

Draft Power System Frequency Risk Review – Appendices

June 2022

Consultation draft

A report for the National Electricity Market





Important notice

Purpose

AEMO has prepared the Draft 2022 Power System Frequency Risk Review Report under clause 5.20A.3 of the National Electricity Rules.

This publication has been prepared by AEMO using information available to 29/03/2022. Information made available after this date may have been included in this publication where practical.

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XX	D/M/YYYY	Initial version

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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	<u>Primary frequency control in the NEM</u> 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 .
	<u>Automating secondary frequency control implementation after separation events</u> 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.
	<u>Circumstances for regional FCAS or frequency control</u> 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.

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>.

Appendix A1. Status of actions arising from major events

Incident	Recommendation	Status	Details
	<u>Frequency response capability models</u> 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.	Open	AEMO continues to work with generators in monitoring their compliance obligations. AEMO plans greater collaboration with NSPs to ensure accuracy of generator models. 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.
	<u>DPV inverter performance standards and analysis</u> 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.
	<u>Protection and control schemes</u> 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.
	<u>Emergency frequency control schemes</u> 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	<u>Root cause of failure of comms multiplexer</u> 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

Appendix A1. Status of actions arising from major events

Incident	Recommendation	Status	Details
			diagnostic testing and it remains unclear why it would not power up. Hence, the root cause of the multiplexer failure cannot be identified.
	<u>Risk mitigation measures associated with comms multiplexer failure</u> AusNet Services to review the mitigation measures for NEM security pending determination of root cause of multiplexer failure.	Open	Most recent status update TBC in final report
	<u>Compliance of DPV systems</u> 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.
04 January 2020 – New South Wales and Victoria Separation Event	<u>TransGrid review of procedures</u> 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.
	<u>Modify constraint formulation</u> 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-optimize the largest generators in NSW with the FCAS requirements. This co-optimisation was already in place for QLD and SA.
	<u>Review unexpected frequency deviation</u> 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.
	<u>Review of PASA tools</u> 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.
	<u>Review of AS/NZS4777.2:2015</u> 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.

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
	<u>Identify sources on non-compliance in DPV systems</u> 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.
	<u>Visibility of DPV systems</u> 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	<u>Risk assessment for extreme weather impacts</u> 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.
	<u>Alcoa Portland Pty Ltd (APD) review options to limit impacts of voltage disturbances</u> 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.
	<u>Pre-contingent regional FCAS</u> 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.
	<u>Fast frequency response from transmission connected solar farms</u>	Closed	Investigation into the VIC-SA separation incident has demonstrated that Tailm Bend SF can provide some form of FFR.

Appendix A1. Status of actions arising from major events

Incident	Recommendation	Status	Details
	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.		AEMO is continuing to engage with SF operators on their ability to provide FFR.
	<u>Fault ride-through capability of distribution connected solar PV</u> 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.
	<u>Manufacturer issue with DPV systems</u> 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.
	<u>AEMO to review and update its internal major incident management and escalation processes</u> 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 is 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.
	<u>Review communication processes for IT issues to market</u> 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.
	<u>AEMO to Work with GE to review best practice for SCADA availability</u> 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.

Appendix A1. Status of actions arising from major events

Incident	Recommendation	Status	Details
12 March 2021 - Trip of Torrens Island A and B West 275 kV busbars	<u>Identify root cause of Torrens CT failure</u> 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: <ul style="list-style-type: none"> • 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	<u>Power station operators to consider learnings from this incident</u> 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.
	<u>AEMO to discuss with Generators the need to:</u> <ul style="list-style-type: none"> • Provide advice to AEMO when protection schemes and associated 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.
	<u>AEMO, TNSPs and Generators to review the emergency communications protocols</u> This review will include: <ul style="list-style-type: none"> • 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. 	Open	This is being progressed as part of the generator reclassification requirements review. This work is planned for completion by Q4 2022.

Appendix A1. Status of actions arising from major events

Incident	Recommendation	Status	Details
	<ul style="list-style-type: none"> A process to assess apparent discrepancies between SCADA and site observations and to agree on action to be taken. <p>This will include any necessary training programmes for operating staff.</p>		
	<u>AEMO to review Stanwell TTHL settings</u> 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 disconnecting following network disturbances. AEMO will review with Stanwell whether to re-establish this trigger with revised settings.	Open	AEMO is targeting completion of this review in Q1 2023.
	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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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	Open	CS Energy has confirmed that the investigation into the root cause of this incident is ongoing.

Appendix A1. Status of actions arising from major events

Incident	Recommendation	Status	Details
	will be shared with AEMO. AEMO and CS Energy may identify additional recommendations based on the outcome of this independent investigation.		

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	<p>AEMO has recently reviewed the IECs⁵ 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.</p> <p>AEMO also found:</p> <ul style="list-style-type: none"> • 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	<p>AEMO recently completed several reviews of EAPT in response to a mal-operation in 2018⁶ 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:</p> <ul style="list-style-type: none"> • 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 2018⁷ 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.

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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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
		<p>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:</p> <ul style="list-style-type: none"> 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 <p>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).</p> <p>Forward UFLS projections</p> <p>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.</p> <p>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.</p> <p>OFGS review</p> <p>AEMO is currently reviewing the SA / Western VIC OFGS scheme as noted above.</p> <p>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.</p>
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.
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,	Ongoing improvement process	<p>AEMO has taken the following steps to improve data and model quality:</p> <ul style="list-style-type: none"> Contacted all Generators with PFR-enabled generation to check that AEMO has current and accurate model information.

Recommendation	Status	Update
several inadequacies in the power system models were identified and addressed.		<ul style="list-style-type: none"> • 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 contingencies⁸.
- Simplified NEM network model considers QNI upgrades without PEC.

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 Victoria Renewable Integration RIT-T upgrades 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 Victoria Renewable Integration RIT-T.

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 (NSW, VIC and QLD 330 kV and SA 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 DPVs were grouped according to their frequency trip bands and connected at 33 kV distribution level buses. The number of regional trip bands modelled were:
 - NSW – 121.
 - VIC – 32.
 - QLD – 33.
 - SA – 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 SVCs.
- The HV network between SESS and MLTS were modelled as per OPDMS network.
- SA 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 SA 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 DPVs.

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 SA 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 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 stopped generating but remained connected to the power system since the generator 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 published incident report⁹.

The sequence of events that took place during this incident were 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 PSSE 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 QLD for the 25 May 2021 event are shown in Figure 3. The simulated frequency traces in all regions except QLD matches 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.

⁹ AEMO (2021) Trip of Multiple Generators and Lines in Queensland and Associated Under-Frequency Load Shedding Report, 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.

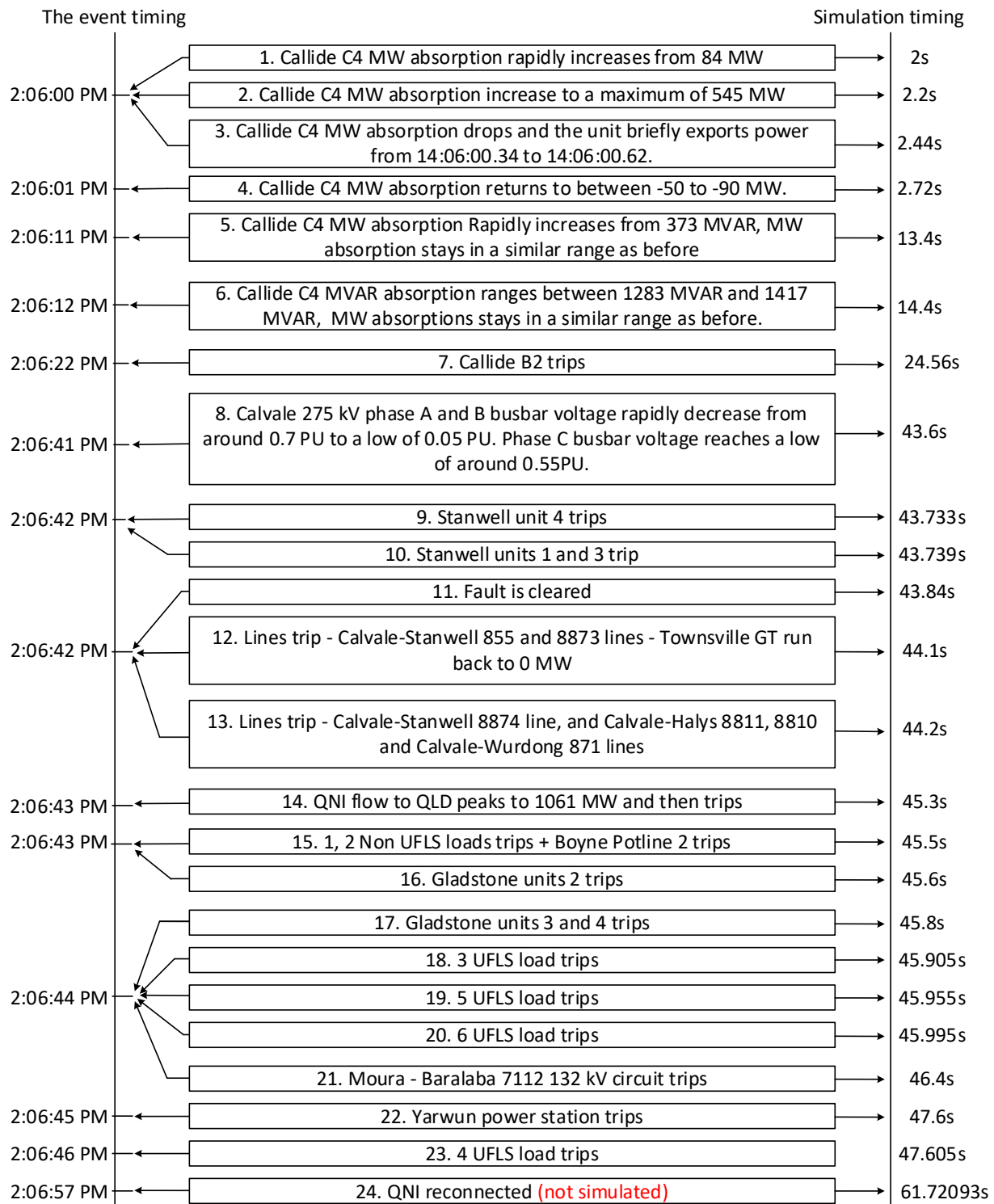
Figure 1 25 May 2021 Callide event sequence and timings along with the corresponding simulation timings


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

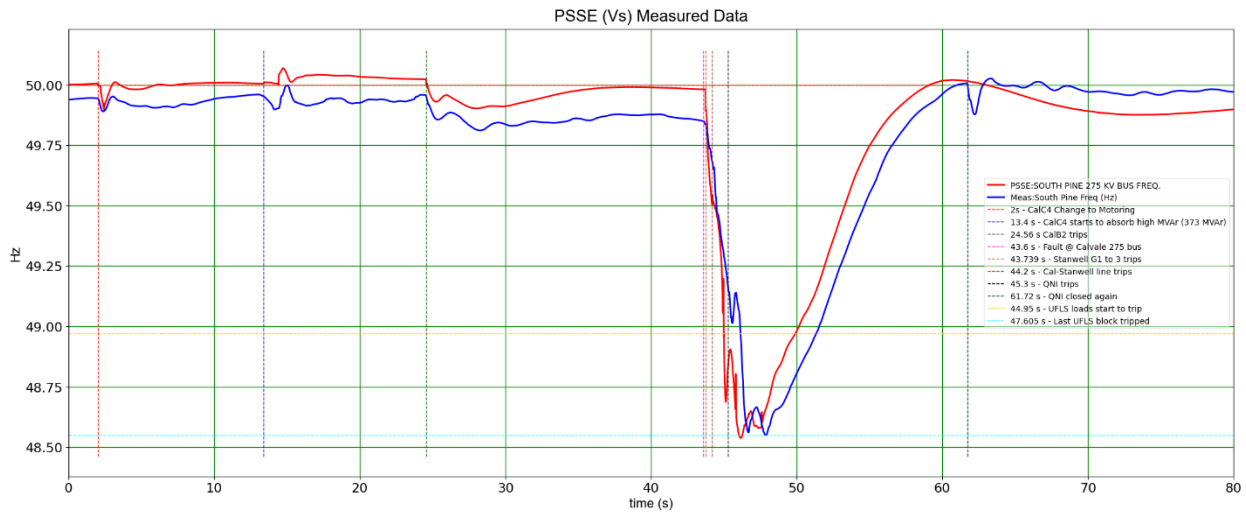
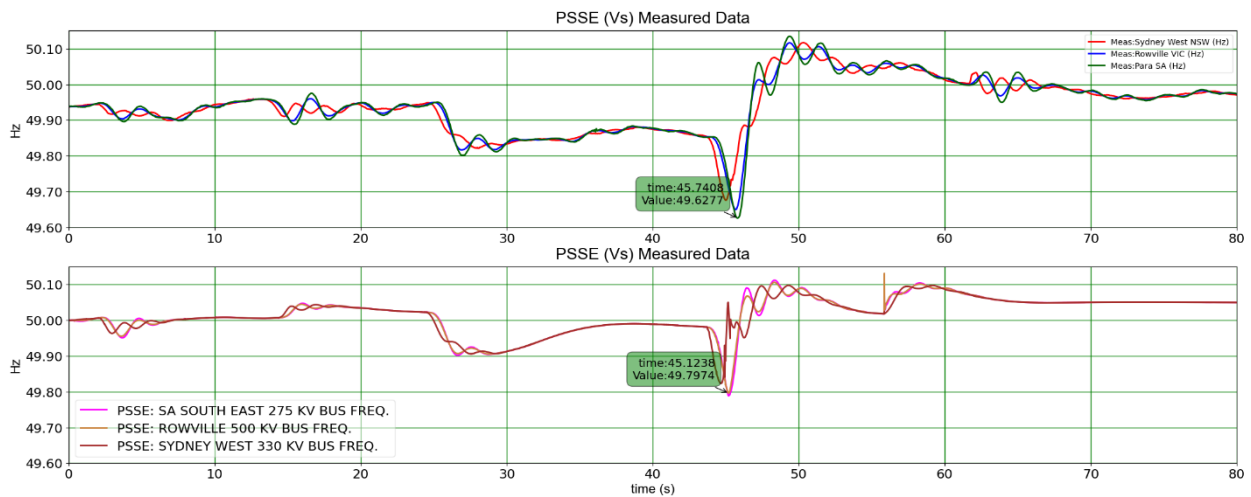


Figure 3 Benchmarking of simulated and measured frequency in all regions except QLD following 25 May 2021 event

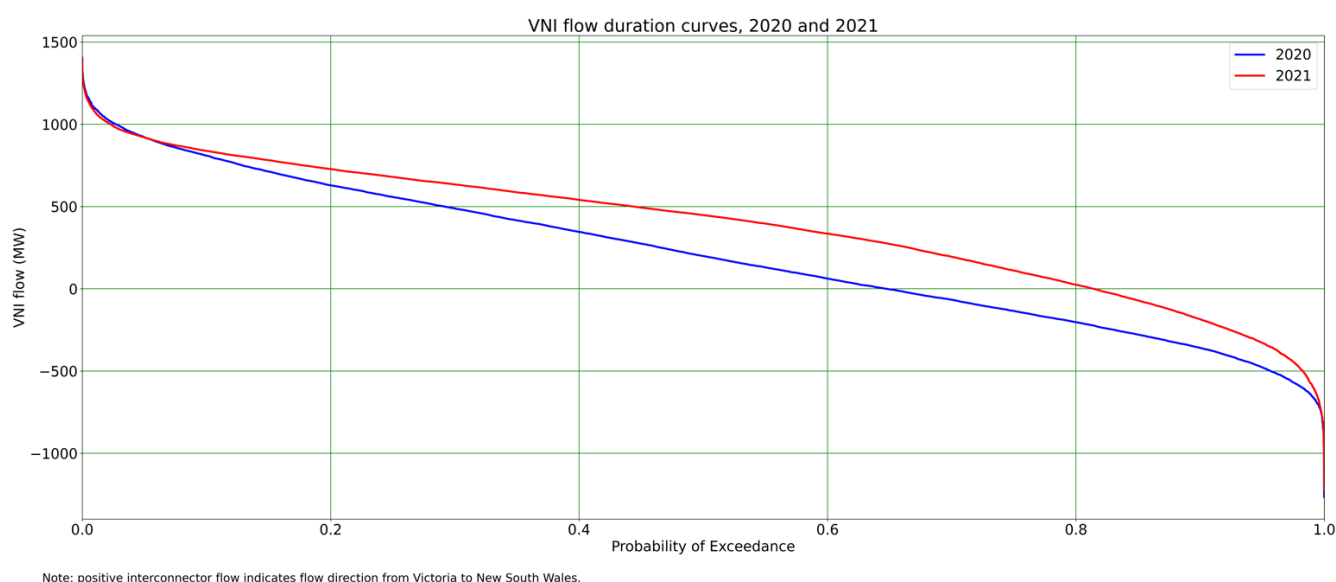


A5. Study results and observations (contd.)

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 700-1600 MW from VIC to NSW and 400-1350 MW from NSW to VIC. Figure 4 shows the duration curves for the power flow from VIC to NSW and NSW to VIC across VNI from 1 January 2020 to 31 December 2021.

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



The non-credible simultaneous loss of the 4 VNI lines (Murray – Lower Tumut, Murray – Upper Tumut and Jindera – Wodonga) was considered for VIC import and VIC export conditions. Both historical and future (2027) operating boundary conditions were included in the study.

A5.1.1 VIC import – historical cases

Study scenarios

Eight cases were considered for the historical studies of the non credible loss of VNI during VIC 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 VIC imports, VIC inertia varied from 11752 to 16303 MW-s and underlying VIC UFLS load ranged from 2777 MW to 3508 MW. In addition, coincident with historic high VIC imports, maximum DPV and VIC renewable generation was 1272 MW and 955 MW respectively. The range of power system variables considered for the

studies are given in Table 4. Detailed parameters of the selected cases are included in the Table 40 in Appendix A6.15.1.

Table 4 System operating points for historical cases (VIC Import)

VIC operational load (MW)	VIC import (MW)	VIC inertia (MW-s)	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.

Whilst the possibility of VNI loss is very remote, during bushfires 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 that an abnormal condition is affecting the power system eventuates, 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, and these substations were also de-energised until the threat had passed. The present measures must be continued to manage VNI separation.

A5.1.2 VIC 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 the VNI separation when VIC is importing. For all regions except SA, 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 SA, four synchronous condensers with no synchronous units were assumed. The range of power system variables considered for the studies are given in Table 5. Detailed parameters of the selected cases are included in the Table 67 in Appendix A6.15.1.

Table 5 System operating points for the future cases (VNI Sep: VIC 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 are summarised in Table 6, Table 7 and Table 8. Detailed results for each case are included in Table 68, Table 69, and Table 70 in Appendix A6.15.1.

Table 6 Simulation results of the future cases for generation dispatch Scenario 1 (VNI Sep: VIC 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 Sep: VIC 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 Sep: VIC 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 (VIC import) simplified studies identified:

- The frequency in NSW/QLD island remained below 51 Hz for all cases.
- The steady state frequency in the VIC/SA island was regulated above 48 Hz in three cases through UFLS action. In Case 1,2,6, and 7, however, the frequency in VIC/SA collapsed due to the UFLS inadequacy in VIC and SA (refer the results in Appendix A6.17.1). Sufficient VIC and SA combined UFLS is required to manage the VIC-SA 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 VIC/SA island increased from 1.57 – 1.95 Hz/s following VNI separation.

A5.1.3 VIC export historical cases

Study scenarios

Nine cases were considered for the historical studies of the non credible loss of VNI during VIC 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 VIC exports, VIC inertia varied from 14913 to 19252 MW-s and underlying VIC UFLS load ranged from 2085 MW to 3563 MW. In addition, coincident with historic high SA imports, maximum DPV and SA renewable generation was 1423 MW and 5039 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 41 in Appendix A6.15.2.

Table 9 System operating points for historical cases (VIC Export)

VIC operational load (MW)	VIC export (MW)	VIC inertia (MW-s)	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 (VIC 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 that an abnormal condition is affecting the power system eventuates, 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, and these substations were also de-energised until the threat had passed. The present measures must be continued to manage VNI separation.

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

Study scenarios

A total of nine cases were considered for the future studies for the VNI contingency when VIC is exporting. For all regions except SA, 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 SA, 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 71 in Appendix A6.15.2.

Table 10 System operating points for future cases (VNI Sep: VIC 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 are summarised in Table 11, Table 12, and Table 13. Detailed results for each case are included in Table 72, Table 73, and Table 74 in Appendix A6.15.2.

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

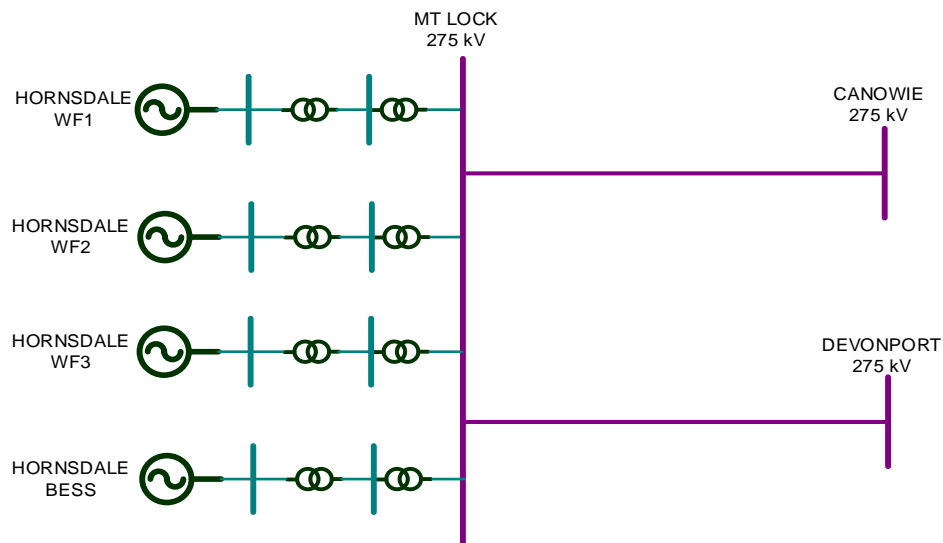
Key findings

The VNI (VIC export) simplified studies identified:

- Frequency in the NSW/QLD island was regulated above 48 Hz due to UFLS action in all cases except Case 8.
- The frequency in the VIC/SA island stabilizes below 51 Hz for all stable cases. In Case 6 and 7, where the OFGS operated in SA, the OFGS was sufficient to stabilize the frequency in VIC/SA island below 51 Hz.
- As the inertia is reduced from Scenario 1 to Scenario 3, the maximum RoCoF in the NSW/QLD island increases from 1.10 – 1.90 Hz/s following VNI separation.
- QNI tends to become unstable as the power inflow from VIC is lost following VNI separation. This is evident in cases where the QLD export is high into NSW 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 SA import and export conditions. Historical cases were selected for study primarily based on maximum/high SA transfer levels and high Hornsdale WF and Bess generation output (as high SA transfers and Hornsdale generation output during Mt Lock busbar loss are likely to cause the largest system frequency excursions). Coincident with historic high SA transfers, SA inertia varied from 5548 to 16155 MW-s and Hornsdale generation ranged from 135 MW to 396 MW. In addition, coincident with historic high SA transfers, maximum SA operational demand was 2528 MW. The range of power system variables considered for the studies are given in Table 14. Detailed parameters of each case are given in Table 42 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 (MW s)	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 43 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	49.81 – 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:

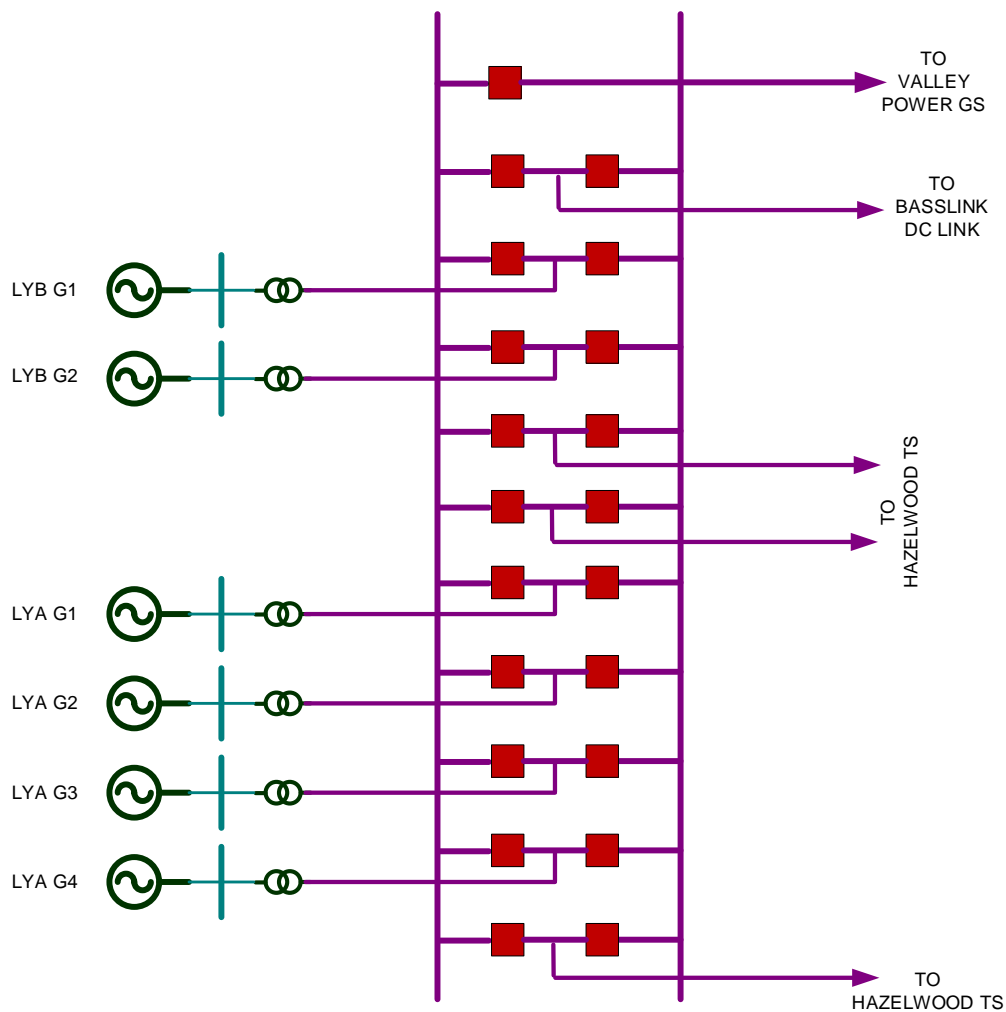
- The minimum frequency nadir is 49.87 Hz and, hence, UFLS was not triggered.

- The maximum RoCoF was around 0.24 Hz/s.
- A maximum of 16.2 MW of DPVs 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 4 units with a total capacity of 2210 MW and Loy Yang B with 2 units with a total capacity of 1160 MW as shown in Figure 6. Non-credible loss 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 are likely to cause the largest system frequency excursions). Coincident with historic high Loy Yang generation levels, VIC inertia varied from 17606 to 37097 MW-s and VIC operational demand ranged from 4042 MW to 7883 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 (MW-s)	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 53 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 VIC frequency nadir did not fall below 49 Hz, except in Cases 10 and 11, where QNI reached its stability limit of 1200 MW.
- Heywood Interconnector 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 TAS UFLS action.
- Following the loss of Loy Yang B units during high QLD export conditions, studies showed that QNI could lose stability.
- Due to large power swings in HIC, EAPT operation could trip HIC leading to SA separation.

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

1. 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 SA 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 VIC to SA direction. For all cases studied, the Murraylink power flow was in the SA to VIC 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 west VIC renewable generation (as high west VIC renewable generation will present more onerous condition during the contingency). Coincident with high NSW export to VIC and VIC import from NSW flows were selected for the study.

The range of power system variables considered for the studies are given in Table 19 and detailed parameters of each case are included in Table 54 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 are summarised in Table 20 and Table 21. More detailed results for each case are included in Table 54 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 and leading severe over voltages above 1.15 pu at several West Murray transmission buses.
- High frequency, voltage and reactive power oscillations were observed in traces of IBR and SVCs 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.

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 – SA separation from HYTS

The non-credible separation of SA 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 SA import condition

Study scenarios

Eleven historical cases were considered for the SA separation from HYTS (SA import). Historical cases were selected for study primarily based on maximum/high HIC SA import levels (as high HIC transfers during SA separation are likely to cause the largest system frequency excursions). Coincident with historic high SA imports, SA inertia varied from 9805 to 20870 MW-s and underlying SA UFLS load ranged from 1090 MW to 2401 MW. In addition, coincident with historic high SA imports, maximum DPV and SA renewable generation was 956 MW and 583 MW respectively. Case details are given in Table 22.

Table 22 SA separation from HYTS: Historical cases considered - SA Variables (SA import)

Case No	SA operational demand (MW)	SA total import (MW)	HIC import (MW)	SA inertia (MW-s)	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 SA separation from HYTS: Historical cases results - SA Variables (SA import)

Case No	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 A6.1.2 where the frequency nadir was just below 48 Hz and settled at 49.4 Hz.

A6.1.2 Case 11 SA separation from HYTS (SA import): HIC flows and SA and remaining NEM frequencies SA export condition

Study scenarios

Twelve historical cases were considered for the SA separation from HYTS (SA export). Historical cases were selected for study primarily based on maximum/high HIC SA export levels (as high HIC transfers during SA separation are likely to cause the largest system frequency excursions). Coincident with historic high SA exports, SA inertia varied from 9527 to 18043 MW-s and underlying SA UFLS load ranged from 967 MW to 1777 MW. In addition, coincident with historic high SA exports, maximum DPV and SA renewable generation was 945 MW and 976 MW respectively. The case details are given in Table 24.

Table 24 SA separation from HYTS: Historical cases considered - SA Variables (SA export)

Case No	SA operational demand (MW)		SA Total export (MW)	HIC export (MW)	SA inertia (MW-s)	SA underlying UFLS load (MW)	SA OFGS available (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
9	1034	790	573	11674		1133	642	520	976

Case No	SA operational demand (MW)		SA Total export (MW)	HIC export (MW)	SA inertia (MW-s)	SA underlying UFLS load (MW)	SA OFGS available (MW)	SA DPV (MW)	SA renewables (MW)
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

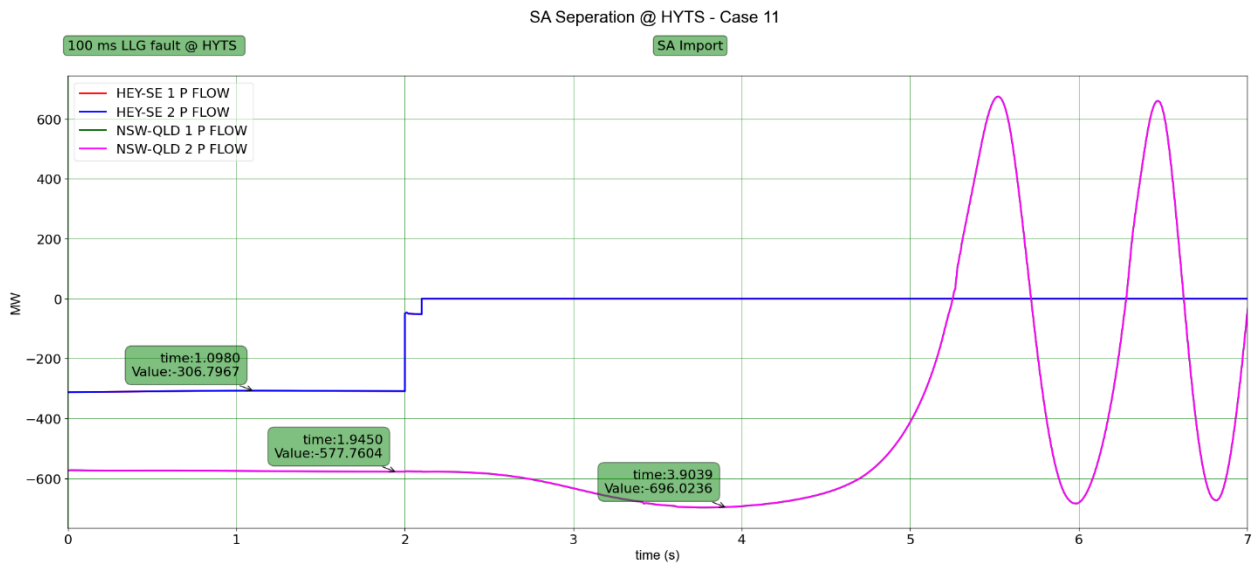
The key results of the historical case simulation studies are given in Table 25.

Table 25 SA separation from HYTS: Historical cases results - SA Variables (SA export)

Case No	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

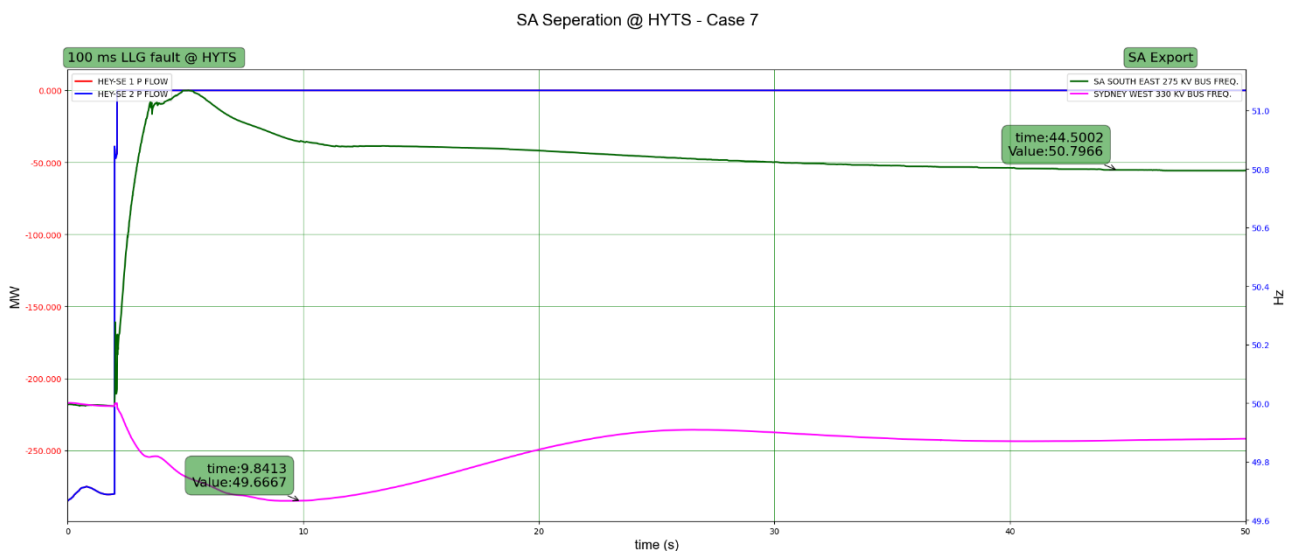
Representative results

The simulation results for Case 11 are shown in Figure 7. Following SA separation, QNI loses stability, and this would lead to the separation of QLD from the rest of the NEM resulting in three islands being formed (SA, VIC-NSW and QLD).

Figure 7 Case 11 SA separation from HYTS: HIC and QNI P flows


HIC Export Case 11 was rerun with the tripping of QNI 150 ms after the loss of the Heywood Interconnector. 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 SA separation, SA 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 8 Case 7 SA separation from HYTS (SA export): HIC P flows and SA and remaining NEM frequencies


A6.2 Contingency 2 – SA separation from MLTS

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

A6.2.1 SA import condition

Study scenarios

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

Table 26 SA separation from MLTS: Historical cases considered - SA Variables (SA import)

Case No	SA operational demand (MW)	Total import (HIC + Murraylink) (MW)	HIC import (MW)	SA Inertia (MW-s)	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.

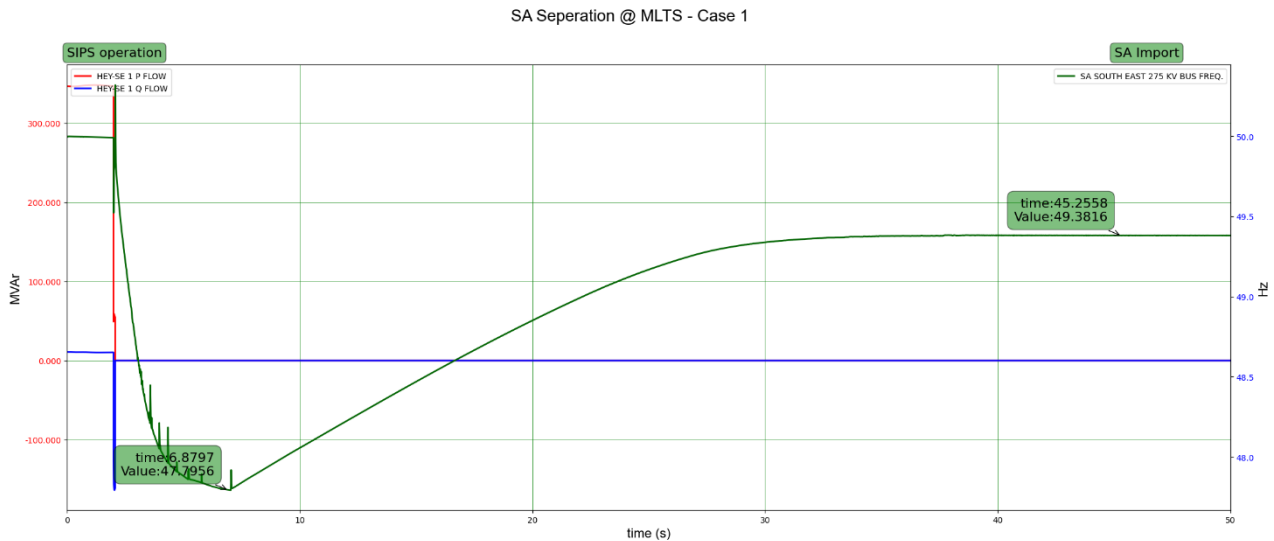
Table 27 SA separation from MLTS: Historical cases results - SA Variables (SA import)

Case No	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. SA frequency fell below 48 Hz with a nadir of 47.8 Hz. HIC flows and SA frequency for Case 1 are included in Figure 9.

Figure 9 Case 1 SA separation from MLTS (SA import): HIC and SA frequency



A6.2.2 SA export condition

Study scenarios

Eleven historical cases were considered for the SA separation from MLTS (SA export). Historical cases were selected for study primarily based on maximum/high SA export levels (as high SA export transfers during SA separation are likely to cause the largest system frequency excursions). Coincident with historic high SA exports, SA inertia varied from 13134 to 22985 MW-s and underlying SA UFLS load ranged from 938 MW to 1897 MW. In addition, coincident with historic high SA exports, maximum DPV and SA renewable generation was 778 MW and 1011 MW respectively. Case details are given in Table 28.

Table 28 SA separation from MLTS: Historical cases considered - SA Variables (SA export)

Case No	SA operational demand (MW)	Total export (HIC + Murraylink) (MW)	HIC export (MW)	SA inertia (MW-s)	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

Case No	SA operational demand (MW)	Total export (HIC + Murraylink) (MW)	HIC export (MW)	SA inertia (MW-s)	SA underlying UFLS load (MW)	SA available OFGS (MW)	SA DPV (MW)	SA renewables (MW)
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.

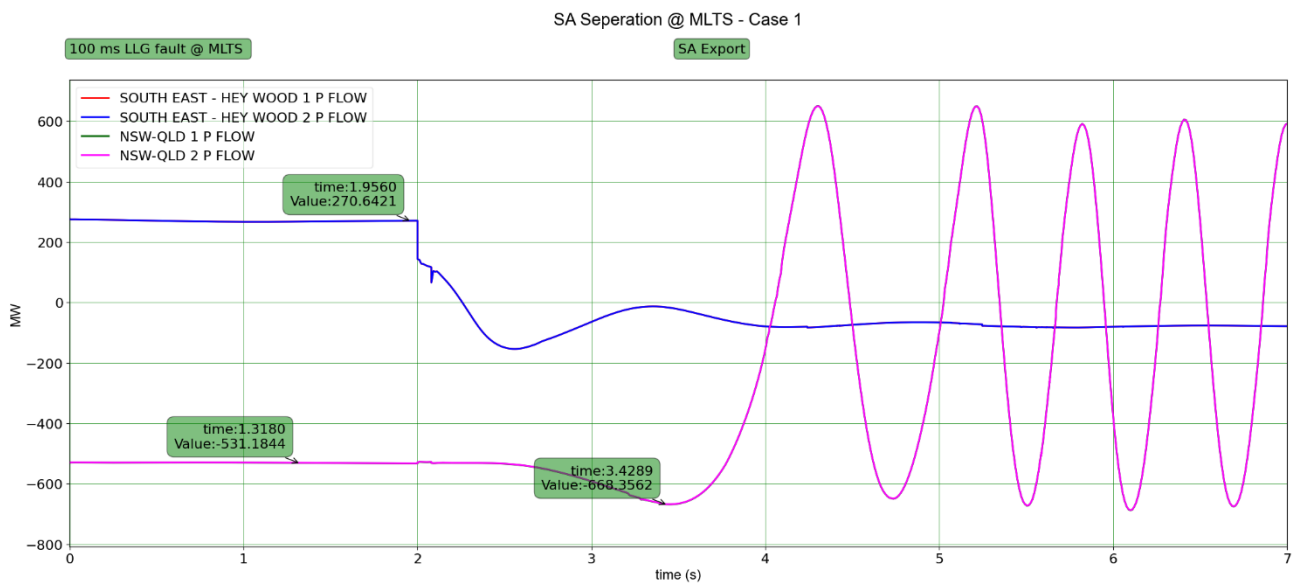
Table 29 SA separation from MLTS: Historical cases results - SA Variables (SA export)

Case No	SA freq peak range (Hz)	SA RoCoF (Hz)	SA OFGS generation tripped (MW)	SA total DPV tripped on protection only (MW)	Is 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

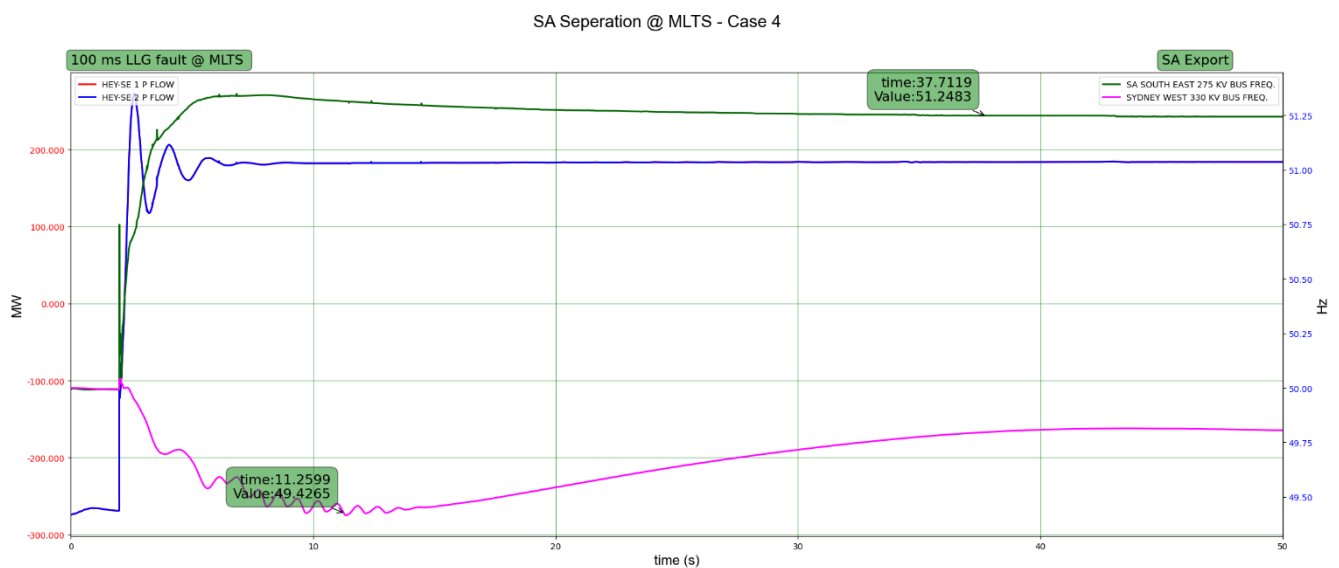
In Cases 1 and 3 for SA separation from MLTS, QNI lost stability. The line flows for Case 1 are shown in Figure 10.

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



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

Figure 11 Case 4 SA separation from MLTS: HIC and SA and remaining NEM frequencies



A6.3 Contingency 3 – QLD separation through QNI loss

A6.3.1 QNI import condition

Study scenarios

Eight historical cases were considered to study QLD separation due to loss of QNI when QLD is importing. Case details are given in Table 30 and Table 31.

Table 30 QNI separation: QLD import historical cases QLD variables

Case No	Operational demand (MW)	Pgen (MW)	Import (MW)	Renewables (MW)	Inertia (MW-s)	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: QLD import historical import cases remaining NEM variables

Case No	Remaining NEM operational demand (MW)	Remaining NEM Pgen (MW)	NEM renewable generation (MW)	NEM inertia (MW-s)	NEM underlying UFLS (MW)	Total NEM DPV (MW)
1	14082	15030	3216	68945	8348	0
2	16676	17622	2735	67979	9688	1801
3	16510	17361	2717	69522	9616	1463
6	17530	18482	2143	67728	10473	3595
7	18888	19770	1579	73820	11280	3856
9	18923	19713	1438	73546	11253	3986
10	18337	18952	3361	63637	10935	3832
11	17611	18496	2034	67674	10592	3814

Study results

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

Table 32 QNI separation: QLD import historical trip results for QNI import

Case No	Region	Freq peak (Hz)	Freq nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁰ (MW)	% Total DPV tripped
1	QLD	50.28	48.98	0.44	304	9.69	0	0
	Rest of NEM	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
	Rest of NEM	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

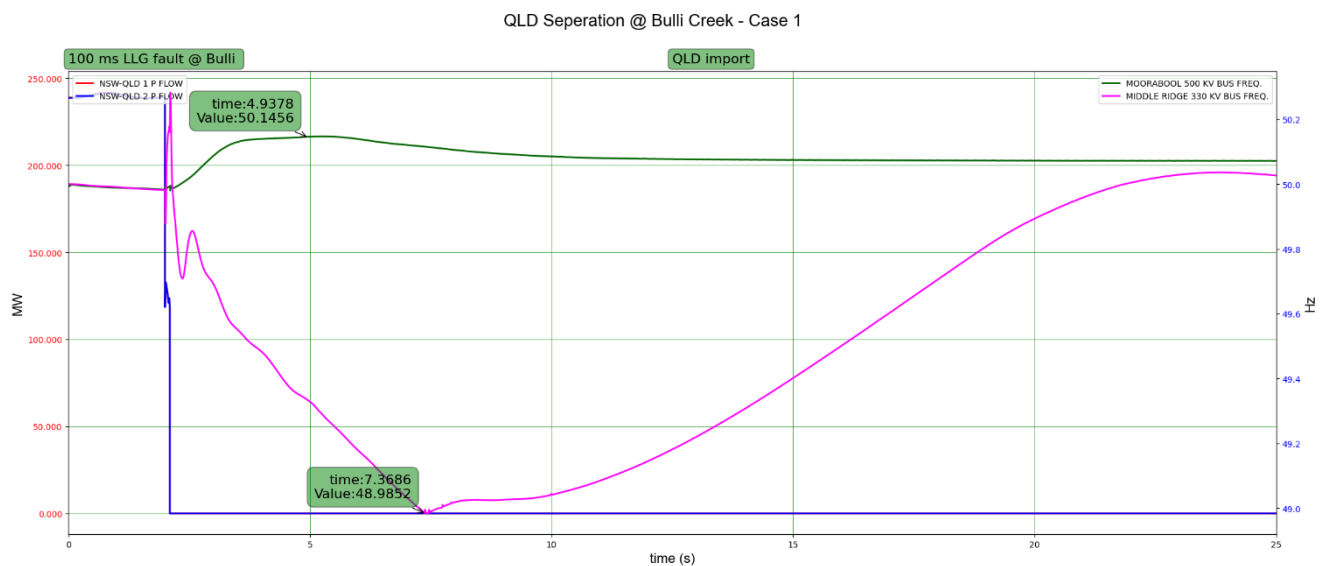
¹⁰ Includes DPV tripped on UFLS action and on protection settings

Case No	Region	Freq peak (Hz)	Freq nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁰ (MW)	% Total DPV tripped
	Rest of NEM	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
	Rest of NEM	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
	Rest of NEM	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
	Rest of NEM	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
	Rest of NEM	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
	Rest of NEM	50.15	50	0.12	0	0	3.58	0.10
	TAS	50.11	50	0.02	-	-	-	-

Representative results

For QNI Import case 1, QLD frequency dropped just below 49 Hz after the QNI trip while QLD importing 496 MW. The QNI flow and QLD and NSW frequency for Case 1 are included in Figure 12.

Figure 12 Case 1 QLD separation from Bulli Creek: QNI P flows and QLD and remaining NEM frequencies



A6.3.2 QNI export condition

Study scenarios

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

Table 33 QNI separation: QLD export historical cases QLD variables

Case No	Operational demand (MW)	Pgen (MW)	export (MW)	Renewables (MW)	Inertia (MW-s)	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: QLD export historical export cases remaining NEM variables

Case No	Remaining NEM operational demand (MW)	Remaining NEM Pgen (MW)	NEM renewable generation (MW)	NEM inertia (MW-s)	NEM underlying UFLS (MW)	Total NEM DPV (MW)
1	21474	20872	416	100033	13202	0
2	20134	19299	1212	83258	12043	2808
5	14651	13756	1431	56370	11201	1970
6	18876	18137	2673	82220	11212	1197
8	14148	13499	3329	55070	8481	2612
9	14861	13905	1744.2	57549	8755	1323
11	17364	16683	2656	66333	10144	1495

Study results

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

Table 35 QNI separation: QLD export historical trip results for QNI export

Case No	Region	Frequency peak (Hz)	Frequency nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	DPV tripped including protection ¹¹ (MW)	% Total DPV tripped
1	QLD	52.5	50	0.37	0	0	0	0
	Rest of NEM	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

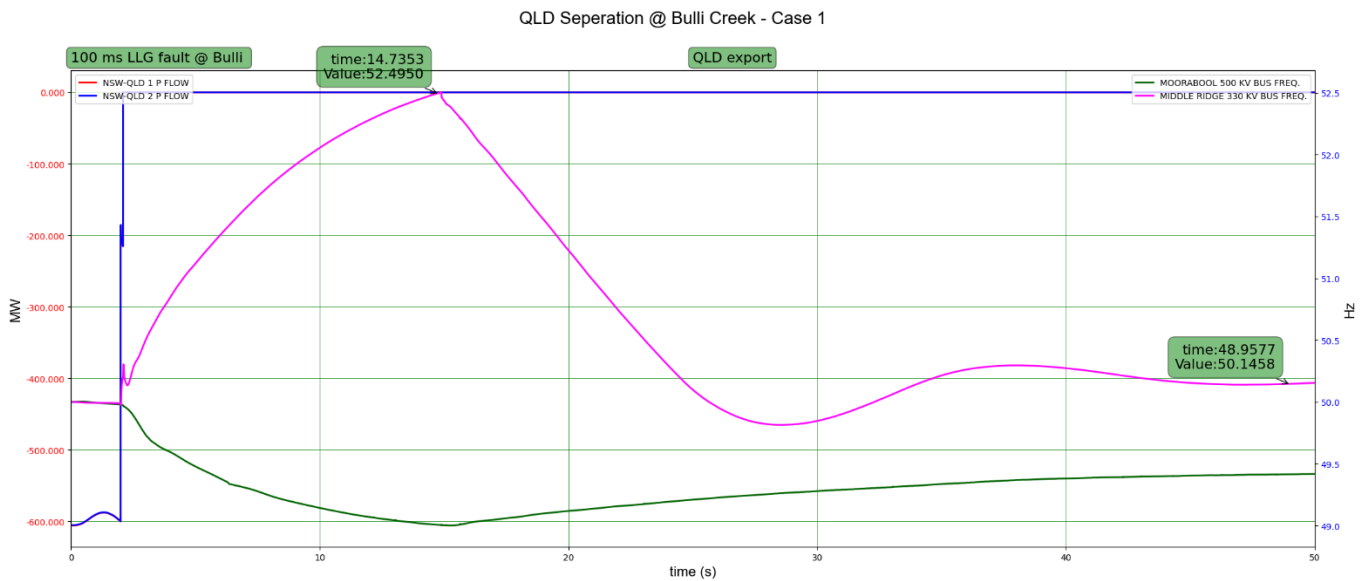
¹¹ Includes DPV tripped on UFLS action and on protection settings

Case No	Region	Frequency peak (Hz)	Frequency nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS load tripped (MW)	% Underlying UFLS load tripped	DPV tripped including protection ¹¹ (MW)	% Total DPV tripped
5	Rest of NEM	50	48.99	0.23	819	6.80	238	8.49
	TAS	50	47.88	0.79	58	-	-	-
	QLD	51.52	50	0.33	0	0	319	24.2
6	Rest of NEM	50	48.96	0.29	1396	12.46	245	12.41
	TAS	50	48.63	0.49	-	-	-	-
	QLD	51.68	50	0.34	0	0	117	18.83
8	Rest of NEM	50	49	0.19	727	6.48	80	6.68
	TAS	50	47.71	0.85	123	-	-	-
	QLD	51	50	0.23	0	0	288	16.02
9	SA	50.86	48.96	2.17	55	7.5	34	12.82
	Rest of NEM	50	48.96	0.39	1118	14.43	216	9.21
	TAS	50	47.81	1.09	64	-	-	-
11	QLD	51.12	50	0.33	0	0	368	25.70
	Rest of NEM	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
	Rest of NEM	50	49	0.24	372	3.67	54	3.61
	TAS	50	47.9	0.92	74	-	-	-

Representative results

For QNI Export Case 1, QLD 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 QLD synchronous generators tripped on their over-frequency protection, which helped frequency recover back to 50 Hz. The QNI flow and QLD and NSW frequency for Case 1 is shown in Figure 13.

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



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

A6.4.1 QNI import condition

Study scenarios

Six historical cases were considered for the Calvale – Halys separation (QNI import). Case details are given in Table 36.

Table 36 Loss of both 275 kV lines between Calvale – Halys cases considered (QNI import)

Case No	QNI 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 37.

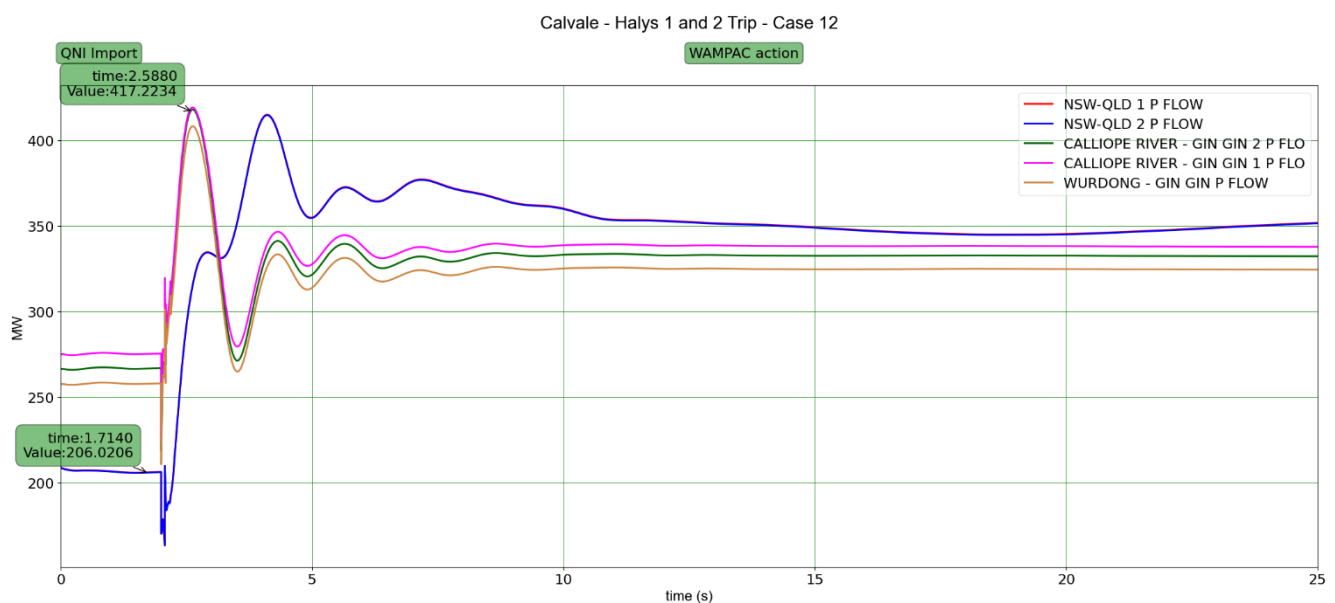
Table 37 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI import)

Case No	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 QLD import are shown in Figure 14.

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



A6.4.2 QNI export condition

Study scenarios

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

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

Case No	QNI 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

Case No	QNI Export (MW)	Calvale – Halys Flow (MW)	CQ-SQ eastern corridor (MW)	CQSQ Flow (MW)	Load available for tripping (MW)	Gen available for tripping (MW)
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

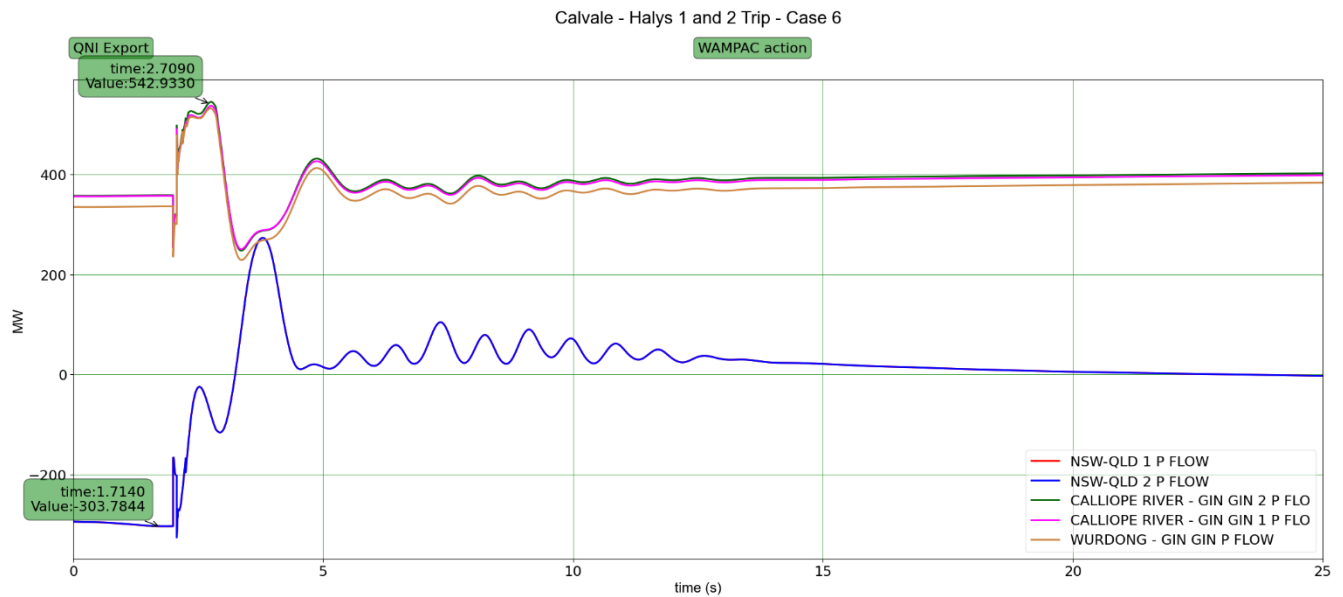
The key results of the historical case simulation studies are given in Table 39.

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

Case No	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 QLD export are shown in Figure 15.

Figure 15 Case 6 key line flows: Calvale – Halys 1 and 2 trip during QLD 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 VIC import and export conditions. Both historical and future (2027) operating boundary conditions were included in the study.

A6.5.1 VIC import condition

Study scenarios

Eight historical cases were considered for the non-credible loss of the VNI lines (VIC import). Case details are given in Table 40.

Table 40 Loss of VNI lines: Historical cases considered (VIC import)

Case No	VIC operational demand (MW)	VIC import (MW)	VIC inertia (MW-s)	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

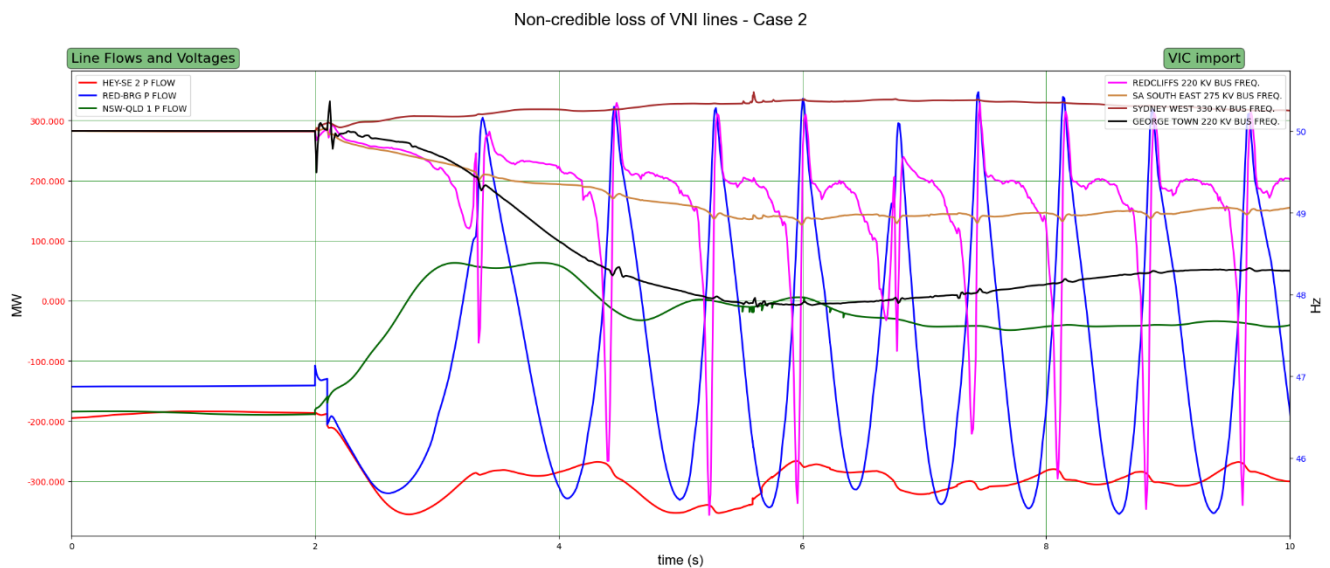
Study results

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 Case2 non-credible loss of VNI lines (VIC import): Line flows and frequencies



A6.5.2 VIC export condition

Study scenarios

Nine historical cases were considered for the non-credible loss of the VNI lines (VIC export). Case details are given in Table 41.

Table 41 Loss of VNI lines: Historical cases considered (VIC export)

Case No	VIC operational demand (MW)	VIC export (MW)	VIC inertia (MW-s)	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

Case No	VIC operational demand (MW)	VIC export (MW)	VIC inertia (MW-s)	VIC underlying UFLS load (MW)	Total VIC DPV (MW)	VIC renewables (MW)
9	4411	669	15009	3310	1299	0

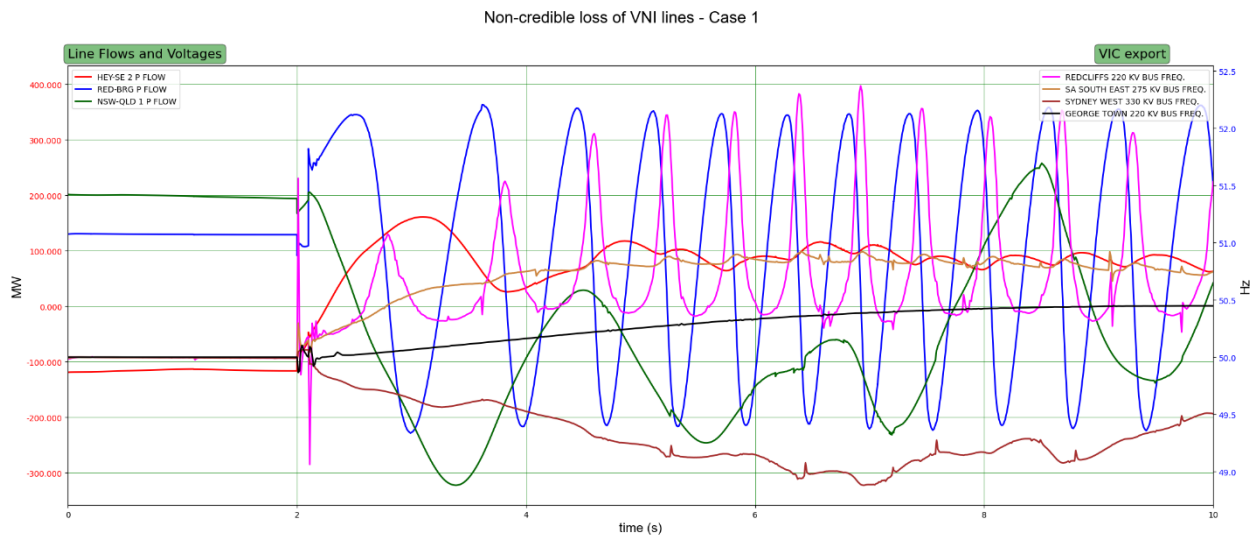
Study results

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 (VIC 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 42.

Table 42 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 (MW s)	Hornsedale WFs (MW)	Hornsedale BESS (MW)	Hornsedale 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

Case	SA operational demand (MW)	SA HIC import (MW)	SA inertia (MW s)	Hornsedale WFs (MW)	Hornsedale BESS (MW)	Hornsedale total output (MW)	SA renewables (MW)
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 43.

Table 43 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 VIC import and export conditions.

A6.7.1 VIC import condition

Study scenarios

Three historical cases were considered for the loss of both Dederang to South Morang 330 kV lines (VIC import). Historical cases were selected for study primarily based on maximum/high VIC import flows on Dederang to South Morang 330 kV lines (as high lines flows will present more onerous condition during the contingency). Coincident with high flows on Dederang to South Morang 330 kV lines, VIC inertia varied from 39614 to 43305 MW-s and VIC operational demand ranged from 8674 to 9122 MW. Case details are given in Table 44.

Table 44 Loss of Dederang to South Morang 330 kV lines: system operating points for the historical cases – VIC variables (VIC import)

Case	Operational demand (MW)	Import (MW)	Inertia (MW s)	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

Case	Operational demand (MW)	Import (MW)	Inertia (MW s)	Total load available for load shedding (MW)			Total generation available for generation shedding (MW)			Renewables (MW)
				1a	1b	1c	1a	1b	1c	
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 45.

Table 45 Loss of Dederang to South Morang 330 kV lines: results of the historical cases for mode 1a – VIC variables (VIC 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 46.

Table 46 Loss of Dederang to South Morang 330 kV lines: results of the historical cases for mode 1b – VIC variables (VIC 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

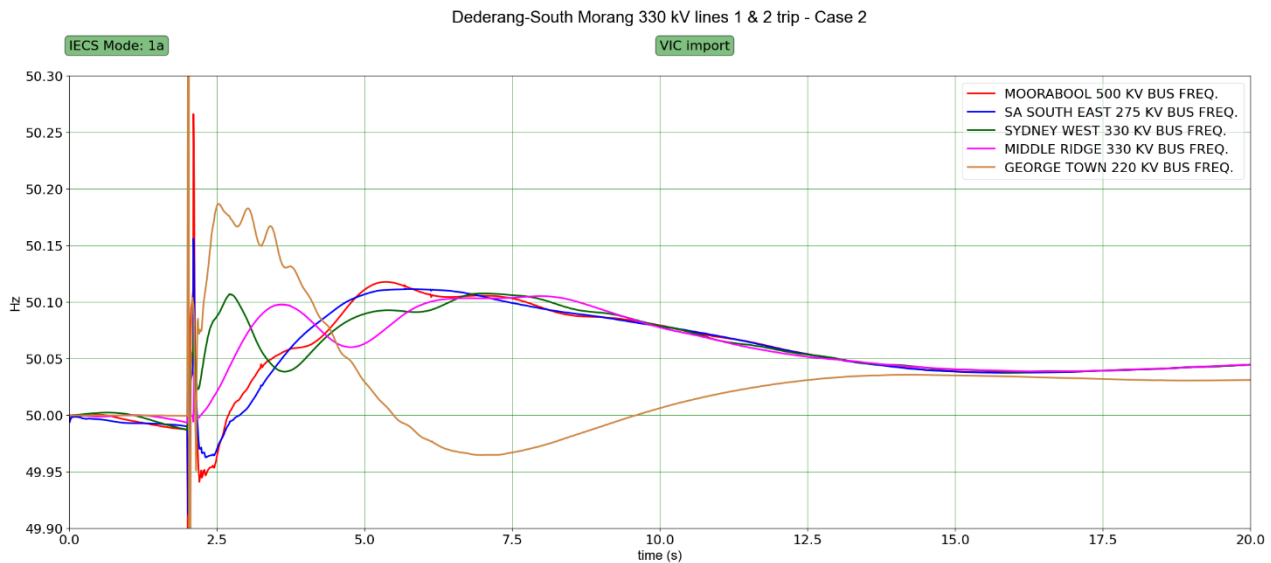
The key results of the historical case simulation studies for the IECS mode 1c are given in Table 47.

Table 47 Loss of Dederang to South Morang 330 kV lines: results of the historical cases for mode 1c – VIC variables (VIC 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 (VIC import): Regional frequencies

A6.7.2 VIC export condition

Study scenarios

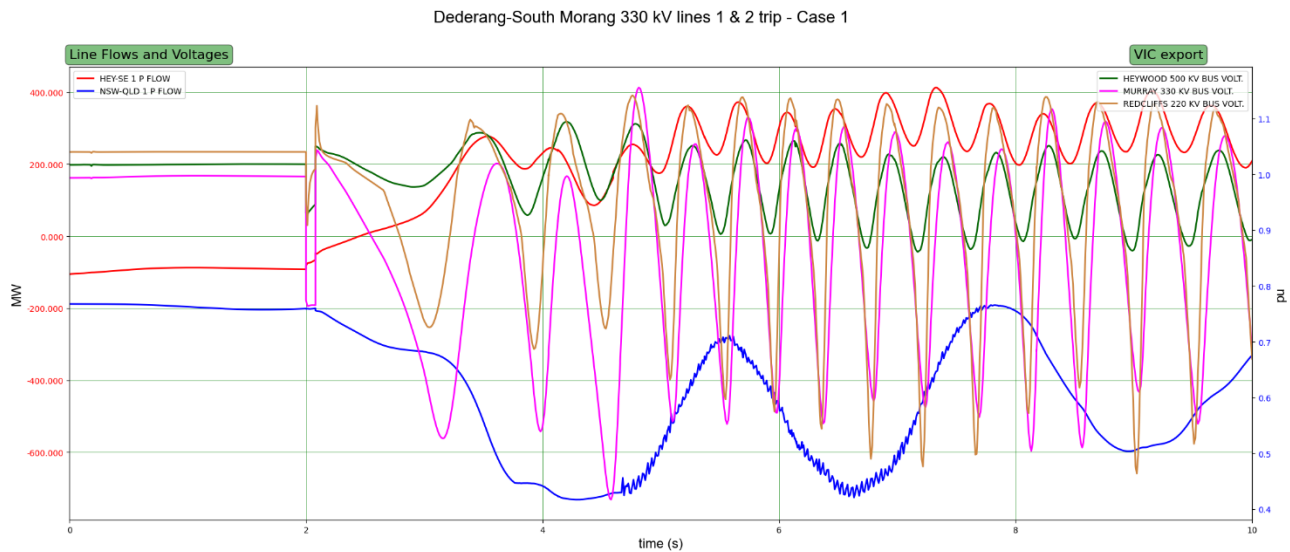
Ten historical cases were considered for the loss of both Dederang to South Morang 330 kV lines (VIC export). Case details are given in Table 48.

Table 48 Loss of Dederang to South Morang 330 kV lines: system operating points for the historical cases – VIC variables (VIC export)

Case	Operational demand (MW)	Export (MW)	Inertia (MW s)	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 VIC export historical cases were unstable. Studies indicate that the loss of both Dederang to South Morang 275 kV lines during high export from VIC 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 (VIC export): Line flows and bus voltages

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

Study scenarios

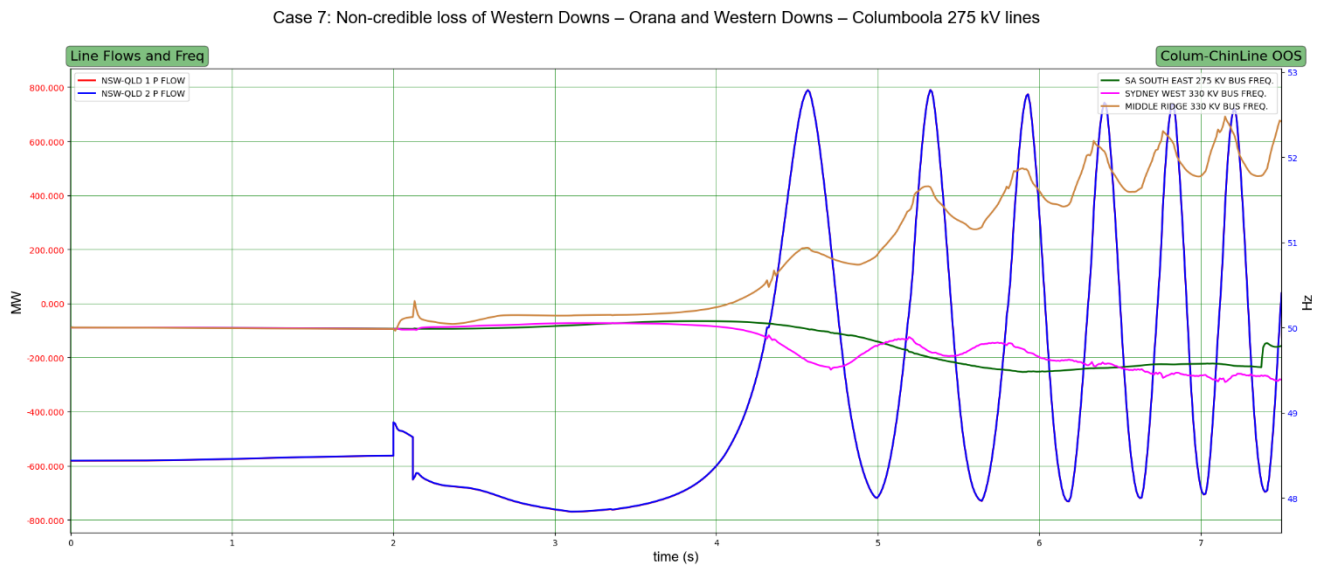
Eight historical cases were considered for the non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines. Case details are given in Table 49.

Table 49 Case details: non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines – QLD variables

Case	Operational load (MW)	QNI 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 50.

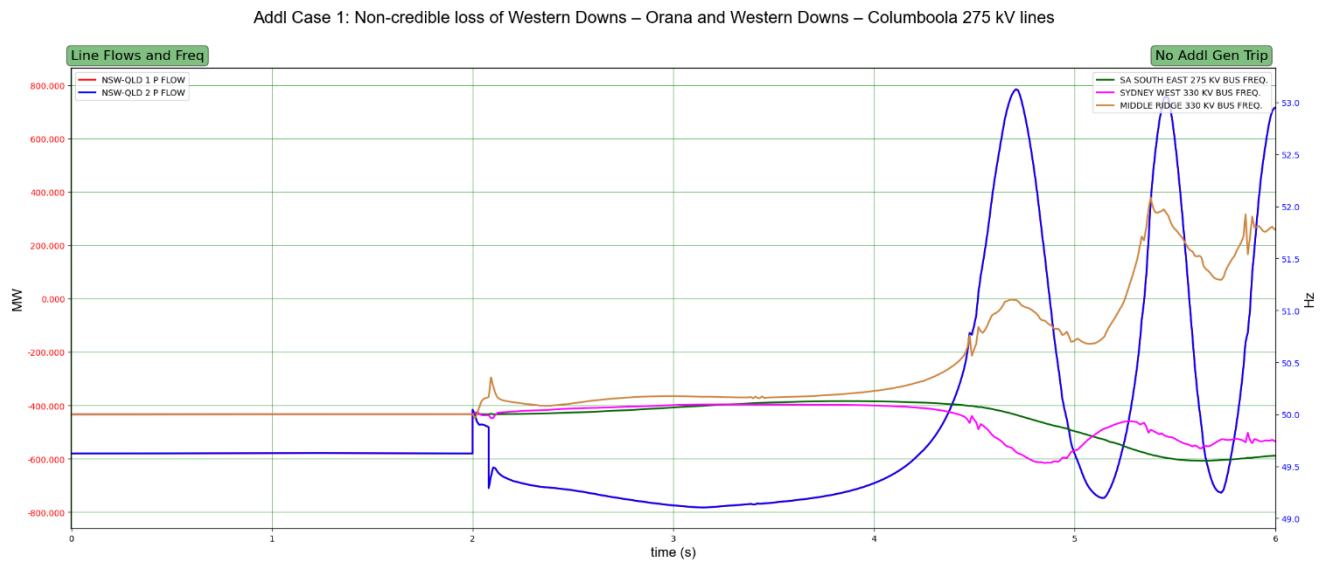
Table 50 Details of the additional cases: non-credible loss of Western Downs – Orana and Western Downs – Columboola 275 kV lines – QLD variables

Case	Operational demand (MW)	QNI 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

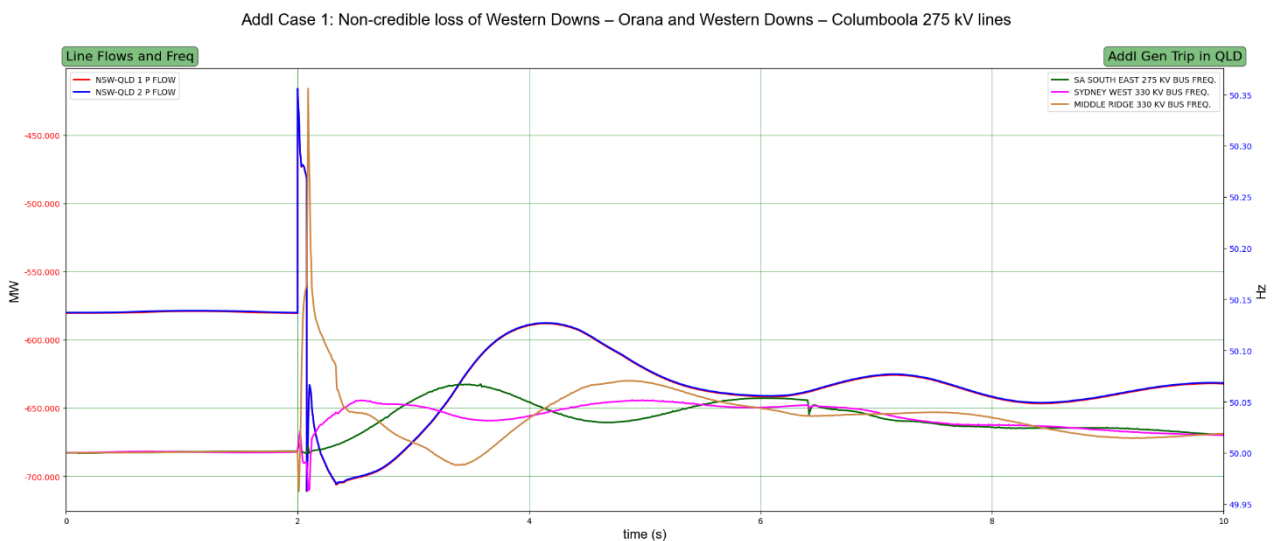
The QNI flow and system frequencies for the additional Case 1 is given in Figure 21 where QNI becomes unstable following the contingency.

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 QLD following the contingency was stable and is 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 51 and Table 52, respectively.

Table 51 Loy Yang generation unit

Case No.	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 52 Loy Yang cases regional variables

Case No	Region	Operational demand (MW)	Pgen (MW)	Export (MW)	Renewable generation (MW)	Inertia (MW-s)	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	-	-
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

Case No	Region	Operational demand (MW)	Pgen (MW)	Export (MW)	Renewable generation (MW)	Inertia (MW-s)	Underlying UFLS load (MW)	Total DPV (MW)
6	TAS	910	1133	181	16	8371	-	-
	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
7	TAS	1293	1823	449	10	8540	-	-
	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
8	TAS	1015	1532	448	51	8461	-	-
	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
10	TAS	971	1494	453	63	8859	-	-
	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
11	TAS	1068	1634	490	29	8845	-	-
	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 53.

Table 53 Results for Loy Yang Group B trip

Case No	Region	Freq Peak (Hz)	Freq Nadir (Hz)	Underlying UFLS load tripped	DPV tripped including protection ¹² (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		

¹² Includes DPV tripped on UFLS action and on protection settings

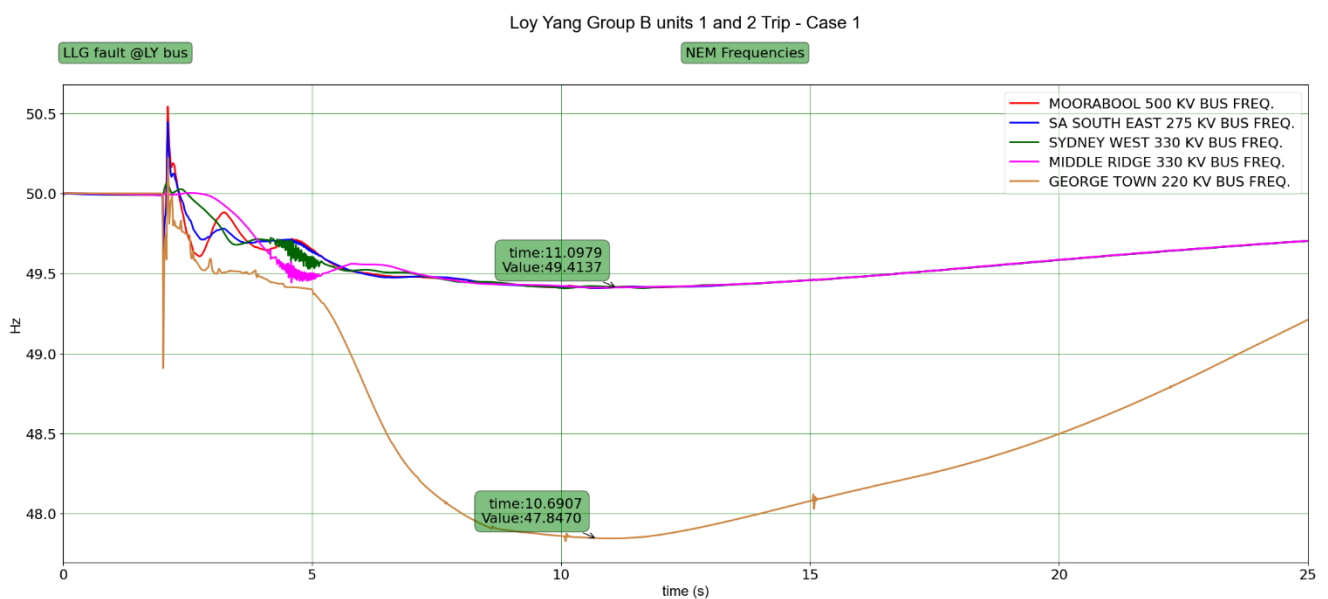
Case No	Region	Freq Peak (Hz)	Freq Nadir (Hz)	Underlying UFLS load tripped	DPV tripped including protection ¹² (MW)	% DPV tripped	Is system security maintained (Yes/No)	QNI instability/ HIC trip
3	TAS	50	47.85	62.1	-	-	Yes	No/No
	NSW	50	49.5	0	0.02	0.35		
	VIC	50	49.5	43	13	45		
	QLD	50	49.53	0	0	0		
	SA	50	49.5	0	0	0.32		
4	TAS	50	48.12	-	-	-	Yes	No/No
	NSW	50	49.58	0	1	2.73		
	VIC	50	49.59	0	3	46.16		
	QLD	50	49.58	0	0	0		
	SA	50	49.58	0	0	0		
5	TAS	50	48.77	-	-	-	Yes	No/Yes
	NSW	50	50	0	16	1.38		
	VIC	50	50	0	234	46.56		
	QLD	50	50	0	0	0		
	SA	50	50	0	1	0.19		
6	TAS	50	50	-	-	-	Yes	No/No
	NSW	50	49.5	11	0	0		
	VIC	50	49.5	0	0	0		
	QLD	50	49.5	0	0	0		
	SA	50	49.5	0	0	0		
7	TAS	50	48.57	0	-	-	Yes	No/No
	NSW	50	49.54	0	0	0.14		
	VIC	50	49.54	0	24	46.06		
	QLD	50	49.54	0	0	0		
	SA	50	49.54	0	0	0.30		
8	TAS	50.24	48.75	-	-	-	Yes	No/No
	NSW	50	49.57	0	1	0.11		
	VIC	50	49.57	0	137	45.61		
	QLD	50	49.54	0	0	0		
	SA	50	49.55	0	2	0.311		
10	TAS	50.25	49	-	-	-	No	Yes/Yes
	NSW	50.23	48.78	1680	199	16.3		
	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		
11	TAS	50.27	49.08	-	-	-	No	Yes/Yes
	NSW	50.4	48.83	2213	4223.18	27.64		
	VIC	50.4	48.84	475	153	49.48		
	QLD	51.93	49.8	0	105	12.74		

Case No	Region	Freq Peak (Hz)	Freq Nadir (Hz)	Underlying UFLS load tripped	DPV tripped including protection ¹² (MW)	% DPV tripped	Is system security maintained (Yes/No)	QNI instability/ HIC trip
	SA	50	49.54	0	0	0		
	TAS	50.45	49.4	-	-	-		

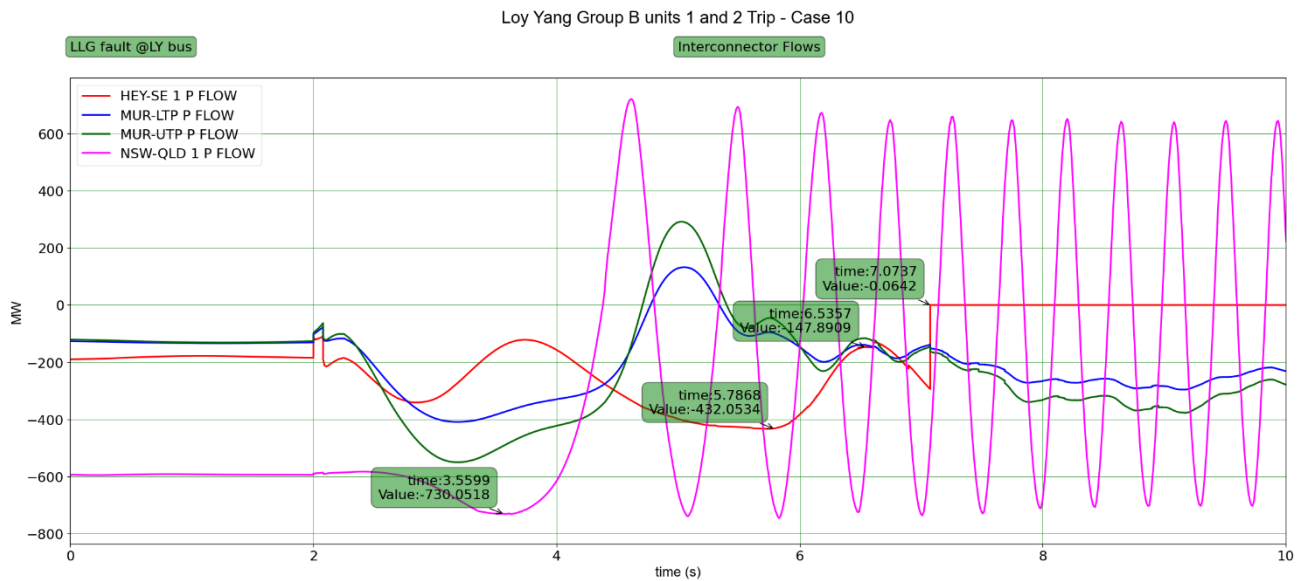
Representative results

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 SA 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 VIC renewable generation (as high west VIC renewable generation will present more onerous condition during the contingency). Coincident with high NSW export to VIC and VIC import from NSW flows were selected for the study. Case details are given in Table 54.

Table 54 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

Case	Region	Operational demand (MW)	Import (MW)	UFLS load (MW)	DPV (MW)	West VIC Renewables (MW)
6	VIC	4260	1018	2550	0	1561
	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 800 MW to 1000 MW. For both contingencies considered there was 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, Darlington Point - Wagga 330 kV (63) line trips

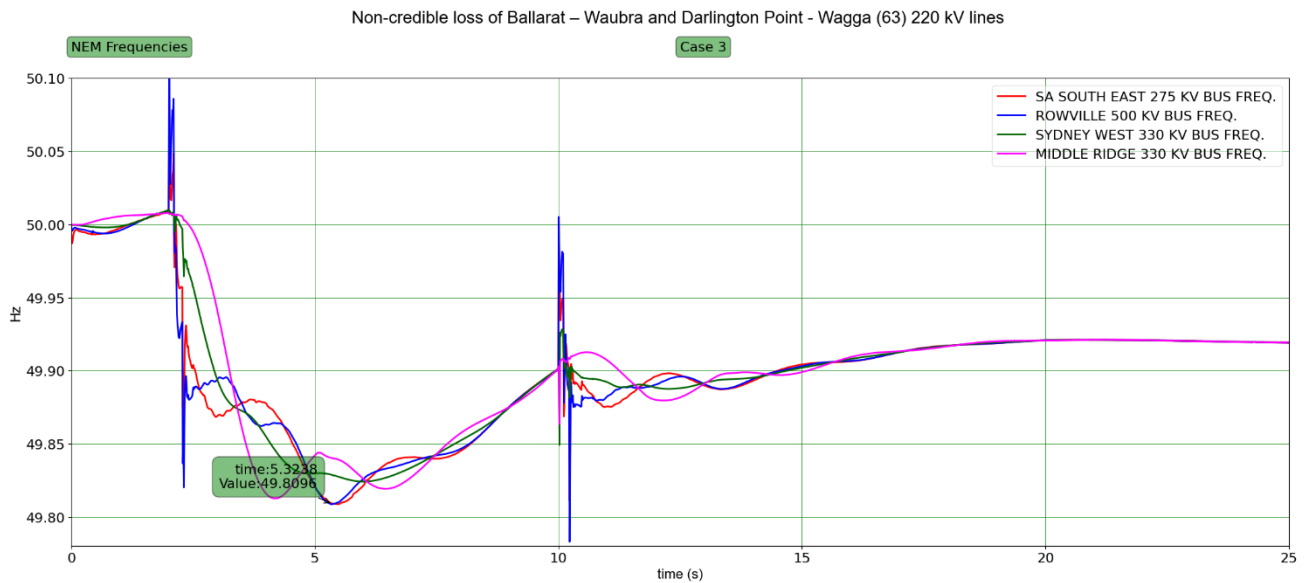
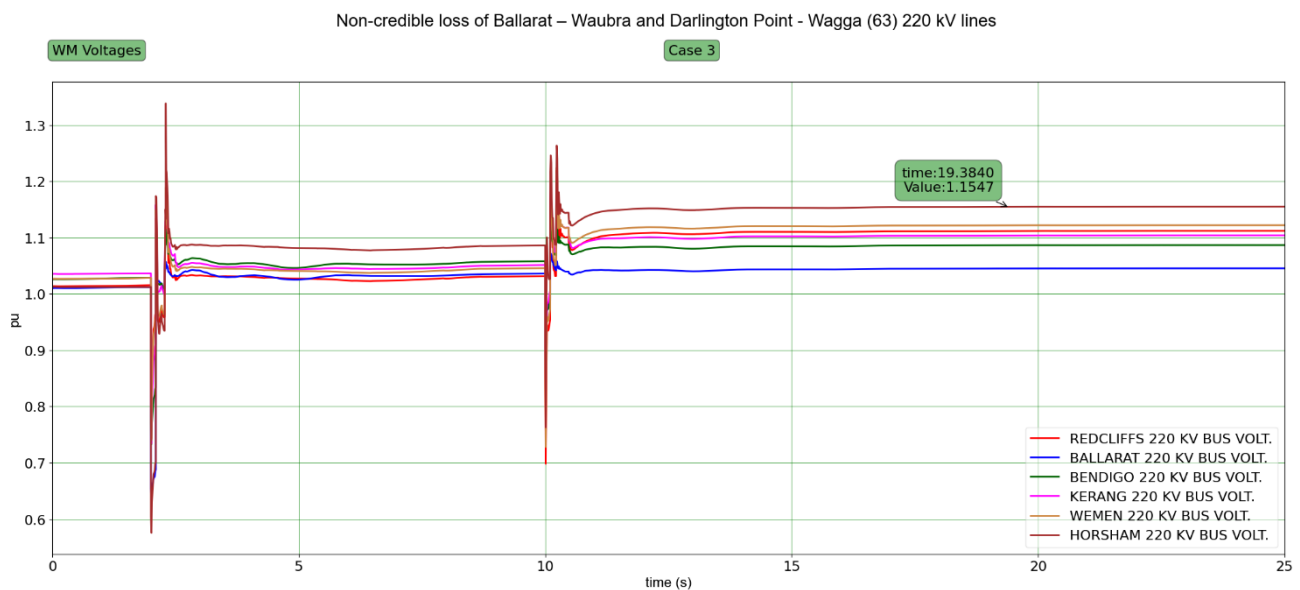


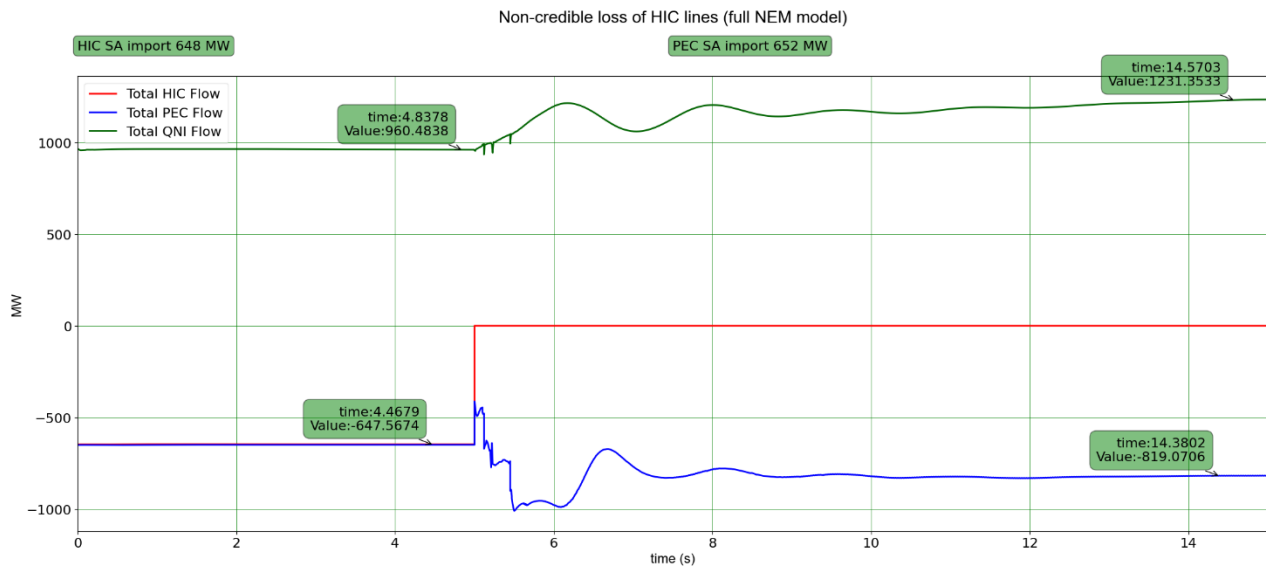
Figure 26 Case 3 West Murray voltages: Ballarat – Waubra, Darlington Point - Wagga 330 kV (63) line trips



A6.11 2027 future scenario: contingency 1 – SA separation from HYTS – Full NEM model

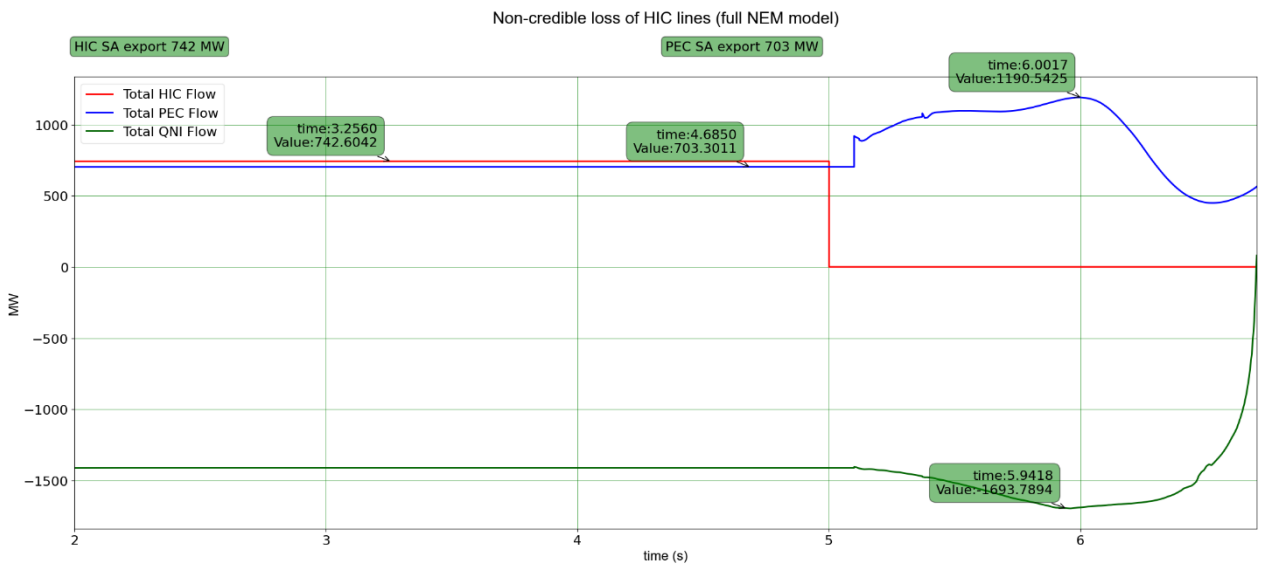
A6.11.1 SA import condition

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

Figure 27 Full NEM model; SA import separation from HYTS - major interconnector flows

A6.11.2 SA export condition

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

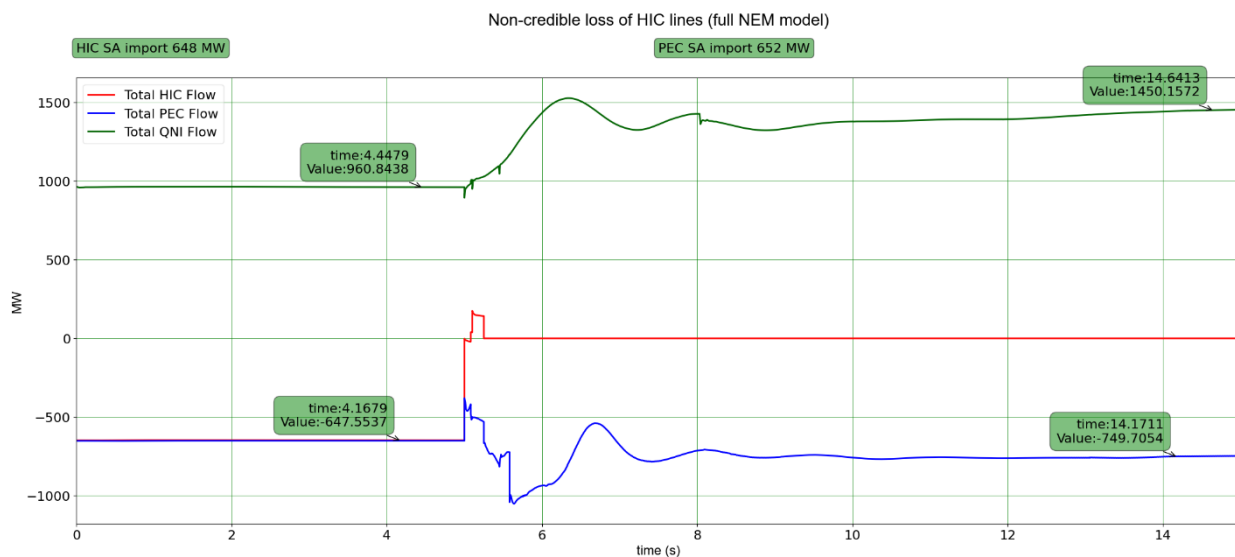
Figure 28 Full NEM model; SA export separation from HYTS - major interconnector flows

A6.12 2027 future scenario: contingency 2 – SA separation from MLTS – Full NEM model

A6.12.1 SA import condition

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

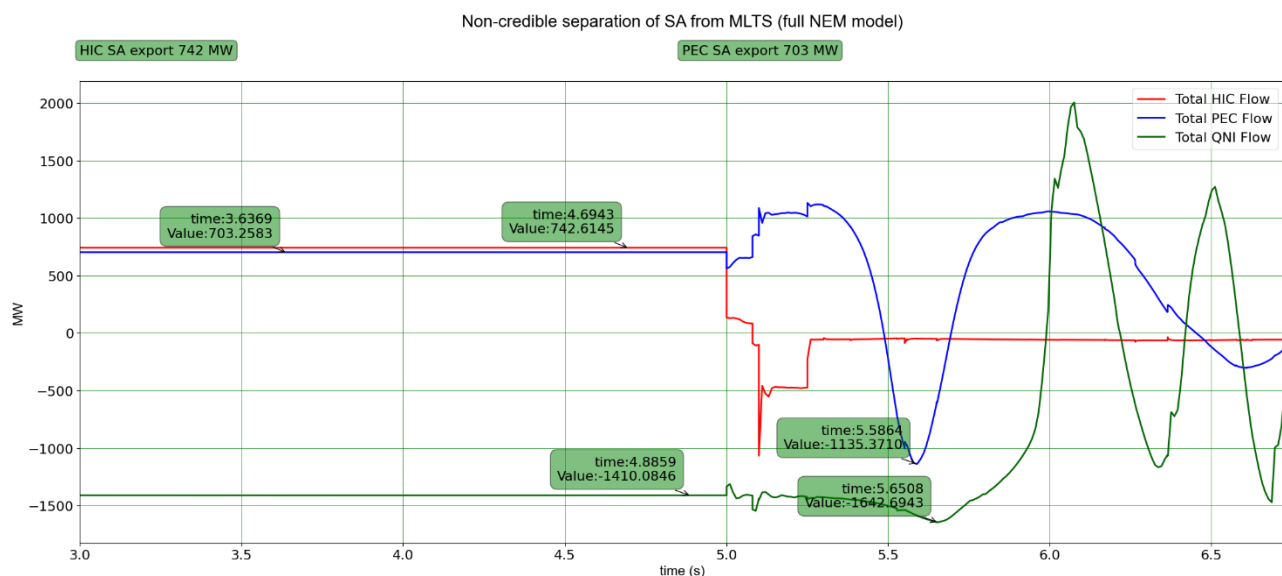
Figure 29 Full NEM model; SA separation from MLTS (SA import) - major interconnector flows



A6.12.2 SA export condition

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

Figure 30 Full NEM model; SA separation from MLTS (SA 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 import condition

Study scenarios

Six future cases were considered for the Calvale – Halys separation (QNI import). 2027 cases were setup 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 QLD 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 55.

Table 55 Loss of both 275 kV lines between Calvale – Halys cases considered (QNI import)

Case No	QNI 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 56.

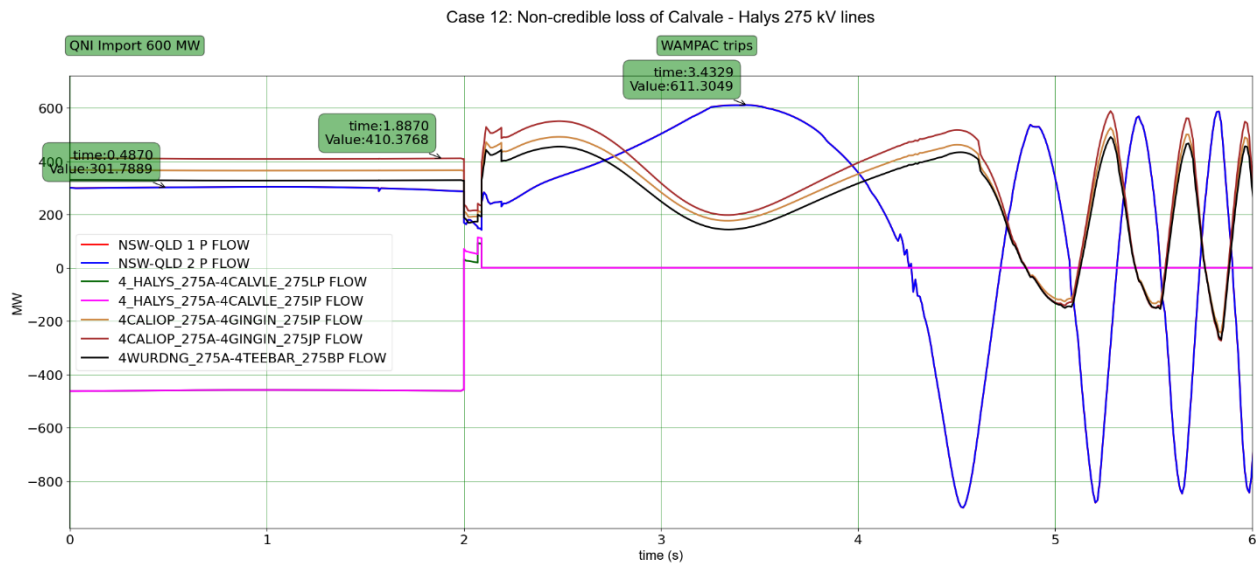
Table 56 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI import)

Case No	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

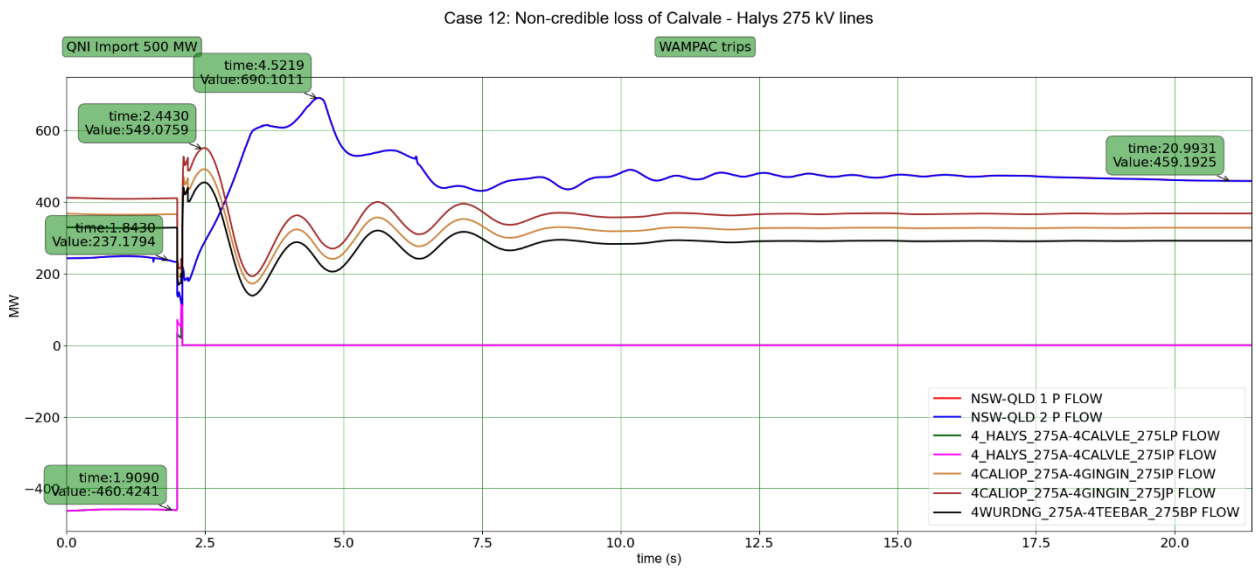
The Case 12 QNI and 275 kV CQ-SQ eastern corridor line flows following the loss of Calvale-Halys lines with QLD import at 600 MW and CQ-SQ transfer at 1991 MW are shown in Figure 31.

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



The QNI import 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 QLD import of 500 MW



A6.13.2 QNI export condition

Study scenarios

Six future cases were considered for the Calvale – Halys separation (QNI export). Case details are given in Table 57.

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

Case No	QNI 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 58.

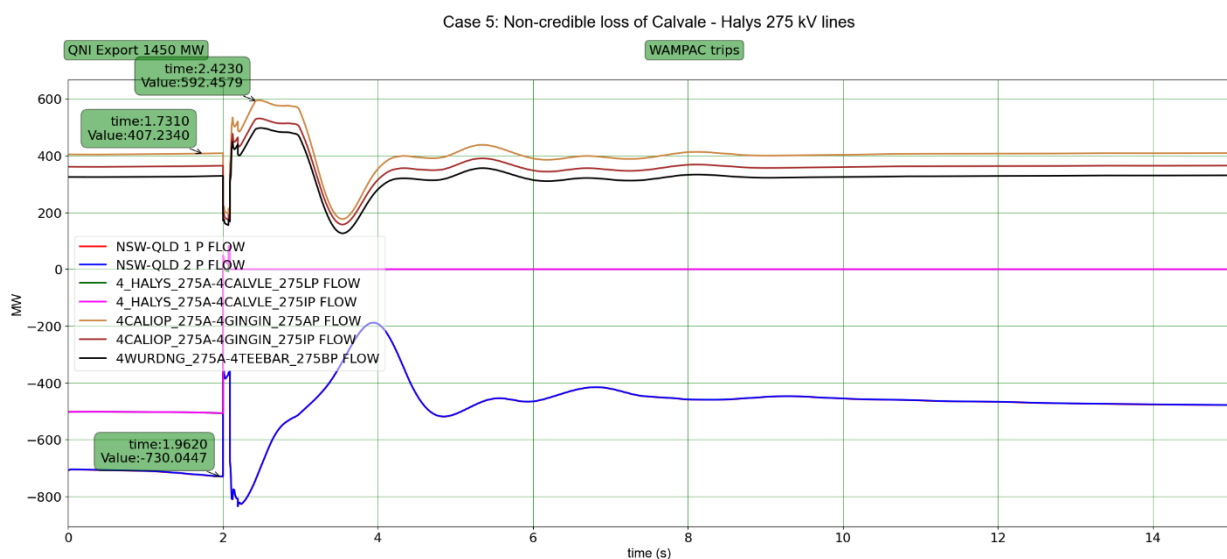
Table 58 Loss of both 275 kV lines between Calvale – Halys simulation results (QNI export)

Case No	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 QLD 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 QLD export



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

A6.14.1 QNI import condition

Study scenarios

Eighteen future cases were considered for the QLD separation due to loss of QNI (QNI import). Case details are given in Table 59.

Table 59 QNI separation: system operating points for future cases (QLD import)

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

Study results

The key results of the simulation studies are given in Table 60, Table 61 and Table 62.

Table 60 QNI Separation: simulation results (generation dispatch scenario 1)

Case No	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹³ (MW)		% DPV tripped	Was the case stable?
1	QLD	48.85	1.0	1160	36.8	0	0	0	Yes
	Remaining NEM	50.85	0.38	0	0	0	0	0	
2	QLD	48.8	1.05	1220	42.8	0	0	0	Yes
	Remaining NEM	50.9	0.42	0	0	0	0	0	
3	QLD	48.84	0.9	1566	27	202	13.2	13.2	Yes
	Remaining NEM	50.6	0.42	0	0	207	4.2	4.2	
4	QLD	48.75	0.9	1840	38.4	698	21.9	21.9	Yes
	Remaining NEM	50.6	0.49	0	0	326	4.3	4.3	
5	QLD	48.63	0.9	2504	41.4	1359	22.8	22.8	Yes
	Remaining NEM	50.53	0.62	0	0	535	4.2	4.2	
6	QLD	-	0.7	3084	60.1	6345	100	100	No
	Remaining NEM	50.54	0.41	0	0	451	4.2	4.2	

Table 61 QNI separation: simulation results (generation dispatch scenario 2)

Case No	Region	Freq Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁴ (MW)		% DPV tripped	Was the case stable?
1	QLD	48.8	1.2	1258	39.8	0	0	0	Yes
	Remaining NEM	50.85	0.38	0	0	0	0	0	
2	QLD	48.7	1.25	1302	45.7	0	0	0	Yes
	Remaining NEM	50.88	0.42	0	0	0	0	0	
3	QLD	48.84	1.1	1566	27	202	13.2	13.2	Yes
	Remaining NEM	50.6	0.48	0	0	207	4.2	4.2	
4	QLD	48.82	1.1	1455	30.4	421	13.2	13.2	Yes
	Remaining NEM	50.56	0.53	0	0	326	4.3	4.3	
5	QLD	48.62	1.1	2504	41.4	1359	22.8	22.8	Yes
	Remaining NEM	50.53	0.63	0	0	535	4.2	4.2	
6	QLD	-	0.8	3084	60.1	6345	100	100	No
	Remaining NEM	50.5	0.42	0	0	451	4.2	4.2	

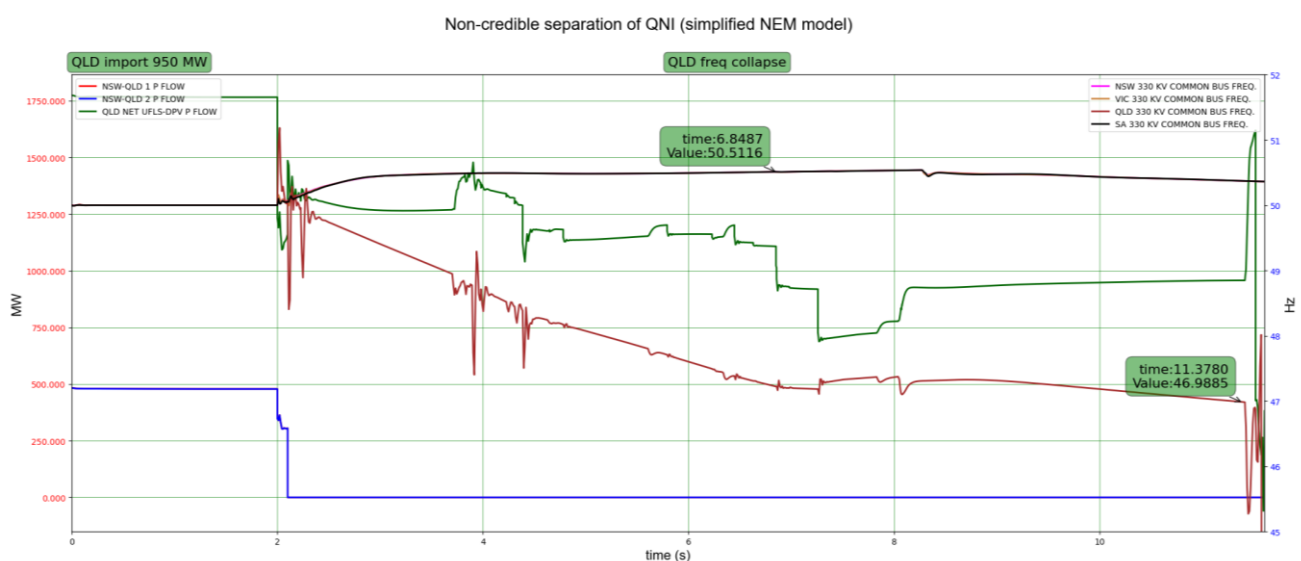
¹³ Includes DPV tripped on UFLS action and on protection settings¹⁴ Includes DPV tripped on UFLS action and on protection settings

Table 62 QNI separation: simulation results (generation dispatch scenario 3)

Case No	Region	Freq Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁵ (MW)	% DPV tripped	Was the case stable?
1	QLD	48.75	1.4	1348	42.7	0	0	Yes
	Remaining NEM	50.86	0.41	0	0	0	0	
2	QLD	48.66	1.45	1384	48.5	0	0	Yes
	Remaining NEM	50.88	0.42	0	0	0	0	
3	QLD	48.8	1.3	1272	22	142	9.3	Yes
	Remaining NEM	50.62	0.52	0	0	207	4.2	
4	QLD	48.74	1.24	1452	30.3	389	12.2	Yes
	Remaining NEM	50.58	0.75	0	0	326	4.3	
5	QLD	48.6	1.3	2720	45	1450	25.1	Yes
	Remaining NEM	50.54	0.59	0	0	535	4.2	
6	QLD	-	0.92	3084	60.1	6345	100	No
	Remaining NEM	50.56	0.36	0	0	451	4.2	

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

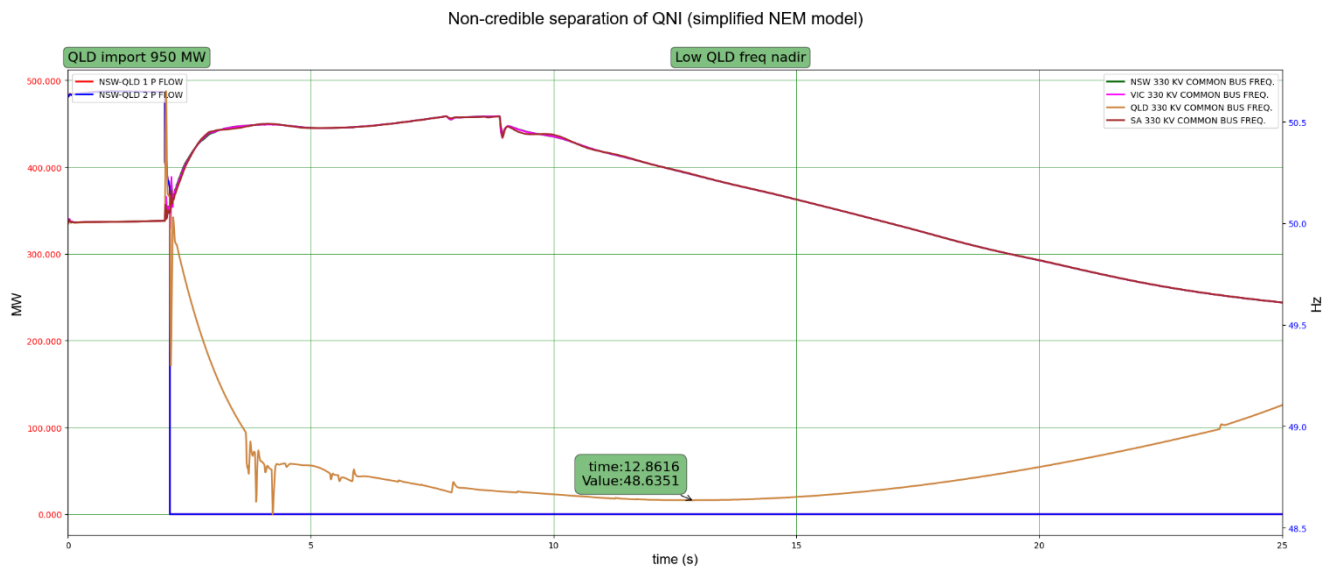
Figure 34 Scenario 1, Case 6 QNI separation (QLD) import: QNI flows and NEM frequencies



¹⁵ Includes DPV tripped on UFLS action and on protection settings

For QNI Import Case 5, the QLD 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 (QLD) export: QNI flow and NEM frequencies



A6.14.2 QNI export condition

Study scenarios

Five future cases were considered for the QLD separation due to loss of QNI (QLD export). Case details are given in Table 63.

Table 63 System operating points of future cases (QNI Sep: QLD exporting)

Case	Region	Operational demand (MW)	Pgen (MW)	QLD Export (MW)	Inertia (MW-s)	Operational UFLS (MW)	DPV (MW)
1	QLD	2388	9632	1450	14861	1774	6345
	Remaining NEM	6684	12600		28473	3108	10806
2	QLD	1865	7211	1450	14861	1363	4266
	Remaining NEM	9260	16192		28473	5627	6203
3	QLD	2338	9421	1450	14861	1800	6168
	Remaining NEM	5061	13680		28473	1948	12780
4	QLD	4402	8583	1450	14861	2466	2991
	Remaining NEM	5728	11284		28473	3293	9746

Case	Region	Operational demand (MW)	Pgen (MW)	QLD Export (MW)	Inertia (MW-s)	Operational UFLS (MW)	DPV (MW)
5	QLD	4646	8134	1450	14861	2661	2232
	Remaining NEM	7993	14280		28473	4467	8085

Study results

Detailed results of key power system variables observed are included in Table 64, Table 65, and Table 66.

Table 64 Simulation results of the future cases for generation dispatch Scenario 1 (QNI Sep: QLD exporting)

Case No	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁶ (MW)	% DPV tripped	Was the case stable?
1	Remaining NEM	48.39	0.81	4745	43	4184	39	Yes.
	QLD	51.03	1.20	0	0	457	7	
2	Remaining NEM	48.72	0.80	2601	26	1688	27	Yes.
	QLD	51.52	1.32	0	0	382	9	
3	Remaining NEM	47.92	0.92	5326	48	5765	45	Yes
	QLD	51.19	1.29	220	4	502	8	
4	Remaining NEM	48.39	0.91	4076	41	3858	40	Yes
	QLD	51.4	1.55	0	0	268	9	
5	Remaining NEM	48.66	0.69	3037	29	1932	24	Yes.
	QLD	51.59	1.63	0	0	205	9	

Table 65 Simulation results of the future cases for generation dispatch Scenario 2 (QNI Sep: QLD exporting)

Case No	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁷ (MW)	% DPV tripped	Was the case stable?
1	Remaining NEM	48.38	0.85	4745	55	4345	40	Yes.
	QLD	51.05	1.28	0	0	457	7	
2	Remaining NEM	48.71	0.82	2370	21	1617	26	Yes.
	QLD	51.57	1.35	0	0	382	9	
3	Remaining NEM	47.9	1.02	5326	58	6025	47	Yes
	QLD	51.22	1.42	227	4	541	9	

¹⁶ Includes DPV tripped on UFLS action and on protection settings

¹⁷ Includes DPV tripped on UFLS action and on protection settings

Case No	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁷ (MW)	% DPV tripped	Was the case stable?
4	Remaining NEM	48.37	0.93	4076	50	3987	41	Yes
	QLD	51.5	1.56	0	0	268	9	
5	Remaining NEM	48.68	0.74	2915	29	1778	22	Yes.
	QLD	51.72	1.74	0	0	200	9	

Table 66 Simulation results of the future cases for generation dispatch Scenario 3 (QNI Sep: QLD exporting)

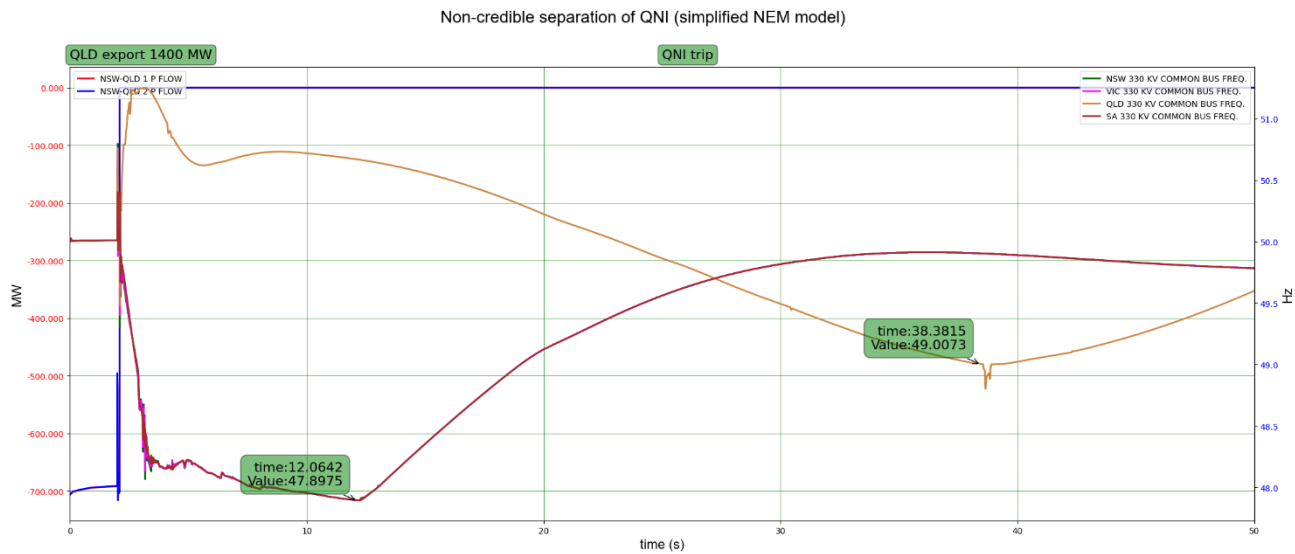
Case No	Region	Frequency Peak/Nadir (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped including protection ¹⁸ (MW)	% DPV tripped	Was the case stable?
1	Remaining NEM	48.34	1.13	4694	55	3783	35	Yes.
	QLD	51.08	2.12	0	0	497	8	
2	Remaining NEM	48.54	1.08	3774	33	2309	37	Yes.
	QLD	51.61	2.40	0	0	382	9	
3	Remaining NEM	47.9	1.23	5423	59	4498	35	Yes
	QLD	51.25	2.54	638	13	940	15	
4	Remaining NEM	48.23	1.15	3971	49	4094	42	Yes
	QLD	51.57	2.47	0	0	268	9	
5	Remaining NEM	48.55	0.95	3400	34	1875	23	Yes.
	QLD	51.82	2.23	0	0	200	9	

Representative results

The simulation results for QNI export Case 3 for Scenario 3 are shown in Figure 36. QLD 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 QLD.

¹⁸ Includes DPV tripped on UFLS action and on protection settings

Figure 36 Scenario 3, Case 3 QNI separation (QLD) export: QNI flows and NEM 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 VIC import and VIC export conditions using simplified NEM model.

A6.15.1 VIC import condition

Study scenarios

Seven future cases were considered for the non-credible loss of the VNI lines (VIC import). Case details are given in Table 67.

Table 67 System operating points for future cases (VNI Sep: VIC 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 68, Table 69 and Table 70.

Table 68 Simulation results of the future cases for Scenario 1 (VNI Sep: VIC 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 69 Simulation results of the future cases for Scenario 2 (VNI Sep: VIC 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 70 Simulation results of the future cases for Scenario 3 (VNI Sep: VIC import)

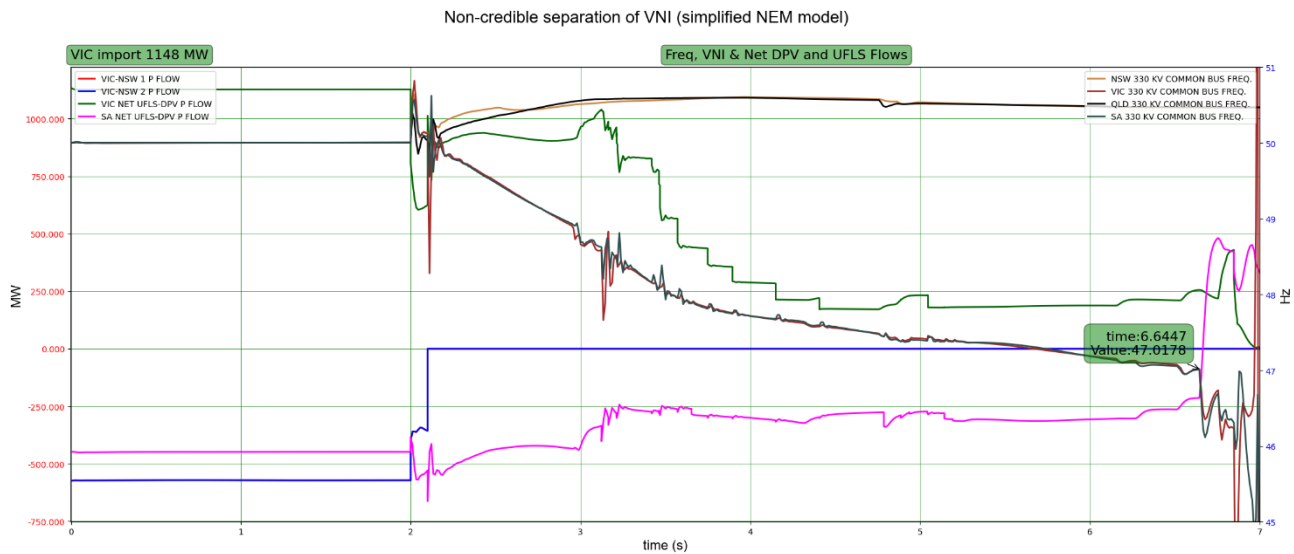
Case	Region	Frequency peak/nadir range (Hz)	Max RoCoF (Hz/s)	Underlying UFLS tripped (MW)	% Underlying UFLS tripped	DPV tripped (MW)	% DPV tripped	Was the case stable?
1	NSW	-	-	0	0	0	0	No. Inadequate UFLS in VIC-SA island to arrest the frequency.
	QLD			0	0	0	0	
	VIC	-	-	1878	87	688	45	

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?
	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	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 NSW and VIC 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 VIC is 1131 MW and in SA had no UFLS in this study scenario¹⁹. The combined UFLS and FCAS in VIC and SA were insufficient to arrest the frequency collapse in VIC – SA island.

¹⁹ AEMO notes this is a conservative assumption and anticipates improvement to UFLS effectiveness prior to 2027.

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

A6.15.2 VIC export condition

Study scenarios

Nine historical cases were considered for the non-credible loss of the VNI lines (VIC export). Case details are given in Table 71.

Table 71 System operating points for future cases (VNI Sep: VIC 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 Table 72, Table 73, and Table 74.

Table 72 Simulation results of the future cases for Scenario 1 (VNI Sep: VIC 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 73 Simulation results of the future cases for Scenario 2 (VNI Sep: VIC 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	

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?
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 74 Simulation results of the future cases for Scenario 3 (VNI Sep: VIC 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	

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?
	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

NSW and VIC frequencies, along with VNI flows for Scenario 3 - Case 5 VIC export VNI separation are shown in Figure 38. This is one of the cases with high RoCoF values around 1.9 Hz/s and 2.4 Hz/s in NSW-QLD and VIC-SA islands, respectively. ROCOF in excess of 2Hz/s poses an increased risk for subsequent GT tripping as noted in Section 7.3 of the main PSFRR report.

Figure 38 Scenario 3 - Case 5 VIC export VNI separation: Frequencies and VNI flows

