Minimum System Demand Issues and Impacts of High DPV at AEMO

Subtitle Here

We acknowledge the Traditional Custodians of the land, seas and waters across Australia. We honour the wisdom of Aboriginal and Torres Strait Islander Elders past and present and embrace future generations.

We acknowledge that, wherever we work, we do so on Aboriginal and Torres Strait Islander lands. We pay respect to the world's oldest continuing culture and First Nations peoples' deep and continuing connection to Country, and hope that our work can benefit both people and Country.

'Journey of unity: AEMO's Reconciliation Path' by Lani Balzan

AEMO Group is proud to have launched its first Reconciliation Action Plan in May 2024. 'Journey of unity: AEMO's Reconciliation Path' was created by Wiradjuri artist Lani Balzan to visually narrate our ongoing journey towards reconciliation – a collaborative endeavour that honours First Nations cultures, fosters mutual understanding, and paves the way for a brighter, more inclusive future.

Read our RAP

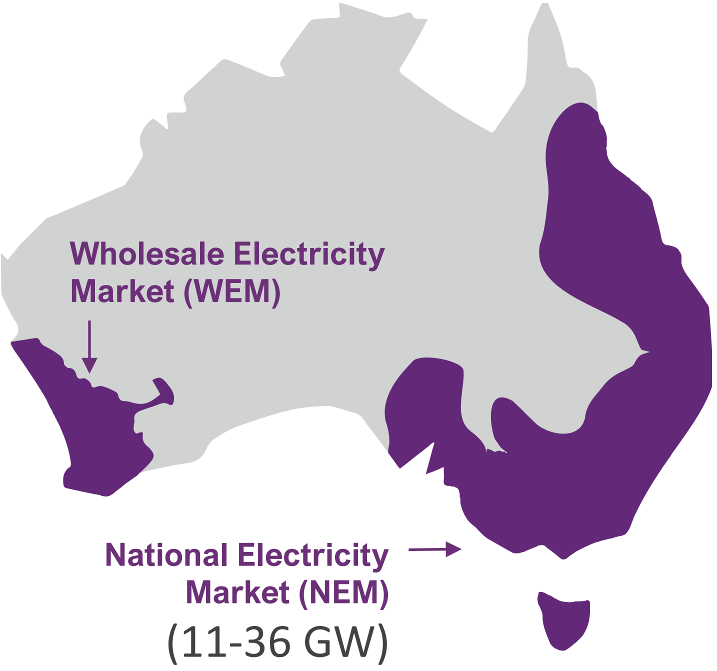
About AEMO

- AEMO is a member-based, not-for-profit organisation.
- We are the independent energy market and system operator for the National Electricity Market (NEM) and the WA Wholesale Electricity Market (WEM), and system planner for the NEM.
- We also operate retail and wholesale gas markets across south-eastern Australia and Victoria's gas pipeline grid.

AEMO SERVICES

AEMO Services is an independent subsidiary of AEMO, established in 2021 to enable the transparent provision of advisory and energy services to National Electricity Market jurisdictions.

Electricity



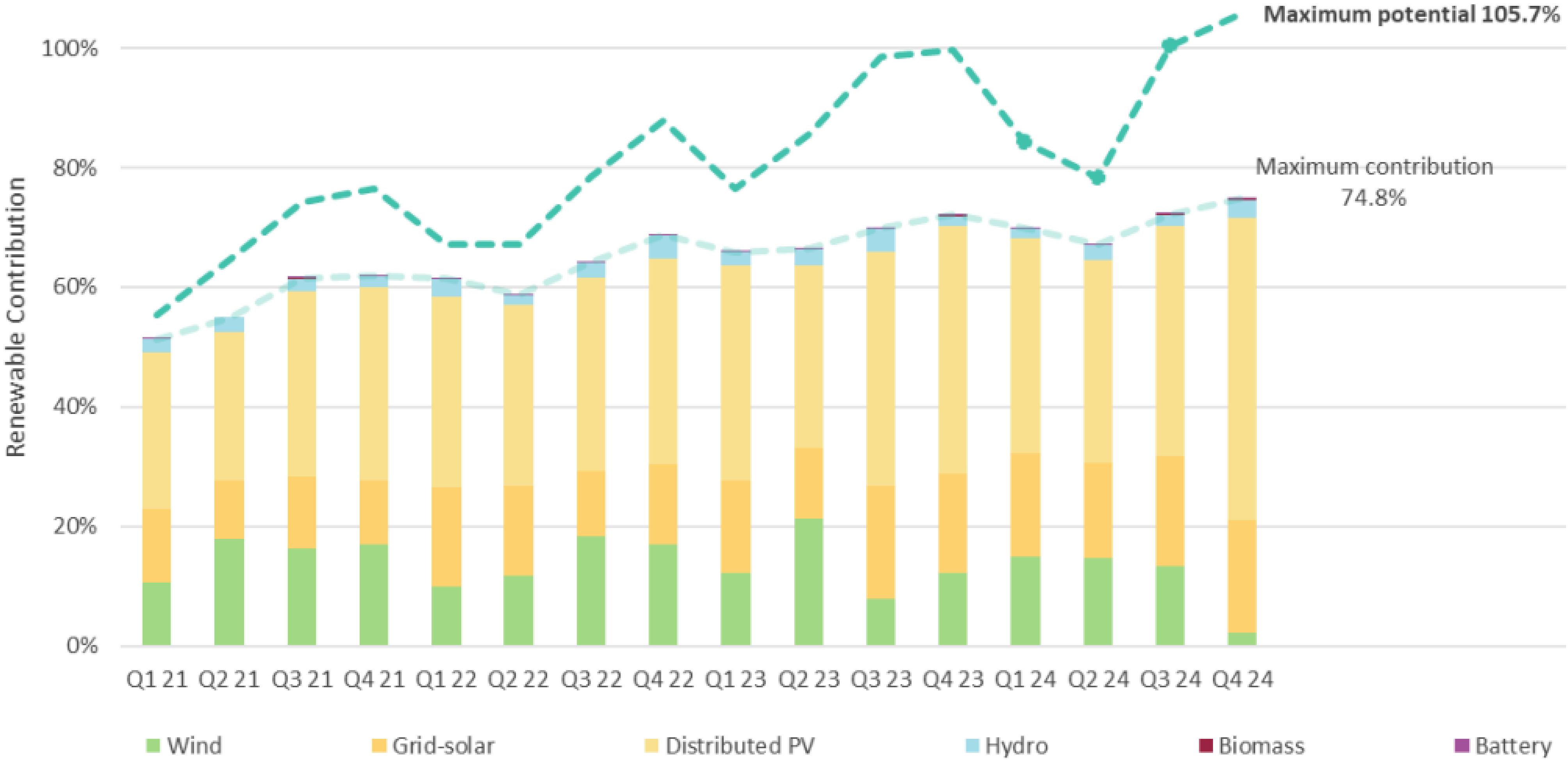
Gas

How big is Australia?

Redrawn based on map from:
www.boredpanda.com/country-size-compared-to-usa-north-america

Redrawn based on map from:
www.trapptours.com.au/motorcycle-trip-planning-australia

Renewable contributions are increasing rapidly

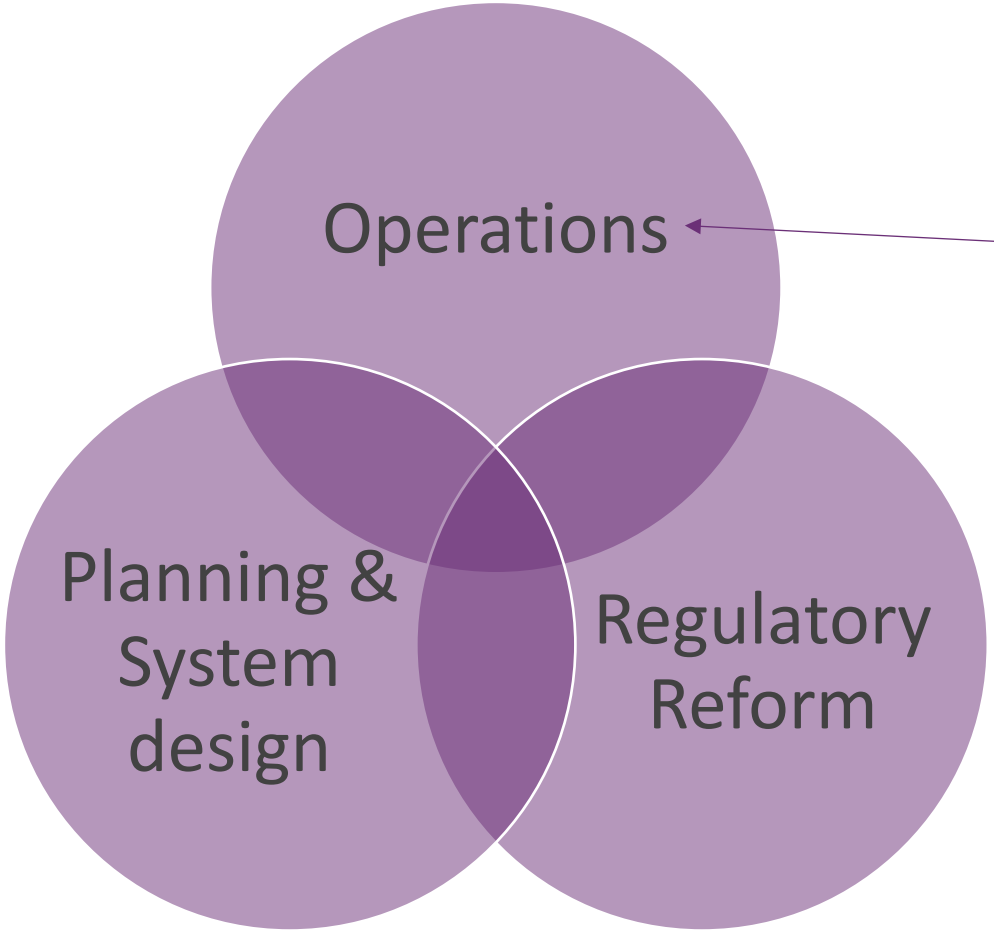


Potential: available renewable generation over a 30-minute window – regardless of actual generation

Contribution: renewable generation produced over a 30-minute window

Integrating DER

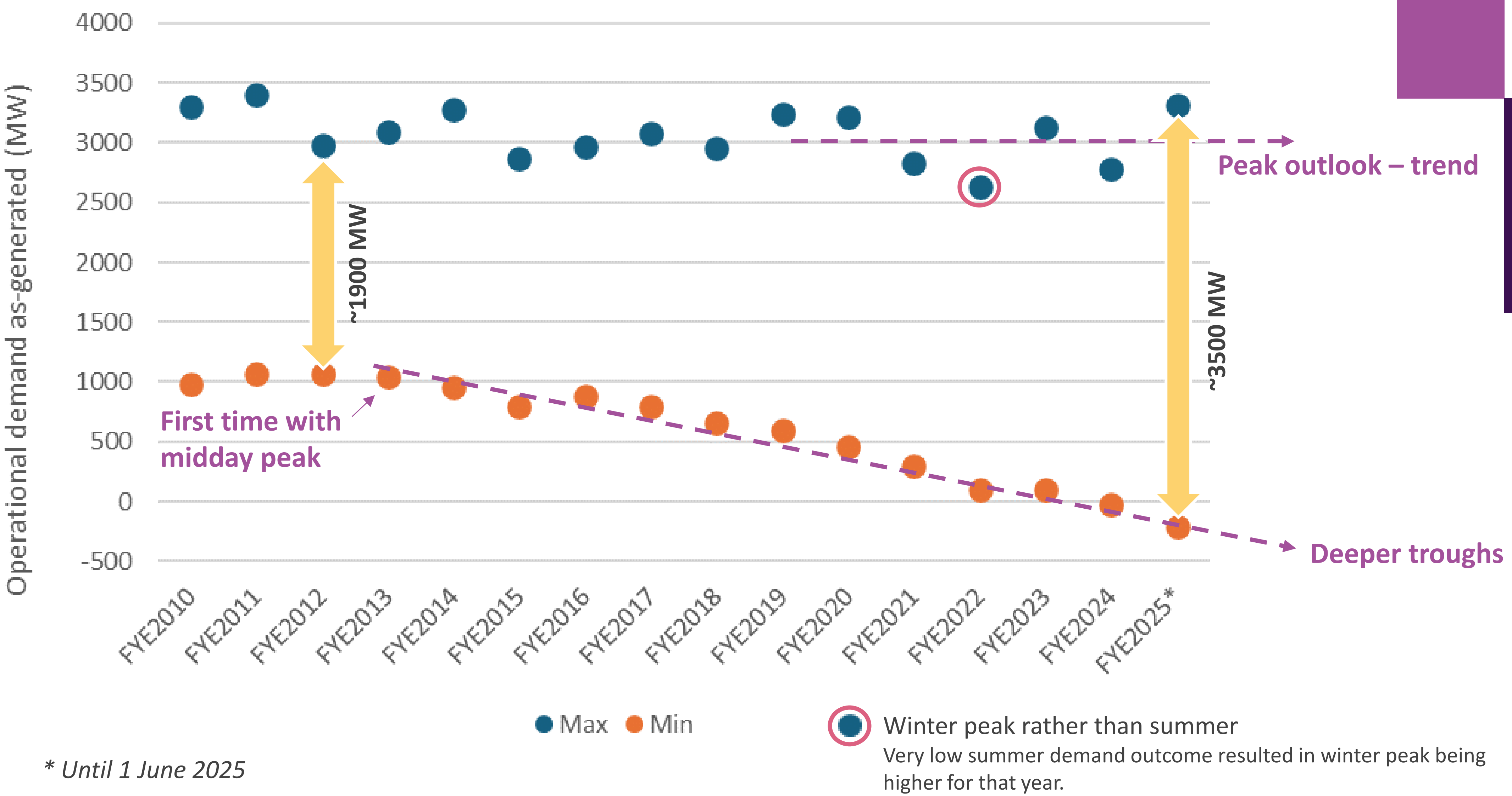
Significant work programs across AEMO working on integration of DER



Today's presentation will share a "deep dive" into few selected elements from our work in Operations

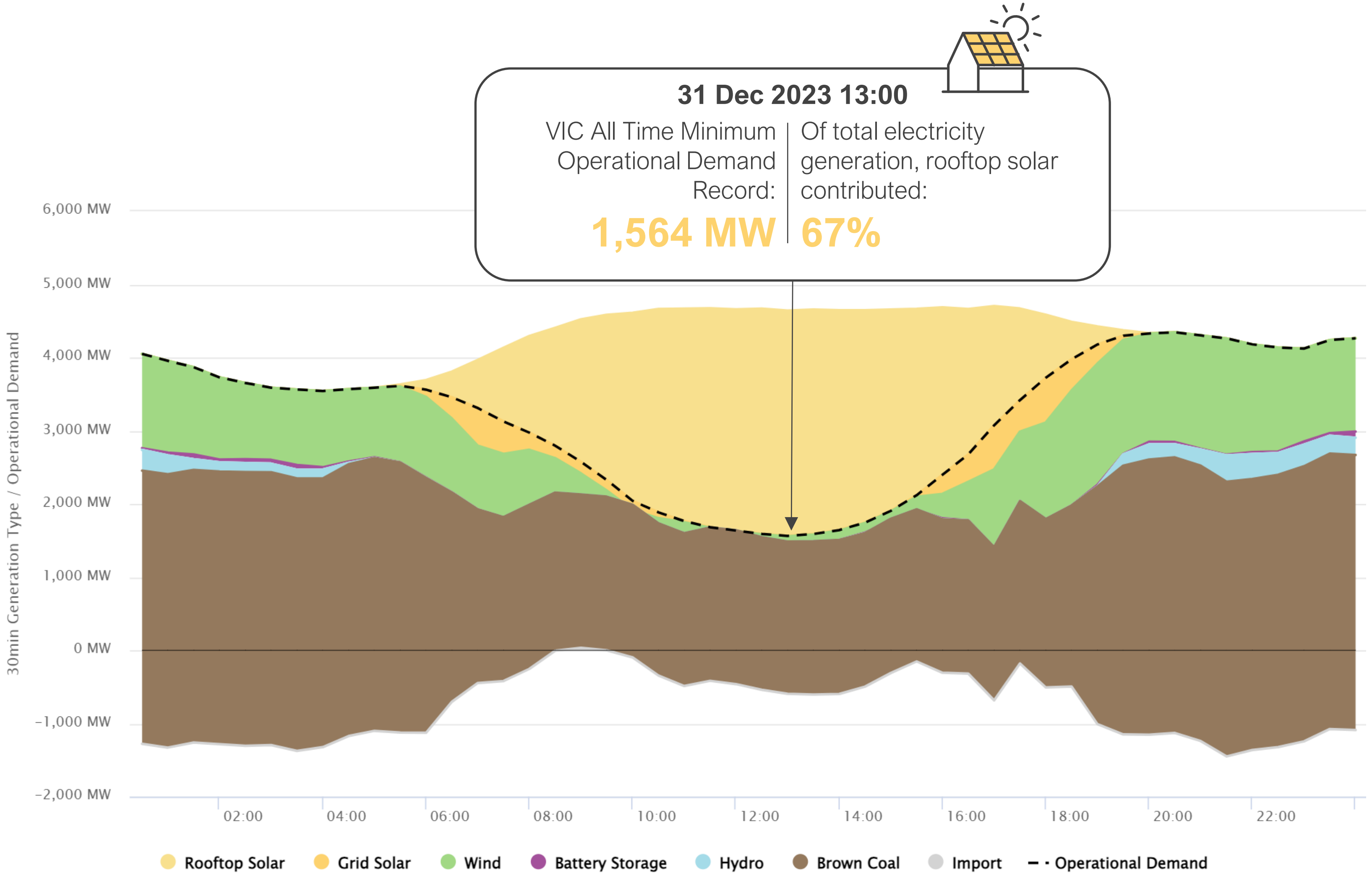
Managing low demand conditions

Changing energy demand – South Australia

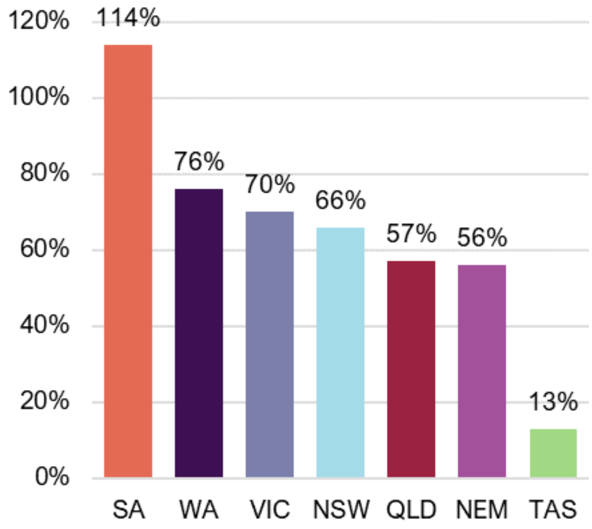


** Until 1 June 2025*

Rooftop solar - Victoria



Record percent of underlying demand met by rooftop solar*



* Record as of 25 Apr 2025

Challenges: The evolving power system

What are the immediate operational risks?

Challenges: The evolving power system

WA DER

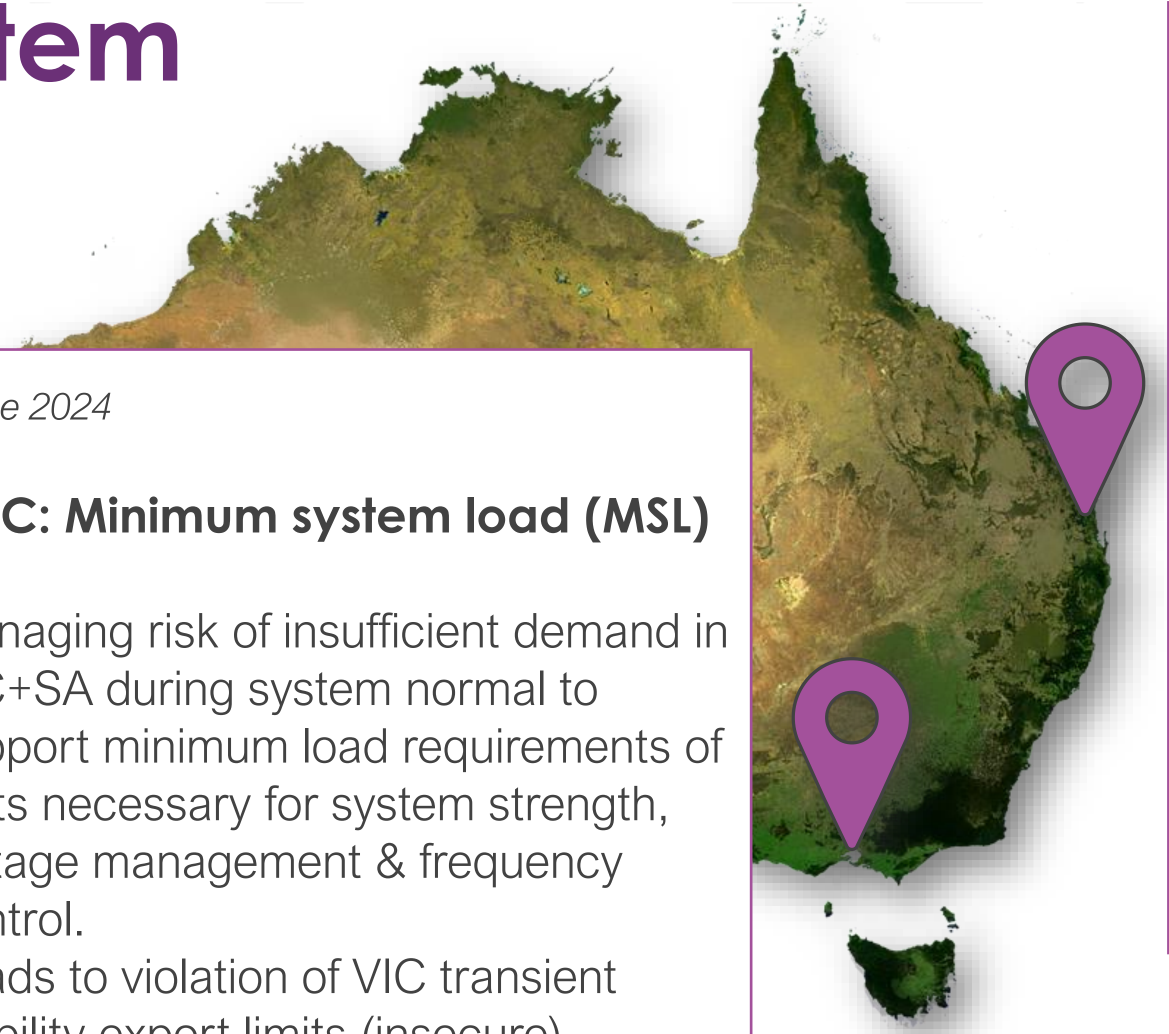
Around a similar time, WA started escalating efforts around management of DPV. WA is an island, so needs to be managed entirely locally.

Since 2020

SA: DPV contingency (DPVC)

Managing risk of possible distributed PV (DPV) “shake-off” in SA island in response to a credible fault, contributing to extremely large credible contingency events. Insufficient fast frequency reserves (insecure).

Challenges: The evolving power system



Since 2024

VIC: Minimum system load (MSL)

Managing risk of insufficient demand in VIC+SA during system normal to support minimum load requirements of units necessary for system strength, voltage management & frequency control.
Leads to violation of VIC transient stability export limits (insecure).

Since 2022

QLD: Minimum system load (MSL)

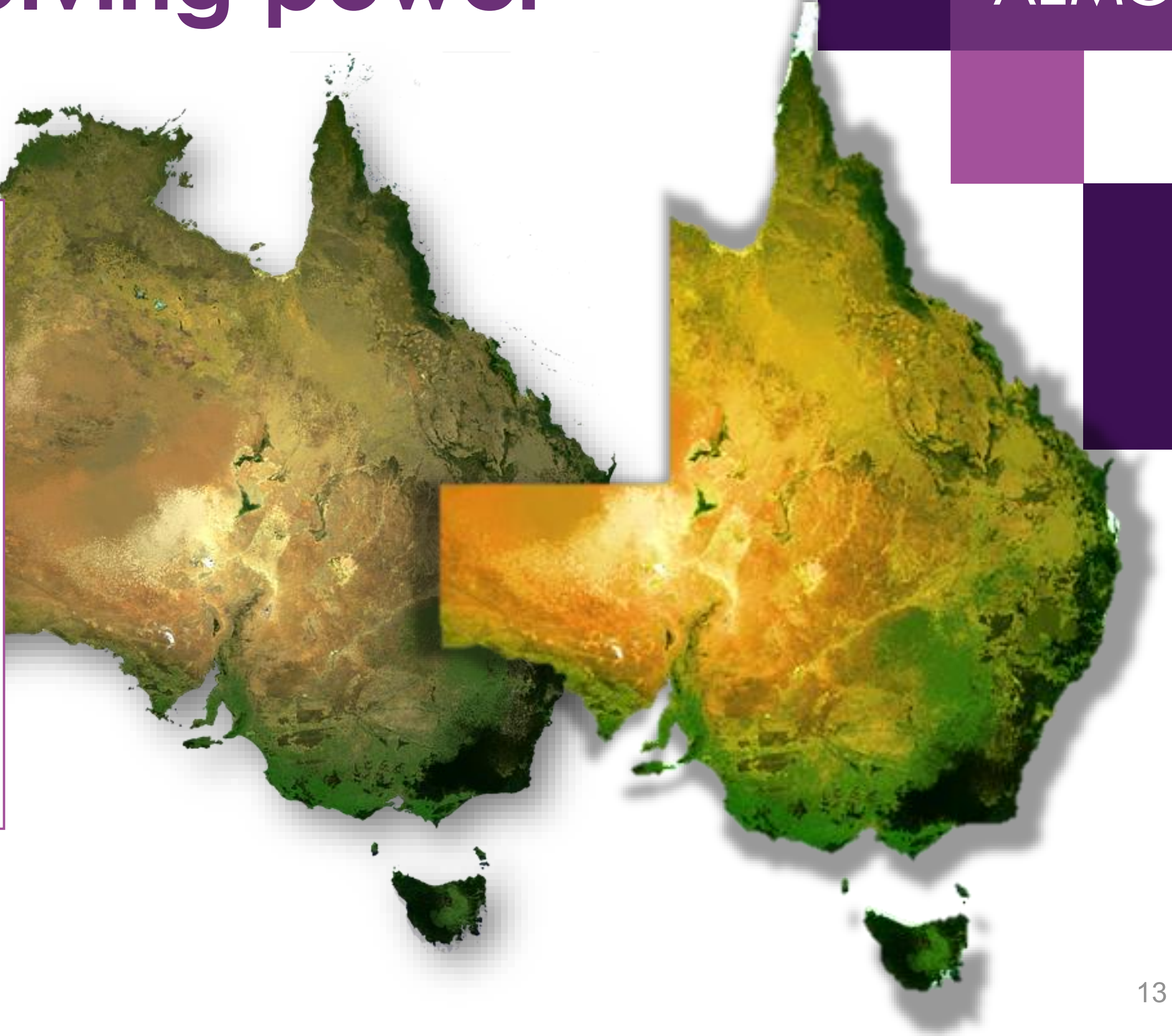
Managing power system security in QLD during island operation or at-risk of island operation. During high DPV periods, there may be periods of insufficient demand to support minimum load requirements of units necessary for system strength, voltage management & frequency control.
Leads to violation energy supply-demand balance and FCAS requirements (insecure).

Challenges: The evolving power system

Now

All NEM

Managing risk of insufficient demand in whole NEM in system normal to support minimum load requirements of units necessary for system strength, voltage management & frequency control. Leads to insufficient system services online (insecure).



“Minimum System Load” (MSL) levels

- MSL framework is modelled after the Lack of Reserve (LOR) framework.
- The LOR framework ensures there is sufficient generation. It is based upon the potential loss of the two largest sources of electricity.
- The MSL framework ensures there is sufficient demand. It manages the potential loss of the two largest loads (includes interconnectors).
- AEMO provides MSL notices to the market and works with the industry to clear them.

MSL1 – Regional demand is two credible load contingencies away from MSL3.

Market notice published for information.

MSL2 – Regional demand is one credible load contingency away from MSL3.

Take actions to land satisfactory following contingency and resecure in 30 mins.

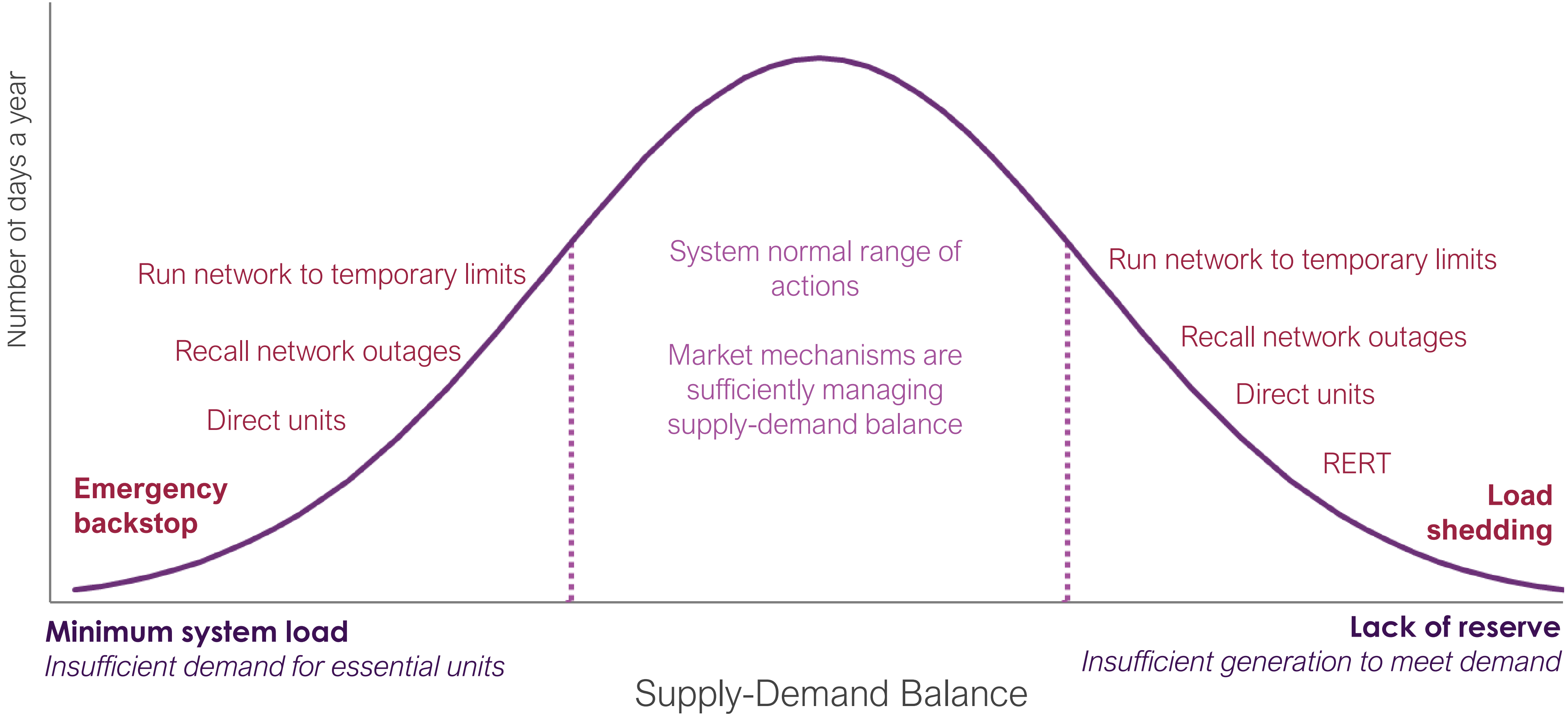
MSL3 – Need to increase regional demand for system security.

Direct NSPs to maintain demand above threshold.

What can we do if demand is below the MSL threshold?

Emergency Backstop includes:

- Curtailing embedded non-scheduled generation
- Direct DPV curtailment (via Smarter Homes Scheme, Relevant Agents, GSDs, Flexible Exports, CSIP-AUS)
- Hot water shifting
- Enhanced Voltage management
- Shedding of reverse flowing feeders



RERT refers to the Reliability and Emergency Reserve Trader, an NER mechanism for AEMO to contract capacity electricity reserves when a reserve shortfall is projected up to nine months in advance.

Procedure summary

0700-0900 (forecast demand<MSL2): BESS to discharge
0900-1300: BESS held in reserve at minimum state of charge

Demand forecast < MSL2: Actions to clear MSL2/3 condition:

- Market notice
- Liaise with TNSPs
- Recall planned outages that reduce region export capability
- Constrain significant non-scheduled generation 0 MW
- Constrain scheduled/semi-scheduled units to 0 MW if not required

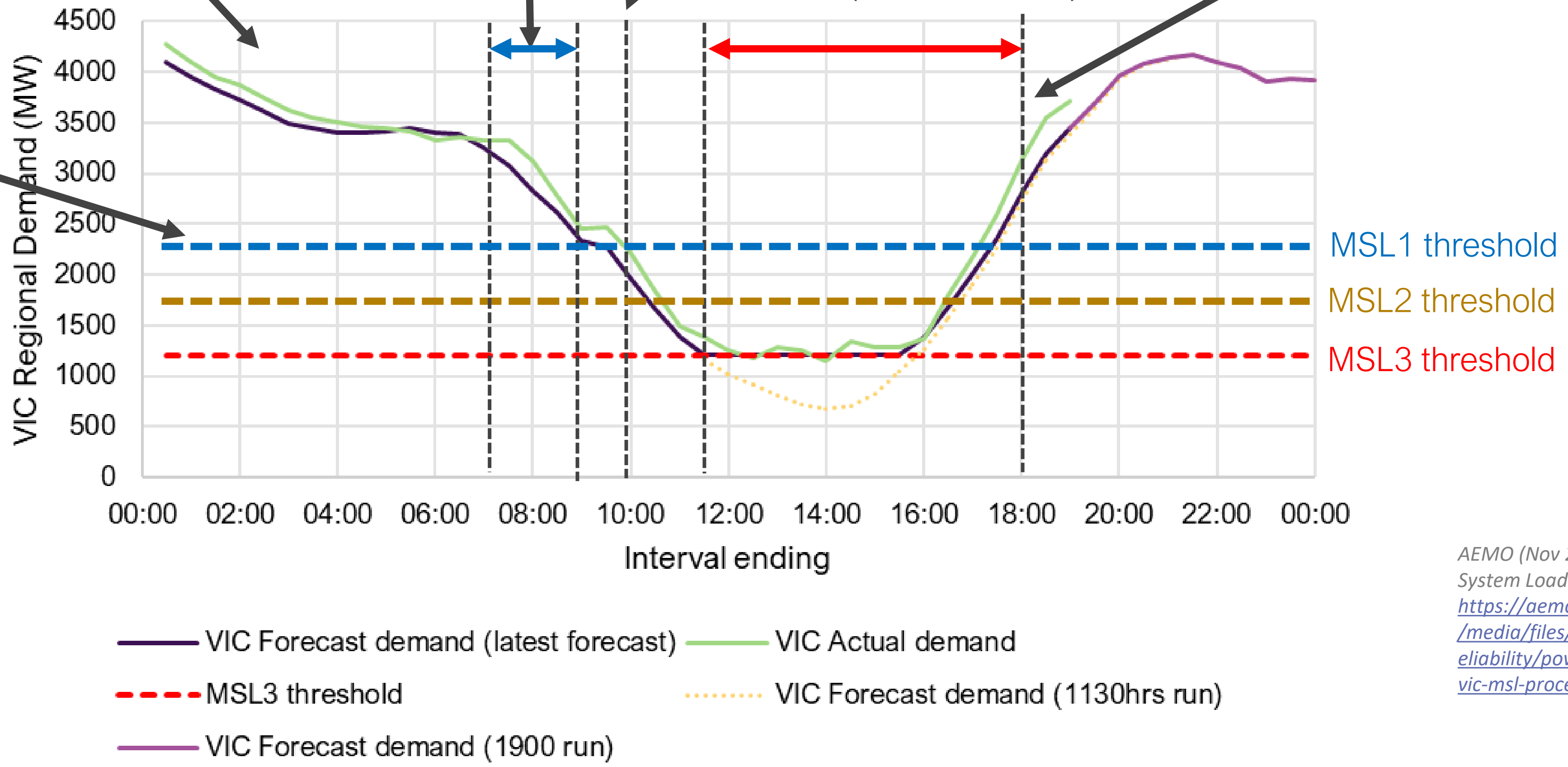
90 mins before MSL3 condition forecast: Instruction to NSPs to maintain demand above MSL3 threshold. Market Notice.

Demand < MSL3: NSP actions to maintain demand above MSL3 threshold (best endeavours)

MSL condition cancelled

Demand forecast < MSL1:

- Market notice

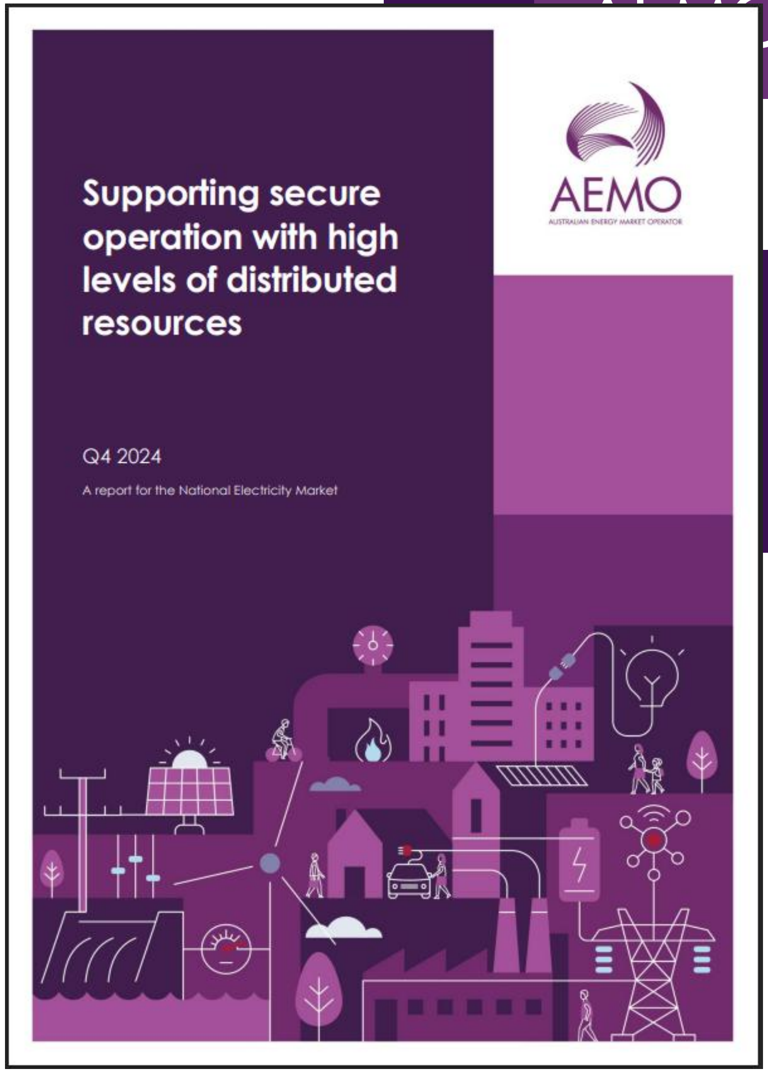


AEMO (Nov 2024) Victorian Minimum System Load Procedure Overview, https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/power_system_ops/2024-11-01-vic-msl-procedure-factsheet_final.pdf?la=en

this chart is for illustrative purposes

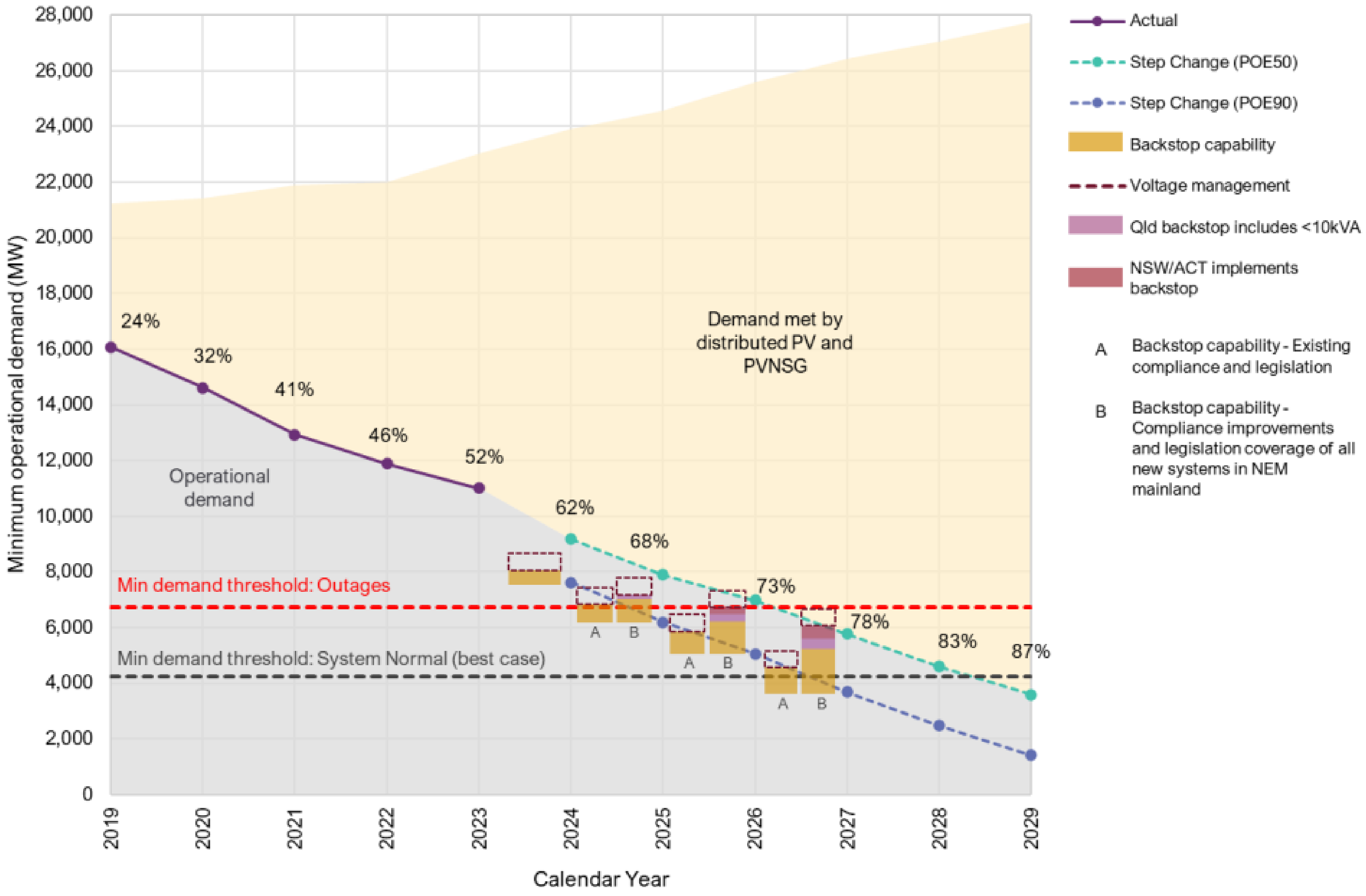
Emergency backstop

- November 2024: AEMO released report highlighting urgent need for work to implement emergency backstop capabilities in all NEM mainland regions
- Emergency backstop refers to operational measures to reduce aggregate distributed PV generation if required for system security, when other options have been exhausted.



AEMO (Q4 2024) Supporting secure operation with high levels of distributed resources, https://aemo.com.au/-/media/files/initiatives/der/managing-minimum-system-load/supporting-secure-operation-with-high-levels-of-distributed-resources-q4-2024.pdf?la=en

Minimum demand in the NEM



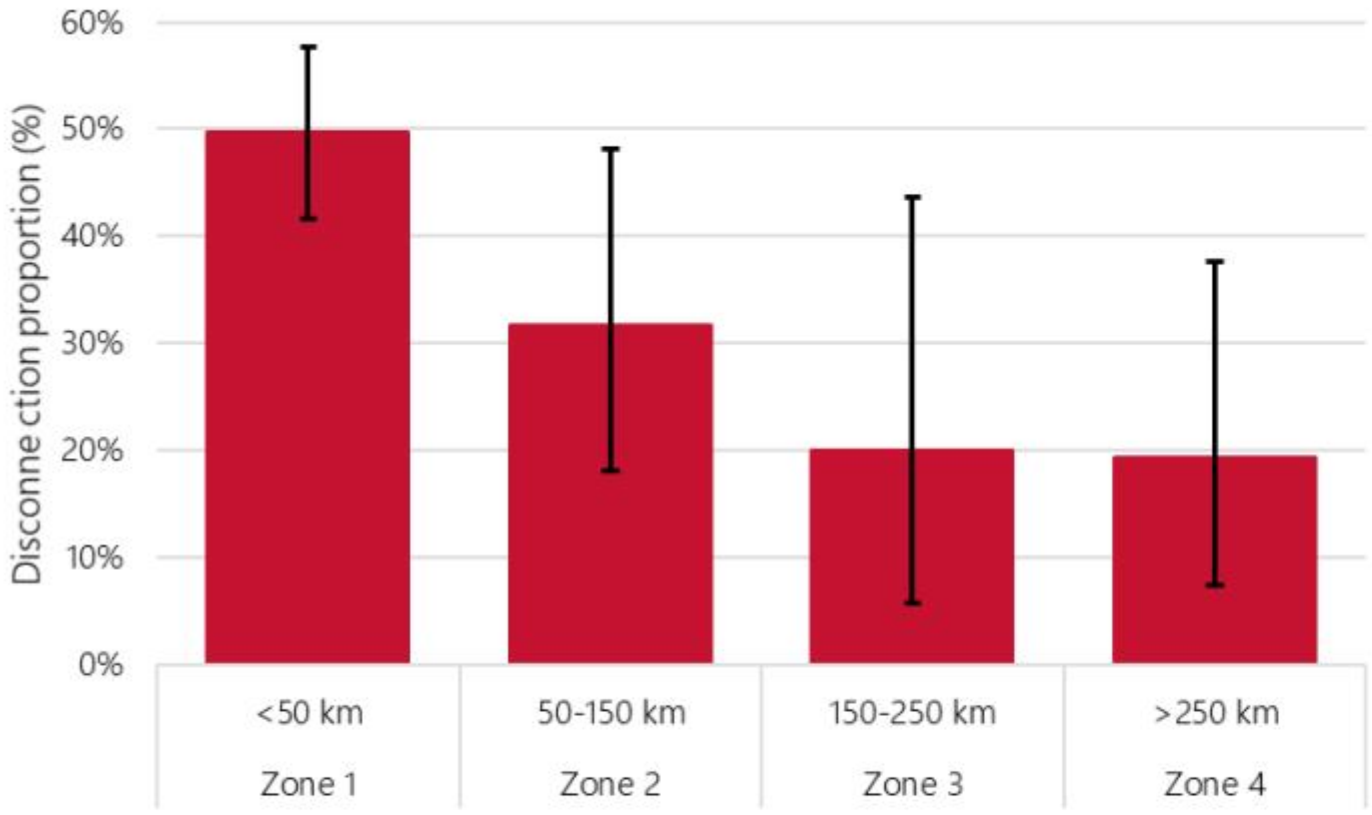
AEMO (Q4 2024) Supporting secure operation with high levels of distributed resources, https://aemo.com.au/-/media/files/initiatives/der/managing-minimum-system-load/supporting-secure-operation-with-high-levels-of-distributed-resources-q4-2024.pdf?la=en

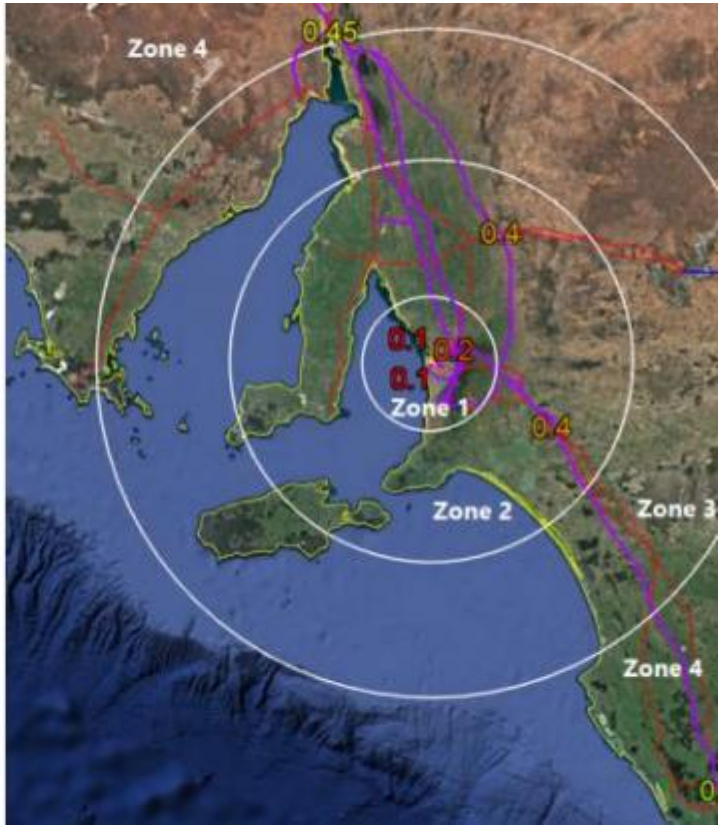
DPV Contingencies

Distributed PV “Shake-off”

- DPV disconnections by distance from fault location in South Australia

3 March 2017, series of faults in ElectraNet’s Torrens Island 275kV switchyard





Numbers on map display minimum single phase voltage reached during disturbance recorded in the transmission network

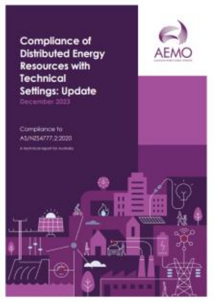
AEMO (May 2021) Behaviour of distributed resources during power system disturbances, https://aemo.com.au/-/media/files/initiatives/der/2021/capstone-report.pdf?la=en&hash=BF184AC51804652E268B3117EC12327A

Australian Standard AS/NZS4777.2 is the performance standard for grid-connected DER inverters across Australia

Incident analysis: observed shake-off

AS/NZS4777.2020 published (improved ride-through requirements)

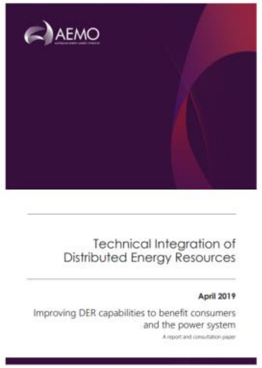
AS/NZS4777.2020 becomes mandatory



AS4777 compliance significantly improved

2018 2019 2020 2021 2022 2023 2024 2025

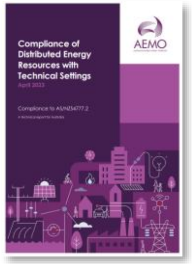
DER shake-off risks



DER behaviours Capstone report

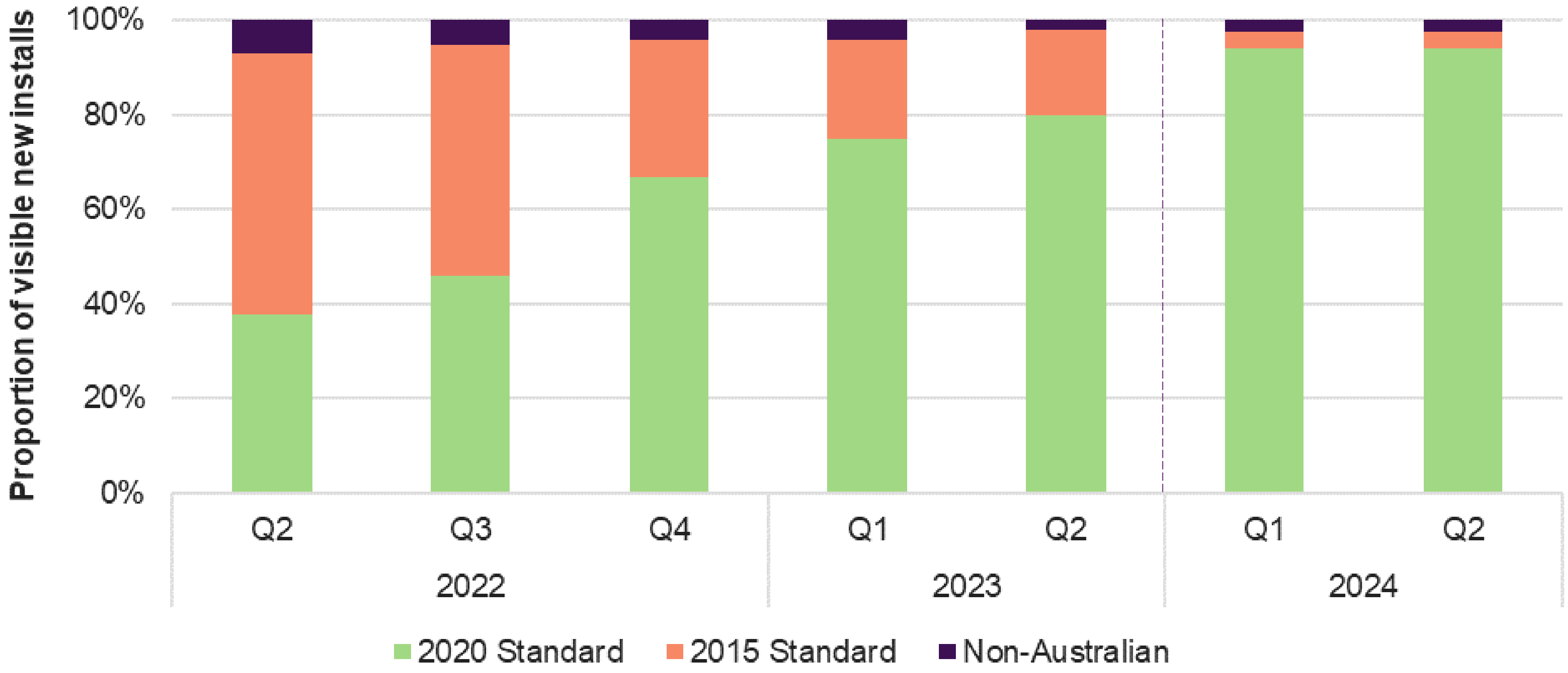
Power system incidents: still observing considerable shake-off from new installations

AS4777 compliance is <50%



Estimates of compliance

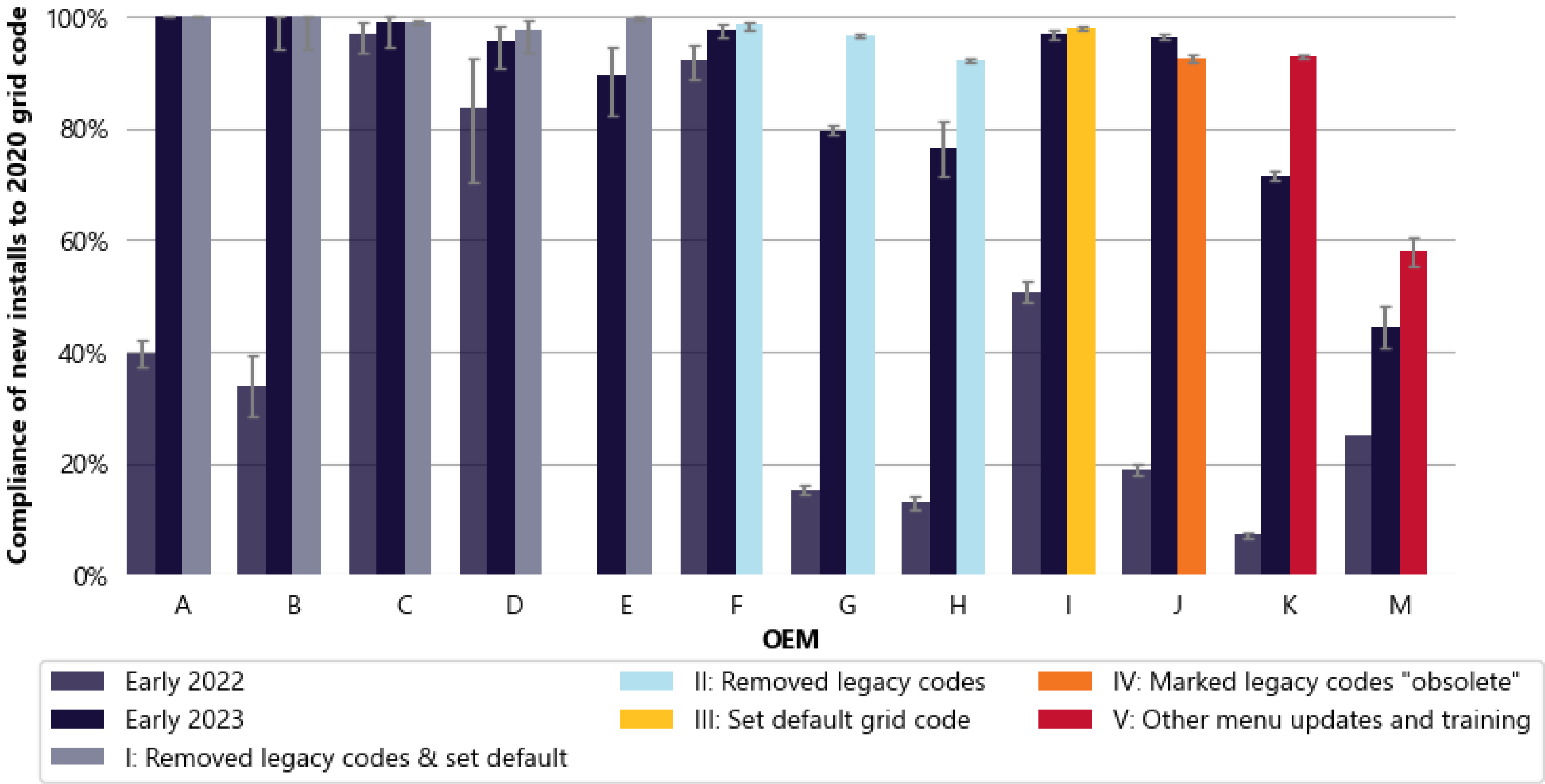
- Compliance to AS/NZS4777.2:2020 grid code



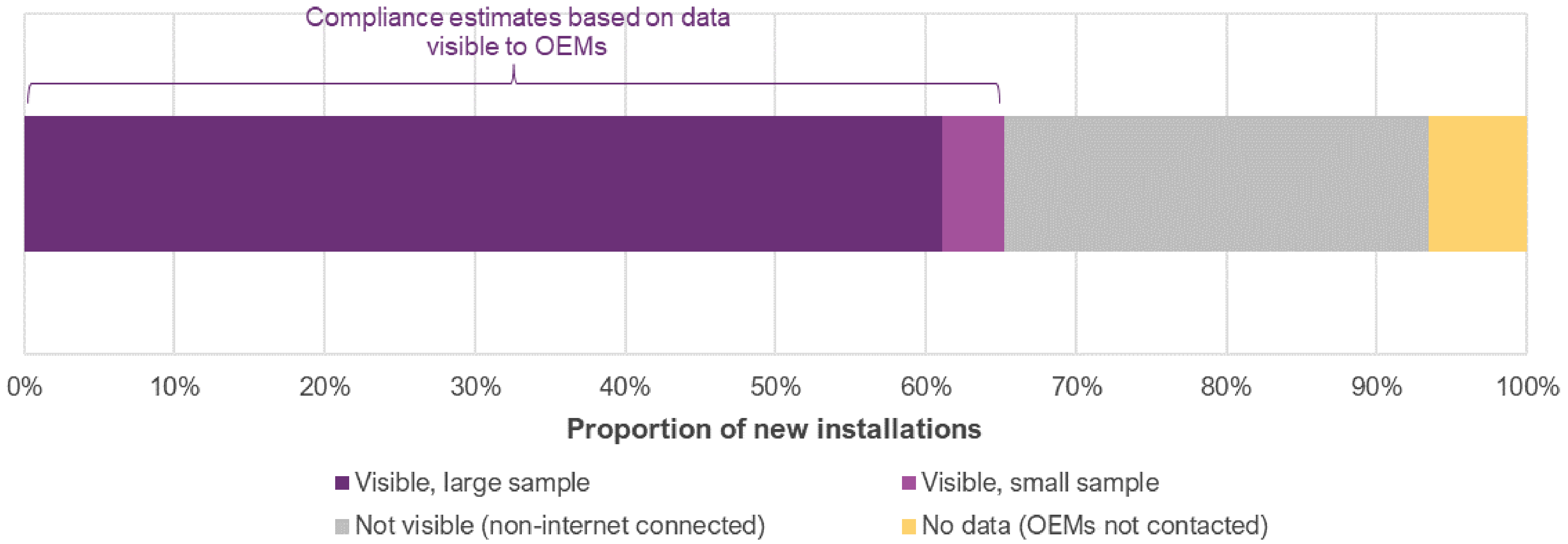
AEMO (Dec 2023) Compliance of Distributed Energy Resources with Technical Settings: Update, https://aemo.com.au/-/media/files/initiatives/der/2023/oem_compliance_report_2023.pdf?la=en&hash=E6BEA93263DE58C64FCC957405808CA6

Compliance rates of new installations to 2020 standard

- Improvement between early 2022 and Q1/Q2 2024



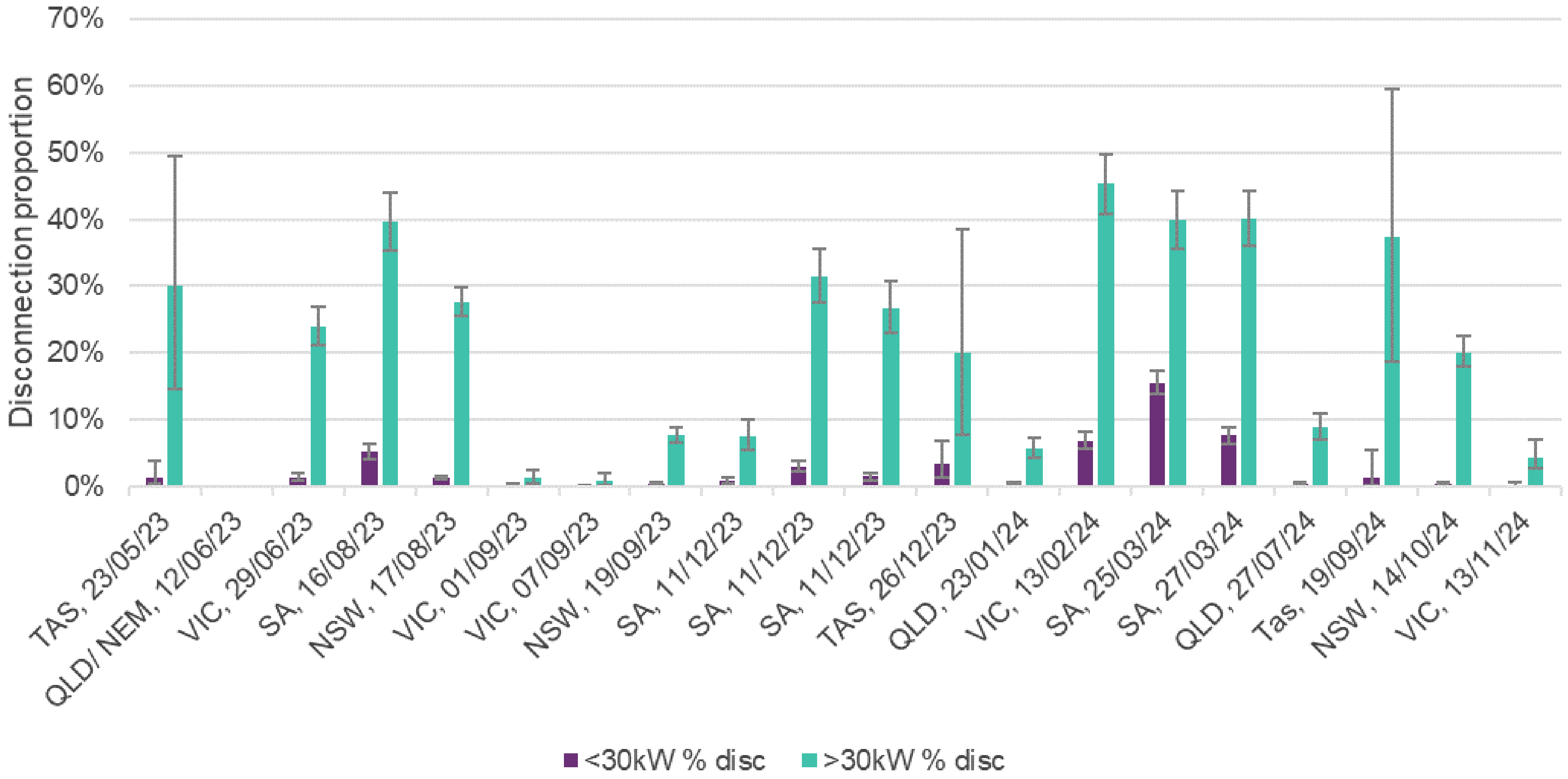
Estimated visibility of compliance



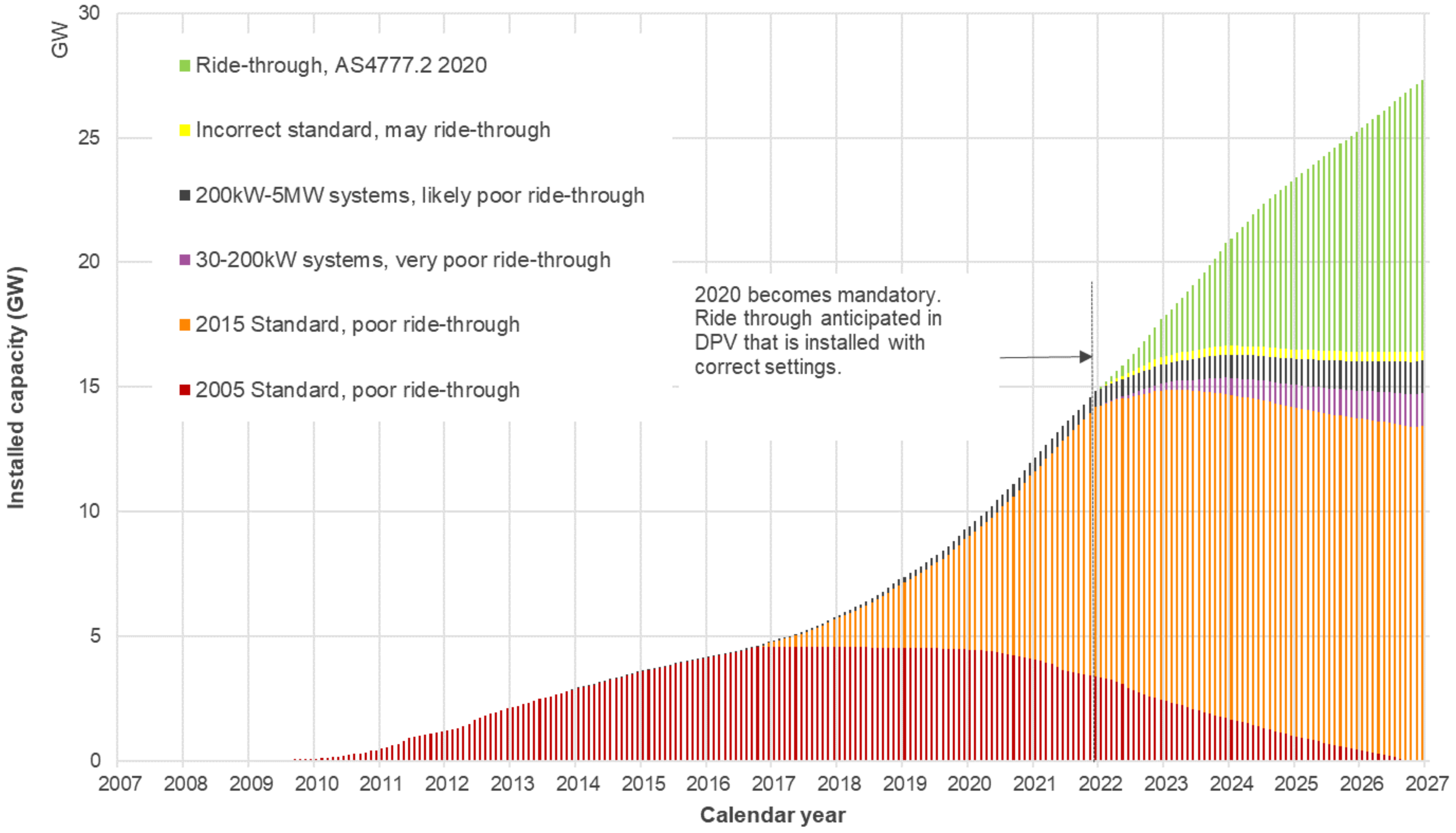
- Q1/Q2 2024 inverter installations, provided by OEM datasets
- Data has improved in quality since 2023

Behaviour of larger DPV

- 30-100kW systems compared with <30kW systems in recent power system events



Ride-through capabilities of installed PV fleet (up to 5 MW)

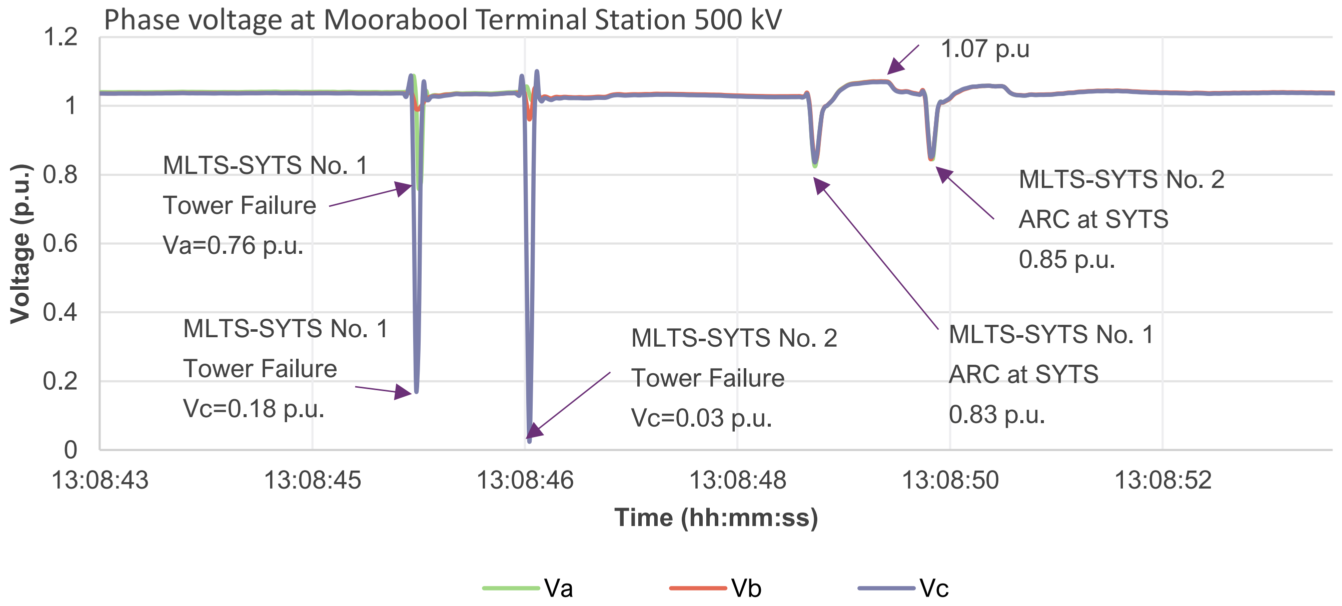


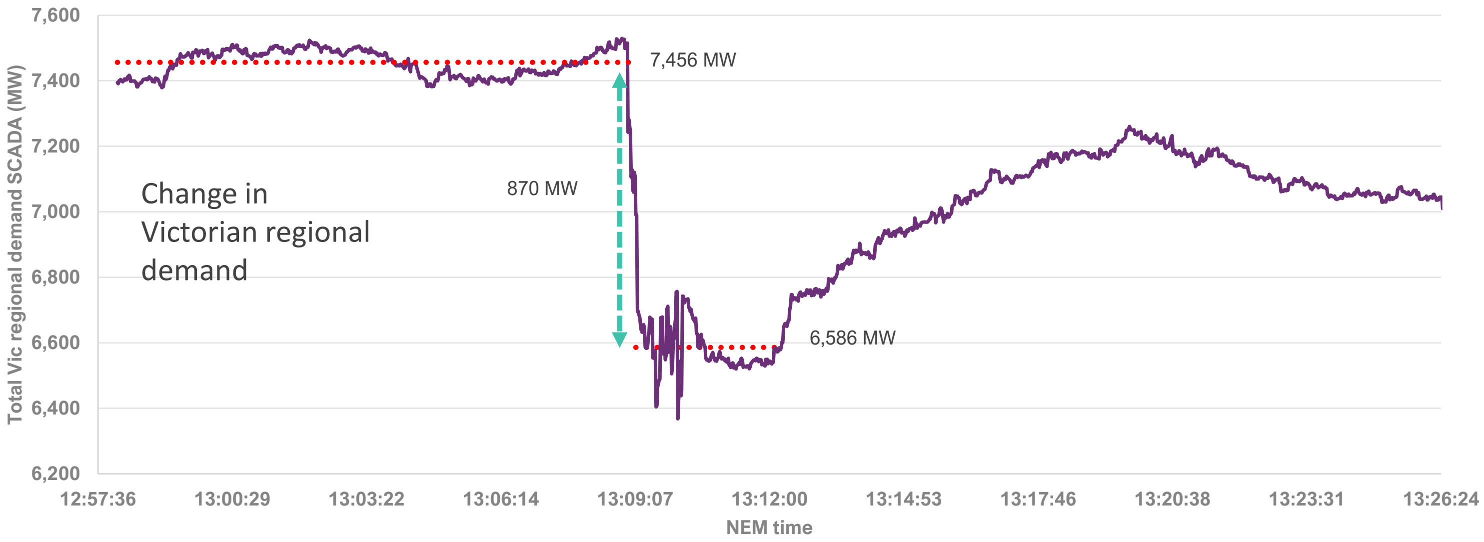
DPVC management remains a concern in South Australia, but hopefully will not be a significant contributor to frequency management risks in other regions

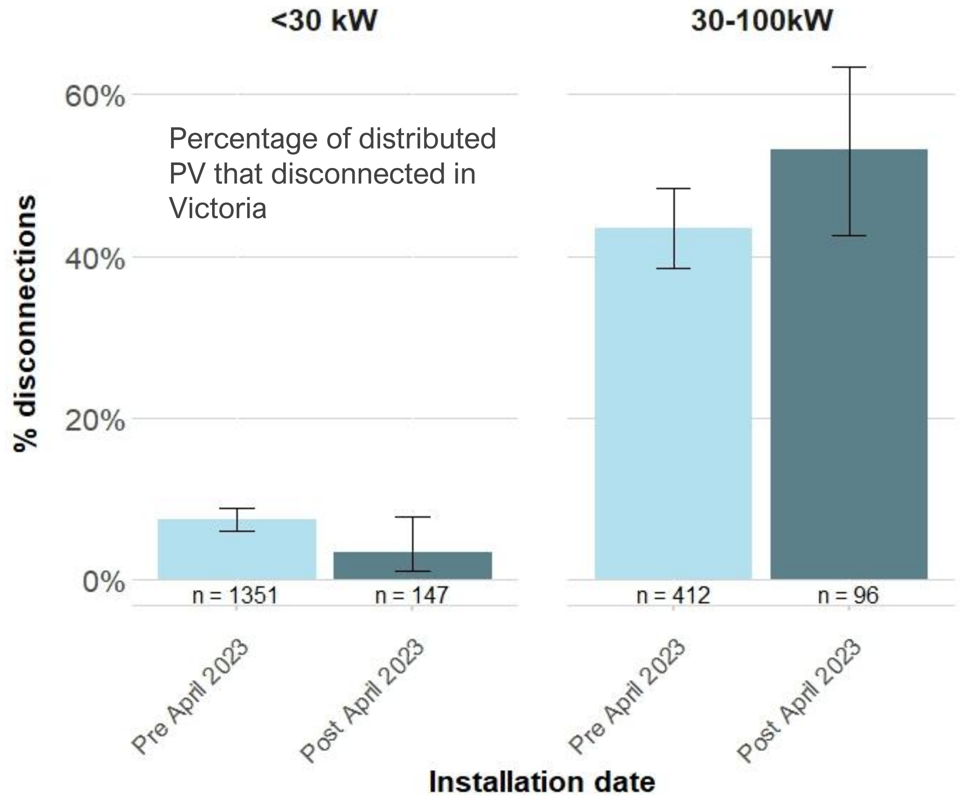
Incident analysis

13 February 2024

Six 500kV towers failed due to convective downburst of wind that exceeded rating of the towers, resulting in fault and subsequent trip of lines.

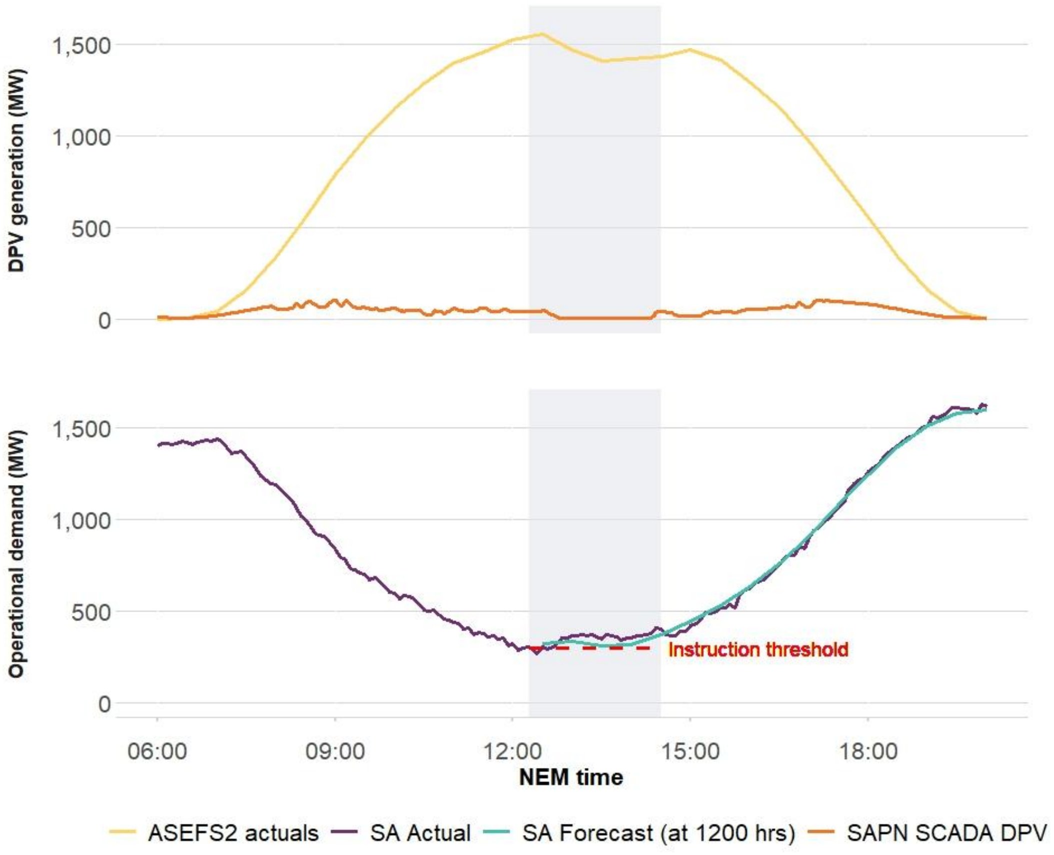






Distributed photovoltaic management during SA island operation

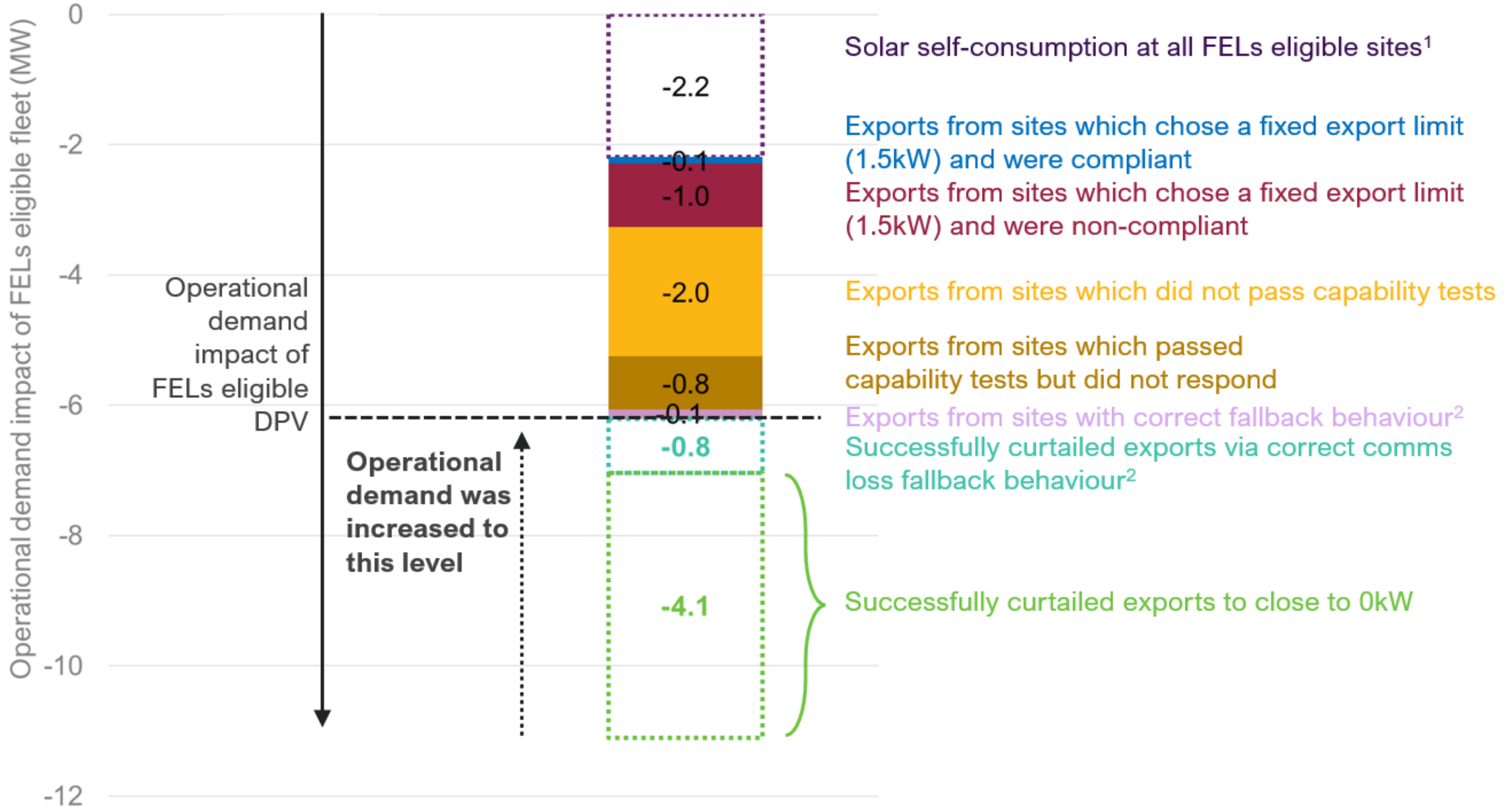
South Australia operational demand and distributed photovoltaic generation on 15 February 2024



- Due to transmission damage on 13 Feb, SA operated at credible risk of separation until 15 Feb.
- On 15 Feb, a DPVC3 (Distributed PV contingency) condition arise, with forecasts of constraint violations on the interconnector.
- The only available action to maintain system security was to reduce distributed PV generation in SA.
- 51 MW of DPV was curtailed (46 MW of larger distributed PV via SCADA control, and 5 MW of small-scale distributed PV curtailed via the Common Smart Inverter Profile – Australia (CSIP-AUS) under the Smarter Homes framework

Distributed PV curtailment

DPV curtailment via flexible export limits (FELs):
Types of responses to curtailment signal on 15 February 2024

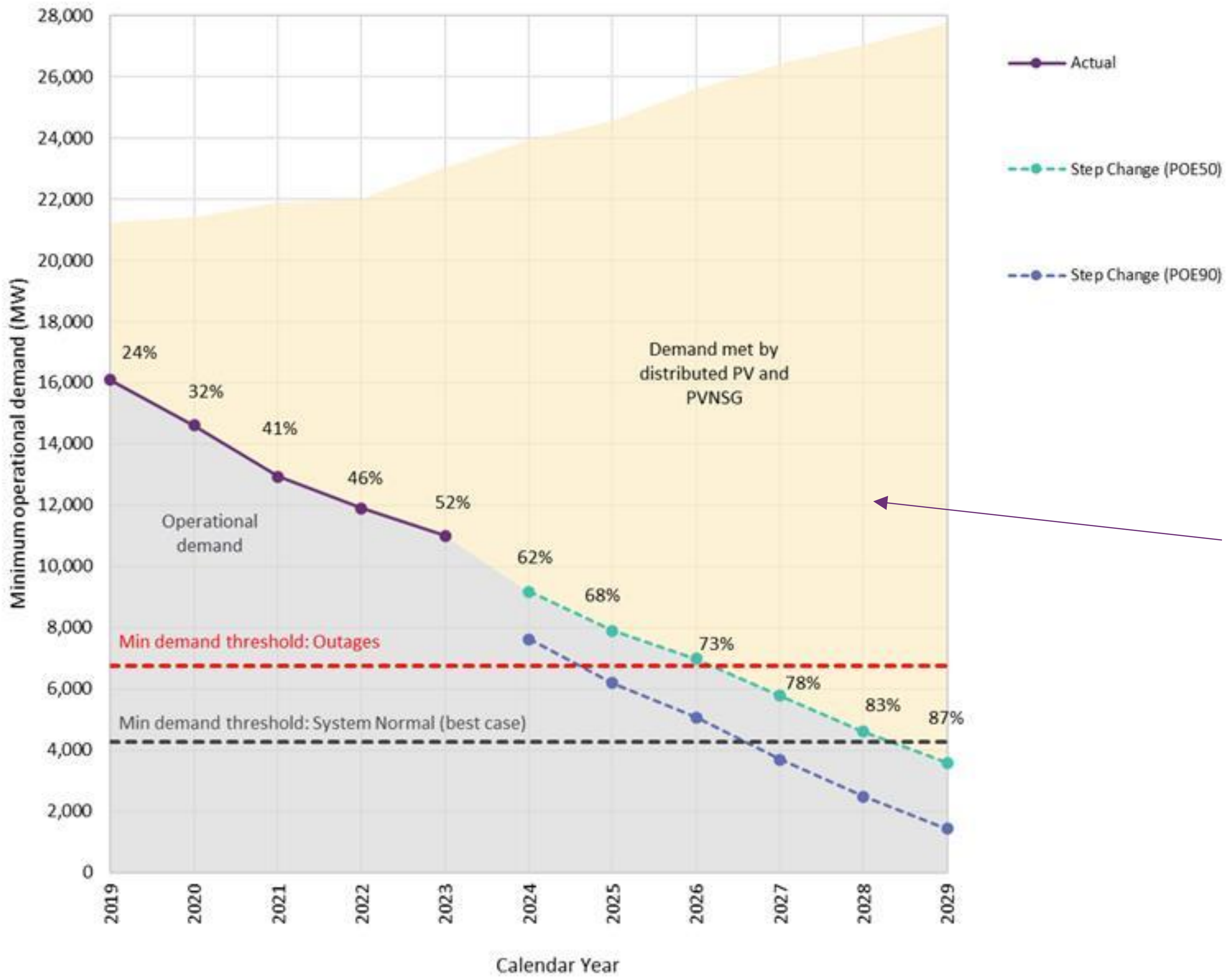


- SAPN estimates approximately 16 MW installed capacity of distributed PV was eligible for the FELs mechanism.
- Based on AEMO analysis of smart meter data as well as data provided by SAPN, this 16 MW of capacity is estimated to generate a total of 11.1 MW, of which:
  - 2.2 MW of this generation is self-consumed at the customer site, and
  - The remaining 8.9 MW exported into the grid.
  - ~5 MW of demand increase was successfully delivered via reduction in distributed PV export.

AEMO (July 2025) Final Report – Trip of Moorabool – Sydenham 500kV No. 1 and No. 2 lines on 13 February 2024, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2024/final-report---loss-of-moorabool---sydenham-500-kv-lines-on-13-feb-2024.pdf?la=en

Power system models

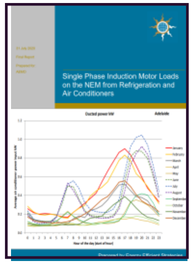
Models for DPV and load

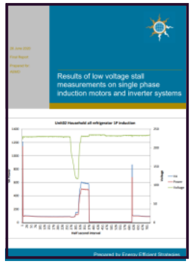


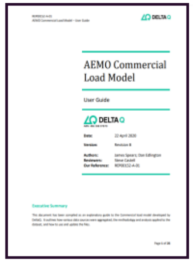
Importance of accurate models for DPV and load

AEMO (Q4 2024) Supporting secure operation with high levels of distributed resources, https://aemo.com.au/-/media/files/initiatives/der/managing-minimum-system-load/supporting-secure-operation-with-high-levels-of-distributed-resources-q4-2024.pdf?la=en

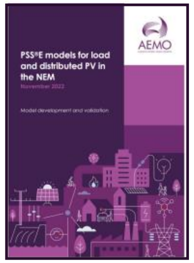
Contributions to incident reporting (DER behaviours)



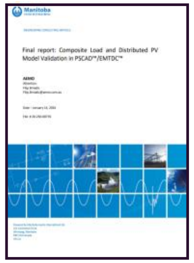




Commercial load parameters



V1 Load & DPV models released for PSS®E



Load & DPV models released for PSCAD™

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025

First prototype models

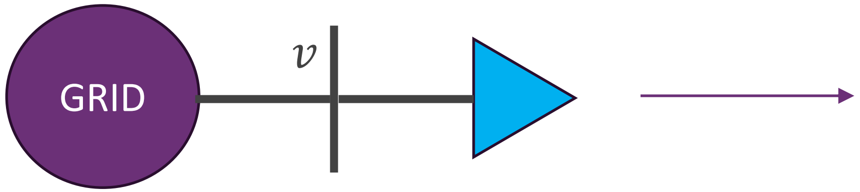
DER behaviours compilation

Application of models to calculating security limits

Load & DPV models updated for PSS®E

OLD (1999)

STATIC MODEL

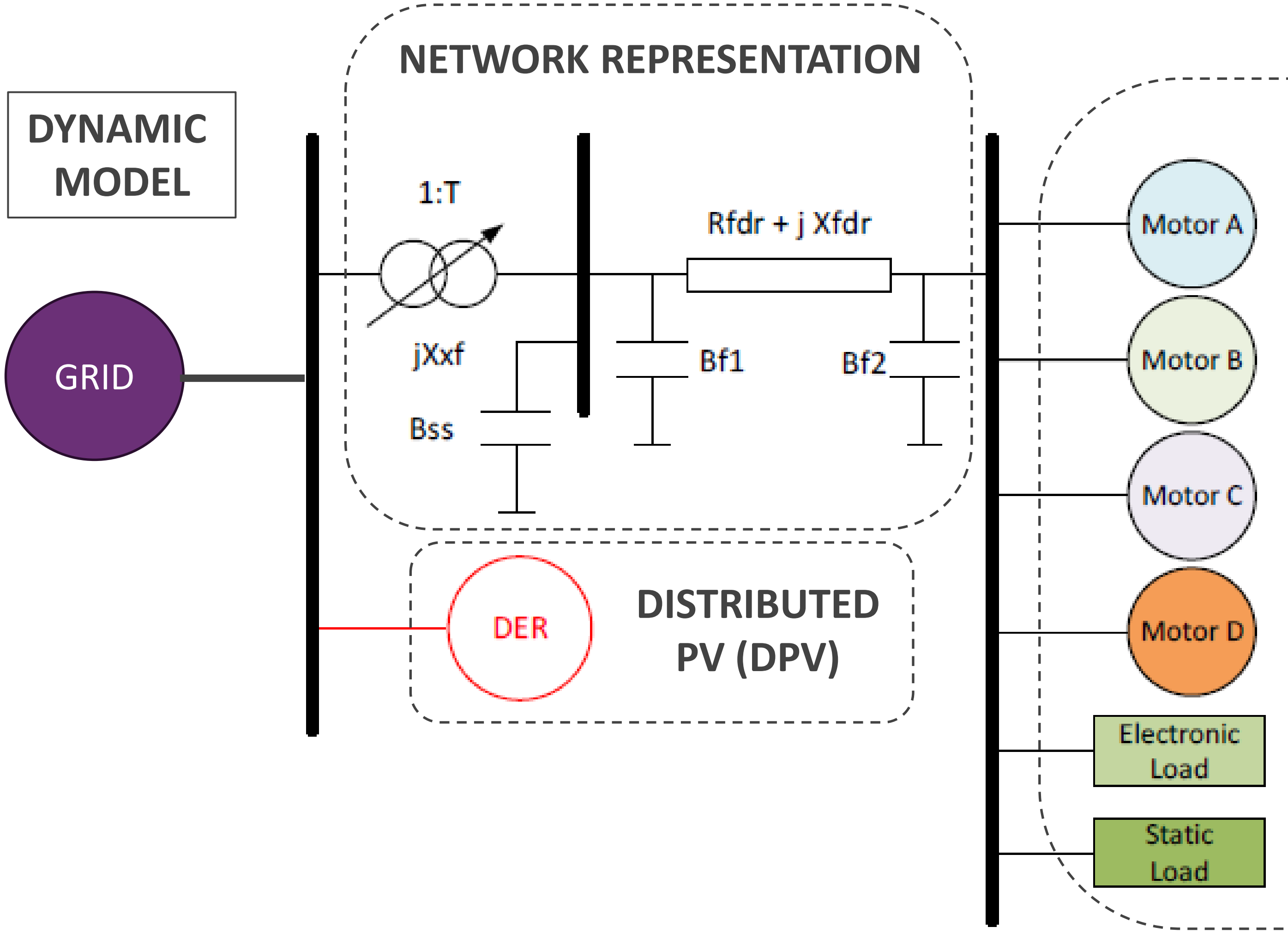


$$P = P_0\, v\, (1 + 0.5 \times \Delta f)$$
$$Q = Q_0\, v^3$$

AEMO

NEW (2022)

DYNAMIC MODEL



LOAD COMPONENTS

- 3ϕ induction motor. Low inertia.
- Constant load torque (τ_L)
- e.g. commercial/industrial ACs + refrigeration

- 3ϕ induction motor. High inertia.
- $\tau_L \propto v^2$
- e.g. ventilation fans

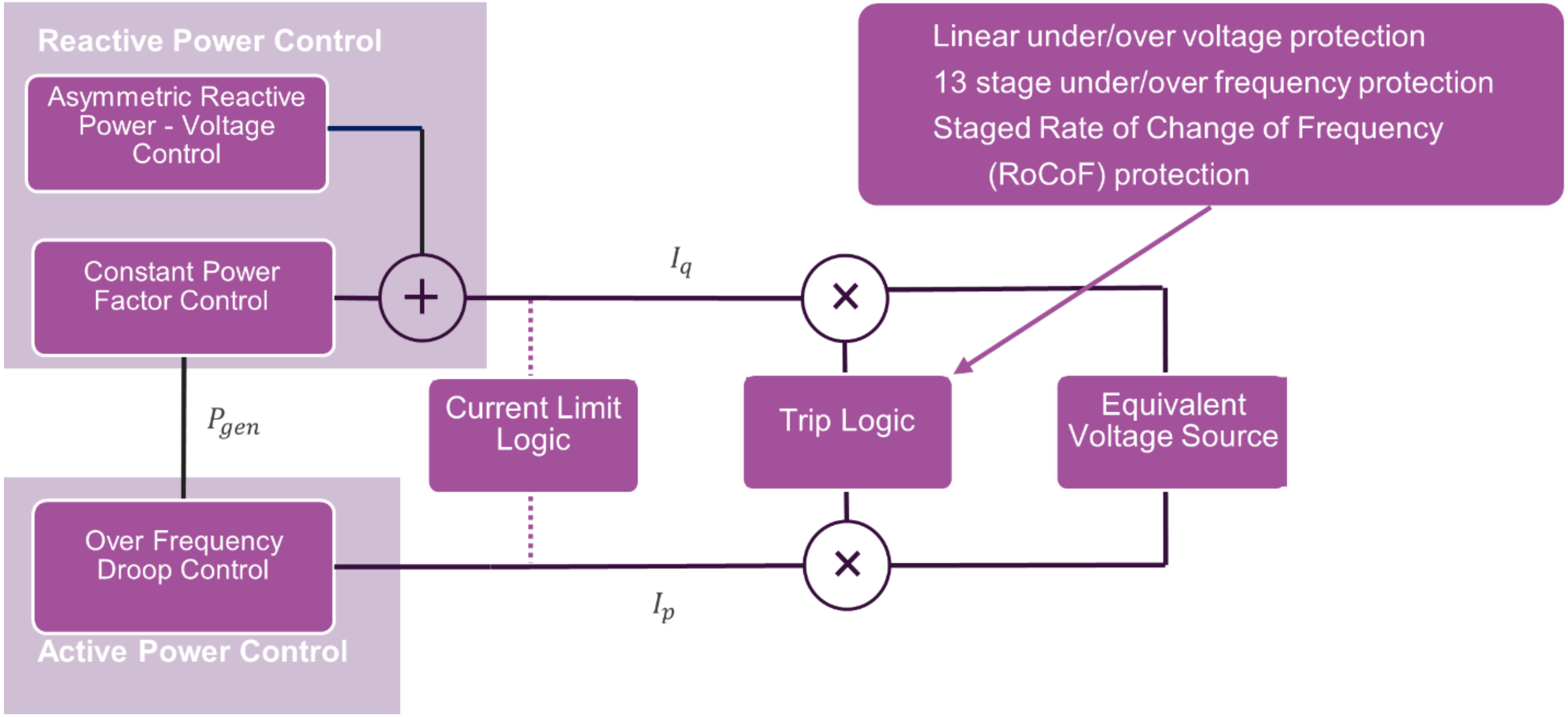
- 3ϕ induction motor. Low inertia.
- $\tau_L \propto v^2$
- e.g. water pumps

- 1ϕ induction motor. Minimal inertia.
- Constant load torque (τ_L)
- e.g. residential ACs + refrigeration

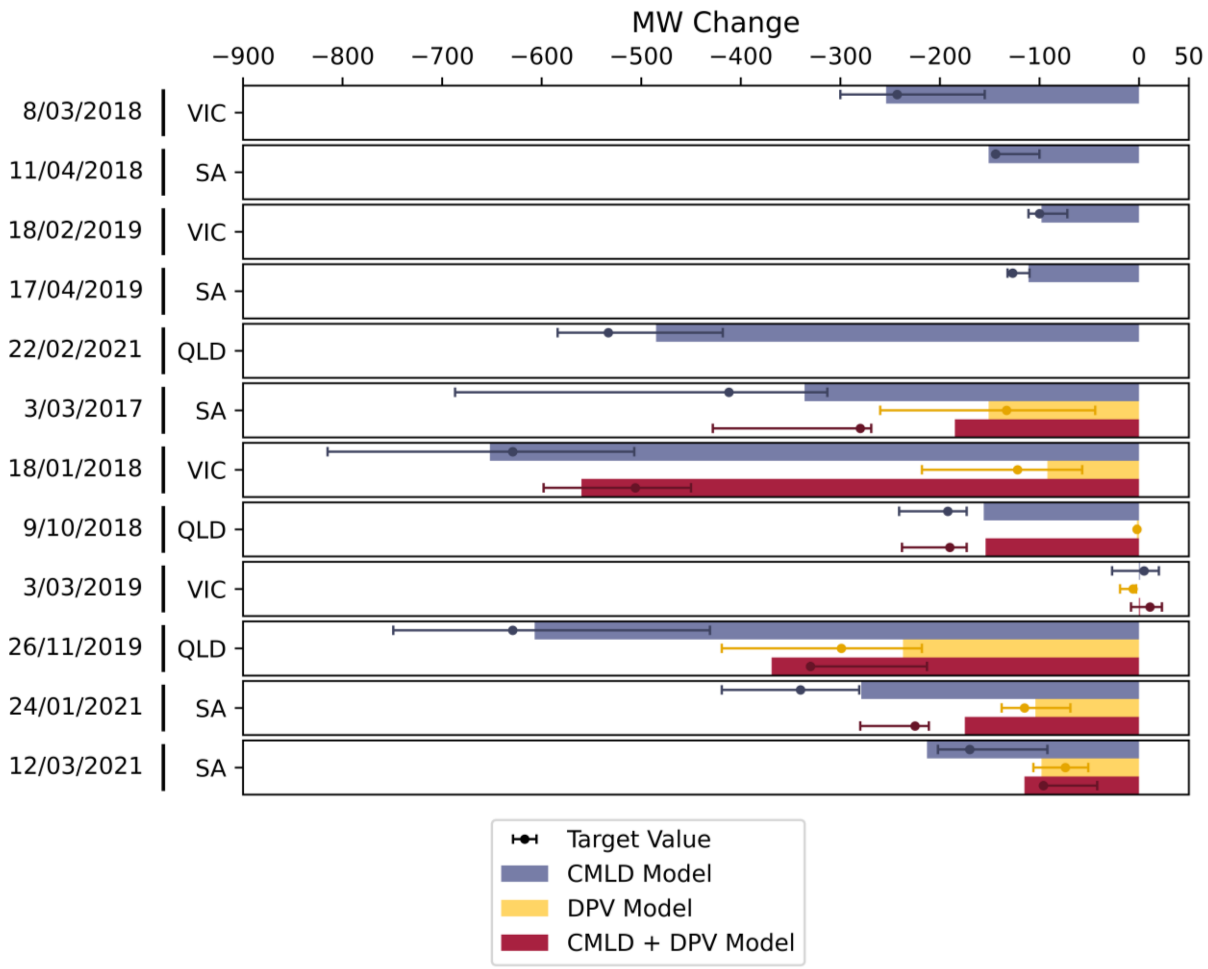
- Power electronic devices
- e.g. computers, televisions, VFDs

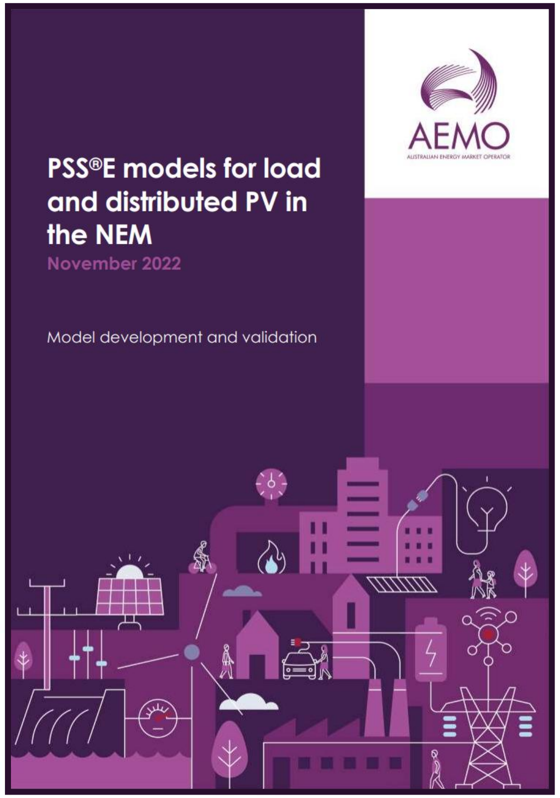
- Constant impedance/current/power loads
- e.g. incandescent lighting

Distributed PV (DPV) Model



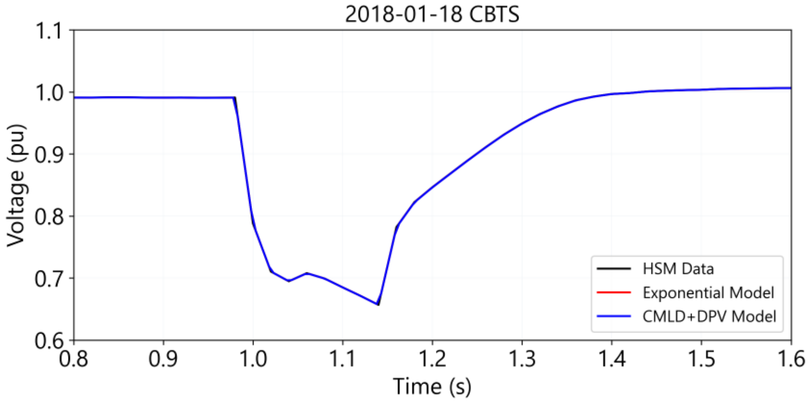
Load & Distributed PV Shake off

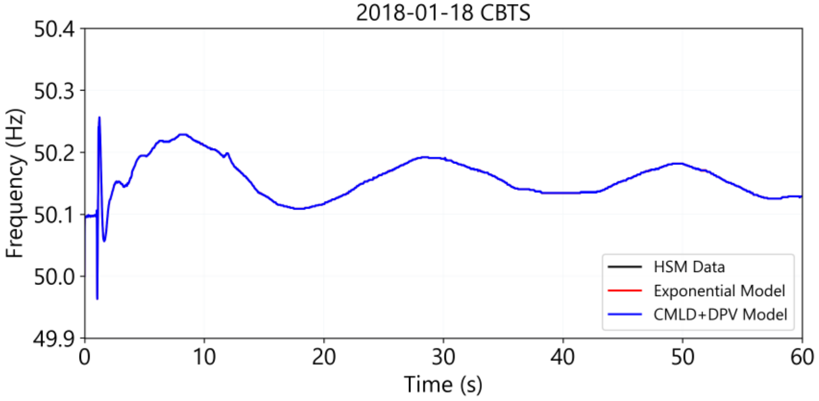


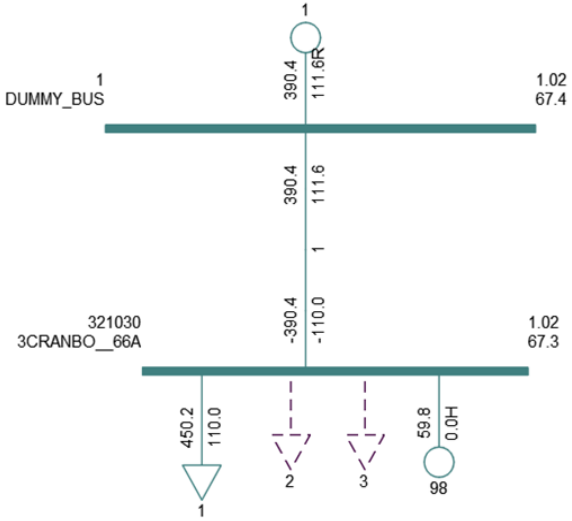


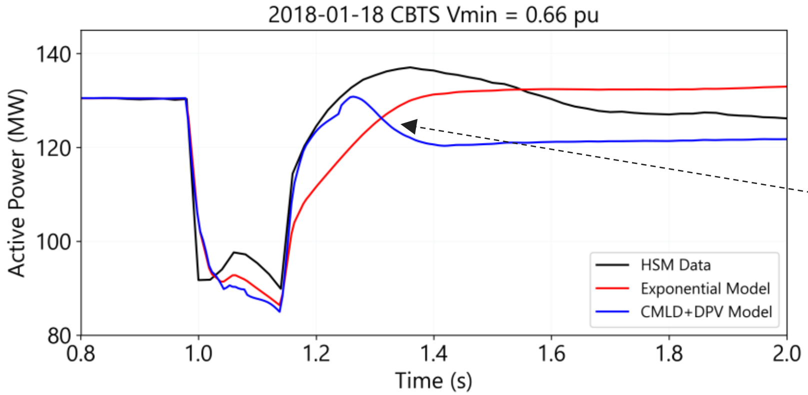
AEMO (Nov 2022) PSSE models for load and distributed PV in the NEM, https://aemo.com.au/-/media/files/initiatives/der/2022/psse-models-for-load-and-distributed-pv-in-the-nem.pdf?la=en

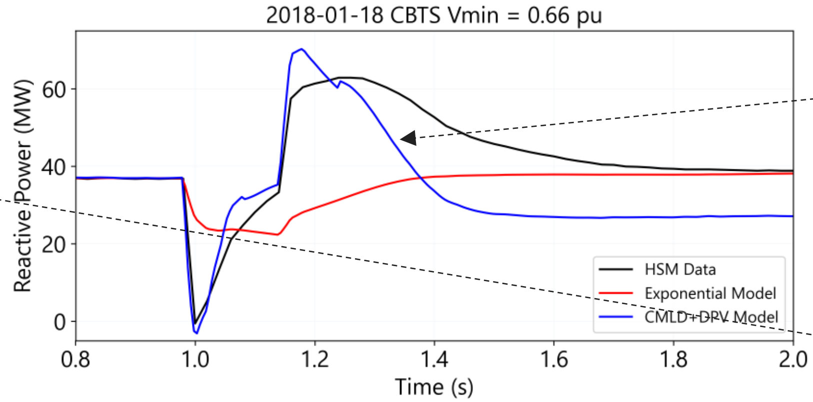
Single Load Infinite Bus (SLIB) Studies





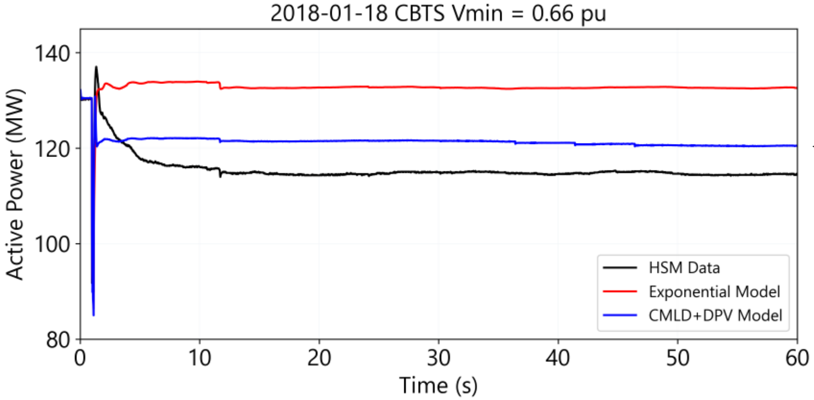


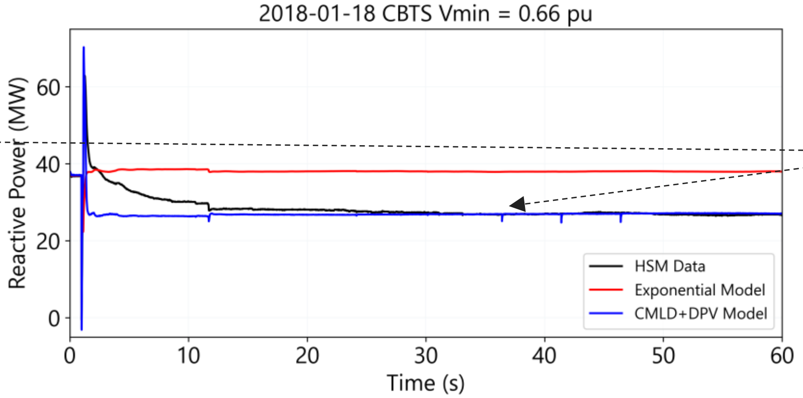




Excellent improvement in trajectory of reactive power (compared with exponential model)

Tend to underestimate post-fault clearance overshoot on active power (but captures general trend at least as well as exponential model)



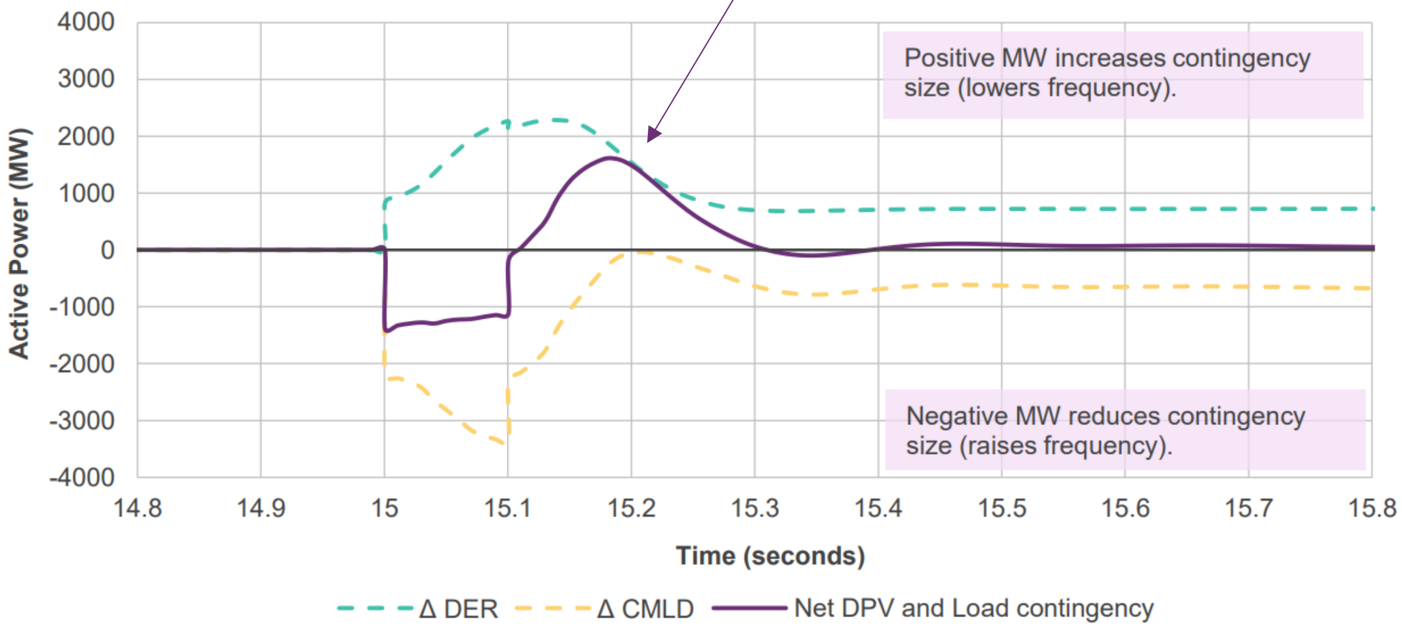


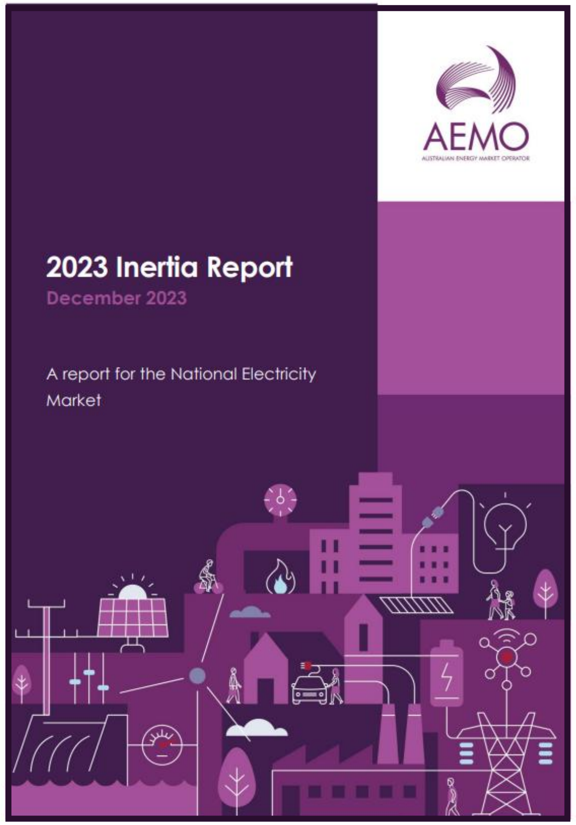
Captures observed steady-state load disconnection reasonably well (and significant improvement over exponential model)

Large swings – is this real?

Transient increase in load
(CMLD model recovers post fault
slightly faster than DPV model)

Figure 9 Net load and distributed PV response to Tarong North 180 MW contingency in an islanded Queensland

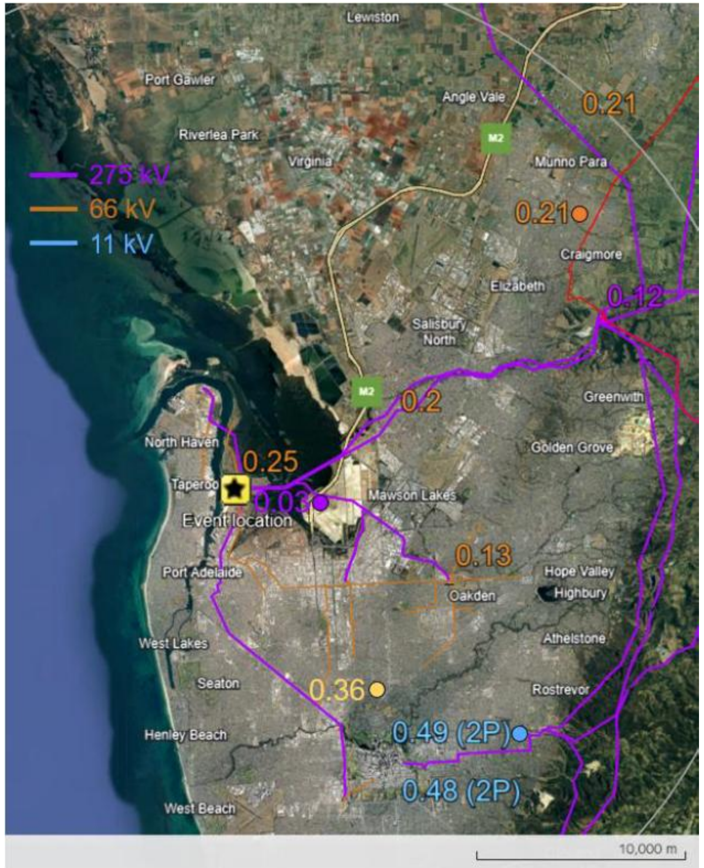




AEMO (Dec 2023) 2023 Inertia Report, https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/system-strength-requirements/2023-inertia-report.pdf

27 March 2024 – Event Summary

275 kV current transformer failures in South Australia



Minimum voltages (pu) recorded, as measured across Adelaide metropolitan area

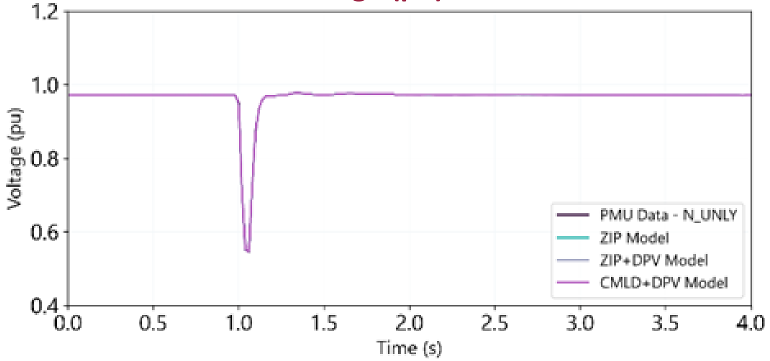
Pre-fault Conditions	
Operational demand	589 MW
Underlying demand	1887 MW
DPV generation	1298 MW

Estimated Change	
Operational demand	68 MW increase (12%)
Underlying demand	75 MW decrease (4%)
DPV generation	143 MW decrease (11%)

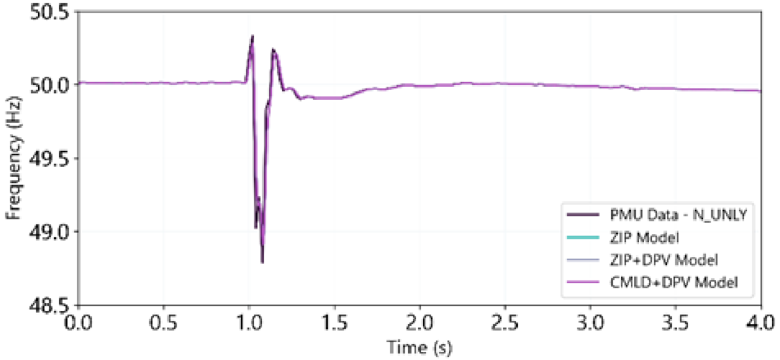
AEMO (Oct 2024) Addendum on DPV and load behaviour: 275kV current transformer failures in South Australia 14-27 March 2024, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2024/addendum-on-dpv-and-load-behaviour275-kv-current-transformer-failures-in-south-australia-1427-march.pdf?la=en

Radial HSM: 11 kV North Unley, SA

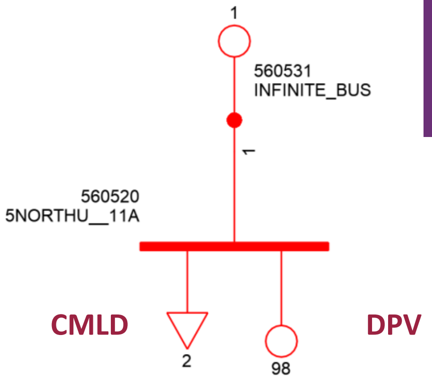
Voltage (pu)



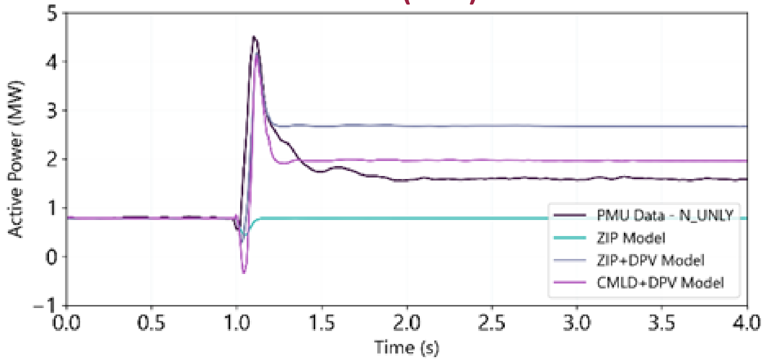
Frequency (Hz)



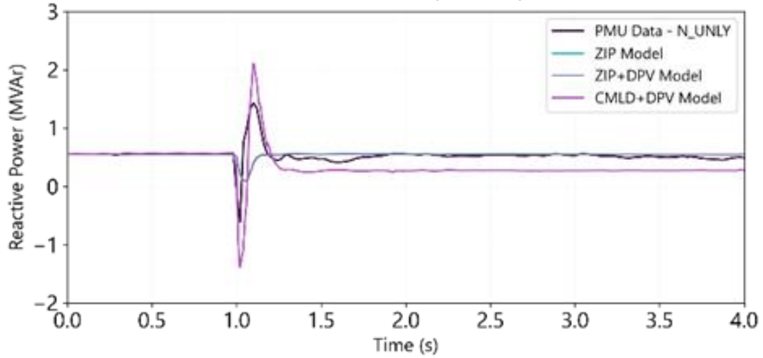
SINGLE LINE DIAGRAM



Active Power (MW)

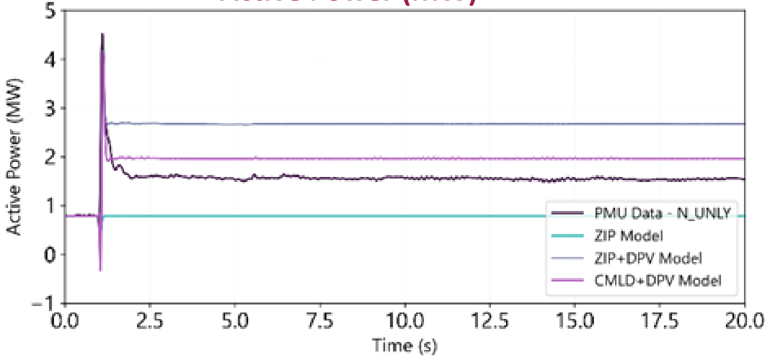


Reactive Power (MVAr)

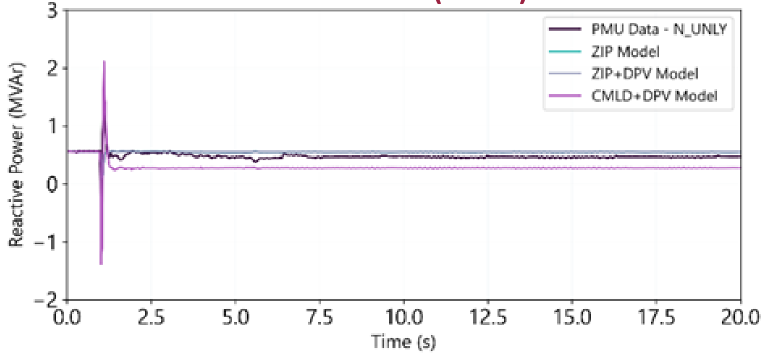


TRANSIENT RESPONSE

Active Power (MW)



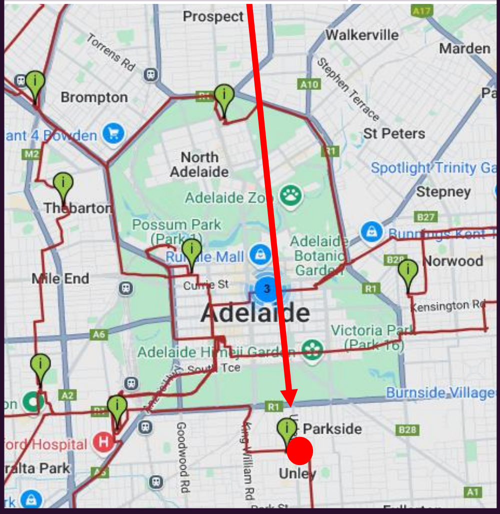
Reactive Power (MVAr)



STEADY STATE RESPONSE

North Unley Zone Substation

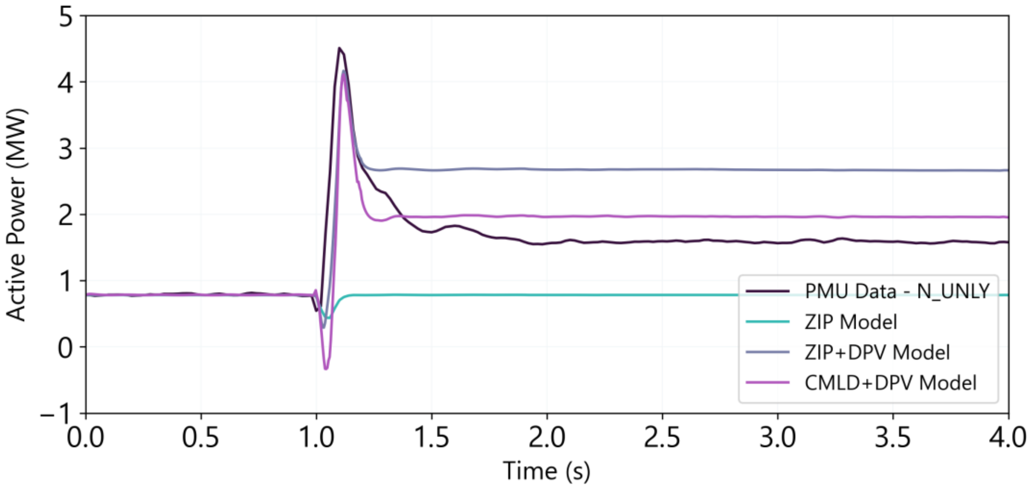
Pre-fault Conditions	
Operational demand	2.4 MW
Underlying demand	7 MW
DPV generation	4.6 MW



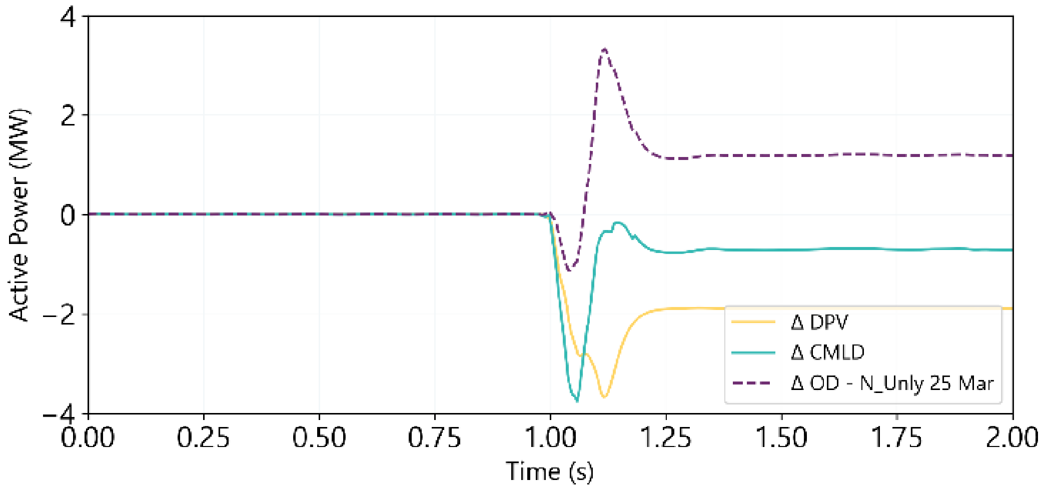
Operational Demand Swings Observed

11 kV North Unley Feeder

Active power measurements & model outcomes

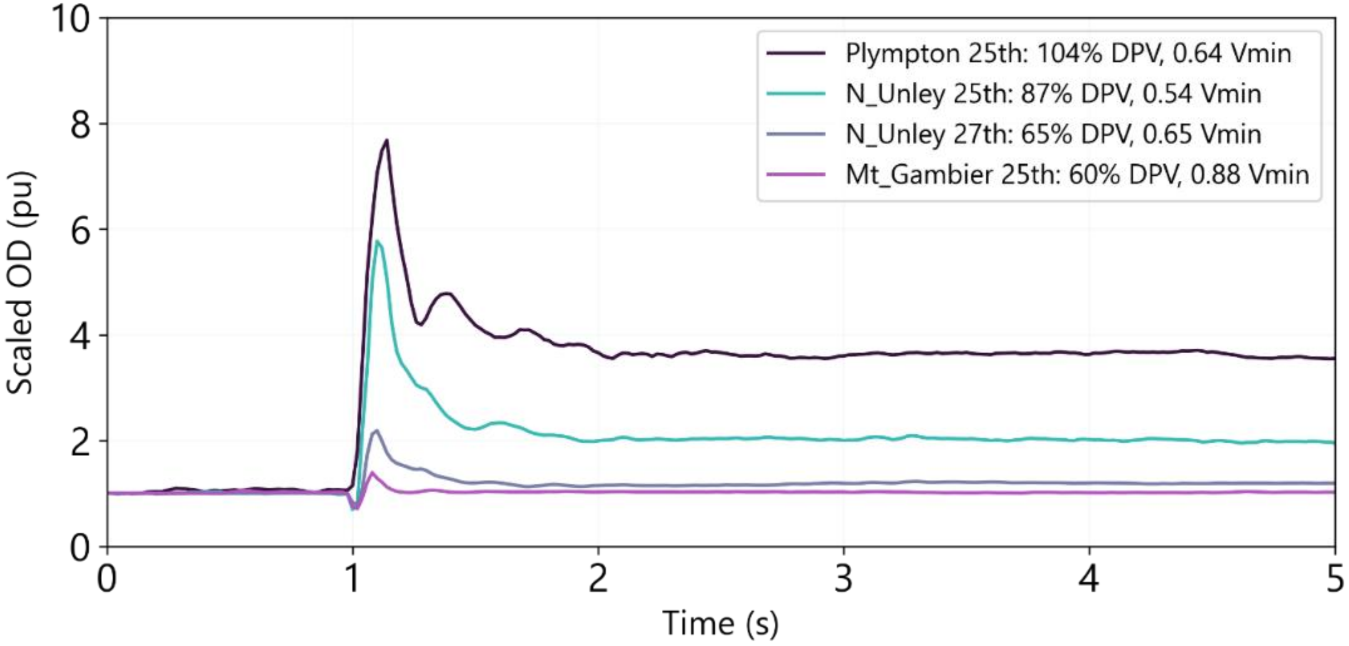


Individual model outcomes: change in active power (MW)



AEMO (June 2025) Validation of dynamic models for distributed PV and composite load, https://aemo.com.au/-/media/files/initiatives/der/2025/validation-of-dynamic-models-for-distributed-pv-and-composite-load_2025.pdf?la=en

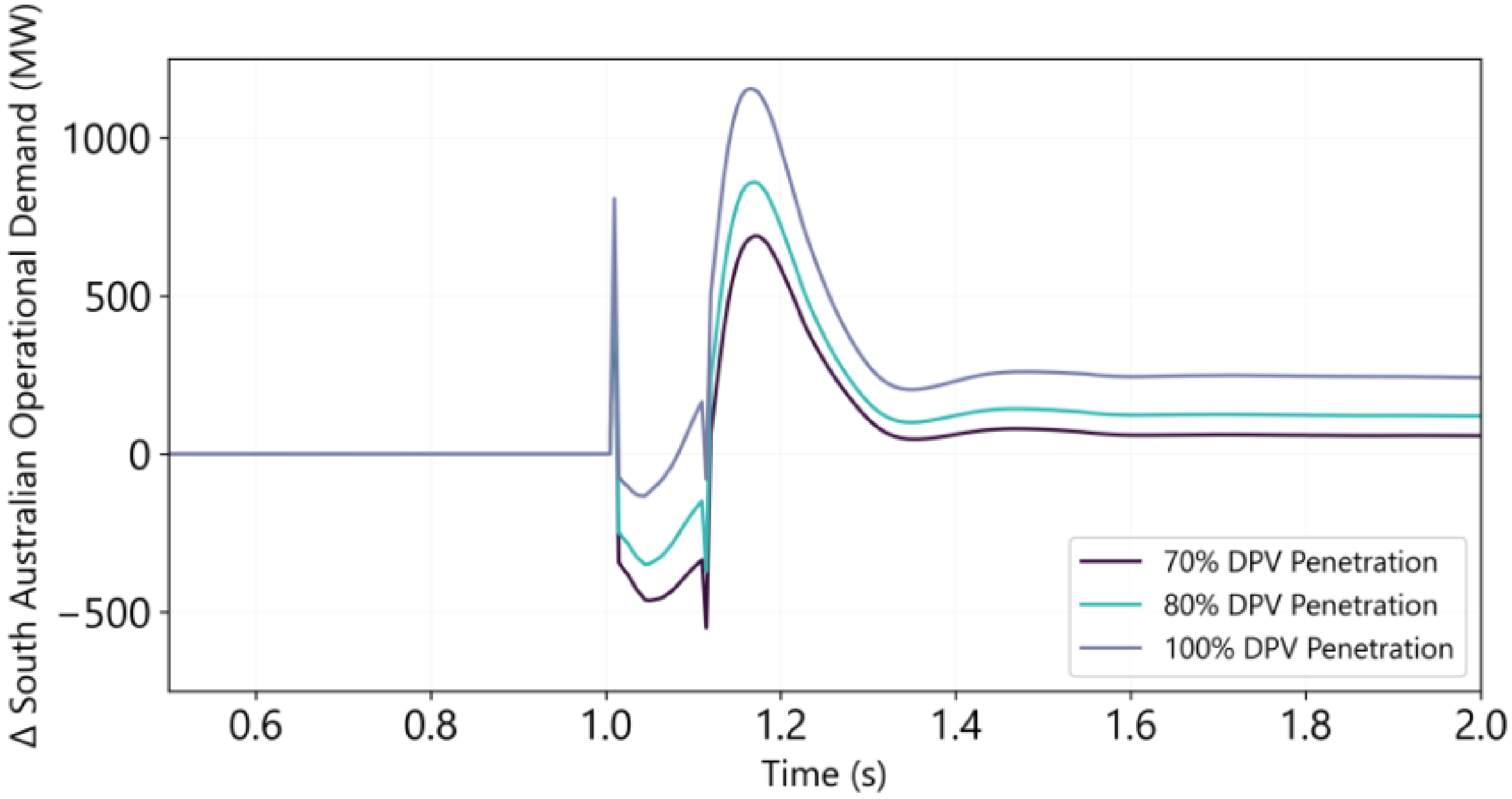
Influence of DPV levels on OD swings



- OD swings are consistently observed
- The size of the swing appears to be strongly affected by
  - DPV penetration level
  - depth of the voltage depression

Simulation outcomes

- 27 March event with more severe credible fault, and increasing DPV penetration



When aggregated across a whole region, this behaviour can lead to a significant transient (~200ms duration) increase in regional operational demand post fault.

Uplift of operational systems

Uplift of operational systems to integrate DER

- Mapping of existing systems, identifying those most impacted by DER, prioritisation for uplift
- High priority initial focus areas:
  - Control room visibility tools for managing Minimum System Load (MSL)
  - Tools for calculating MSL thresholds
  - Incident analysis tools – Automating triggering & handling large complex datasets
  - Distributed PV into Energy Management System in correct locations, with automated updates
  - Integrate DER models into AEMO Modelling Platform for robust ease of use

For more information:

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Distributed Energy Resources Program

- About the DER Program
- Markets and Framework
- DER Demonstrations
- Managing Distributed Energy Resources in Operations
  - DER behaviour during disturbances
  - Power system model development
  - Managing Minimum System Load (MSL)
  - Adapting and managing Under Frequency Load Shedding at times of low demand
- Standards and connections

Managing Distributed Energy Resources in Operations

The Operations workstream addresses the operational impacts of increasing levels of DER penetrating the electricity grid.

Its objectives are to ensure the operational systems are in place to maintain energy system security with regards to:

- Understanding how distributed resources behave during disturbances →
- Developing power system models of DER and load behaviour →
- Managing Minimum System Load →
- Adapting Under Frequency Load Shedding at times of low demand →

Findings and references in each area are summarised in the relevant sub-page.

- https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/managing-distributed-energy-resources-in-operations

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