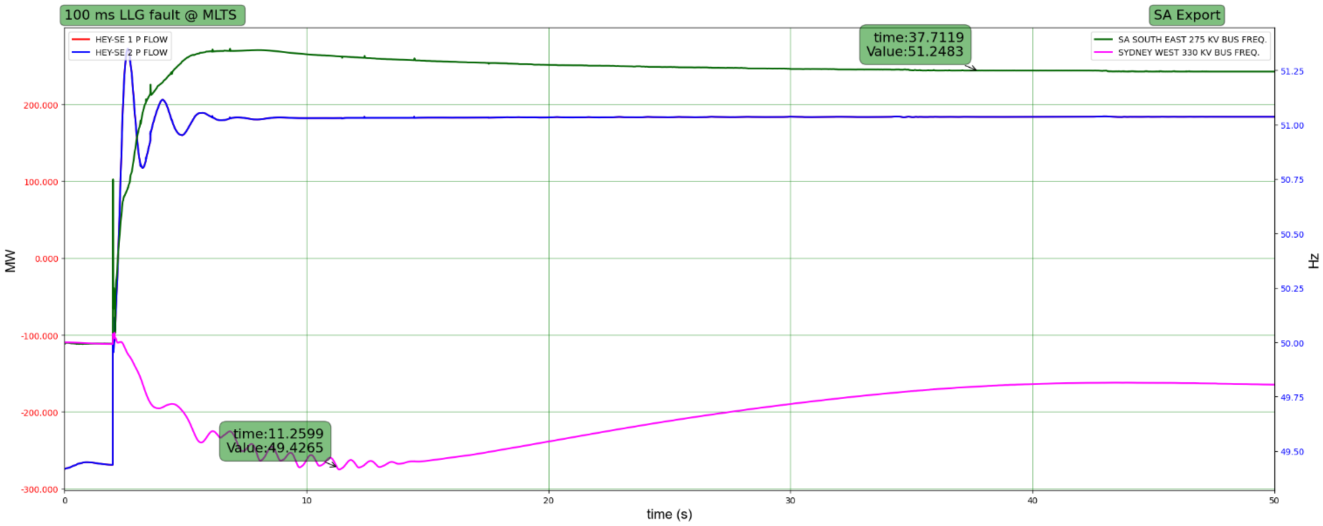
In Cases 1 and 3 for South Australia separation from MLTS, QNI lost stability. The line flows for Case 1 are shown in Figure 10.

Figure 10 Case 1 South Australia separation from MLTS: HIC and QNI P flows



For Case 4, following the separation, South Australian frequency settled above 51 Hz, as shown in Figure 11.

Figure 11 Case 4 South Australia separation from MLTS: HIC and South Australian and remaining mainland frequencies



Impact of IBR frequency response

During the 2022 PSFRR consultation period, AEMO identified a need to undertake additional sensitivity studies with IBR frequency control disabled for historic studies where there is a risk of over-frequency.

AEMO understands that ahead of implementing and enabling PFR capabilities, many IBR generators disable frequency responsiveness, despite providing models to AEMO with these frequency controls enabled. Additional studies were therefore undertaken to assess the frequency outcomes with IBR over-frequency response disabled.

The specific contingencies that will be most impacted are:

- South Australia separation from HYTS and MLTS when South Australia is exporting (presented in Sections 5.2.3 and 5.3.3**Error! Reference source not found.**).
- Queensland synchronous separation for a non-credible loss of QNI when Queensland is exporting (presented in Section 5.4.3).
- To confirm, the sensitivity study on the impact of disabling IBR frequency response for South Australia separation at MLTS showed only minimal peak frequency difference. This is because South Australian over-frequency is already managed by the South Australian OFGS scheme.

A6.3 Contingency 3 – Queensland separation through QNI loss

A6.3.1 QNI – Queensland import condition

Study scenarios

Eight historical cases were considered to study Queensland separation due to loss of QNI when Queensland is importing. Case details are given in Table 30 and **Error! Reference source not found.**.

Table 30 QNI separation: Queensland import historical cases Queensland variables

Case	Operational demand (MW)	Pgen (MW)	Import (MW)	Renewables (MW)	Inertia (MWs)	Underlying UFLS (MW)	Total DPV (MW)
1	5761	5398	496	99	25912	3143	0
2	8150	7816	535	503	29262	4240	636
3	8110	7883	439	329	30387	4195	547
6	8877	8542	510	1042	27085	4838	2148
7	10532	10308	529	1056	34126	5713	2019
9	10401	10237	449	1075	34046	5673	2137
10	9811	9938	115	936	32817	5268	2183
11	9153	8885	458	1027	28077	4964	2815

Table 31 QNI separation: Queensland import historical import cases remaining mainland variables

Case	Operational demand (MW)	Pgen (MW)	Renewable generation (MW)	Inertia (MWs)	Underlying UFLS (MW)	Total DPV (MW)
1	13087	13705	3151	62812	8348	0
2	15689	16435	2673	62335	9688	1801
3	15515	16161	2658	63878	9616	1463
6	16645	17422	2080	62137	10473	3595
7	17836	18394	1579	67294	11280	3856
9	17874	18355	1438	67116	11253	3986
10	17523	17960	3289	58208	10935	3832
11	16761	17437	1974	62082	10592	3814

Study results

The key results of historical case simulation studies are given in Table 32.

Table 32 QNI separation: Queensland import historical trip results for QNI – Queensland import

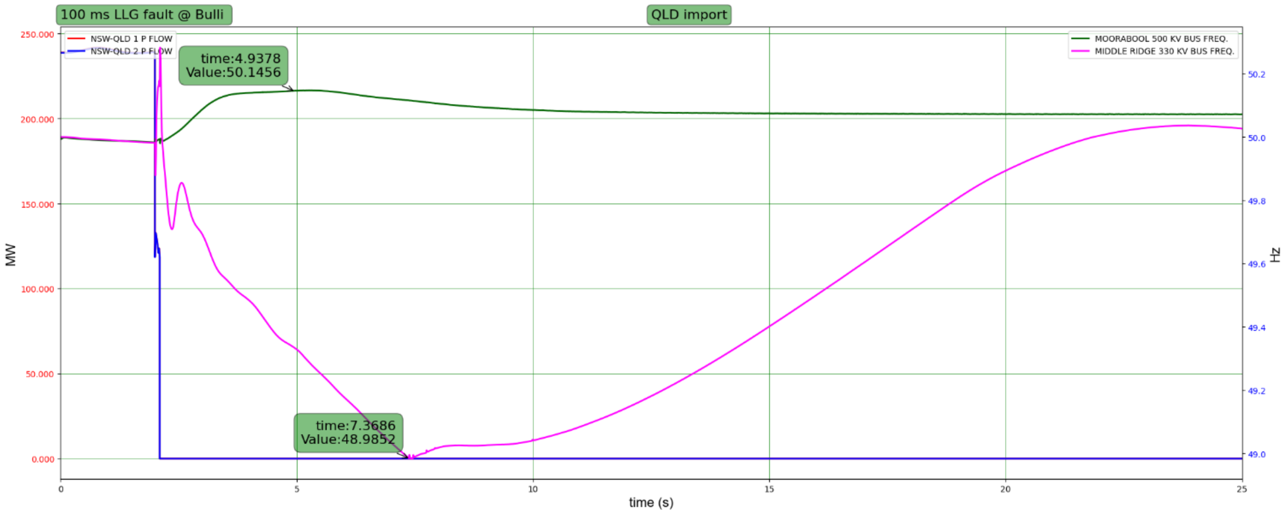
Case	Region	Freq peak (Hz)	Freq nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% Total DPV tripped
1	QLD	50.28	48.98	0.44	304	9.69	0	0
	Remaining mainland	50.16	49.99	0.03	0	0	0	0
	TAS	50.12	50	0.15	-	-	-	-
2	QLD	50.22	48.98	0.34	657	15.49	102	15.98
	Remaining mainland	50.17	49	0.16	0	0	0.29	0.02
	TAS	50.12	50	0.04	-	-	-	-
3	QLD	50.11	48.99	0.26	287	6.84	85.12	15.55
	Remaining mainland	50.14	50	0.15	0	0	0.19	0.01
	TAS	50.11	50	0.02	-	-	-	-
6	QLD	50.15	48.94	0.40	688	14.22	362	16.86
	Remaining mainland	50.18	50	0.14	0		2.6	0.07
	TAS	50.12	50	0.05	-	-	-	-
7	QLD	50.1	48.97	0.27	644	11.27	305	15.09
	Remaining mainland	50.17	50	0.13	0	0	2.38	0.06
	TAS	50.12	50	0.03	-	-	-	-
9	QLD	50.17	48.97	0.24	630	11.10	315	14.75
	Remaining mainland	50.15	50	0.03	0	0	1.59	0.04
	TAS	50.13	50	0.11	-	-	-	-
10	QLD	50	49.53	0.14	0	0	203	9.28
	Remaining mainland	50.05	50	0.05	0	0	0.07	0
	TAS	50.05	50	0.01	-	-	-	-
11	QLD	50.19	48.96	0.37	678	13.65	349	15.99
	Remaining mainland	50.15	50	0.12	0	0	3.58	0.10
	TAS	50.11	50	0.02	-	-	-	-

A. Includes DPV tripped on UFLS action and on protection settings.

Representative results

For QNI – Queensland import case 1, Queensland frequency dropped just below 49 Hz after the QNI trip while Queensland was importing 496 MW. The QNI flow and Queensland and New South Wales frequency for Case 1 are included in Figure 12.

Figure 12 Case 1 Queensland separation at Bulli Creek: QNI P flows and Queensland and remaining mainland frequencies



A6.3.2 QNI – Queensland export condition

Study scenarios

Seven historical cases were considered for the Queensland separation due to loss of QNI (QNI – Queensland export). Case details are given in Table 33 and Table 34.

Table 33 QNI separation: Queensland export historical cases Queensland variables

Case	Operational demand (MW)	Pgen (MW)	export (MW)	Renewables (MW)	Inertia (MWs)	Underlying UFLS load (MW)	Total QLD DPV (MW)
1	7023	8604	1345	126	41427	3781.7	0
2	7929	9508	1347	370	34467	4202	1447
5	5799	7266	1292	764	23254	3857	1320
6	6710	8253	1310	498	32265	3724	620
8	6236	7583	1164	893	26124	3401	1796
9	6031	7637	1374	954	23254	3299	1431
11	6872	8276	1182	399	26008	3808	1148

Table 34 QNI separation: Queensland export historical export cases remaining mainland variables

Case	Operational demand (MW)	Pgen (MW)	Renewable generation (MW)	Inertia (MWs)	Underlying UFLS (MW)	Total DPV (MW)
1	20077	18935	400	91490	13202	0
2	19185	18718	1198	75598	12043	2808
5	13785	12993	1368	50461	11201	1970
6	17813	17412	2638	75887	11212	1197
8	13280	12929	3258	48965	7746	2348
9	12103	13912	1548	44671	8755	1323
11	13816	14727	1504	49630	10144	1495

Study results

The key results of historical case simulation studies are given in Table 35.

Table 35 QNI separation: Queensland export historical trip results for QNI - Queensland export

Case	Region	Frequency peak (Hz)	Frequency nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	DPV tripped including protection[10] (MW)	% Total DPV tripped
1	QLD	52.5	50	0.37	0	0	0	0
	Remaining mainland	50	49	0.24	469	3.56	0	0
	TAS	50	48.95	0.33	-	-	-	-
2	QLD	51.14	50	0.28	0	0	223	15.43
	Remaining mainland	50	48.99	0.23	819	6.80	238	8.49
	TAS	50	47.88	0.79	58	-	-	-
5	QLD	51.52	50	0.33	0	0	319	24.2
	Remaining mainland	50	48.96	0.29	1396	12.46	245	12.41
	TAS	50	48.63	0.49	-	-	-	-
6	QLD	51.68	50	0.34	0	0	117	18.83
	Remaining mainland	50	49	0.19	727	6.48	80	6.68
	TAS	50	47.71	0.85	123	-	-	-
8	QLD	51	50	0.23	0	0	288	16.02
	SA	50.86	48.96	2.17	55	7.5	34	12.82
	Remaining mainland	50	48.96	0.39	1118	14.43	216	9.21
	TAS	50	47.81	1.09	64	-	-	-
9	QLD	51.12	50	0.33	0	0	368	25.70
	Remaining mainland	50	48.95	0.29	1173	13.40	128	9.69
	TAS	50	47.66	1.01	135	-	-	-
11	QLD	51.19	50	0.23	0	0	216	18.81
	Remaining mainland	50	49	0.24	372	3.67	54	3.61
	TAS	50	47.9	0.92	74	-	-	-

Representative results

For QNI – Queensland export Case 1, Queensland frequency increased to 52.5 Hz following the QNI trip and the frequency in the rest of the NEM dropped to 49 Hz. Some of the Queensland synchronous generators tripped on their over-frequency protection, which helped frequency recover back to 50 Hz. The QNI flow and Queensland and New South Wales frequency for Case 1 is shown in Figure 13.

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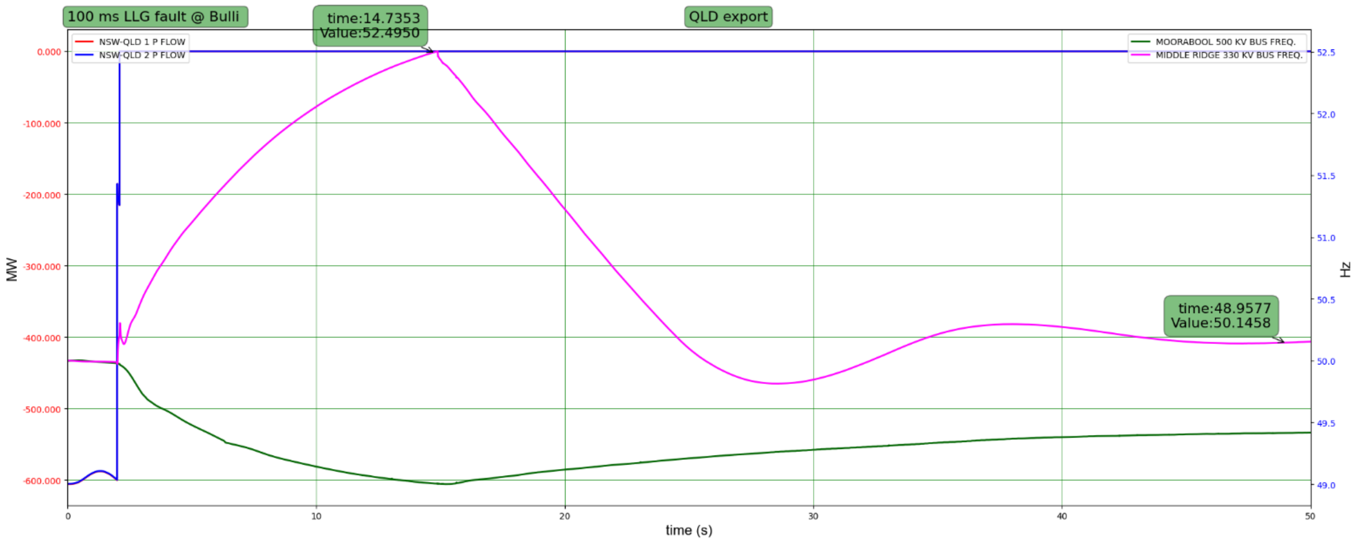
[10] Includes DPV tripped on UFLS action and on protection settings

Figure 13 Case 1 Queensland separation at Bulli Creek: QNI P flows and Queensland and frequencies in the rest of the NEM



Impact of IBR frequency response

During the 2022 PSFRR consultation period, AEMO identified a need to undertake additional sensitivity studies with IBR frequency control disabled for historic studies where there is a risk of over-frequency.

AEMO understands that ahead of implementing and enabling PFR capabilities, many IBR generators disable frequency responsiveness, despite providing models to AEMO with these frequency controls enabled. Additional studies were therefore undertaken to assess the frequency outcomes with IBR over-frequency response disabled.

The specific contingencies that will be most impacted are:

- South Australia separation from HYTS and MLTS when South Australia is exporting (presented in Sections 5.2.3 and 5.3.3).
- Queensland synchronous separation for a non-credible loss of QNI when Queensland is exporting (presented in Section 5.4.3 and in this section).

As Queensland does not have OFGS implemented, to assess the impact of IBR frequency response on QNI loss, AEMO repeated the historical Queensland export cases referred in Table 33 with all Queensland IBR frequency response disabled. The corresponding maximum values of key power system variables observed during simulations are summarised in Table 36. The difference in frequency peak, RoCoF and the amount of DPV trips with and with without Queensland IBR frequency responses are also included in Table 37.

Table 36 QNI separation sensitivity study: Queensland export historical trip results for QNI – Queensland export

Case	Region	Frequency peak (Hz)	Frequency nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	DPV tripped including protection[A] (MW)	% Total DPV tripped
1	QLD	52.5	50	0.55	0	0	0	0
	Rest of NEM	50	49	0.35	469	3.56	0	0
	TAS	50	48.95	0.18	-	-	-	-
2	QLD	51.2	50	0.50	0	0	221	15
	SA	50.45	49.66	0.35	0	0	2.5	0.4
	Rest of NEM	50	48.93	0.34	1397	13	215	9.6
	TAS	50.19	47.8	0.67	58	-	-	-
5	QLD	51.61	50	0.63	0	0	323	24.5
	SA	50.18	49.6	0.35	0	0	0	0
	Rest of NEM	50	49.93	0.43	1236	27	111	11
	TAS	50.1	48.6	0.11	-	-	-	-
6	QLD	51.92	50	0.61	0	0	121	19.6
	SA	50.24	49.67	0.27	0	0	0	0
	Rest of NEM	50	49.94	0.33	915	19	79	8
	TAS	50.14	47.7	0.1	123	-	-	-
8	QLD	51.18	50	0.45	0	0	296	16.5
	SA	50.58	49.65	0.33	0	0	0	0
	Rest of NEM	50.17	48.82	0.37	1813	44	318	14
	TAS	50.44	47.72	0.14	128	-	-	-
9	QLD	51.63	50	0.34	0	0	368	25.8
	SA	50.28	49.63	0.41	0	0	0	0
	Rest of NEM	50.16	48.93	0.5	1596	38	106	9
	TAS	50.43	47.66	0.06	135	-	-	-
11	QLD	51.3	50	0.49	0	0	215	18.75
	Rest of NEM	50	49	0.34	372	3.67	53.9	3.6
	TAS	50	47.9	0.7	74	-	-	-

A. Includes DPV tripped on UFLS action and on protection settings.

Table 37 QNI separation sensitivity study Queensland results comparison

Case	Difference in frequency peak (Hz)	Difference in max RoCoF (Hz/s)	Difference in DPV tripped including protection[A] (MW)	Difference in % total DPV tripped
1	0	0.18	0	0
2	0.06	0.22	-2	-0.43
5	0.09	0.3	4	0.3
6	0.24	0.27	4	0.77
8	0.18	0.22	8	3.68
9	0.51	0.012	0	0.1
11	0.11	0.26	-1	-0.05

A. Includes DPV tripped on UFLS action and on protection settings.

A6.4 Contingency 4 – loss of both 275 kV lines between Calvale – Halys

A6.4.1 QNI – Queensland import condition

Study scenarios

Six historical cases were considered for the Calvale – Halys separation (QNI – Queensland import). Case details are given in Table 38.

Table 38 Loss of both 275 kV lines between Calvale – Halys cases considered (QNI – Queensland import)

Case	QNI – Queensland import (MW)	Calvale – Halys Flow (MW)	CQ-SQ eastern corridor (MW)	CQSQ Flow (MW)	Load available for tripping (MW)	Gen available for tripping (MW)
8	557	731	816	1547	405	1135
11	492	546	844	1390	172	1204
12	420	530	799	1329	172	1193
13	156	519	741	1260	176	1046
17	242	884	1151	2035	184	1110
18	323	809	1117	1926	184	1089

Study results

The key results of the historical case simulation studies are given in Table 39.

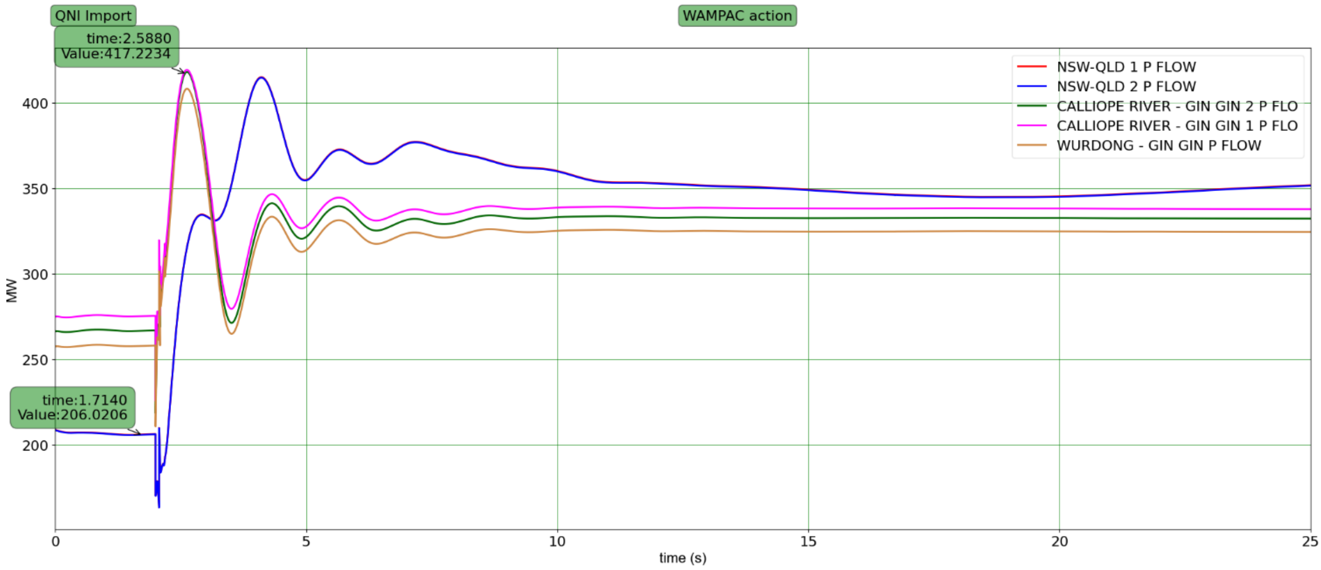
Table 39 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI - Queensland import)

Case	WAMPAC required Gen to Trip (MW)	WAMPAC required Load to trip (MW)	Net Gen Tripped (MW)	Net Load tripped (MW)	DPV tripped in QLD on protection only (MW)	Target load/gen available to WAMPAC	Simulation outcome
8	596	0	759	0	135	No	Stable
11	386	0	413	0	107	No	Stable
12	305	0	410	0	65	No	Stable
13	213	0	399	0	32	No	Stable
17	1247	300	1110	184	35	Yes	Stable
18	1101	144	1089	184	37	Yes	Stable

Representative results

The QNI and 275 kV CQ-SQ eastern corridor line flows following the loss of Calvale-Halys lines for Case 12 with Queensland import are shown in Figure 14.

Figure 14 **Case 12 key line flows: Calvale – Halys 1 and 2 trip during Queensland import**



A6.4.2 QNI – Queensland export condition

Study scenarios

Eight historical cases were considered for the Calvale – Halys separation (QNI – Queensland export). Case details are given in Table 40.

Table 40 **Loss of both 275 kV lines between Calvale – Halys cases considered (QNI – Queensland export)**

Case	QNI – Queensland export (MW)	Calvale – Halys Flow (MW)	CQ-SQ eastern corridor (MW)	CQSQ Flow (MW)	Load available for tripping (MW)	Gen available for tripping (MW)
1	1219	664	548	1212	172	1119
2	1159	636	583	1219	178	1124
3	789	1064	1025	2089	176	881
4	673	1009	922	1931	80	1218
5	1052	1033	946	2009	90	1224
6	587	1027	1051	2078	416	1170
7	1173	953	1107	2060	170	872
9	1129	946	1118	2064	170	961

Study results

The key results of the historical case simulation studies are given in Table 41.

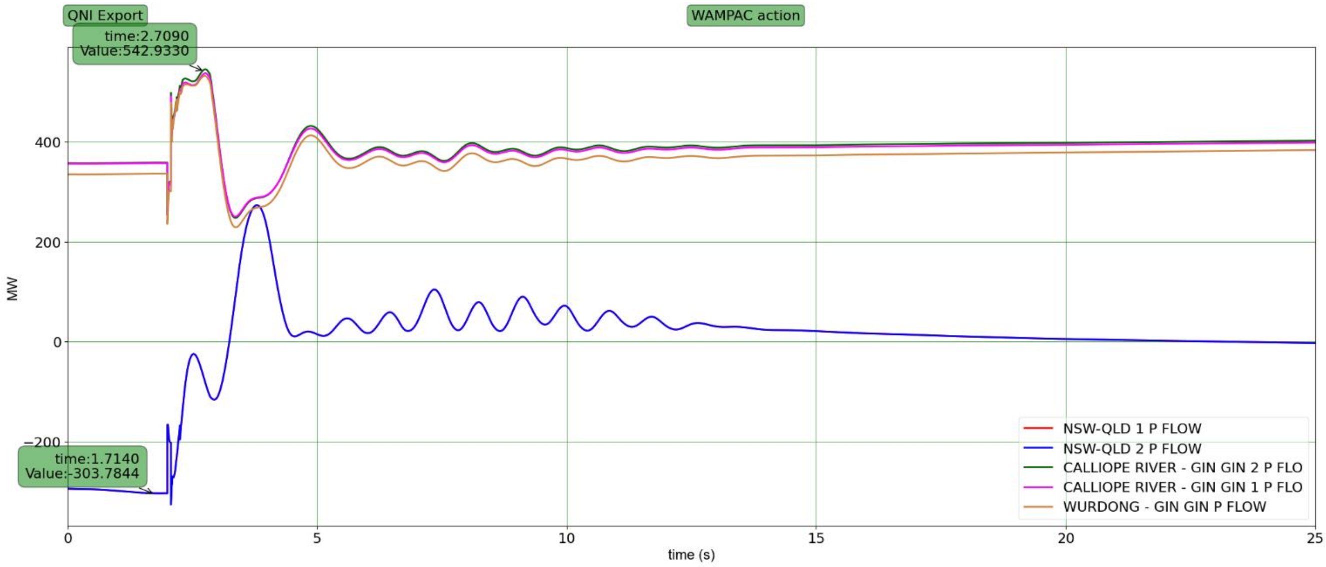
Table 41 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI - Queensland export)

Case	WAMPAC required Gen to Trip (MW)	WAMPAC required Load to trip (MW)	Net Gen Tripped (MW)	Net Load tripped (MW)	DPV tripped in QLD on protection only (MW)	Deficiency in WAMPAC Gen/Load trip	Simulation outcome
1	149	0	414	0	8	No	Stable
2	158	0	401	0	24	No	Stable
3	1319	377	881	176	0	Yes	Stable
4	1108	151	1125	80	5	Yes	Stable
5	1212	263	1224	90	2	Yes	Stable
6	1304	361	1170	416	171	Yes	Stable
7	1280	336	872	170	115	Yes	Stable
9	1285	341	961	170	76	Yes	Stable

Representative results

The QNI and 275 kV CQ-SQ eastern corridor line flows following the loss of Calvale-Halys lines for Case 6 with Queensland export are shown in Figure 15.

Figure 15 Case 6 key line flows: Calvale – Halys 1 and 2 trip during Queensland export



A6.5 Contingency 5 – non-credible loss of VNI

The non-credible simultaneous loss of the VNI lines (Murray – Lower Tumut, Murray – Upper Tumut and Jindera – Wodonga) was considered for Victorian import and export conditions. Both historical and future (2027) operating boundary conditions were included in the study.

A6.5.1 Victorian import condition

Study scenarios

Eight historical cases were considered for the non-credible loss of the VNI lines (Victorian import). Case details are given in Table 42.

Table 42 Loss of VNI lines: Historical cases considered (Victorian import)

Case	VIC operational demand (MW)	VIC import (MW)	VIC inertia (MWs)	VIC underlying UFLS load (MW)	Total VIC DPV (MW)	VIC renewables (MW)
1	4860	945	14802	3179	616	309
2	4787	970	14932	2777	0	348
5	5168	795	16303	3233	402	306
6	5356	1133	13540	3480	611	889
7	5266	1004	13540	3507	638	955
8	4291	660	11752	3206	1272	308
9	4305	680	11752	3192	1124	395
10	4938	1035	13540	3440	804	765

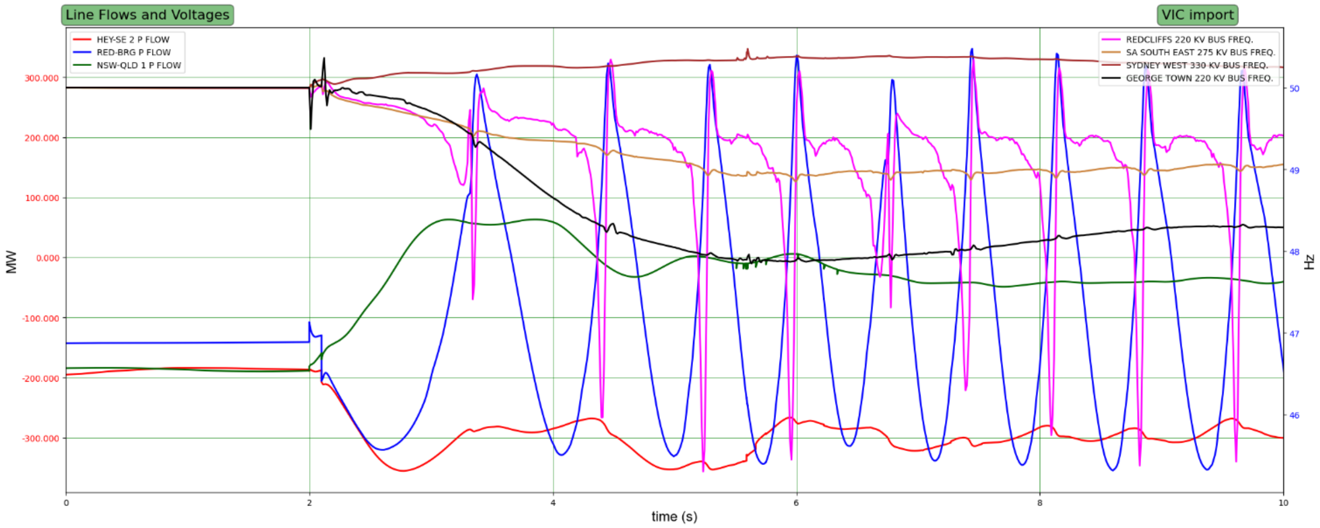
Study results

All the contingency cases considered for the studies were found to lose stability and fail indicating potential for multiple line loss and instability.

Representative results

All VNI import cases were found to be unstable and large oscillations can be observed in the results. This contingency will lead to the loss of multiple lines and voltage collapse. A typical result is shown in Figure 16.

Figure 16 Case 2 non-credible loss of VNI lines (Victorian import): Line flows and frequencies



A6.5.2 Victorian export condition

Study scenarios

Nine historical cases were considered for the non-credible loss of the VNI lines (Victorian export). Case details are given in Table 43.

Table 43 Loss of VNI lines: Historical cases considered (Victorian export)

Case	VIC operational demand (MW)	VIC export (MW)	VIC inertia (MWs)	VIC underlying UFLS load (MW)	Total VIC DPV (MW)	VIC renewables (MW)
1	4416	686	14913	3304	1358	1163
2	4518	608	15379	3404	1280	5039
3	3795	1338	18486	2772	1087	1231
4	3668	1423	18390	2085	0	1524
5	4800	513	19252	3563	1423	530
6	3882	1305	18390	2153	0	1491
7	3588	1168	18390	2676	823	1610
8	4737	989	16679	2880	0	1589
9	4411	669	15009	3310	1299	0

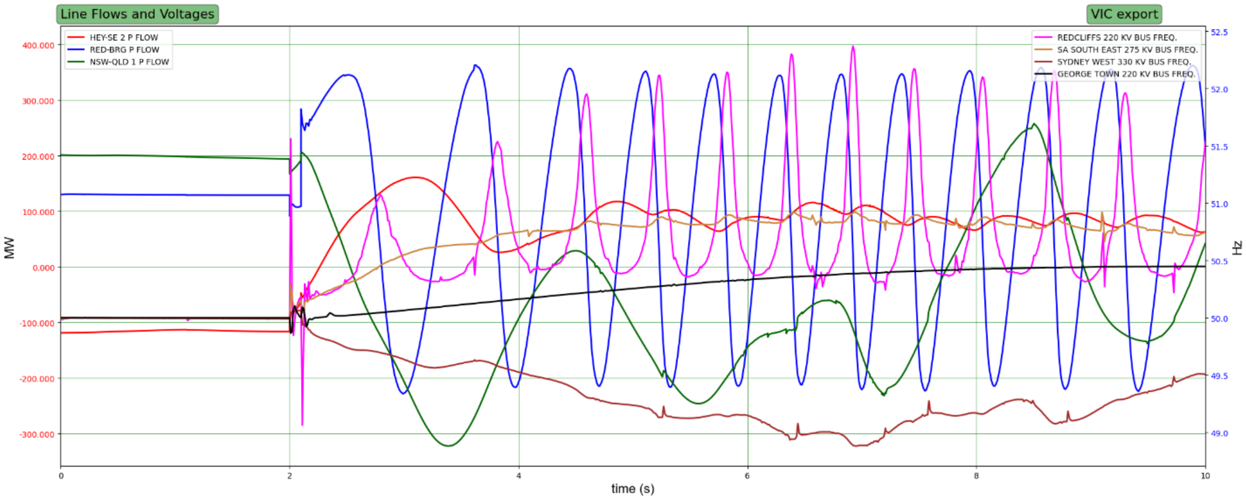
Study results

All the contingency cases considered for the studies found to lose stability and failed indicating multiple line loss and instability.

Representative results

All VNI Export cases were found to be unstable and large oscillations can be observed in the results. The contingency will lead to the loss of multiple lines and voltage collapse. A typical result is shown in Figure 17.

Figure 17 Case1 non-credible loss of VNI lines (Victorian export): Line flows and frequencies



A6.6 Contingency 6 – Mt Lock 275 kV bus bar failure

Study scenarios

Seven historical cases were considered for the non-credible contingency of Mt Lock 275 kV bus bar failure. Case details are given in Table 44.

Table 44 Mt Lock 275 kV bus bar failure: system operating points for the historical cases.

Case	SA operational demand (MW)	SA HIC import (MW)	SA inertia (MWs)	Hornsdale WFs (MW)	Hornsdale BESS (MW)	Hornsdale total output (MW)	SA renewables (MW)
1	2434	538	12853	232	-27	205	812
2	1449	550	5548	182	16	198	537
3	2474	-604	14934	143	-8	135	501
4	1653	-496	7727	135	25	160	439
5	1520	-530	13134	163	0	163	211
6	2248	428	14934	222	-7	215	590
7	2528	494	16155	121	51	172	467

Study results

The key results of the historical case simulation studies are given in Table 45.

Table 45 Mt Lock 275 kV bus bar failure: results of the historical cases.

Case	Region	Freq nadir range (Hz)	RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	Total DPV tripped (MW)	Total DPV tripped on protection only (MW)	% DPV tripped
1	SA	49.89	0.10	0	0	0	38	5
2	SA	49.87	0.07	0	0	0	5	8
3	SA	49.94	0.10	0	0	0.11	0.11	4.9
4	SA	49.87	0.21	0	0	0	0	0
5	SA	49.90	0.24	0	0	0	0	0
6	SA	49.92	0.14	0	0	0	0	0
7	SA	49.93	0.13	0	0	16.2	16.2	4.8

A6.7 Contingency 7 – loss of both Dederang to South Morang 330 kV lines

The non-credible loss of both Dederang to South Morang 330 kV lines under IECS modes 1a, 1b, and 1c was considered during high Victorian import and export conditions.

A6.7.1 Victorian import condition

Study scenarios

Three historical cases were considered for the loss of both Dederang to South Morang 330 kV lines (Victorian import). Historical cases were selected for study primarily based on maximum/high Victorian import flows on Dederang to South Morang 330 kV lines (as high line flows will present more onerous conditions during the contingency). Coincident with high flows on Dederang to South Morang 330 kV lines, Victorian inertia varied from 39,614 MWs to 43,305 MWs and Victorian operational demand ranged from 8,674 to 9,122 MW. Case details are given in Table 46.

Table 46 Loss of Dederang to South Morang 330 kV lines: system operating points for the historical cases – Victoria variables (Victorian import)

Case	Operational demand (MW)	Import (MW)	Inertia (MWs)	Total load available for load shedding (MW)			Total generation available for generation shedding (MW)			Renewables (MW)
				1a	1b	1c	1a	1b	1c	
2	8916	858	40799	1716	1292	1292	577	577	488	438
6	9122	639	43305	1563	1234	1234	519	519	448	269
8	8674	1069	39614	1526	1134	1134	591	591	501	537

Study results

The key results of the historical case simulation studies for the IECS mode 1a are given in Table 47.

Table 47 Loss of Dederang to South Morang 330 kV lines: results of the historical cases for mode 1a – Victoria variables (Victorian import)

Case	Frequency peak (Hz)	Frequency nadir (Hz)	RoCoF (Hz/s)	Total load shed (MW)	Total generation shed (MW)
2	50.12	49.93	0.071	1231	577
6	50.08	49.92	0.042	1187	519
8	50.09	49.95	0.057	1090	591

The key results of the historical case simulation studies for the IECS mode 1b are given in Table 48.

Table 48 Loss of Dederang to South Morang 330 kV lines: results of the historical cases for mode 1b – Victoria variables (Victorian import)

Case	Frequency peak (Hz)	Frequency nadir (Hz)	RoCoF (Hz/s)	Total load shed (MW)	Total generation shed (MW)
2	50.13	50	0.069	1292	577
6	50.08	50	0.042	1234	519
8	50.1	50	0.048	1134	591

The key results of the historical case simulation studies for the IECS mode 1c are given in Table 49.

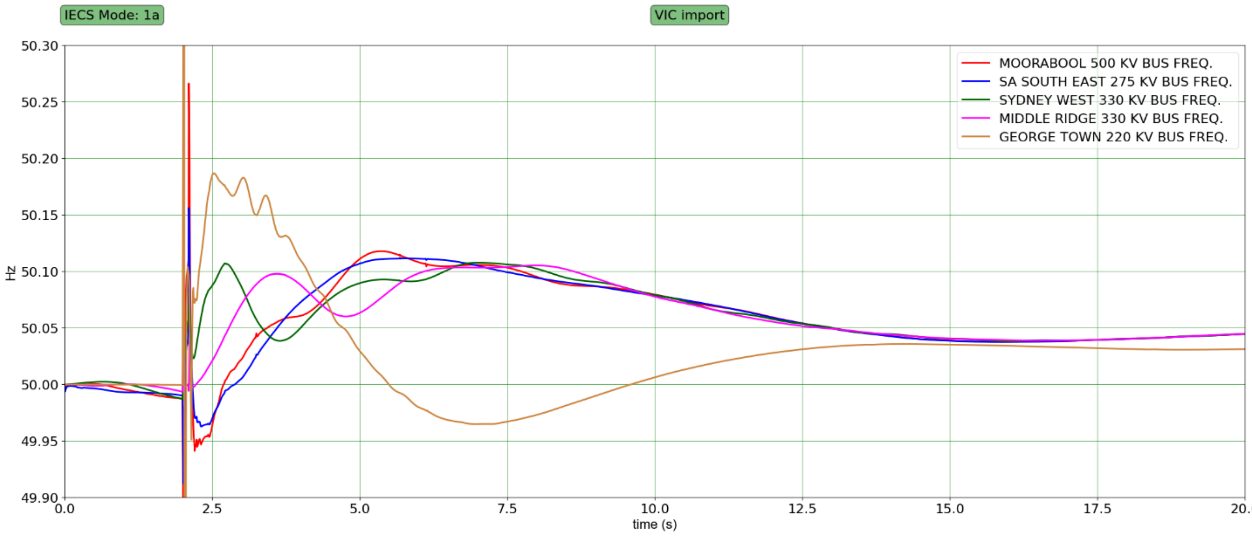
Table 49 Loss of Dederang to South Morang 330 kV lines: results of the historical cases for mode 1c – Victoria variables (Victorian import)

Case	Frequency peak (Hz)	Frequency nadir (Hz)	RoCoF (Hz/s)	Total load shed (MW)	Total generation shed (MW)
2	50.14	50	0.065	1292	488
6	50.1	50	0.052	1234	448
8	50.11	50	0.046	1134	501

Representative results

All cases considered for the non-credible loss of both Dederang to South Morang 330 kV lines were stable and a typical simulation result for Case 2 is included in Figure 18.

Figure 18 Case 2 Dederang-South Morang line loss (Victorian import): Regional frequencies



A6.7.2 Victorian export condition

Study scenarios

Ten historical cases were considered for the loss of both Dederang to South Morang 330 kV lines (Victorian export). Case details are given in Table 50.

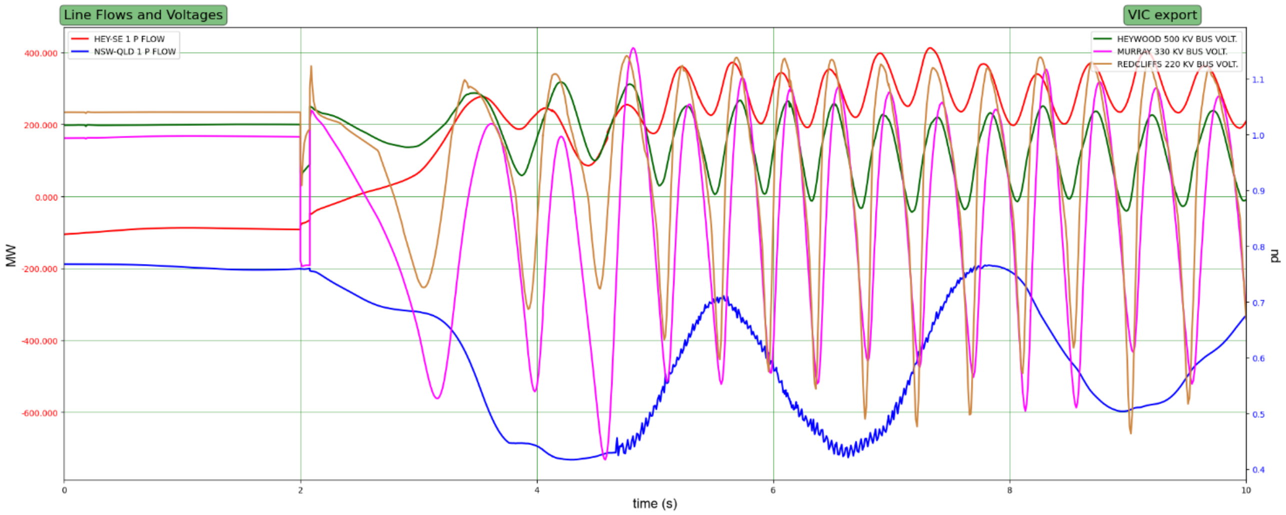
Table 50 Loss of Dederang to South Morang 330 kV lines: system operating points for the historical cases – Victoria variables (Victorian export)

Case	Operational demand (MW)	Export (MW)	Inertia (MWs)	Total load available for load shedding (MW)	Total generation available for generation shedding (MW)	Renewables (MW)
1	3984	1168	17606	-	-	799
2	3882	1306	18390	-	-	1490
3	3668	1423	18390	-	-	1524
4	4163	1169	17606	-	-	968
5	4172	977	14854	-	-	1197
6	4142	933	14854	-	-	1254
7	3836	1397	17606	-	-	510
8	4288	941	14854	-	-	1295
9	3717	1429	17606	-	-	669
10	4385	1255	18509	-	-	1552

Representative results

All Victorian export historical cases were unstable. Studies indicate that the loss of both Dederang to South Morang 275 kV lines during high export from Victoria could lead to subsequent outages. A typical power system response following the event is given in Figure 19.

Figure 19 Case 1 Dederang-South Morang line loss (Victorian export): Line flows and bus voltages



A6.8 Contingency 8 – loss of Columboola – Western Downs 275 kV lines

Study scenarios

Eight historical cases were considered for the non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines. Case details are given in Table 51.

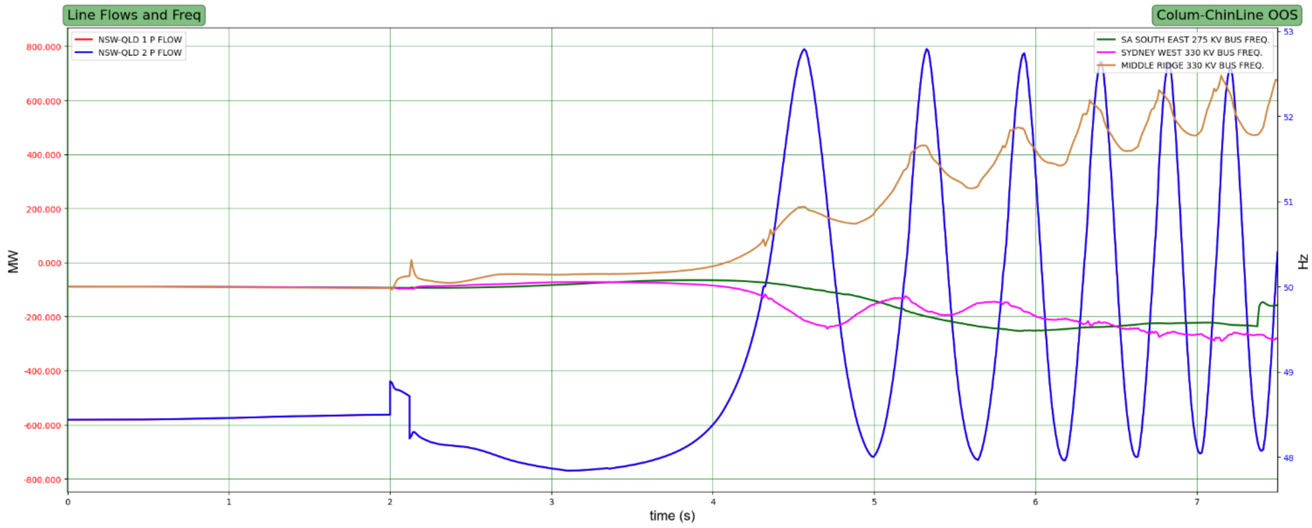
Table 51 Case details: non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines – Queensland variables

Case	Operational load (MW)	QNI – Queensland export (MW)	Surat net load (MW)	WDow-Col (MW)	Orana-Col (MW)	Col-WanS (MW)	Chin-Col (MW)
1	5396	1209	527	260	301	403	48
2	7285	1193	519	259	298	410	18
3	7805	1182	511	251	289	406	24
4	4854	1177	531	277	262	398	61
5	6133	1169	548	271	314	409	36
6	5605	1164	572	299	283	405	46
7	4877	1169	573	297	281	374	0
8	4631	1166	563	291	276	375	0

Representative results

The QNI flow and power system frequencies for Case 7 are given in Figure 20, where QNI becomes unstable following the contingency.

Figure 20 Case 7 non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines



Additional studies

The details of three additional cases considered for the non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines are given in Table 52.

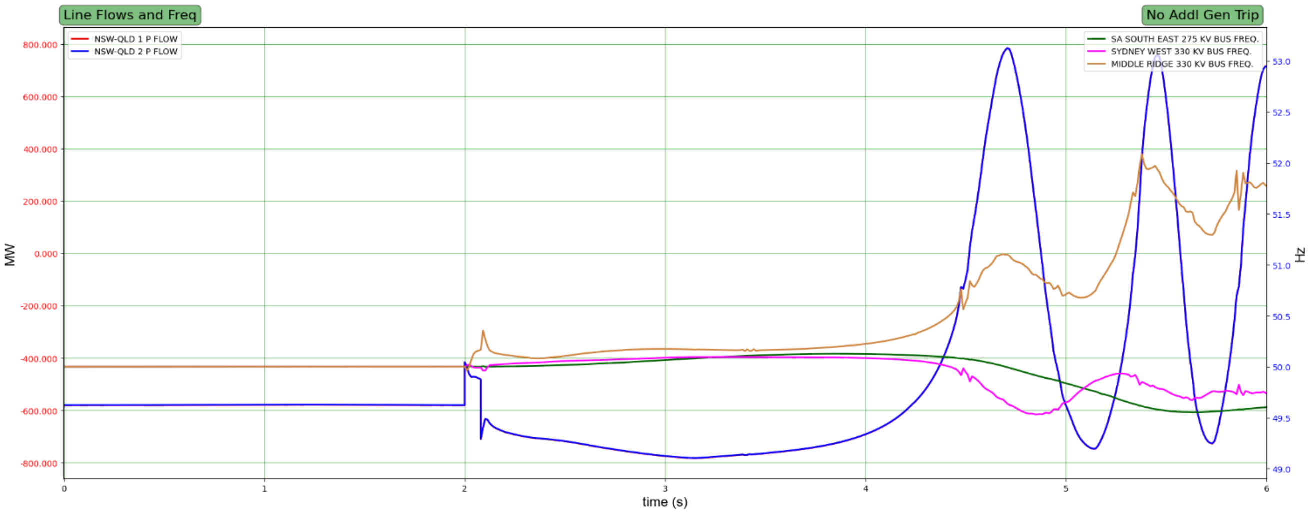
Table 52 Details of the additional cases: non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines – Queensland variables

Case	Operational demand (MW)	QNI – Queensland export (MW)	Surat net load (MW)	Generation at Columboola 132 kV (MW)	Orana-Col (MW)	WDow-Col (MW)	Col-WanS (MW)	Tripped generation (MW)
1	5105	1186	571	0	280	297	382	462
2	4669	1189	571	0	280	297	383	-
3	5359	1185	605	0	298	314	405	502

Representative results

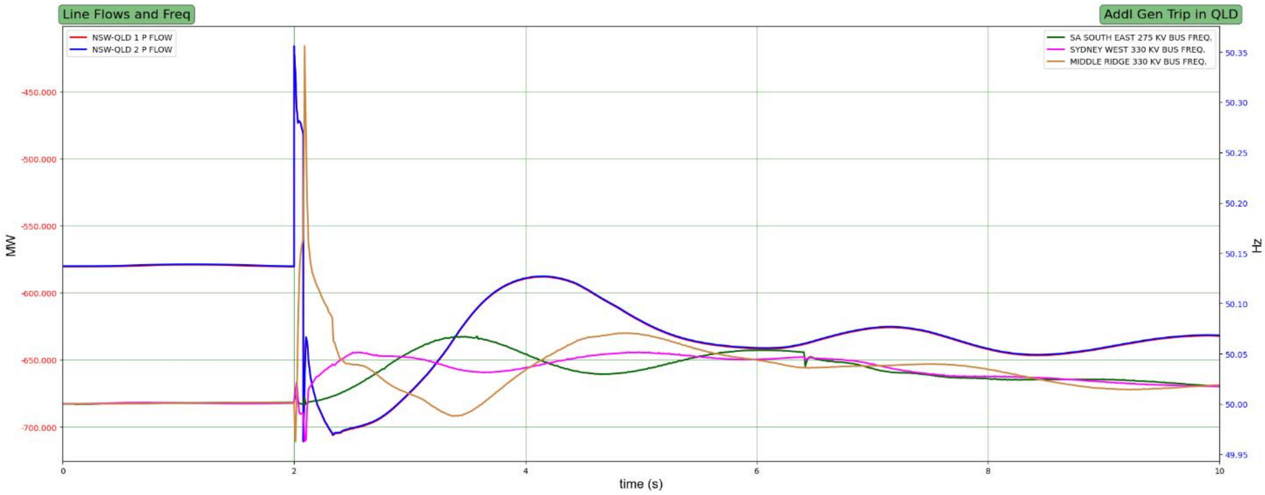
The QNI flow and system frequencies for the additional Case 1 are given in Figure 21, where QNI becomes unstable following the contingency.

Figure 21 Additional Case 1: System frequencies and QNI flows without additional generation trip



The QNI flow and power system frequencies for the additional Case 1 with 462 MW additional generation tripped in Queensland following the contingency were stable and are given in Figure 22.

Figure 22 Additional Case 1: Power system frequencies and QNI flows with 462 MW of additional generation trip



A6.9 Contingency 9 – simultaneous loss of multiple Loy Yang generating units

Study scenarios

Ten historical cases were considered for the loss of various Loy Yang generating units. The details of Loy Yang unit dispatches and the power system variables for each region are given in Table 53 and Table 54, respectively.

Table 53 Loy Yang generation unit

Case	LYA unit 1 (MW)	LYA unit 2 (MW)	LYA unit 3 (MW)	LYA unit 4 (MW)	LYA total (MW)	LYB unit 1 (MW)	LYB unit 2 (MW)	LYB total (MW)
1	558	529	558	559	2204	536	535	1071
2	563	534	562	564	2223	538	537	1075
3	557	529	536	548	2170	535	533	1068
4	552	523	554	484	2113	537	531	1068
5	561	529	563	562	2215	538	539	1077
6	556	530	559	562	2207	535	577	1112
7	561	531	562	561	2215	534	573	1107
8	549	521	548	548	2166	524	525	1049
10	502	506	532	510	2050	464	486	950
11	558	525	556	549	2188	529	527	1056

Table 54 Loy Yang cases regional variables

Case	Region	Operational demand (MW)	Pgen (MW)	Export (MW)	Renewable generation (MW)	Inertia (MWs)	Underlying UFLS load (MW)	Total DPV (MW)
1	NSW	6272	6085	-374	755	31573	4080	0
	VIC	4042	4917	774	254	17606	2354	0
	QLD	5628	6321	562	16	33790	2925	0
	SA	1098	654	-475	140	11265	761	0
	TAS	983	526	-487	0	7197	-	-
2	NSW	7623	7896	-795	593	32848	5436	876
	VIC	4244	5753	442	91	17606	3120	982
	QLD	5957	8611	914	409	32270	4060	1570
	SA	934	1519	-61	214	13312	1136	627
	TAS	1097	630	-499	0	6620	-	-
3	NSW	7996	7945	-266	780	33981	5039	6
	VIC	5065	5540	337	573	20318	3154	29
	QLD	7346	8102	521	0	39753	3872	5
	SA	1499	1512	-98	484	14034	1078	81
	TAS	1129	673	-494	0	6355	-	-

Case	Region	Operational demand (MW)	Pgen (MW)	Export (MW)	Renewable generation (MW)	Inertia (MWs)	Underlying UFLS load (MW)	Total DPV (MW)
4	NSW	8264	8227	-258	420	39231	5099	40
	VIC	5129	5560	289	758	18207	3040	7
	QLD	6407	7034	399	13	34894	3467	26
	SA	1396	1492	64	552	13134	975	0
	TAS	984	551	-492	63	5480	-	-
5	NSW	8731	9279	-785	599	36204	6198	1137
	VIC	5375	5789	-189	406	19594	3492	502
	QLD	6939	9122	781	189	32965	4362	1186
	SA	1301	1698	13	321	13257	1192	366
	TAS	910	1133	181	16	8371	-	-
6	NSW	9566	8914	-969	653	34774	6221	0
	VIC	6455	6447	-148	37	30111	4030	0
	QLD	6393	7608	1027	174	33055	3386	0
	SA	1897	1589	-358	87	16273	1456	0
	TAS	1293	1823	449	10	8540	-	-
7	NSW	8285	7978	-492	640	30853	5287	13
	VIC	5849	6622	560	630	24714	3564	51
	QLD	7040	7285	28	35	32867	3771	3
	SA	1862	1472	-544	108	12786	1510	92
	TAS	1015	1532	448	51	8461	-	-
8	NSW	10865	10965	-886	1102	42915	7447	622
	VIC	7848	7598	-733	482	32658	5266	300
	QLD	7368	9252	1073	146	37780	4222	538
	SA	1741	2368	93	358	17068	1686	498
	TAS	971	1494	453	63	8859	-	-
10	NSW	10608	11349	-795	436	47134	7644	1219
	VIC	7883	7568	-1486	981	27017	5637	980
	QLD	6600	9743	1294	164	31548	4297	1530
	SA	1422	2580	500	811	14934	1471	576
	TAS	1068	1634	490	29	8845	-	-
11	NSW	8924	8939	-1124	476	33621	6112	808
	VIC	7811	7647	-644	592	37097	5219	310
	QLD	6087	8474	1323	378	34002	3650	824
	SA	1786	2139	-98	480	16184	1669	407
	TAS	936	1545	543	38	10283	-	-

Study results

The key results of the simulation studies for the loss of Loy Yang Group B generating units are given in Table 55.

Table 55 Results for Loy Yang Group B trip

Case	Region	Freq Peak (Hz)	Freq Nadir (Hz)	Underlying UFLS load tripped	DPV tripped including protection[11] (MW)	% DPV tripped	Is system security maintained (Yes/No)	QNI instability/ HIC trip
1	NSW	50	49.4	0	0	0	Yes	No/No
	VIC	50	49.4	0	0	0		
	QLD	50	49.46	0	0	0		
	SA	50	49.4	0	0	0		
	TAS	50	47.85	62.1	-	-		
3	NSW	50	49.5	0	0.02	0.35	Yes	No/No
	VIC	50	49.5	43	13	45		
	QLD	50	49.53	0	0	0		
	SA	50	49.5	0	0	0.32		
	TAS	50	48.12	-	-	-		
4	NSW	50	49.58	0	1	2.73	Yes	No/No
	VIC	50	49.59	0	3	46.16		
	QLD	50	49.58	0	0	0		
	SA	50	49.58	0	0	0		
	TAS	50	48.77		-	-		
5	NSW	50	50	0	16	1.38	Yes	No/Yes
	VIC	50	50	0	234	46.56		
	QLD	50	50	0	0	0		
	SA	50	50	0	1	0.19		
	TAS	50	50	-	-	-		
6	NSW	50	49.5	11	0	0	Yes	No/No
	VIC	50	49.5	0	0	0		
	QLD	50	49.5	0	0	0		
	SA	50	49.5	0	0	0		
	TAS	50	48.57	0	-	-		
7	NSW	50	49.54	0	0	0.14	Yes	No/No
	VIC	50	49.54	0	24	46.06		
	QLD	50	49.54	0	0	0		
	SA	50	49.54	0	0	0.30		
	TAS	50.24	48.75	-	-	-		
8	NSW	50	49.57	0	1	0.11	Yes	No/No
	VIC	50	49.57	0	137	45.61		
	QLD	50	49.54	0	0	0		
	SA	50	49.55	0	2	0.311		
	TAS	50.25	49	-	-	-		

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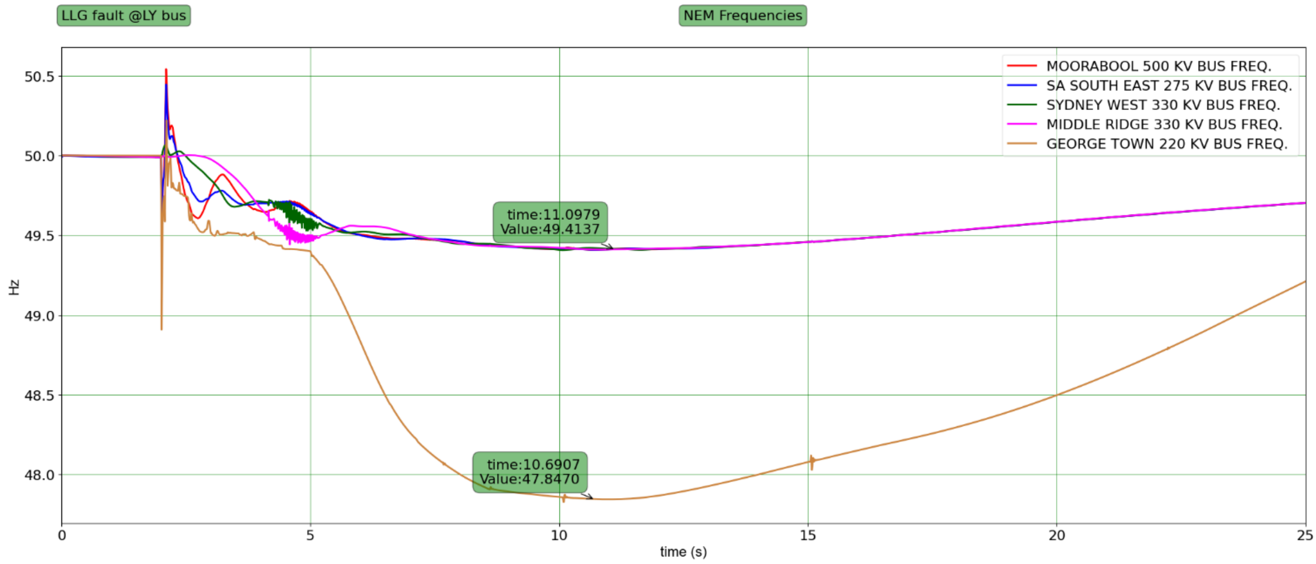
[11] Includes DPV tripped on UFLS action and on protection settings

Case	Region	Freq Peak (Hz)	Freq Nadir (Hz)	Underlying UFLS load tripped	DPV tripped including protection[11] (MW)	% DPV tripped	Is system security maintained (Yes/No)	QNI instability/ HIC trip
10	NSW	50.23	48.78	1680	199	16.3	No	Yes/Yes
	VIC	50.23	48.78	878	512	52.97		
	QLD	51.54	49.58	0	92	6		
	SA	51	48.92	124	140	24.25		
	TAS	50.27	49.08	-	-	-		
11	NSW	50.4	48.83	2213	4223.18	27.64	No	Yes/Yes
	VIC	50.4	48.84	475	153	49.48		
	QLD	51.93	49.8	0	105	12.74		
	SA	50	49.54	0	0	0		
	TAS	50.45	49.4	-	-	-		

Representative results

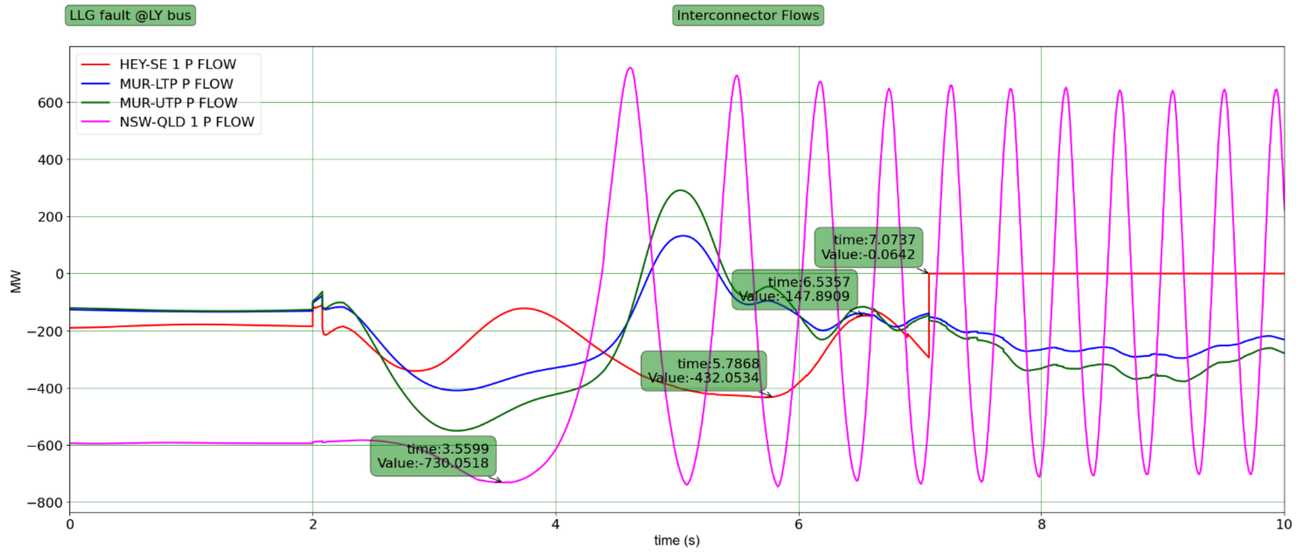
Regional frequencies following the trip of Loy Yang Group B units 1 and 2 for Case 1 are shown in Figure 23. Frequencies were found to be regulated above 49.4 Hz except for Tasmania.

Figure 23 Case 1 Loy Yang Group B units trip: NEM frequencies



The major interconnector power flows following a trip of Loy Yang Group B units 1 and 2 for Case 1 are shown in Figure 24. The figure shows that QNI loses stability and South Australia separates due to EAPT action following large power swings after the Loy Yang contingency.

Figure 24 Case 10 Loy Yang Group B units trip: major interconnector power flows



A6.10 Contingency 10 – loss of Ballarat – Waubra 220 kV, Balranald – Darlington Point 220 kV (x5) and Darlington Point – Wagga 330 kV (63) lines

Study scenarios

Twelve historical cases were considered for the loss of Ballarat – Waubra 220 kV and either the Balranald – Darlington Point 220 kV (X5) line or the Darlington Point – Wagga 330 kV (63) line. Historical cases were selected for study primarily based on high west Victoria renewable generation (as high west Victoria renewable generation will present more onerous conditions during the contingency). Times of high import into Victoria from New South Wales were selected for the study. Case details are given in Table 56.

Table 56 Loss of Ballarat – Waubra 220 kV and the Balranald – Darlington point 220 kV (X5) line or the Darlington Point – Wagga 330 kV (63) line: system operating points for the historical cases

Case	Region	Operational demand (MW)	Import (MW)	UFLS load (MW)	DPV (MW)	West VIC Renewables (MW)
1	VIC	3414	1062	1990	0	1421
	NSW	5451	-880	3689	0	819
2	VIC	3398	1060	1995	0	1467
	NSW	5423	-912	3682	0	828
3	VIC	3746	1098	2168	0	1411
	NSW	6009	-1045	4031	0	908
4	VIC	4045	1063	2310	0	1207
	NSW	6390	-1135	4318	0	899
5	VIC	3745	1070	2183	0	1396
	NSW	5988	-1023	4057	0	880
6	VIC	4260	1018	2550	0	1561

Case	Region	Operational demand (MW)	Import (MW)	UFLS load (MW)	DPV (MW)	West VIC Renewables (MW)
	NSW	6770	-1290	4365	0	713
7	VIC	3899	1165	2244	0	1289
	NSW	6186	-1111	4199	0	907
8	VIC	4246	1290	2458	0	1629
	NSW	6765	-1372	4595	0	1270
9	VIC	4101	1129	2382	0	1560
	NSW	6606	-1251	4249	0	727
10	VIC	3671	1422	2085	0	1526
	NSW	6022	-1095	3874	0	978
11	VIC	4221	665	2425	0	1481
	NSW	6971	-1223	4658	0	758
12	VIC	4244	1034	2399	0	1446
	NSW	6767	-1343	4362	0	781

Study results

The results of the simulation studies for the Loss of Ballarat – Waubra 220 kV and the Balranald – Darlington point 220 kV (x5) and the loss of Ballarat – Waubra 220 kV and the Darlington Point – Wagga 330 kV (63) showed a maximum frequency drop of -0.3 Hz and a maximum RoCoF of 0.13 Hz/s. The amount of generation tripped for the contingencies by the run back schemes varied from 700 MW to 800 MW. For both contingencies considered there were no UFLS/OFGS trips.

Representative results

The typical frequency excursion result graphs for the loss of Ballarat – Waubra 220 kV and the Balranald – Wagga 330 kV (63) lines are given in Figure 25 and Figure 26.

Figure 25 Case 3 Regional frequencies: Ballarat – Waubra 220 kV, Darlington Point – Wagga 330 kV (63) 330 kV line trips

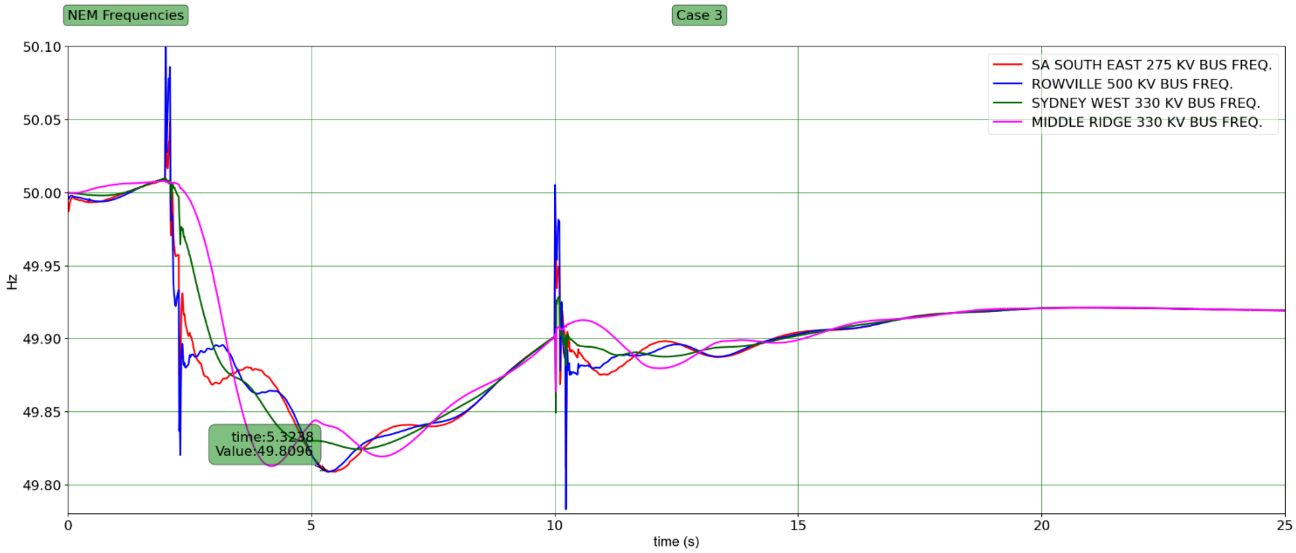
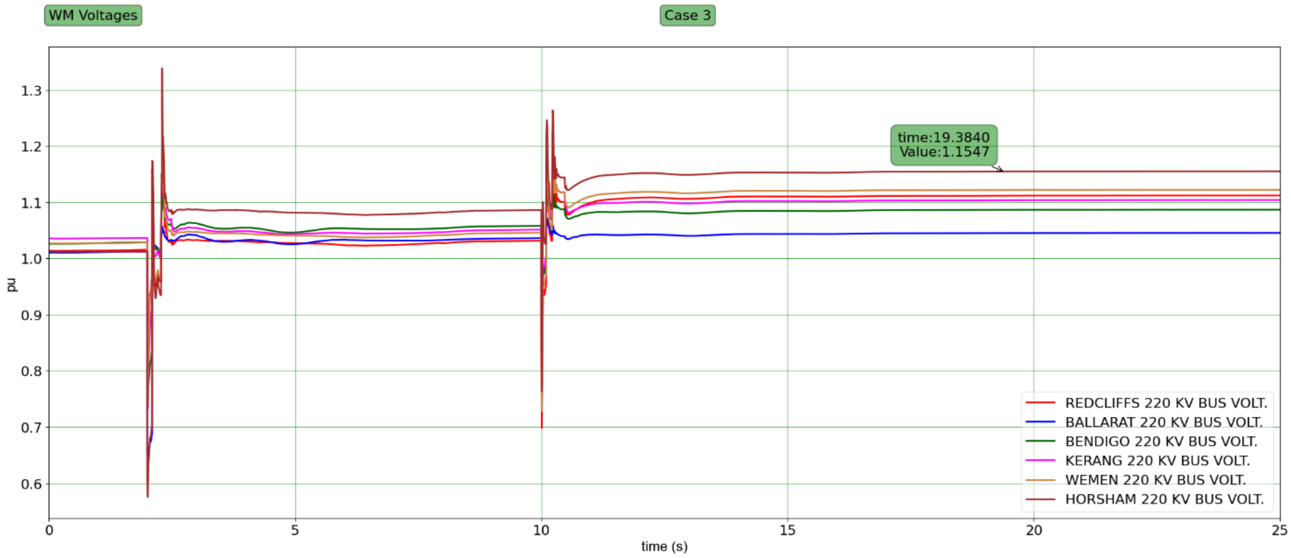


Figure 26 Case 3 West Murray voltages: Ballarat – Waubra 220 kV, Darlington Point - Wagga 330 kV (63) line trips

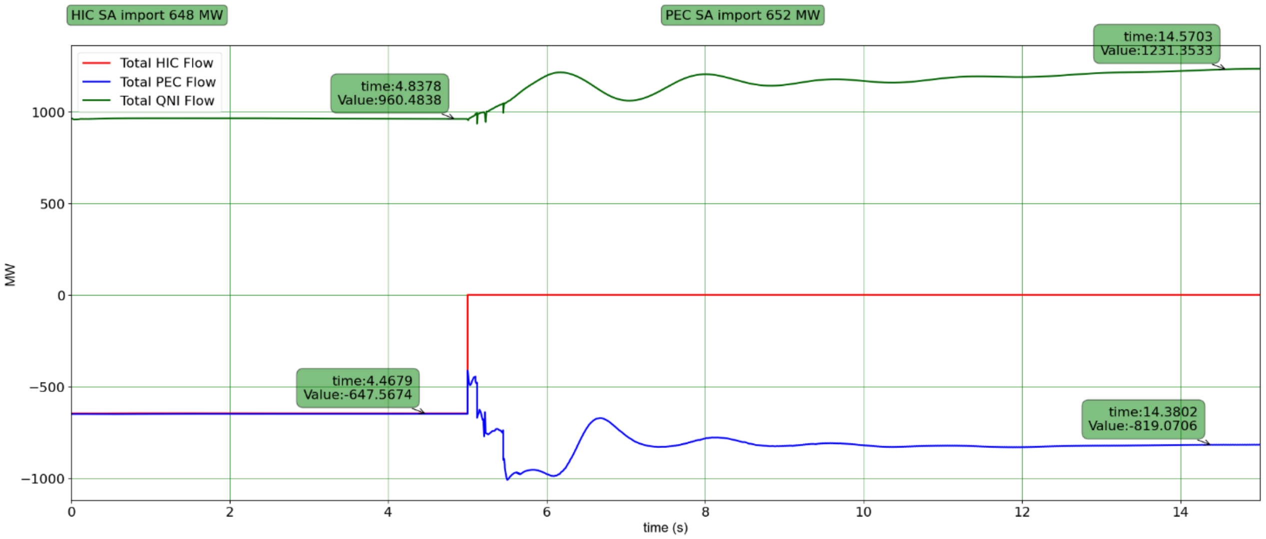


A6.11 2027 future scenario: contingency 1 – South Australia separation from HYTS – full NEM model

A6.11.1 South Australian import condition

The QNI, HIC and PEC interconnector flows following HYTS separation for the South Australian import full NEM case are shown in Figure 27.

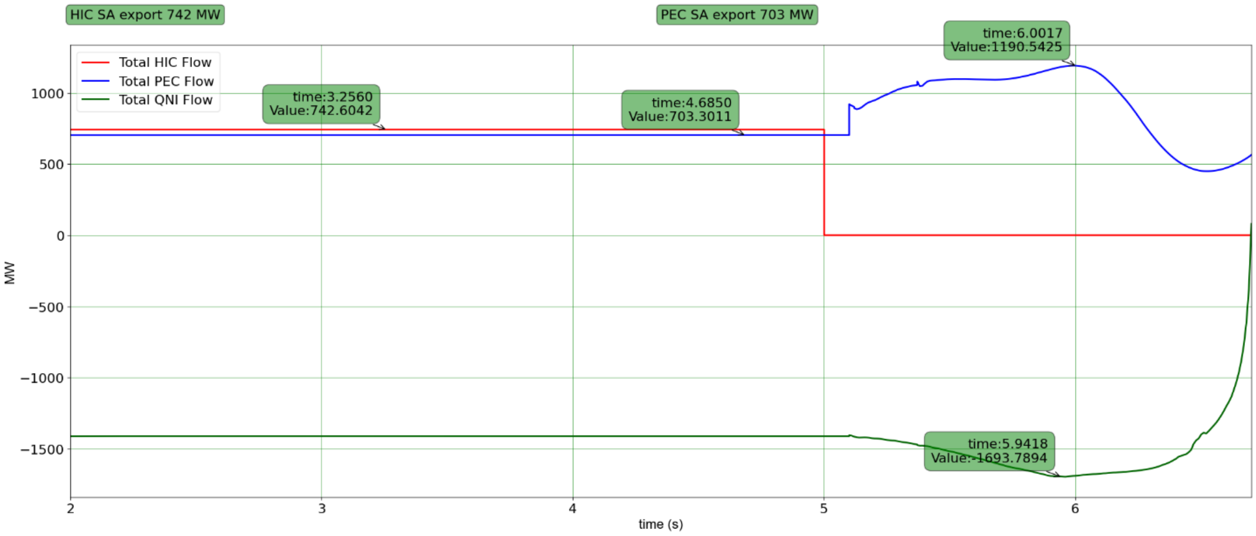
Figure 27 Full NEM model; South Australian import separation from HYTS – major interconnector flows



A6.11.2 South Australian export condition

The QNI, HIC and PEC interconnector flows following HYTS separation for the South Australian export full NEM case are shown in Figure 28. QNI lost stability following the separation.

Figure 28 Full NEM model; South Australian export separation from HYTS – major interconnector flows

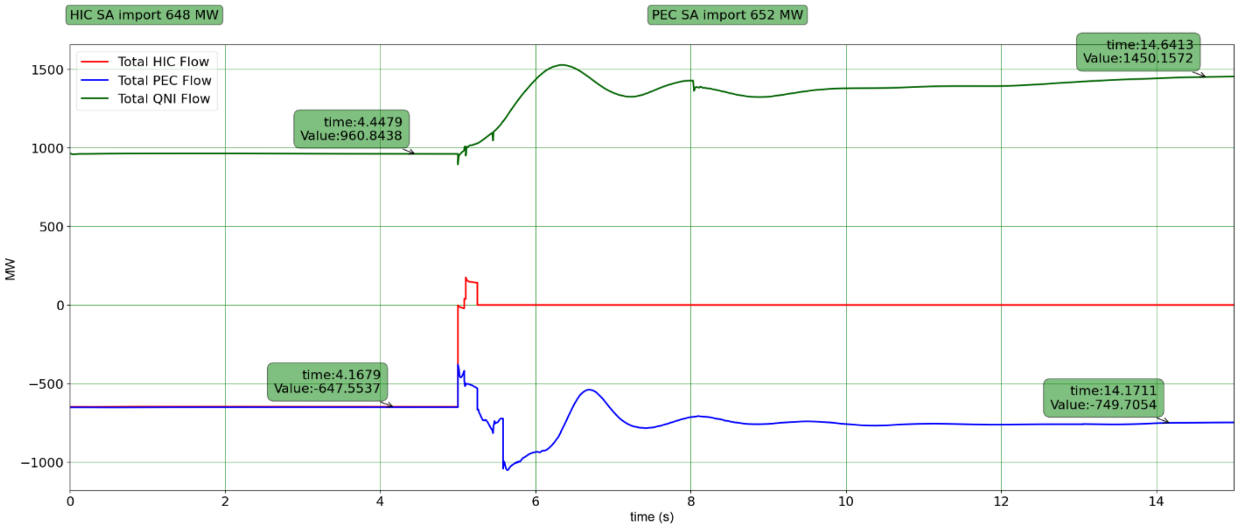


A6.12 2027 future scenario: contingency 2 – South Australia separation from MLTS – full NEM model

A6.12.1 South Australian import condition

The QNI, HIC and PEC interconnector flows following MLTS separation for the South Australian import full NEM case are shown in Figure 29.

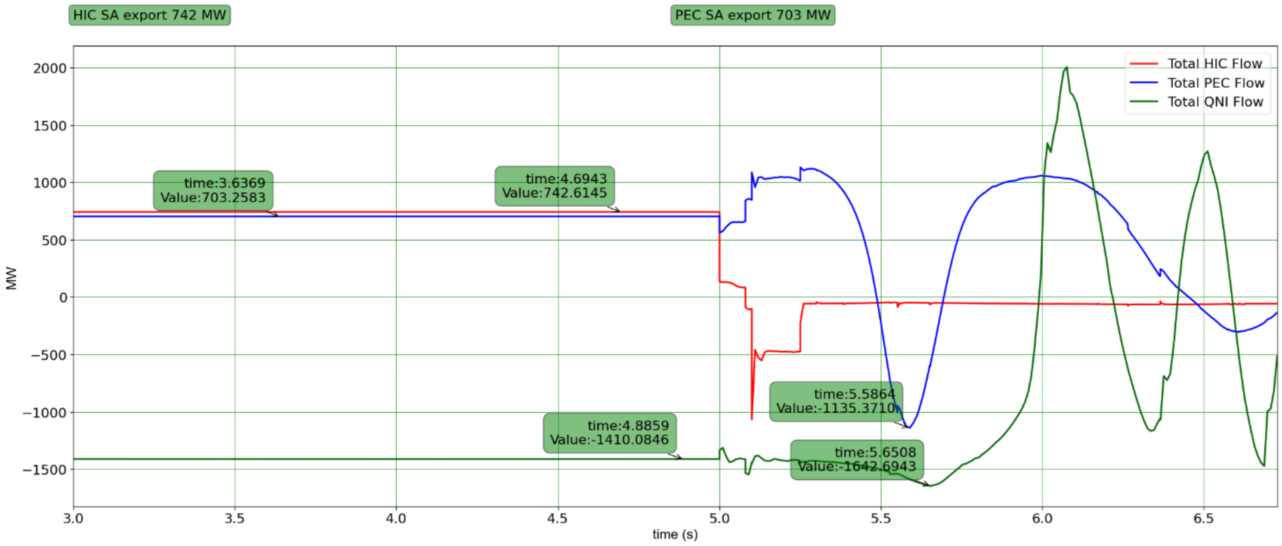
Figure 29 Full NEM model; South Australia separation from MLTS (South Australian import) – major interconnector flows



A6.12.2 South Australian export condition

The QNI, HIC and PEC interconnector flows following MLTS separation for the South Australian export full NEM case are shown in Figure 30.

Figure 30 Full NEM model; South Australia separation from MLTS (South Australian export) – major interconnector flows



A6.13 2027 future scenario: contingency 4 – loss of both 275 kV lines between Calvale – Halys – full NEM model

A6.13.1 QNI – Queensland import condition

Study scenarios

Six future cases were considered for the Calvale – Halys separation (QNI – Queensland import). The 2027 cases were set up primarily based on maximum/high CQ-SQ flows (as high CQ-SQ flow during this contingency are likely to cause onerous conditions). Coincident with historic high CQ-SQ flow, Calvale – Halys flow varied from 482 MW to 752 MW and Queensland imports varied from 482 MW to 930 MW, reflecting increased QNI flow following planned QNI upgrades. The regional generator distribution is dispatched meeting current minimum synchronous generator dispatch conditions. Case details are given in Table 57.

Table 57 Loss of both 275 kV lines between Calvale – Halys cases considered (QNI - Queensland import)

Case	QNI – Queensland import (MW)	Calvale – Halys Flow (MW)	CQ-SQ eastern corridor (MW)	CQSQ Flow (MW)	Load available for tripping (MW)	Gen available for tripping (MW)
7	925	710	1216	1927	168	1801
8	922	737	1252	1989	408	1970
9	917	717	1280	1997	394	1435
10	482	736	1241	1978	408	1970
11	930	482	1111	1594	162	1725
12	594	752	1239	1991	395	1392

Study results

The key results of the simulation studies are given in Table 58.

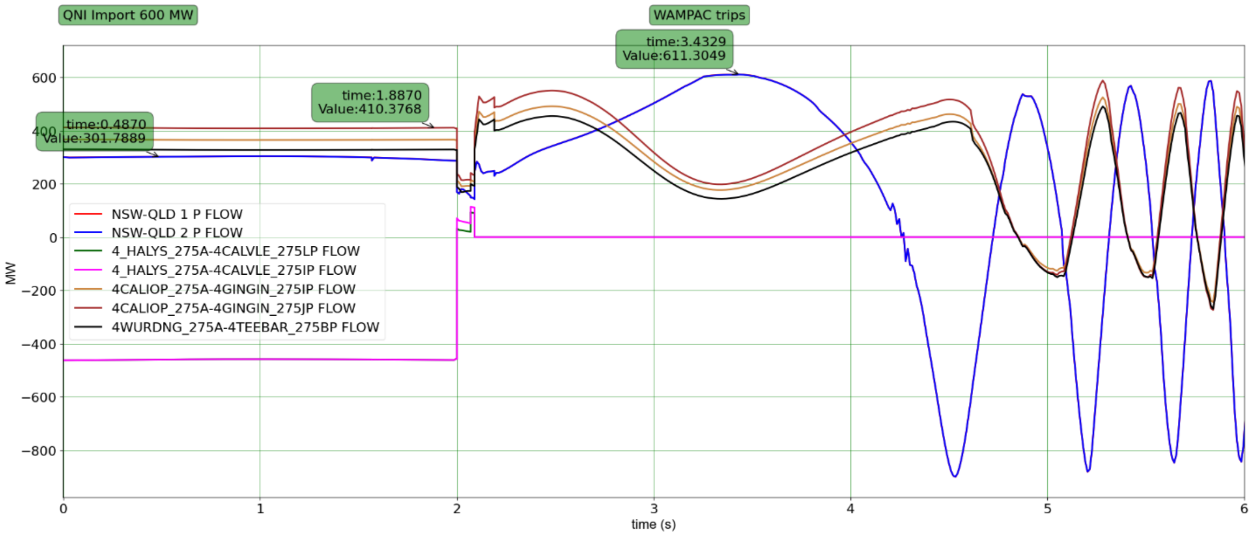
Table 58 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI – Queensland import)

Case	WAMPAC required Gen to Trip (MW)	WAMPAC required Load to trip (MW)	Net Gen Tripped (MW)	Net Load tripped (MW)	Deficiency in WAMPAC Gen/Load trip	Simulation outcome
7	1152	185	1092	168	Yes	Unstable
8	1238	272	1353	408	Yes	Unstable
9	1247	281	1256	361	No	Unstable
10	1224	257	1353	408	No	Stable
11	682	0	800	0	No	Unstable
12	1245	278	1208	360	No	Unstable

Representative results

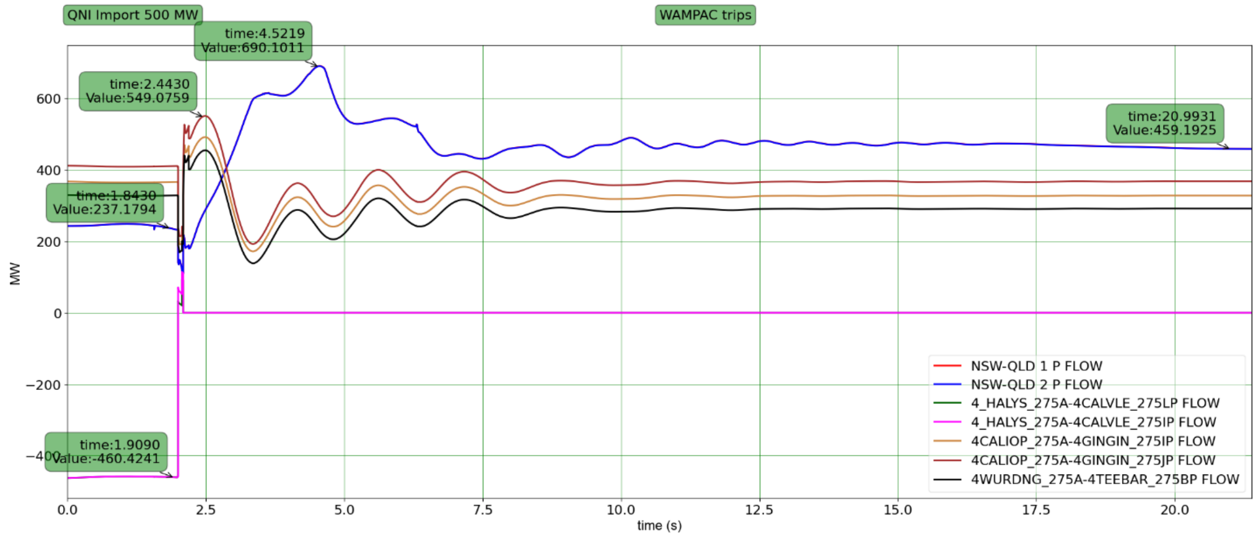
The Case 12 QNI and 275 kV CQ-SQ eastern corridor line flows following the loss of Calvale – Halys lines with Queensland import at 600 MW and CQ-SQ transfer at 1,991 MW are shown in Figure 31.

Figure 31 Case 12 key line flows: Calvale – Halys 1 and 2 trip during Queensland import of 600 MW



The QNI – Queensland import was reduced to 500 MW to see the sensitivity of QNI import level on instability observed in Case 12 in Figure 31 and the results are included in Figure 32.

Figure 32 Case 12 key line flows: Calvale – Halys 1 and 2 trip during Queensland import of 500 MW



A6.13.2 QNI – Queensland export condition

Study scenarios

Six future cases were considered for the Calvale – Halys separation (QNI – Queensland export). Case details are given in Table 59.

Table 59 Loss of both 275 kV lines between Calvale – Halys cases considered (QNI – Queensland export)

Case	QNI – Queensland export (MW)	Calvale – Halys Flow (MW)	CQ-SQ eastern corridor (MW)	CQSQ Flow (MW)	Load available for tripping (MW)	Gen available for tripping (MW)
1	1318	678	1286	1965	164	1717
2	1441	716	1341	2058	405	1275
3	1392	749	1344	2094	157	1418
4	1416	700	1365	2065	172	1851
5	1450	739	1313	2053	406	1510
6	1443	629	1397	2026	402	1831

Study results

The key results of the simulation studies are given in Table 60.

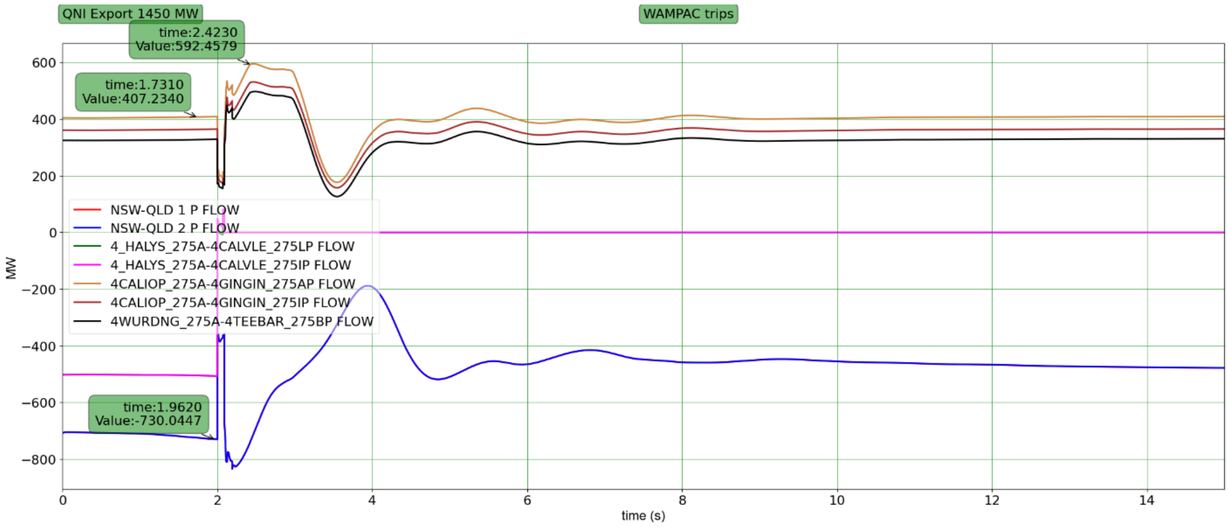
Table 60 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI – Queensland export)

Case	WAMPAC required Gen to Trip (MW)	WAMPAC required Load to trip (MW)	Net Gen Tripped (MW)	Net Load tripped (MW)	Deficiency in WAMPAC Gen/Load trip	Simulation outcome
1	1200	234	1036	164	No	Stable
2	1326	359	1275	371	No	Stable
3	1382	415	1100	157	No	Stable
4	1318	352	1138	172	No	Stable
5	1324	358	1191	371	No	Stable
6	1262	295	1209	369	No	Stable

Representative results

The Case 5 QNI and 275 kV CQ-SQ eastern corridor line flows for Queensland export following the loss of Calvale – Halys lines are shown in Figure 33.

Figure 33 Case 5 key line flows: Calvale – Halys 1 and 2 trip during Queensland export



A6.14 2027 future scenario: contingency 3 – Queensland separation through QNI loss – simplified NEM model

A6.14.1 QNI – Queensland import condition

Study scenarios

Eighteen future cases were considered for the Queensland separation due to loss of QNI (QNI import). Case details are given in Table 61.

Table 61 QNI separation: system operating points for future cases (Queensland import)

Case	Region	Operational demand (MW)	Pgen (MW)	QNI Import (MW)	Inertia (MWs)	Operational UFLS (MW)	DPV (MW)
1	QLD	6066	5116	950	10877-14861	3157	0
	Remaining mainland	13820	14874		26615-28473	9108	0
2	QLD	4962	4012	950	10877-14861	2852	0
	Remaining mainland	12802	13835		26615-28473	7909	0
3	QLD	9370	9949	950	10877-14861	5002	1529
	Remaining mainland	13005	18990		24132-28473	8176	4952
4	QLD	5501	7746	950	10877-14861	3098	3195
	Remaining mainland	11180	19836		19166-28473	6728	7630
5	QLD	4572	9591	950	10877-14861	2887	5969
	Remaining mainland	5999	19679		19166-28473	2869	12660
6	QLD	2388	7784	950	10877-14861	1774	6346
	Remaining mainland	6684	18511		19166-28473	3108	10806

Study results

The key results of the simulation studies are given in Table 62, 0 and 0.

Table 62 QNI Separation: simulation results (generation dispatch scenario 1)

Case	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% DPV tripped	Was the case stable?
1	QLD	48.85	1.0	1160	36.8	0	0	Yes
	Remaining mainland	50.85	0.38	0	0	0	0	
2	QLD	48.8	1.05	1220	42.8	0	0	Yes
	Remaining mainland	50.9	0.42	0	0	0	0	
3	QLD	48.84	0.9	1566	27	202	13.2	Yes
	Remaining mainland	50.6	0.42	0	0	207	4.2	
4	QLD	48.75	0.9	1840	38.4	698	21.9	Yes
	Remaining mainland	50.6	0.49	0	0	326	4.3	
5	QLD	48.63	0.9	2504	41.4	1359	22.8	Yes
	Remaining mainland	50.53	0.62	0	0	535	4.2	
6	QLD	-	0.7	3084	60.1	6345	100	No
	Remaining mainland	50.54	0.41	0	0	451	4.2	

A. Includes DPV tripped on UFLS action and on protection settings.

Table 63 QNI separation: simulation results (generation dispatch scenario 2)

Case	Region	Freq Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% DPV tripped	Was the case stable?
1	QLD	48.8	1.2	1258	39.8	0	0	Yes
	Remaining mainland	50.85	0.38	0	0	0	0	
2	QLD	48.7	1.25	1302	45.7	0	0	Yes
	Remaining mainland	50.88	0.42	0	0	0	0	
3	QLD	48.84	1.1	1566	27	202	13.2	Yes
	Remaining mainland	50.6	0.48	0	0	207	4.2	
4	QLD	48.82	1.1	1455	30.4	421	13.2	Yes
	Remaining mainland	50.56	0.53	0	0	326	4.3	
5	QLD	48.62	1.1	2504	41.4	1359	22.8	Yes
	Remaining mainland	50.53	0.63	0	0	535	4.2	
6	QLD	-	0.8	3084	60.1	6345	100	No
	Remaining mainland	50.5	0.42	0	0	451	4.2	

A. Includes DPV tripped on UFLS action and on protection settings.

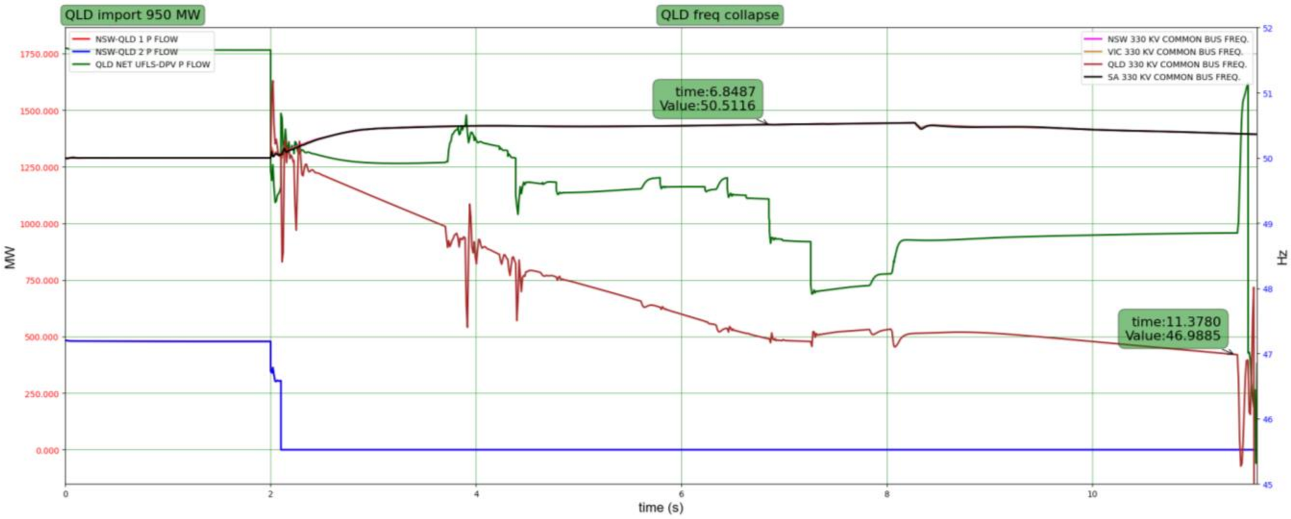
Table 64 QNI separation: simulation results (generation dispatch scenario 3)

Case	Region	Freq Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% DPV tripped	Was the case stable?
1	QLD	48.75	1.4	1348	42.7	0	0	Yes
	Remaining mainland	50.86	0.41	0	0	0	0	
2	QLD	48.66	1.45	1384	48.5	0	0	Yes
	Remaining mainland	50.88	0.42	0	0	0	0	
3	QLD	48.8	1.3	1272	22	142	9.3	Yes
	Remaining mainland	50.62	0.52	0	0	207	4.2	
4	QLD	48.74	1.24	1452	30.3	389	12.2	Yes
	Remaining mainland	50.58	0.75	0	0	326	4.3	
5	QLD	48.6	1.3	2720	45	1450	25.1	Yes
	Remaining mainland	50.54	0.59	0	0	535	4.2	
6	QLD	-	0.92	3084	60.1	6345	100	No
	Remaining mainland	50.56	0.36	0	0	451	4.2	

A. Includes DPV tripped on UFLS action and on protection settings.

As shown in the representative graph below, the Queensland frequency did not recover following UFLS action. This is due to the large amount of underlying DPV that tripped in Queensland, which led to a further frequency drop. The QNI flow and Queensland frequency for Case 6 are included in Figure 34, which shows that Queensland frequency fails to recover following the contingency indicating frequency collapse in islanded Queensland and the remaining NEM frequency was regulated below 50.51 Hz.

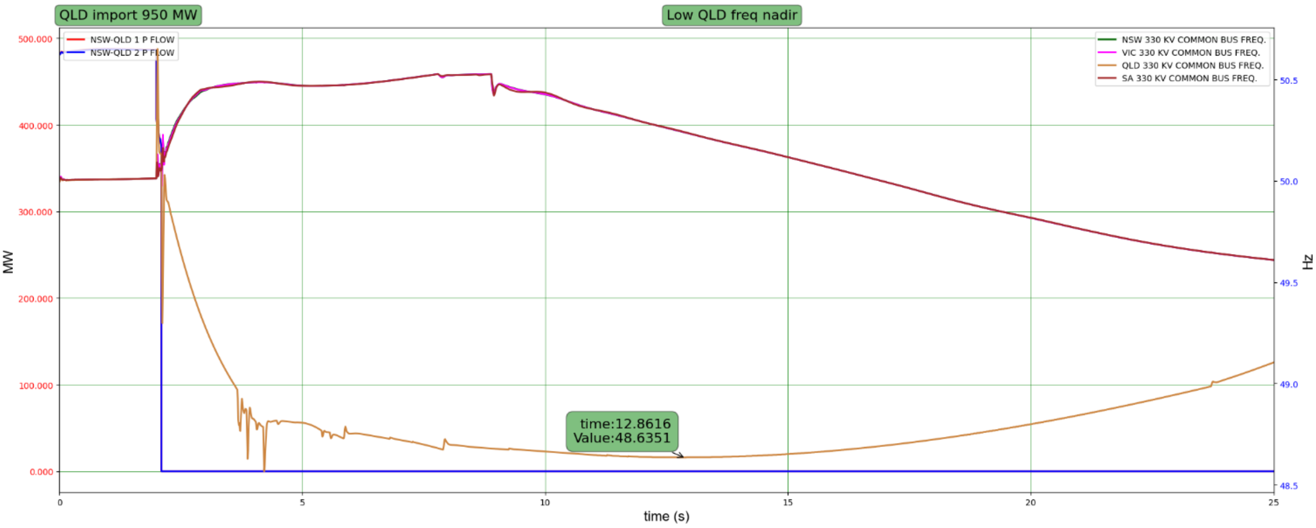
Figure 34 Scenario 1, Case 6 QNI separation (Queensland) import: QNI flows and mainland frequencies



Representative results

For QNI Import Case 5, the Queensland frequency nadir reached 48.63 Hz while RoCoF was 0.9 Hz/s. The QNI flow and regional frequencies are shown in Figure 35.

Figure 35 Scenario 1, Case 5 QNI separation (Queensland) export: QNI flow and mainland frequencies



A6.14.2 QNI – Queensland export condition

Study scenarios

Five future cases were considered for the Queensland separation due to loss of QNI (Queensland export). Case details are given in Table 65.

Table 65 System operating points of future cases (QNI Sep: Queensland exporting)

Case	Region	Operational demand (MW)	Pgen (MW)	QLD Export (MW)	Inertia (MWs)	Operational UFLS (MW)	DPV (MW)
1	Remaining mainland	6684	12600	1450	28473	3108	10806
	QLD	2388	9632		14861	1774	6345
2	Remaining mainland	9260	16192	1450	28473	5627	6203
	QLD	1865	7211		14861	1363	4266
3	Remaining mainland	5061	13680	1450	28473	1948	12780
	QLD	2338	9421		14861	1800	6168
4	Remaining mainland	5728	11284	1450	28473	3293	9746
	QLD	4402	8583		14861	2466	2991
5	Remaining mainland	7993	14280	1450	28473	4467	8085
	QLD	4646	8134		14861	2661	2232

Study results

Detailed results of key power system variables observed are included in Table 66, 0, and 0.

Table 66 Simulation results of the future cases for generation dispatch Scenario 1 (QNI Sep: Queensland exporting)

Case	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% DPV tripped	Was the case stable?
1	Remaining mainland	48.39	0.81	4745	43	4184	39	Yes
	QLD	51.03	1.20	0	0	457	7	
2	Remaining mainland	48.72	0.80	2601	26	1688	27	Yes
	QLD	51.52	1.32	0	0	382	9	
3	Remaining mainland	47.92	0.92	5326	48	5765	45	Yes
	QLD	51.19	1.29	220	4	502	8	
4	Remaining mainland	48.39	0.91	4076	41	3858	40	Yes
	QLD	51.4	1.55	0	0	268	9	
5	Remaining mainland	48.66	0.69	3037	29	1932	24	Yes
	QLD	51.59	1.63	0	0	205	9	

A. Includes DPV tripped on UFLS action and on protection settings.

Table 67 Simulation results of the future cases for generation dispatch Scenario 2 (QNI Sep: Queensland exporting)

Case	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% DPV tripped	Was the case stable?
1	Remaining mainland	48.38	0.85	4745	55	4345	40	Yes
	QLD	51.05	1.28	0	0	457	7	
2	Remaining mainland	48.71	0.82	2370	21	1617	26	Yes
	QLD	51.57	1.35	0	0	382	9	
3	Remaining mainland	47.9	1.02	5326	58	6025	47	Yes
	QLD	51.22	1.42	227	4	541	9	
4	Remaining mainland	48.37	0.93	4076	50	3987	41	Yes
	QLD	51.5	1.56	0	0	268	9	
5	Remaining mainland	48.68	0.74	2915	29	1778	22	Yes
	QLD	51.72	1.74	0	0	200	9	

A. Includes DPV tripped on UFLS action and on protection settings.

Table 68 Simulation results of the future cases for generation dispatch Scenario 3 (QNI Sep: Queensland exporting)

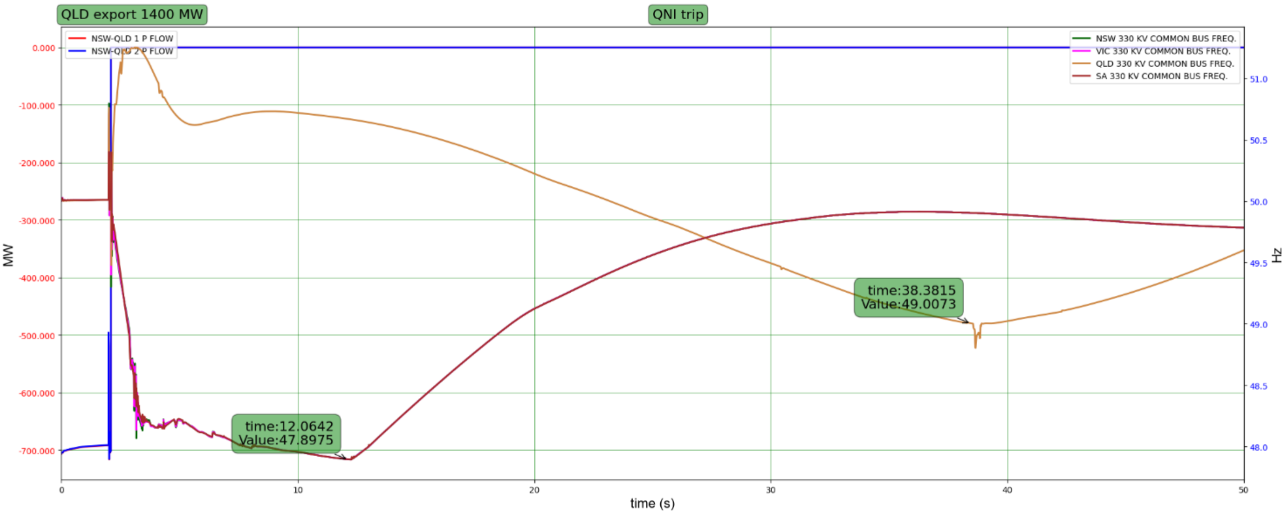
Case	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection[A] (MW)	% DPV tripped	Was the case stable?
1	Remaining mainland	48.34	1.13	4694	55	3783	35	Yes.
	QLD	51.08	2.12	0	0	497	8	
2	Remaining mainland	48.54	1.08	3774	33	2309	37	Yes.
	QLD	51.61	2.40	0	0	382	9	
3	Remaining mainland	47.9	1.23	5423	59	4498	35	Yes
	QLD	51.25	2.54	638	13	940	15	
4	Remaining mainland	48.23	1.15	3971	49	4094	42	Yes
	QLD	51.57	2.47	0	0	268	9	
5	Remaining mainland	48.55	0.95	3400	34	1875	23	Yes.
	QLD	51.82	2.23	0	0	200	9	

A. Includes DPV tripped on UFLS action and on protection settings.

Representative results

The simulation results for QNI - Queensland export Case 3 for Scenario 3 are shown in Figure 36. Queensland frequency increased to 51.25 Hz following QNI trip. Frequency in the rest of the NEM dropped to 47.9 Hz, and a maximum RoCoF of 2.54 Hz/s was observed following synchronous separation of Queensland.

Figure 36 Scenario 3, Case 3 QNI separation (Queensland) export: QNI flows and mainland frequencies



A6.15 2027 future scenario: contingency 5 – non-credible loss of VNI – simplified NEM model

Non-credible concurrent loss of all VNI circuits is remote and included in the review only for illustrative purposes. VNI is comprised of four transmission lines: three 330 kV transmission lines between Murray – Upper Tumut, Murray – Lower Tumut, and Jindera – Wodonga substations, and a 275 kV transmission line from Buronga to Red Cliffs. The non-credible simultaneous loss of the VNI was considered for Victorian import and Victorian export conditions using the simplified NEM model.

A6.15.1 Victorian import condition

Study scenarios

Seven future cases were considered for the non-credible loss of the VNI lines (Victorian import). Case details are given in Table 69.

Table 69 System operating points for future cases (VNI Sep: Victorian import)

Case	VIC operational demand (MW)	NSW operational demand (MW)	VIC import (MW)	VIC operational UFLS (MW)	VIC DPV (MW)	NSW operational UFLS (MW)	NSW DPV (MW)
1	2712	2745	1150	1151	3525	1192	6836
2	2578	4555	1150	1134	3775	2423	4623
3	1968	2292	1150	936	3257	1251	5887
4	4538	4155	1150	2546	1039	2518	4012
5	8464	8980	1150	5093	0	5576	0
6	1134	3175	1150	163	4983	1603	6124
7	2537	5912	1150	1194	3241	3728	2746

Study results

Detailed results of key power system variables observed during simulations of all considered cases are included in Table 70, 0 and Table 72.

Table 70 Simulation results of the future cases for Scenario 1 (VNI Sep: Victorian import)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Power system security maintained?
1	NSW	-	-	0	0	0	0.0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0.0	
	VIC	-	-	1878	87	688	44.7	
	SA			302	17	338	14.6	
2	NSW	-	-	0	0	0	0.0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0.0	
	VIC	-	-	1611	97	40	4.8	
	SA			443	26	2256	97.7	
3	NSW	50.75	0.61	0	0	0	0.0	Yes
	QLD			0	0	0	0.0	
	VIC	48.05	1.57	2185	74	1449	47.0	
	SA			1256	52	739	56.8	
4	NSW	50.67	0.42	0	0	0	0.0	Yes.
	QLD			0	0	0	0.0	
	VIC	48.37	1.51	2654	55	1380	38.8	
	SA			409	26	390	34.6	
5	NSW	50.85	0.23	0	0	0	0.0	Yes.
	QLD			0	0	0	0.0	
	VIC	48.7	1.24	2125	42	0	0.0	
	SA			470	37	0	0.0	
6	NSW	-	-	0	0	0	0.0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0.0	
	VIC	-	-	1634	54	803	23.6	
	SA			2341	87	1670	84.5	
7	NSW	-	-	0	0	0	0.0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0.0	
	VIC	-	-	2689	83	1521	48.1	
	SA			220	16	291	14.6	

Table 71 Simulation results of the future cases for Scenario 2 (VNI Sep: Victorian import)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Is system security maintained?
1	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	1878	87	688	45	
	SA			302	17	338	15	
2	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	1611	97	59	7	
	SA			443	26	2256	98	
3	NSW	50.77	0.66	0	0	319	5	Yes
	QLD			0	0	124	2	
	VIC	48.05	1.57	2258	74	1628	50	
	SA			1289	52	794	58	
4	NSW	50.9	0.35	0	0	218	5	Yes.
	QLD			0	0	94	2	
	VIC	48.68	1.51	1788	55	460	44	
	SA			417	26	413	36	
5	NSW	50.91	0.40	0	0	0	0	Yes
	QLD			0	0	0	0	
	VIC	48.68	1.30	1695	33	0	0	
	SA			179	14	0	0	
6	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	1634	54	1038	24	
	SA			2367	88	1694	85	
7	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	2689	83	1521	48	
	SA			220	16	291	15	

Table 72 Simulation results of the future cases for Scenario 3 (VNI Sep: Victorian import)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
1	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	1878	87	688	45	
	SA			302	17	338	15	
2	NSW	-	-	0	0	0	0	

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
	QLD			0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	VIC	-	-	1611	97	1370	167	
	SA			443	26	2256	98	
3	NSW	50.84	0.70	838	16	1528	26	Yes
	QLD			1058	26	573	10	
	VIC	48.1	1.95	2258	74	1625	50	
	SA			1321	54	803	59	
4	NSW	50.76	0.44	0	0	218	5	Yes
	QLD			0	0	94	2	
	VIC	48.36	1.69	1788	55	426	41	
	SA			489	30	461	40	
5	NSW	51.03	0.60	0	0	0	0	Yes
	QLD			0	0	0	0	
	VIC	48.68	1.50	1695	33	0	0	
	SA			253	19	0	0	
6	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	1634	54	1229	28	
	SA			2545	95	1755	88	
7	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	2689	83	1521	48	
	SA			220	16	291	15	

Representative results

The New South Wales and Victorian frequencies, VNI and total DPV/UFLS flows for Scenario 1 Case 2 are shown in Figure 37. In this particular case the net available UFLS in Victoria is 1131 MW and in South Australia had no UFLS in this study scenario[12]. The combined UFLS and FCAS in Victoria and South Australia were insufficient to arrest the frequency collapse in the Victoria/South Australia island.

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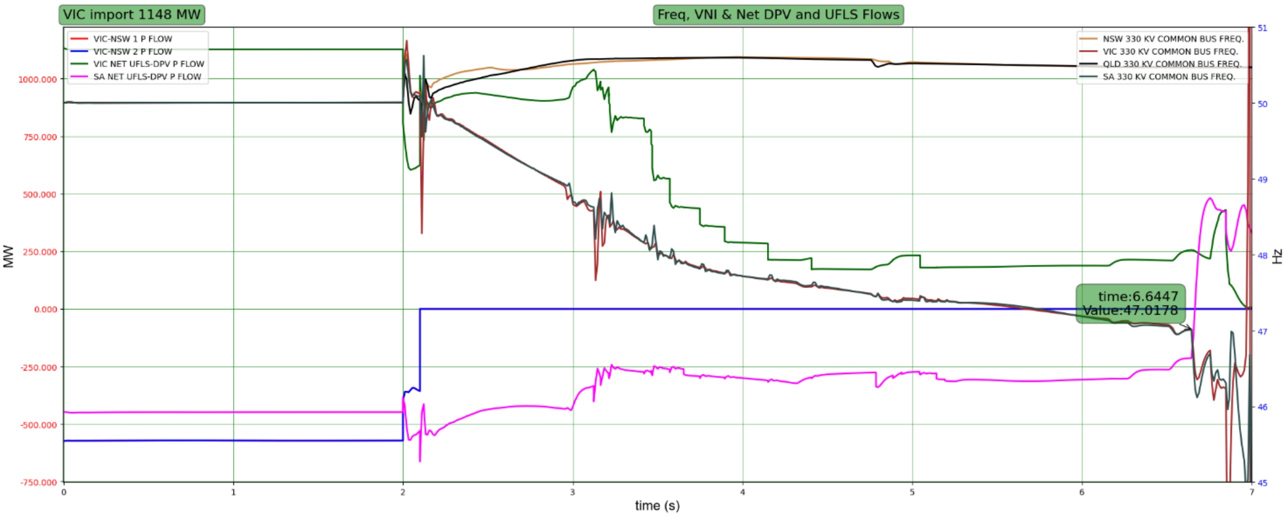
[12] AEMO notes this is a conservative assumption and anticipates improvement to UFLS effectiveness prior to 2027.

Figure 37 Scenario 1 Case 2 Victorian import VNI separation: Frequencies, VNI and total DPV/UFLS flows



A6.15.2 Additional Victorian import condition studies

During the 2022 PSFRR question and answer session (held on 17 June 2022), Transgrid asked AEMO whether the loss of VNI during high QNI flows could cause QNI to trip (full details of key questions raised during the question and answer session can be found in Appendix A7.3). VNI separation studies showed that when Victoria is exporting to New South Wales, QNI could lose stability. QNI became unstable for Cases 2, 6 and 9 and the results are included in Appendix A6.15.3, 0 of this report. However, QNI instability was not observed when Victoria was importing from New South Wales. Following the question and answer session, to address Trangrid's question in detail, AEMO undertook further sensitivity studies for Victorian import conditions.

The details of the additional case considered for the VNI separation study are in Table 73 (the case corresponds to generation dispatch Scenario 1).

Table 73 System operating points for future cases (VNI separation: additional Victorian import study case)

Case	VIC operational demand (MW)	NSW operational demand (MW)	VIC import (MW)	VIC operational UFLS (MW)	VIC DPV (MW)	NSW operational UFLS (MW)	NSW DPV (MW)
9	5374	9189	1150	3220	102	6239	22

The results of the simulation are in Table 74.

Table 74 Simulation results of the future cases for Scenario 3 (VNI separation: additional Victorian import case study)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
9	NSW	51.18	0.27	0	0	5	23	Yes.
	QLD			0	0	0.1	12	
	VIC	48.7	1.5	1166	36	33	32	
	SA			339	23	71	35	

The frequencies of different regions and the voltages of New South Wales and Queensland buses are shown in Figure 38 and Figure 39.

Figure 38 VNI separation: Case 9 regional frequencies

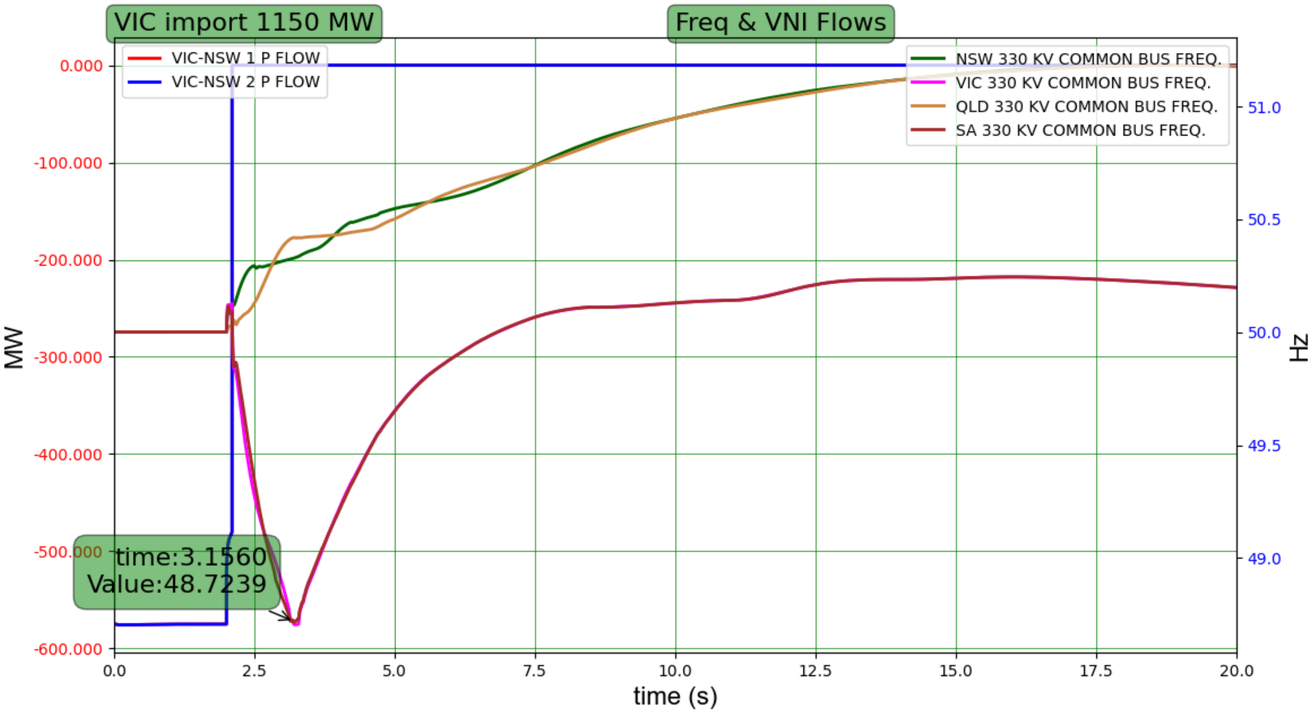
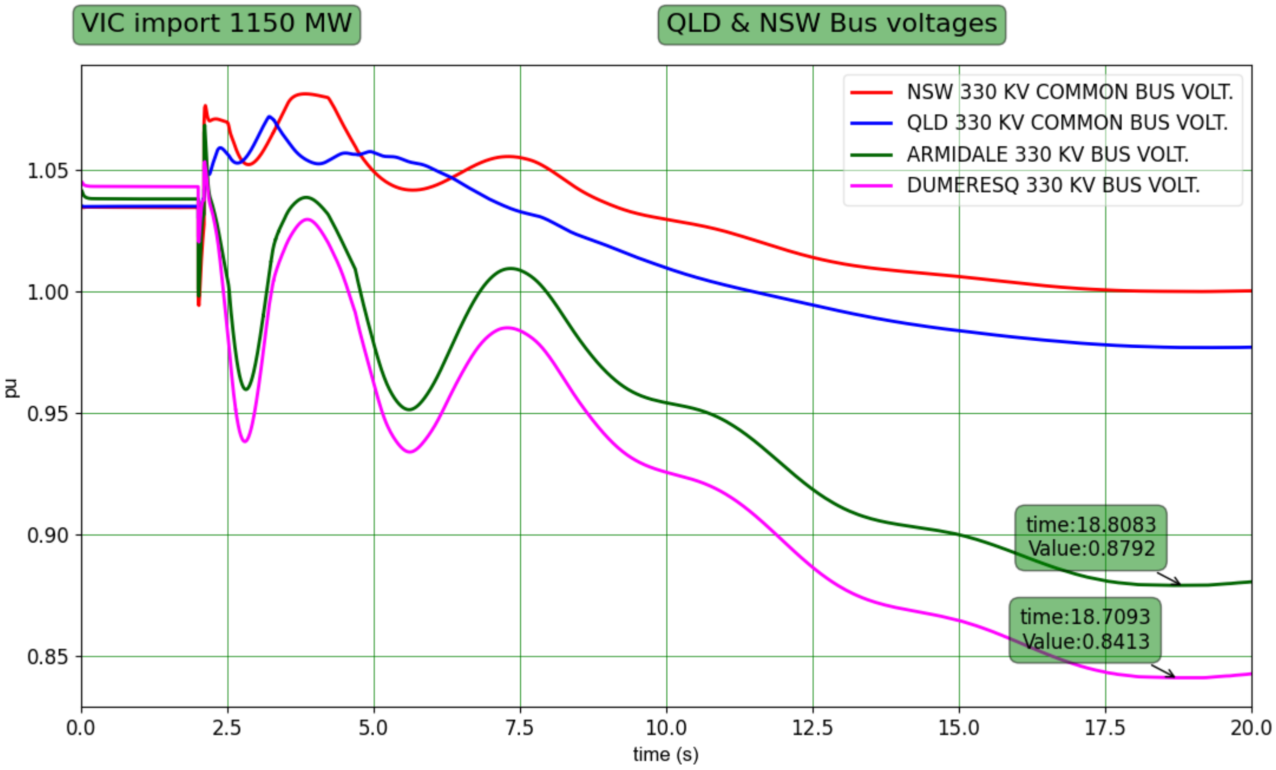


Figure 39 VNI separation: Case 9 New South Wales and Queensland bus voltages



The following observations are made based on additional studies:

- QNI did not lose stability in the additional sensitivity studies; however, the study results indicated that there could be voltage collapse in the 330 kV buses south of Bulli Creek.
- For VNI separation during high Victorian import conditions along with high Queensland import through QNI, voltage collapse could occur in the 330 kV buses between Armidale and Bulli Creek.

These observations reinforce the recommendation that AEMO conduct further investigation to consider appropriate measures to manage the impact on QNI for loss of HIC. AEMO plans to explore measures such as a protected event or working with Powerlink to implement an SPS under NER S5.1.8. As part of this work, AEMO will also consider how other major non-credible contingencies may impact QNI. Given limitations of the simplified model to predict voltage performance, further analysis of VNI separation events may be required. This will be considered as part of the 2023 GPSRR.

A6.15.3 Victorian export condition

Study scenarios

Nine historical cases were considered for the non-credible loss of the VNI lines (Victorian export). Case details are given in Table 75.

Table 75 System operating points for future cases (VNI separation: Victorian export)

Case	VIC operational demand (MW)	NSW operational demand (MW)	VIC import (MW)	VIC operational UFLS (MW)	VIC DPV (MW)	NSW operational UFLS (MW)	NSW DPV (MW)
1	1302	4747	1350	326	4602	3204	6177
2	386	6476	1350	-275	5364	4338	5817
3	3670	5772	1350	2038	0	3785	0
4	374	3775	1350	-77	4891	2071	5107
5	3743	6567	1350	1962	2294	3918	3455
6	5196	12300	1350	3016	0	8015	0
7	5133	9422	1350	3065	3	6036	2
8	2712	2745	1350	1151	3525	1192	6836
9	3317	5661	1350	1797	2882	3094	4323

Study results

Detailed results of key power system variables observed during the simulations are included in 0, Table 77, and Table 78.

Table 76 Simulation results of the future cases for Scenario 1 (VNI Sep: Victorian export)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
1	NSW	48.74	0.81	2296	31	1960	32	Yes
	QLD			1844	39	1058	18	
	VIC	51.06	1.43	0	0	496	11	
	SA			0	0	126	9	
2	NSW	-	-	4962	60	3072	53	No. QNI becomes unstable
	QLD			2061	44	1368	26	
	VIC	-	-	0	0	199	4	
	SA			0	0	126	5	
3	NSW	-	-	272	7	0	0	No. Simulation becomes unstable.
	QLD			1105	40	0	0	
	VIC	-	-	1903	93	0	0	
	SA			1035	98	0	0	
4	NSW	48.57	0.64	1913	34	2078	41	Yes
	QLD			1794	40	971	18	
	VIC	51.02	1.85	0	0	403	8	
	SA			0	0	152	9	
5	NSW	48.79	0.67	659	10	514	15	Yes
	QLD			1512	29	427	12	
	VIC	51.12	1.53	0	0	266	12	
	SA			0	0	187	9	
6	NSW	-	-	2339	29	0	0	No. QNI becomes unstable. Simulation could not be completed satisfactorily.
	QLD			287	6	0	0	
	VIC	-	-	0	0	0	0	
	SA			0	0	0	0	
7	NSW	48.89	0.825	505	8	0	11	Yes
	QLD			1265	24	0	0	
	VIC	51.62	1.93	0	0	0	6	
	SA			0	0	6	6	
8	NSW	47.92	0.88	2743	47	5283	77	Yes
	QLD			2669	53	1734	28	
	VIC	51.02	1.3	0	0	261	7	
	SA			0	0	188	8	
9	NSW	-	-	1250	21	7010	162	No. QNI becomes unstable. Simulation could not be completed satisfactorily.
	QLD			0	0	14	0	
	VIC	-	-	0	0	214	7	
	SA			0	0	11	4	

Table 77 Simulation results of the future cases for Scenario 2 (VNI separation: Victorian export)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
1	NSW	48.74	0.89	2183	29	1864	30	Yes
	QLD			1844	39	1058	18	
	VIC	51.06	1.43	0	0	496	11	
	SA			0	0	126	9	
2	NSW	48.85	0.13	1587	19	1280	25	Yes
	QLD			1441	31	692	14	
	VIC	50.98	1.40	0	0	199	9	
	SA			0	0	126	5	
3	NSW	-	-	635	17	0	0	No. Simulation becomes unstable.
	QLD			1099	40	0	0	
	VIC	-	-	0	0	0	0	
	SA			0	0	0	0	
4	NSW	48.58	0.75	1315	21	678	15	Yes
	QLD			1074	21	249	5	
	VIC	51.03	1.87	0	0	263	10	
	SA			0	0	187	11	
5	NSW	48.77	0.92	1285	21	488	16	Yes
	QLD			680	14	192	6	
	VIC	51.12	1.82	0	0	98	6	
	SA			0	0	111	6	
6	NSW	-	-	2048	26	0	0	No. QNI becomes unstable. Simulation could not be completed satisfactorily.
	QLD			218	5	0	0	
	VIC	-	-	0	0	0	0	
	SA			0	0	0	0	
7	NSW	48.76	0.97	1090	18	0	15	Yes
	QLD			661	12	0	0	
	VIC	51.62	2.15	0	0	0	6	
	SA			0	0	6	6	
8	NSW	47.89	1.10	2870	49	5691	94	Yes
	QLD			2669	53	1734	31	
	VIC	51.02	1.71	0	0	261	17	
	SA			0	0	188	8	
9	NSW	-	-	1250	21	6999	182	No. QNI becomes unstable. Simulation could not be completed satisfactorily.
	QLD			0	0	16	0	
	VIC	-	-	0	0	214	15	
	SA			0	0	11	4	

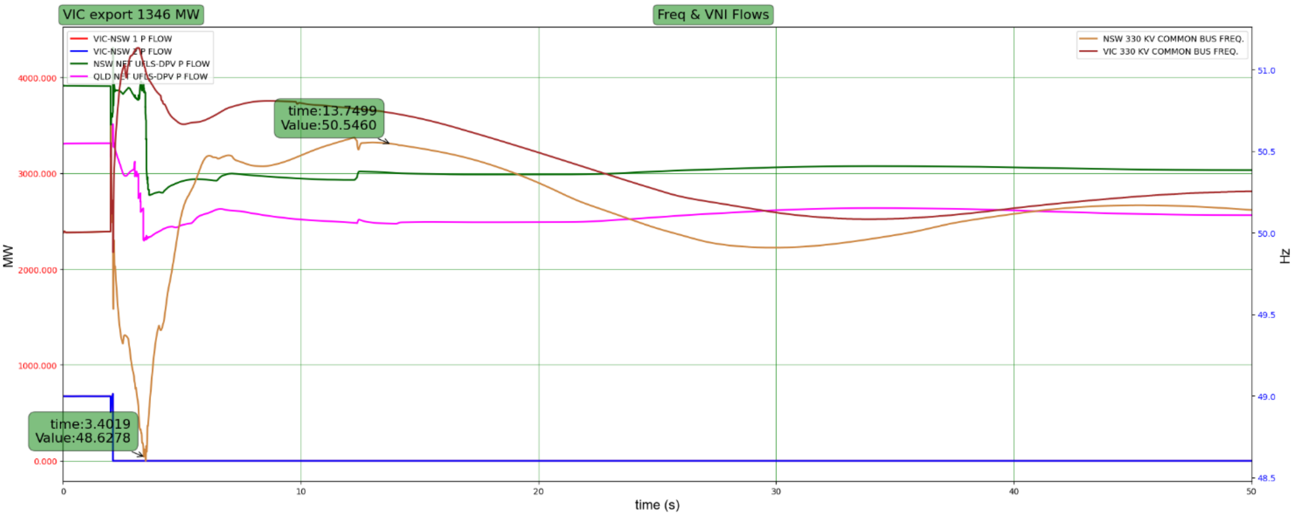
Table 78 Simulation results of the future cases for Scenario 3 (VNI Sep: Victorian export)

Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
1	NSW	48.74	1.02	2183	29	1864	34	Yes
	QLD			1844	39	1058	20	
	VIC	51.09	1.93	0	0	512	16	
	SA			0	0	126	9	
2	NSW	48.86	2.15	1643	20	1267	25	Yes. But QNI swings close to its stability limit
	QLD			1224	26	543	11	
	VIC	50.97	2.01	0	0	155	7	
	SA			0	0	98	4	
3	NSW	-	-	1032	27	0	0	No. Simulation becomes unstable.
	QLD			2673	96	0	0	
	VIC	-	-	1394	68	0	0	
	SA			1035	98	0	0	
4	NSW	48.57	0.70	1913	34	1846	41	Yes
	QLD			1794	40	971	20	
	VIC	51.05	2.05	659	21	1267	51	
	SA			120	7	379	23	
5	NSW	48.6	1.90	2051	33	1133	37	Yes
	QLD			1488	29	476	15	
	VIC	51.15	2.36	0	0	245	16	
	SA			0	0	187	10	
6	NSW	-	-	2552	32	0	0	No. QNI becomes unstable. Simulation could not be completed satisfactorily.
	QLD			328	7	0	0	
	VIC	-	-	2941	98	0	0	
	SA			1401	100	0	0	
7	NSW	48.73	1.63	1171	19	0	16	Yes
	QLD			1511	28	0	0	
	VIC	51.7	2.46	0	0	0	6	
	SA			0	0	6	6	
8	NSW	47.89	1.56	2906	49	2537	42	Yes
	QLD			2575	51	1652	29	
	VIC	51.06	1.79	0	0	351	23	
	SA			0	0	188	8	
9	NSW	-	-	1250	21	6994	182	No. QNI becomes unstable. Simulation could not be completed satisfactorily.
	QLD			0	0	17	0	
	VIC	-	-	0	0	214	15	
	SA			0	0	11	4	

Representative results

New South Wales and Victorian frequencies, along with VNI flows for Scenario 3 Case 5 Victorian export VNI separation, are shown in Figure 40. This is one of the cases with high RoCoF values around 1.9 Hz/s and 2.4 Hz/s in New South Wales/Queensland and Victoria/South Australia islands, respectively. RoCoF in excess of 2 Hz/s poses an increased risk for subsequent GT tripping, as noted in Section 7.3 of the main PSFRR report.

Figure 40 Scenario 3 Case 5 Victorian export VNI separation: frequencies and VNI flows



A7. PSFRR 2022 consultation

The publication of the final PSFRR 2022 report concludes the consultation by AEMO on the 2022 draft PSFRR report.

AEMO sought submissions from all persons interested in the 2022 PSFRR during a public consultation between 1 June 2022 and 17 June 2022.

AEMO received two written submissions on the draft 2022 PSFRR report, one from ElectraNet and one from Energex and Ergon Energy. These submissions can be found on AEMO's website[13]. AEMO thanks ElectraNet, Energex and Ergon Energy for their submissions and contributions to finalising the 2022 PSFRR.

On 10 June 2022, AEMO held a question-and-answer session with industry stakeholders, at which attendees were invited to ask questions and provide any feedback in relation to the 2022 PSFRR.

The following sections include summaries of comments or questions from the submissions and stakeholder session, together with AEMO's responses where relevant.

A7.1 ElectraNet Consultation submission

Summary of ElectraNet comments

ElectraNet and AEMO are working collaboratively to develop a Wide Area Protection Scheme (WAPS) designed to detect multiple generator loss events and provide a proportionate response to mitigate the risk of cascading failures. ElectraNet is progressing the detailed design of the scheme and construction activities have commenced with an in-service date in early 2023.

The WAPS design is based on maintaining two large synchronous generator units online in South Australia to maintain system security before PEC is in service. This approach is consistent with the 2018 and 2020 ISP planning assumptions. System inertia plays a critical role in the system response in the event of multiple generator loss; hence, the effectiveness of the WAPS to provide a timely and proportionate response. ElectraNet is assisting AEMO to explore whether the minimum number of synchronous generator units in South Australia could be reduced. ElectraNet notes that additional assessment of the adequacy of the WAPS settings would be required to cater for fewer synchronous generator units, which may result in WAPS setting revisions. These settings revisions would be required prior to transitioning to operation with a lower minimum number of synchronous generators online and may delay the in-service date of the WAPS to mid-2023.

AEMO response

AEMO is working closely with ElectraNet both to progress the WAPS scheme, and to investigate the impact of reducing the minimum number of synchronous generators in South Australia. AEMO will collaborate with ElectraNet to understand and manage any changes to WAPS settings or design to ensure it remains effective.

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[13] https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-frequency-risk-review

A7.2 Ergon Energy and Energex consultation submission

Summary of Ergon Energy and Energex comment

One of the recommendations relates to immediately seeking to identify and implement measures to restore emergency under-frequency response to as close as possible to the level of 60% of underlying load at all times. We note from modelling undertaken by AEMO in 2021, net UFLS load is strong in Queensland for periods with low or moderate volumes of DPV and does not present an immediate concern. However, the observed UFLS load falls below AEMO historic expectations in periods of high DPV operation. We understand that AEMO are continuing to undertake detailed modelling (known as “Phase 2 – Frequency studies”) to understand the appropriate target levels of UFLS load when there is a significant volume of DPV operating. We support this modelling, and we trust that this next phase can be conducted promptly to ensure common understanding of the risks and assist in determining the appropriateness of and proposed recommendations. Notwithstanding, Ergon Energy and Energex have already begun to identify and implement least regret measures to reinforce UFLS capability.

It is noted that AEMO has engaged in a number of workshops and discussions with transmission network service providers in developing this report. While that is essential, it is also clear that with the emergence of DPV and the rising importance of distribution networks for the security of the power system, the engagement model may need to evolve for future reviews of this nature to involve distribution networks earlier in the process.

AEMO response

AEMO agrees with the observations above and thanks Ergon Energy and Energex for their collaboration and the actions already taken to reinforce UFLS capability in Queensland. AEMO will continue to collaborate with Ergon Energy, Energex and Powerlink to determine appropriate target levels of emergency under-frequency performance, and to implement least regret measures to reinforce UFLS capability.

For the upcoming 2023 GPSRR, AEMO intends to engage more closely with distribution network operators throughout the process. As part of this engagement AEMO will seek to understand the power system risks that affect or may arise from distribution networks.

A7.3 2022 PSFRR consultation question and answer session

A summary of key questions raised during the 10 June 2022 session is provided below with AEMO responses.

Question: Why were two types of network configuration (full NEM model and simplified NEM model) used in the future 2027 PSFRR studies?

AEMO response: Due to the time required to configure full NEM models, AEMO developed a simplified modelling approach to enable consideration of a broader range of contingencies and system conditions. This simplified model is comparatively easier to setup and can accurately represent system inertia, generation dispatch, regional demand and frequency response. Limitations of the simplified NEM model include its inability to assess voltage related impacts as the regional generators and loads are lumped and the network impedances are approximated. In addition, PEC cannot be modelled in the simplified model due to the network structure assumed.

Where modelling PEC was key for a particular contingency event, AEMO chose to study a limited number of key contingency cases using a full NEM model with PEC included. AEMO took this approach to manage the complexity and time for setting up full NEM 2027 study cases.

More details on the modelling approaches used for the 2022 PSFRR are included in the report.

Question: How were interconnector angular stability limits considered in the studies?

AEMO response: For both the simplified and full NEM models AEMO completed benchmarking of the 25 May 2021 trip of multiple generators and lines in Queensland and under-frequency load shedding event. In these studies, AEMO compared the modelled angular swing to the observed angular swing and found the simplified model is less conservative compared to the full NEM model when predicting the angular power swing on the interconnector and instability. In both models, angular stability is determined by the stability of active power swings of the interconnectors flows between regions.

Question: Was high QNI flow considered in tripping VNI contingency? While Queensland inertia is high, will losing VNI cause Queensland to be islanded?

AEMO response: To assess a broad range of regional inertia levels, AEMO assumed the minimum unit commitments as per the 2022 ISP projections, with three scenarios considered for 2027 cases:

- Current minimum unit commitments,
- Current minimum unit commitments minus future decommissioned units, and
- The 99-percentile market forecast.

For VNI separation studies when Victoria is exporting to New South Wales, studies showed that QNI could lose stability. QNI became unstable for Cases 2, 6 and 9 and the results are included in 0, Appendix A6.15.3 of this report. However, QNI instability was not observed when Victoria was importing from New South Wales. Following the Q&A session, to address the question in detail, AEMO undertook further sensitivity studies for Victorian import conditions. QNI did not lose stability in the sensitivity studies; however, the study results indicated that there could be voltage collapse in the 330 kV buses south of Bulli Creek. The results of these sensitivity studies can be found in Appendix A6.15.2 of this report. AEMO subsequently shared these sensitivity study outcomes with Transgrid and Powerlink.

Question: How will the recommendations identified in the PSFRR be implemented by the respective TNSPs? Is there a particular timeline for the actions?

AEMO response: AEMO is working with TNSPs to agree on a reasonable timeline for implementation and expects to provide updates in subsequent risk review reports on the status of recommendations, including any modifications arising from major power system incidents. Going forward the GPSRR, including these updates, will be published annually. In addition, TNSPs would normally include updates on any recommendations assigned to them their annual planning reports.

Question: Did any of the scenario results identify periods of time that the frequency might be potentially between 51.5 Hz and 52 Hz? It is noted that this frequency range could be quite damaging to steam turbines.

AEMO response: Frequency peaks exceeding 52 Hz were observed in Queensland for non-credible separation of QNI. AEMO did not see any sustained frequency above 51.5 Hz in any regions for the studied contingencies. To address the Queensland over-frequency events (in excess of 52 Hz), a new OFGS scheme is recommended.

Question: Regarding the recommendation to maintain UFLS availability as close as possible to 60% of the underlying load – can this be achieved despite the high level of distributed PV?

AEMO response: AEMO acknowledges the challenges with maintaining UFLS effectiveness given UFLS scheme design and the impact of distributed PV. In order to maintain effective emergency capabilities, AEMO has suggested a number of measures in Section 6.1.2 of the 2022 PSFRR, such as:

- Adding more load into UFLS schemes.
- Addressing reverse power flows on UFLS circuits.
- Introducing active monitoring of UFLS load.
- Exploring long-term pathways for restoring emergency under-frequency response.