MEI Seminar Series

Seminar #5: Enhancing Grid Resilience Towards Net-Zero

19 August 2026

Melbourne Energy Institute

THE UNIVERSITY OF MELBOURNE

Speakers:

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Senior Engineer - Future Energy Systems
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Moderator:

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Chair of Electrical Power Systems
Dept of Electrical and Electronic Engineering
University of Melbourne

MEI Seminar Series 2026

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4. Advances and Challenges in Carbon Capture	June
5. Enhancing Grid Resilience Towards Net-Zero	**Aug**
6. The Future of the Australian Car Market: Policy, Competition & Electrification	Sep
7. The case for fusion - Cleantech commercialisation	Oct

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Today's speakers

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MODERATOR:
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Reliability and resilience in low-carbon power systems

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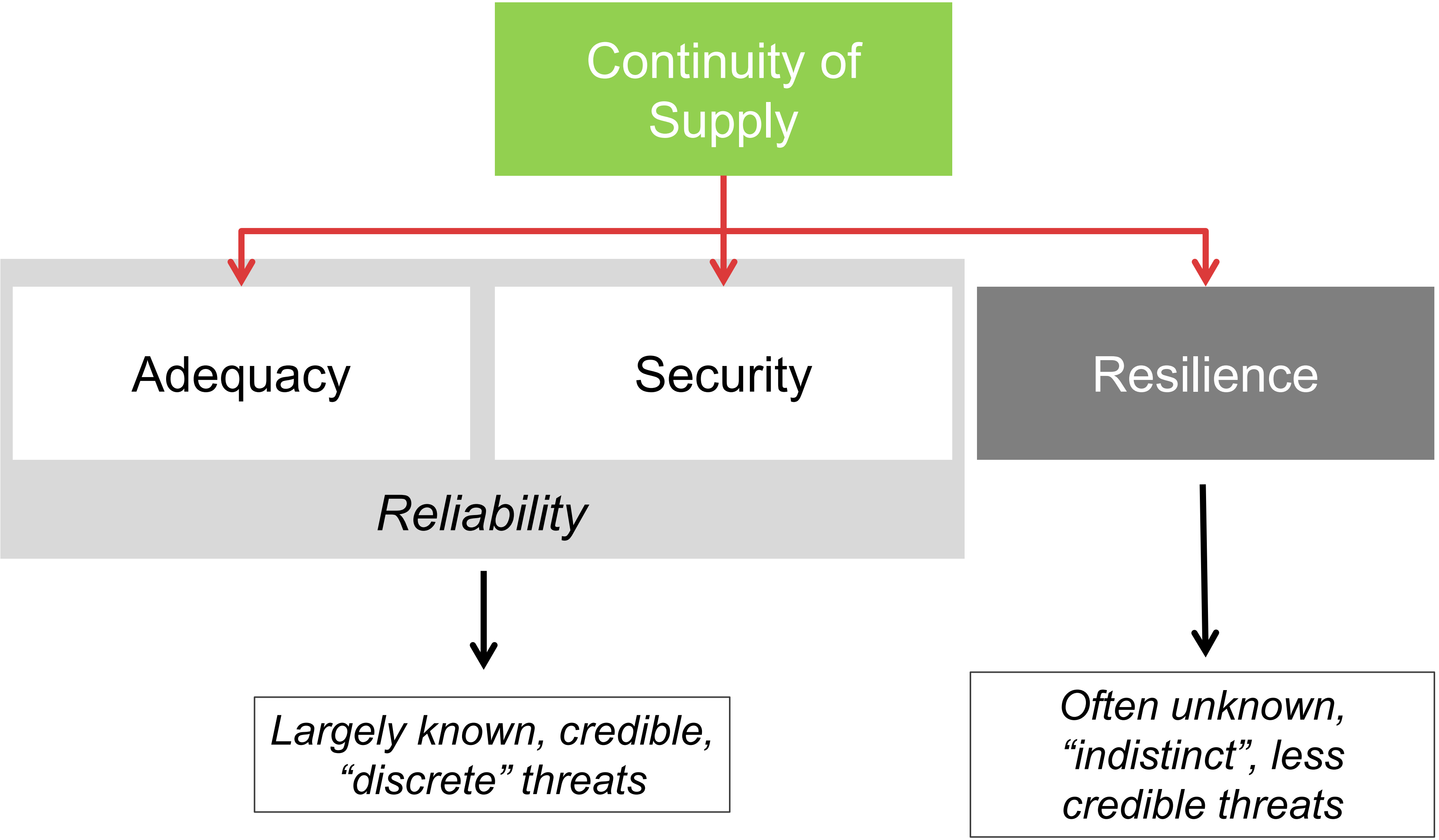
Melbourne Energy Institute Seminar

19 August 2026

Reliability, resilience and continuity of supply



Reliability, resilience and continuity of supply

Continuity of Supply

"Rara avis in terris nigroque simillima cygno"

Juvenal, 82 AD

Ad

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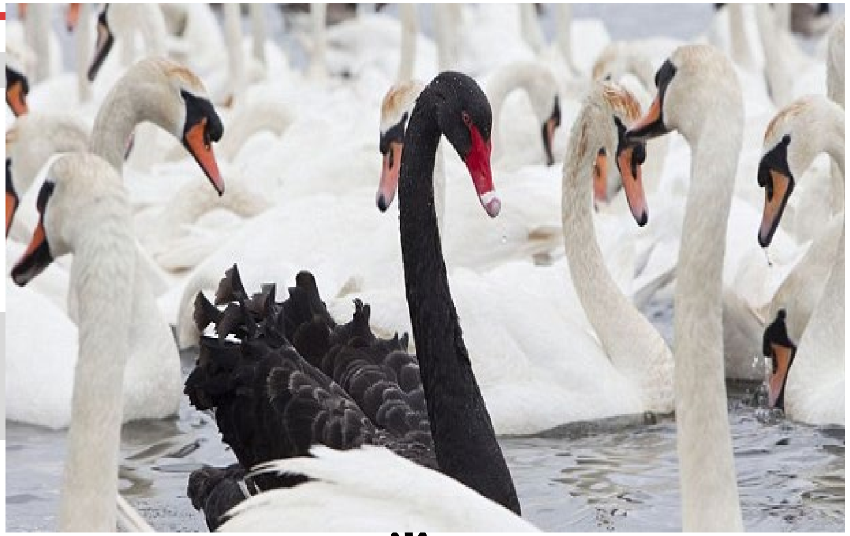
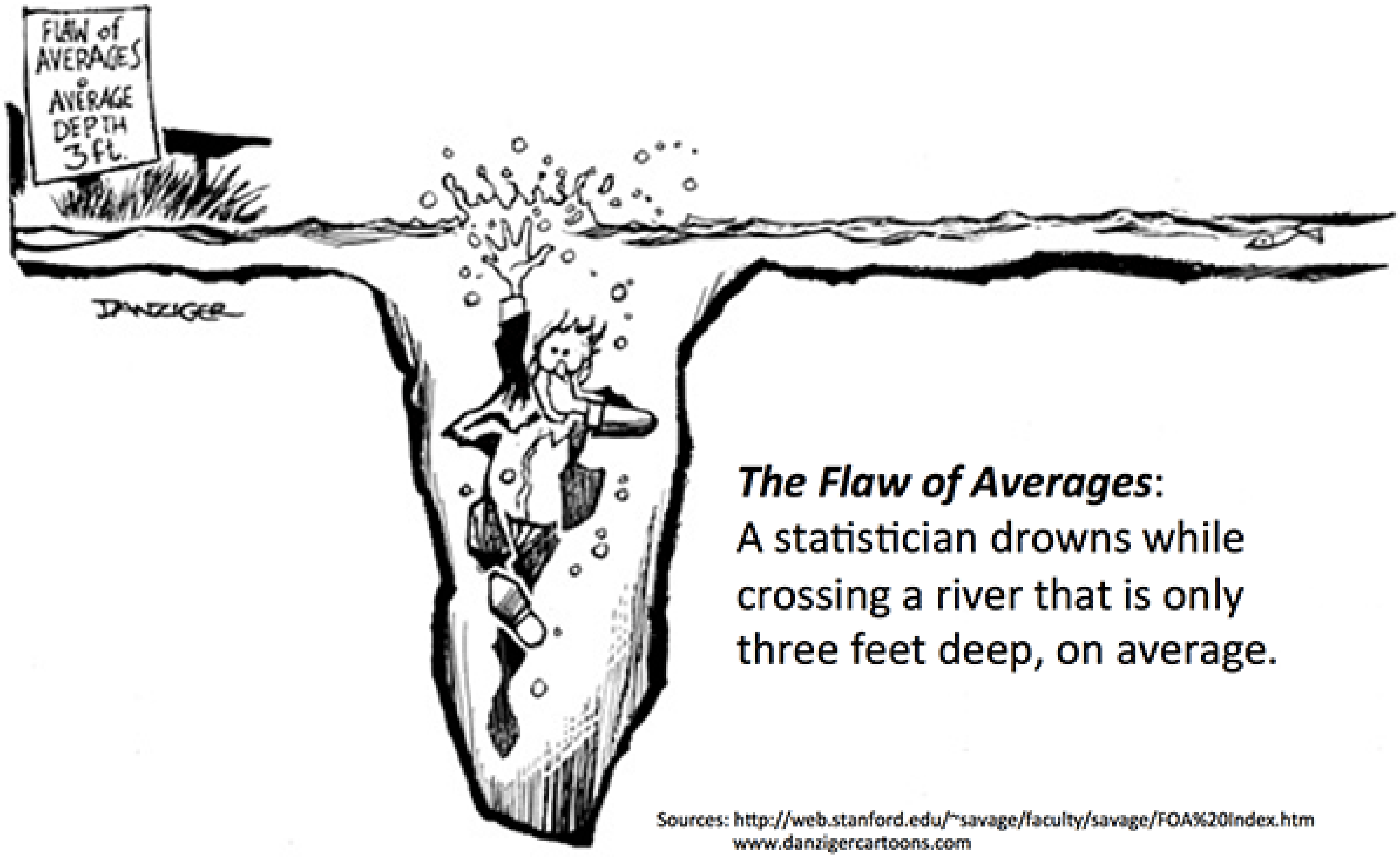


Largely known, credible, "discrete" threats

Often unknown, "indistinct", less credible threats

Why traditional reliability-thinking may not be good enough?



The Flaw of Averages:
A statistician drowns while crossing a river that is only three feet deep, on average.

Sources: http://web.stanford.edu/~savage/faculty/savage/FOA%20Index.htm
www.danzigercartoons.com

Reliability vs Resilience

- Power systems have been traditionally designed to be ***secure and reliable*** against the so-called **credible** (“expected”, “average”) events, i.e., N-1 or N-2 outages

- However, what if a “**black swan**”, high impact low probability (HILP), extreme event occurs?

- **N-X outages**
- **Common mode failures**
- **Cascaded failures**

Reliability vs Resilience

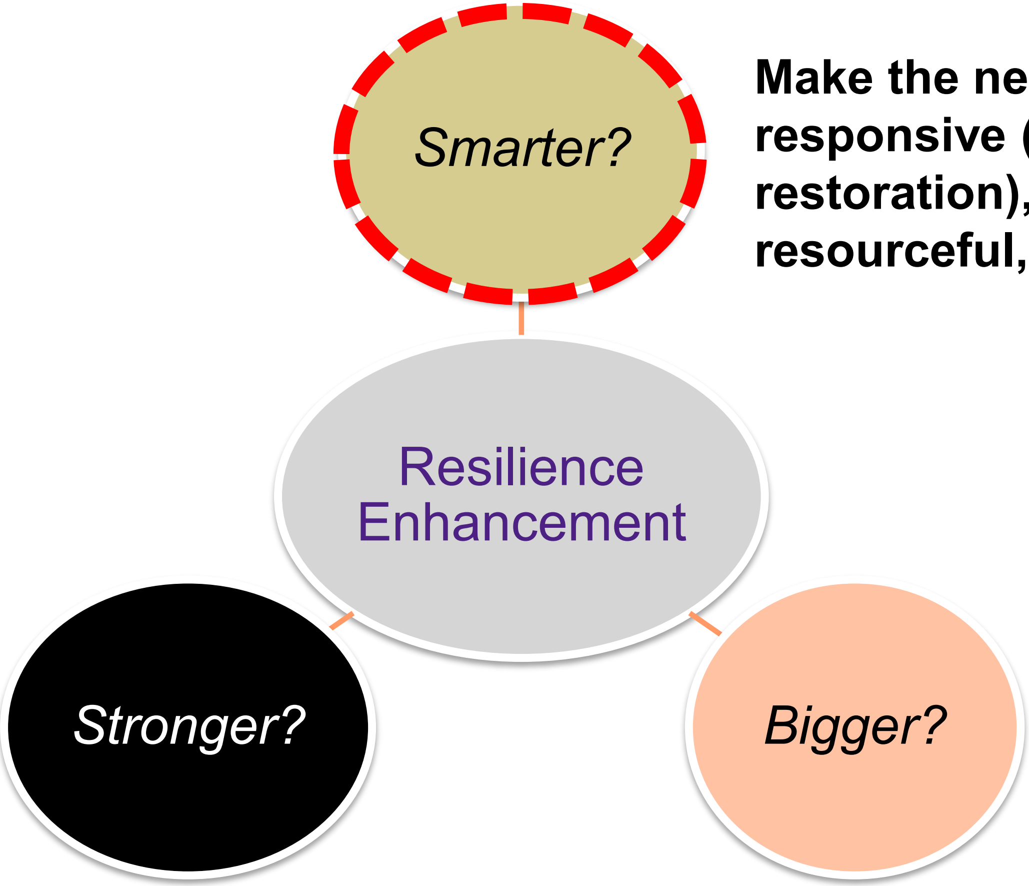
- Power systems have been traditionally designed to be ***secure and reliable*** against the so-called **credible** (“expected”, “average”) events, i.e., N-1 or N-2 outages

- However, what if a “**black swan**”, high impact low probability (HILP), extreme event occurs?

- **N-X outages**
- **Common mode failures**
- **Cascaded failures**

Need to move towards resilience-thinking and engineering

The *resilience trilemma*

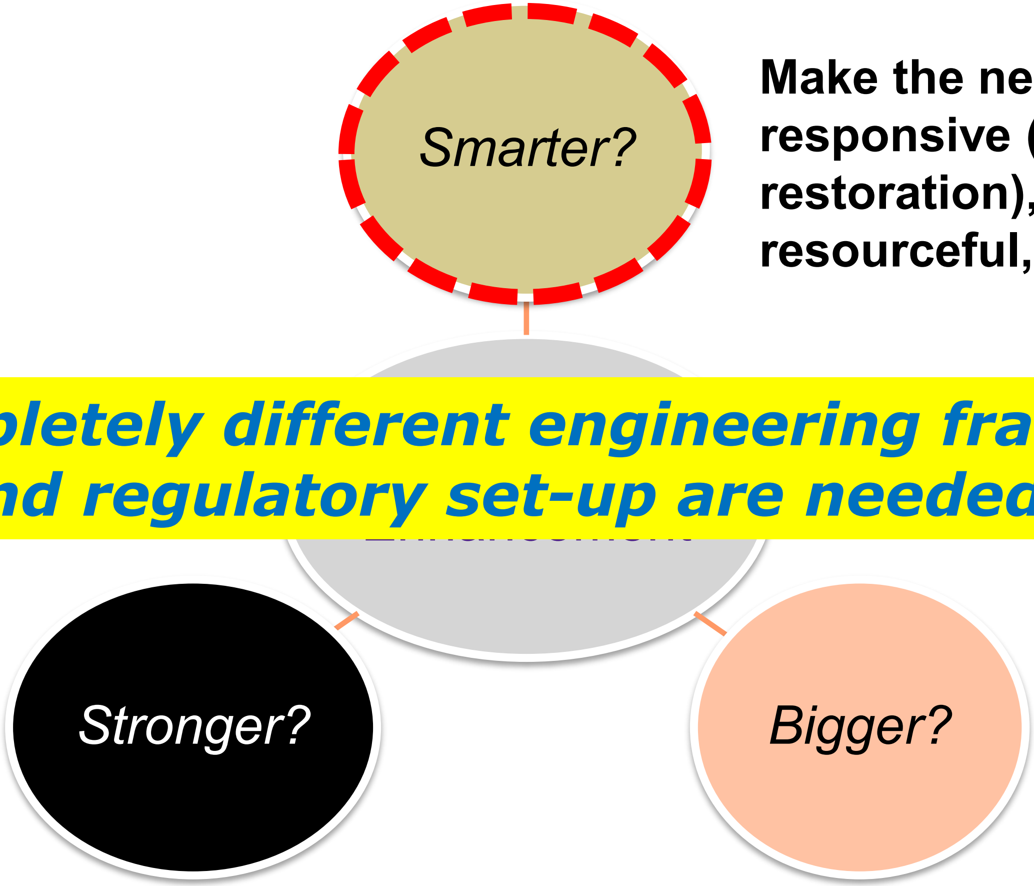


Make the network more responsive (e.g. faster restoration), self-adaptive, resourceful, etc.

Upgrade existing infrastructure, asset life extension, etc.

Build new infrastructure, e.g. transmission lines, substations, etc.

The *resilience trilemma*



Make the network more responsive (e.g. faster restoration), self-adaptive, resourceful, etc.

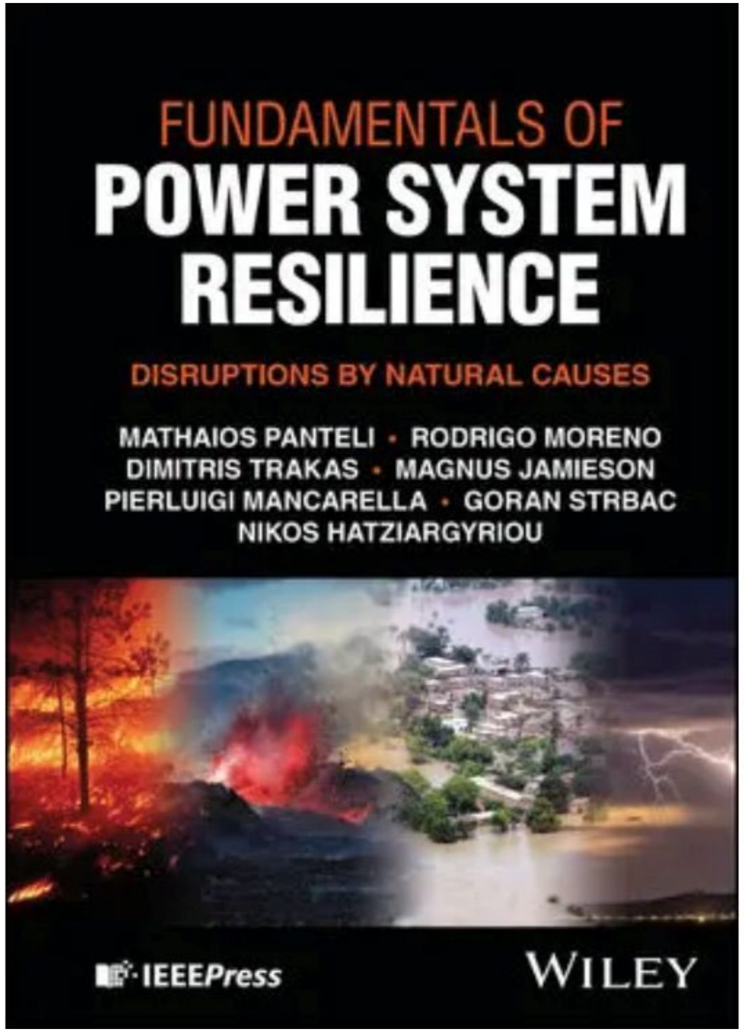
But completely different engineering framework and regulatory set-up are needed!

Upgrade existing infrastructure, asset life extension, etc.

Build new infrastructure, e.g. transmission lines, substations, etc.

References

- M. Panteli *et al.*, "Fundamentals on power system resilience", *IEEE Press and Wiley*, December 2025
- M. Panteli et al., "Fundamentals of Power System Resilience: Concepts, Models, and Decision-Making under Extreme Events", *Electric Power System Research*, 2026
- Lecture notes from ELEN90092 "Low-carbon grid: Operation and economics", Master in Electrical and Electronic Engineering, Low-carbon Power Systems specialization, University of Melbourne



Resilience-related Operational Risks in Energy Transition

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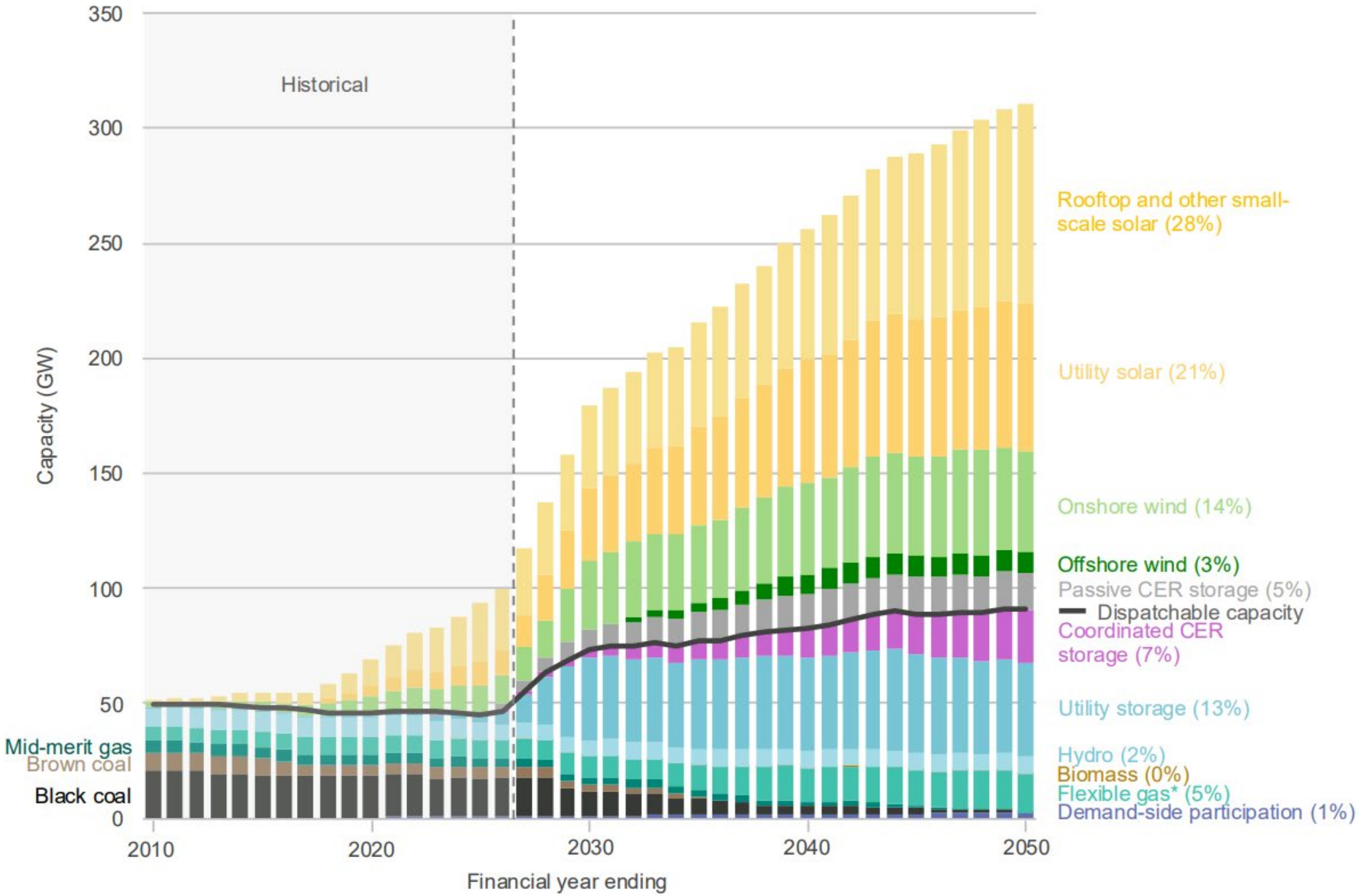
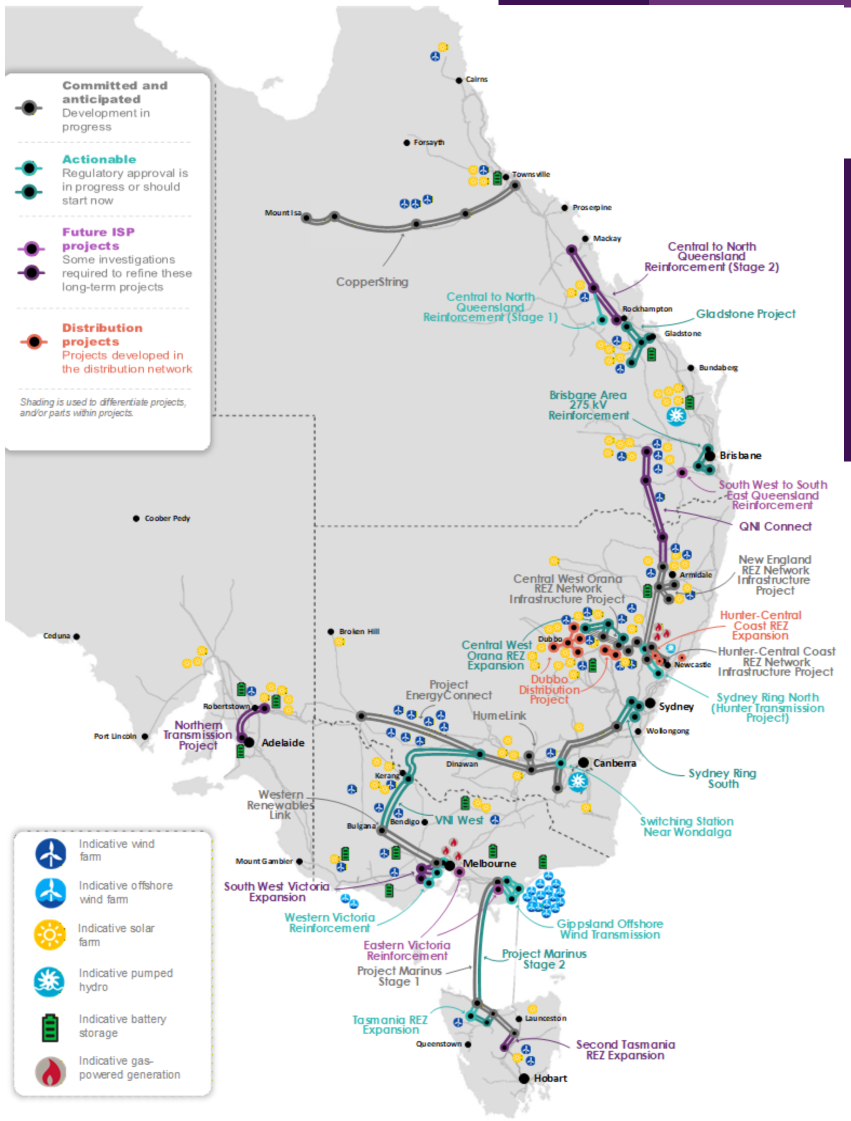
August 2026

Integrated System Plan (ISP)





2026-integrated-system-plan-isp.pdf

AEMO

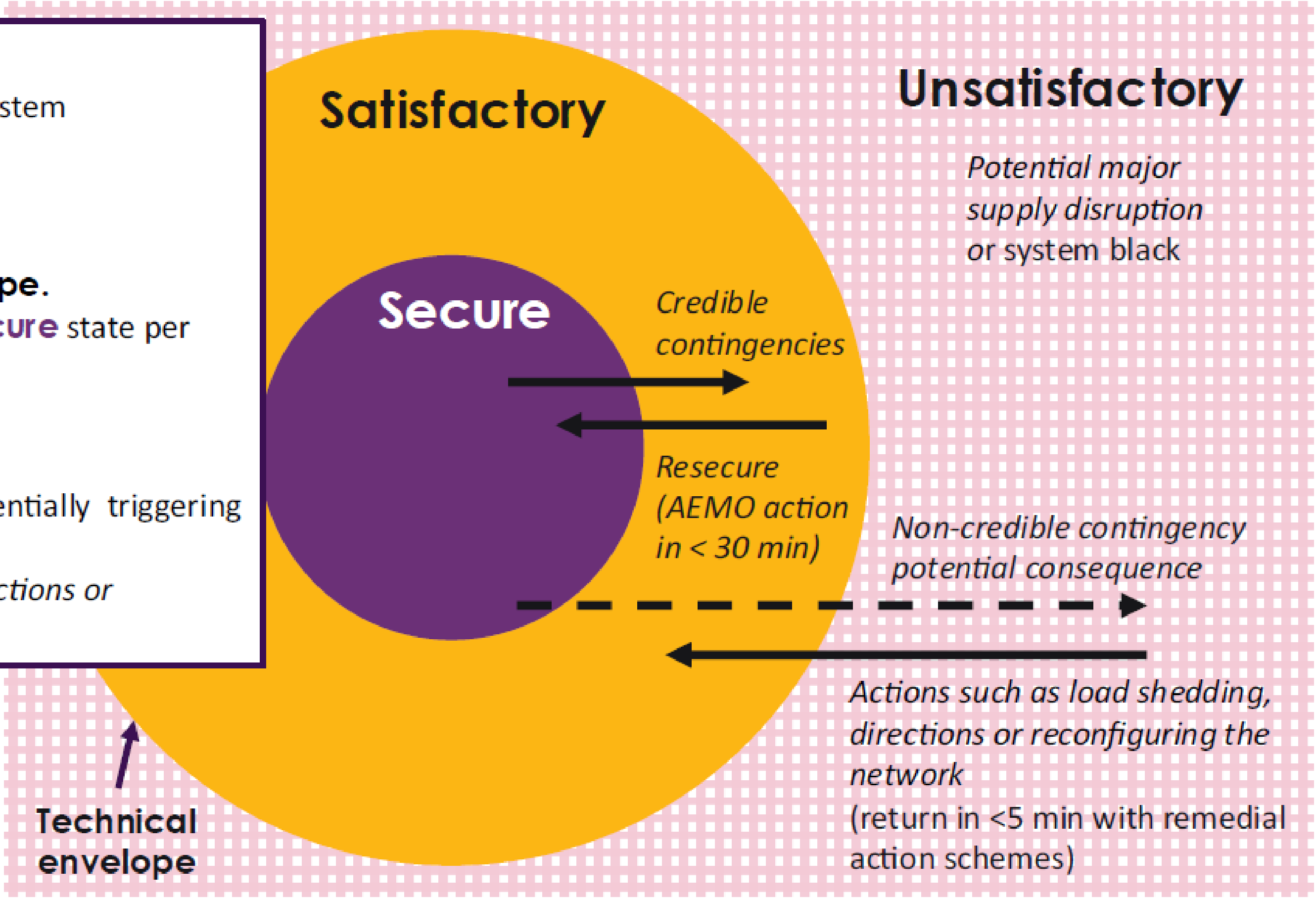
Power system security

A ***secure*** power system is one operated safely within defined technical limits, with ability to withstand credible disturbances, return to secure operation, and restart following a widespread outage.

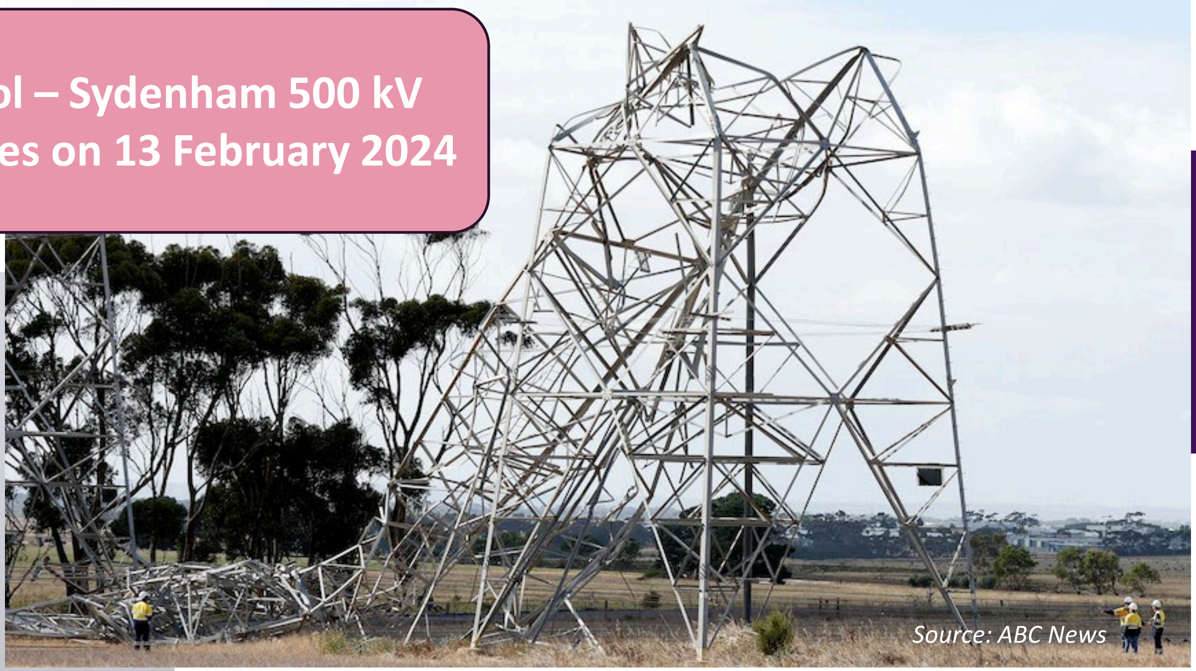
Secure
Credible contingencies will, at worst, push system to **Satisfactory**.

Satisfactory
System operates within **technical envelope.**
AEMO action within 30 min to return to **Secure** state per rules obligation.

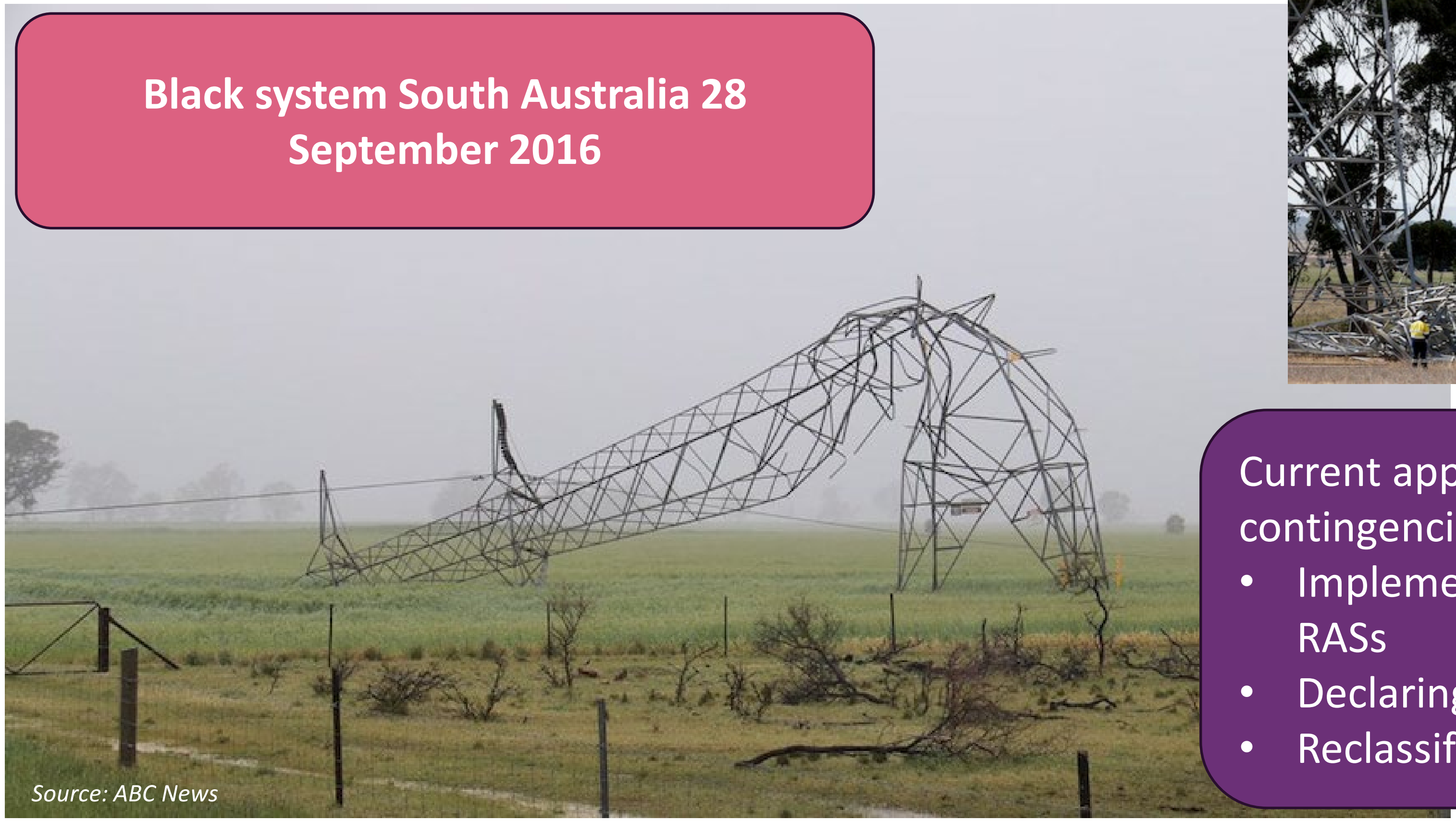
Unsatisfactory
System outside **technical envelope**, potentially triggering *major supply disruption* or *system black.*
Requires actions such as *load shedding, directions or reconfiguring the network.*



Non-credible events


Source: ABC News

Trip of Moorabool – Sydenham 500 kV No. 1 and No. 2 lines on 13 February 2024


Source: ABC News

Black system South Australia 28 September 2016

Current approaches to managing non-credible contingencies:

- Implementing emergency controls such as EFCS or RASs
- Declaring a protected event
- Reclassifying non-credible events.

Reclassifying Contingency Events

Non-credible → credible when abnormal conditions make occurrence reasonably possible

abnormal conditions

↓

reclassify as credible

Added power system risk and reasonably possible occurrence

Abnormal event list

Bushfires	Lightning	Specific plant operation risks	Severe wind
Geomagnetic disturbances	Floods	Widespread pollutants	Landslides
Sudden / unexpected solar generation change	Earthquakes and tsunamis	Large-scale social unrest	Cyber attack

506 reclassifications from 1 Nov 2025 to 30 Apr 2026

Dominant drivers in the period: lightning 1090, severe wind 14, plant-operation specific risk 6, Bushfires 5, geomagnetic disturbance 3.

Reference: Power System Security Guidelines

Response measures

Widespread risks

Apply reasonable and appropriate measures for the risk and circumstances. Common measures AEMO may implement after reclassification to maintain power system security

- Constraining scheduled resources
- Limiting interconnector flows
- Directions
- Additional market ancillary services
- Network reconfiguration
- Recall planned network outages
- Recall planned generation outages
- Maximise reactive reserves
- Activate contingency plans
- Temporary SCADA limits
- DPV curtailment
- Pre/post-contingent load shedding

Reference: Power System Security Guidelines

General Power System Risk Review

01

EMERGING SYSTEM CHANGE

New technologies, retirements and operating conditions

02

TAIL-RISK ASSESSMENT

Scenarios that could cascade or disrupt major supply

03

MITIGATION ACTIONS

Controls, standards, planning and procedures

04

IMPROVED RESILIENCE

Lower likelihood and/or consequence

Annual NER requirement

Complements TPSS, the Engineering Roadmap and established operational processes

Reference: [2026 General Power System Risk Review]

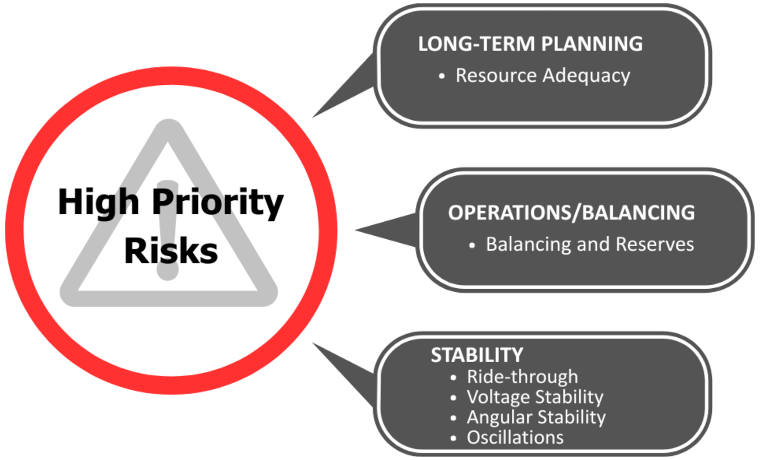
Increasing large-load connections

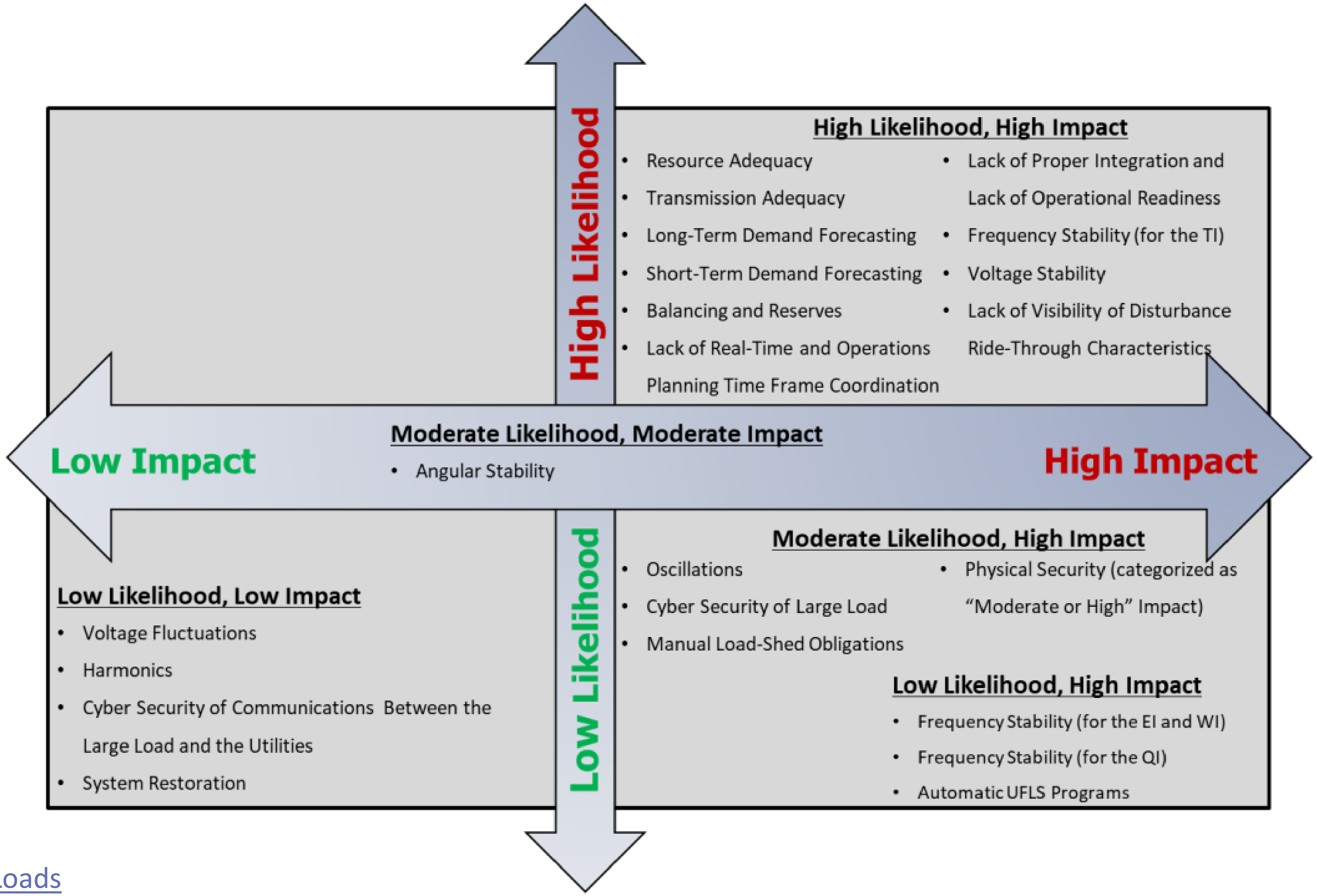
AI Training and Data Centres

Hydrogen Electrolysis Plant

System Challenges

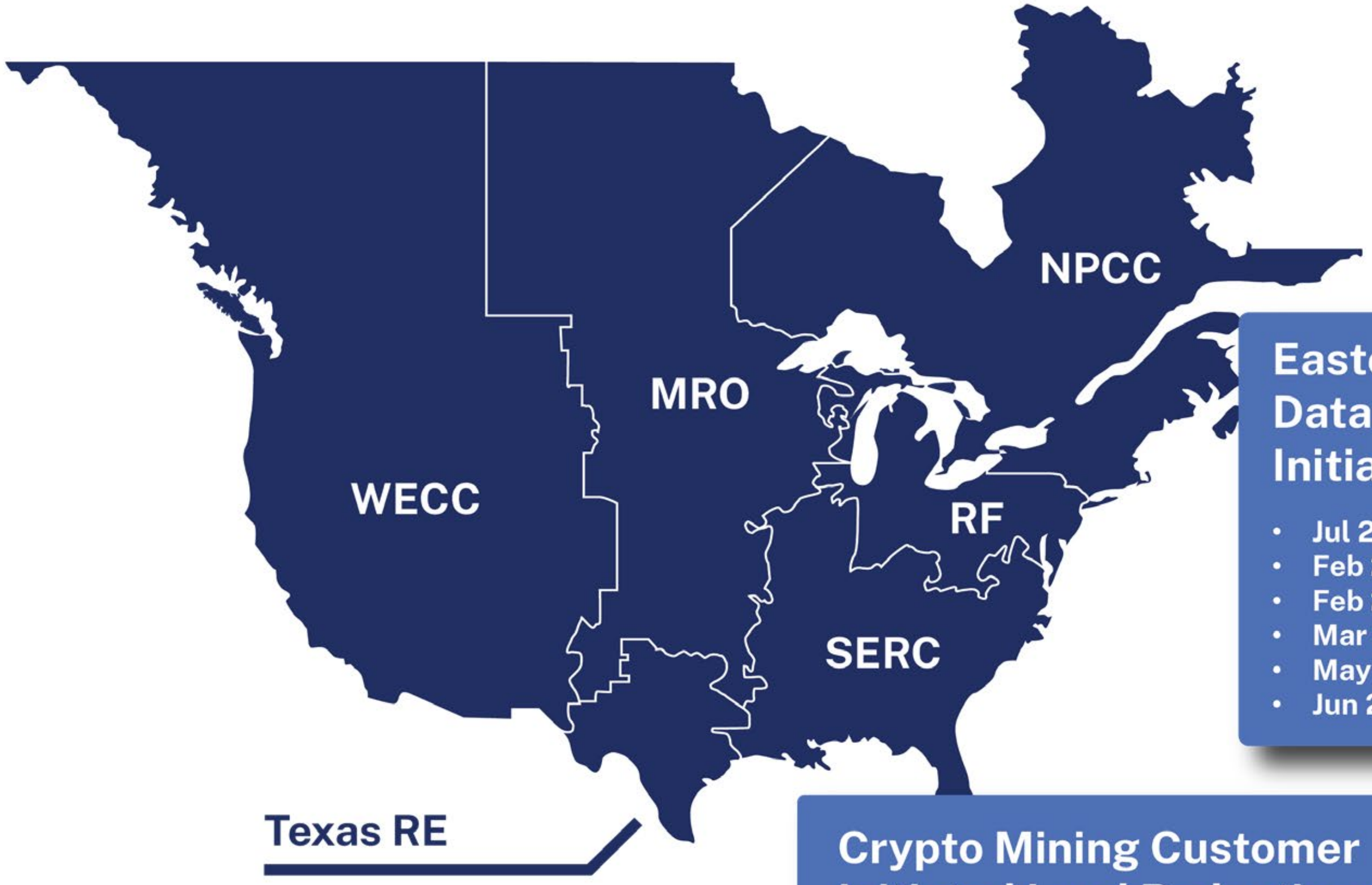
- Scale and speed of developments
- Load reduction disturbances
- Fast demand variations
- Protection and control coordination
- Rapid ramp rates





Reference: [Characteristics and Risks of Emerging Large Loads]

Large-load disturbances



Eastern Interconnection Data Center Customer Initiated Load Reductions

- **Jul 2024:** 1,500 MW
- **Feb 2025:** 1,800 MW
- **Feb 2025:** 428 MW
- **Mar 2025:** 227 MW
- **May 2025:** 540 MW
- **Jun 2025:** 1,300 MW

Crypto Mining Customer Initiated Load Reductions

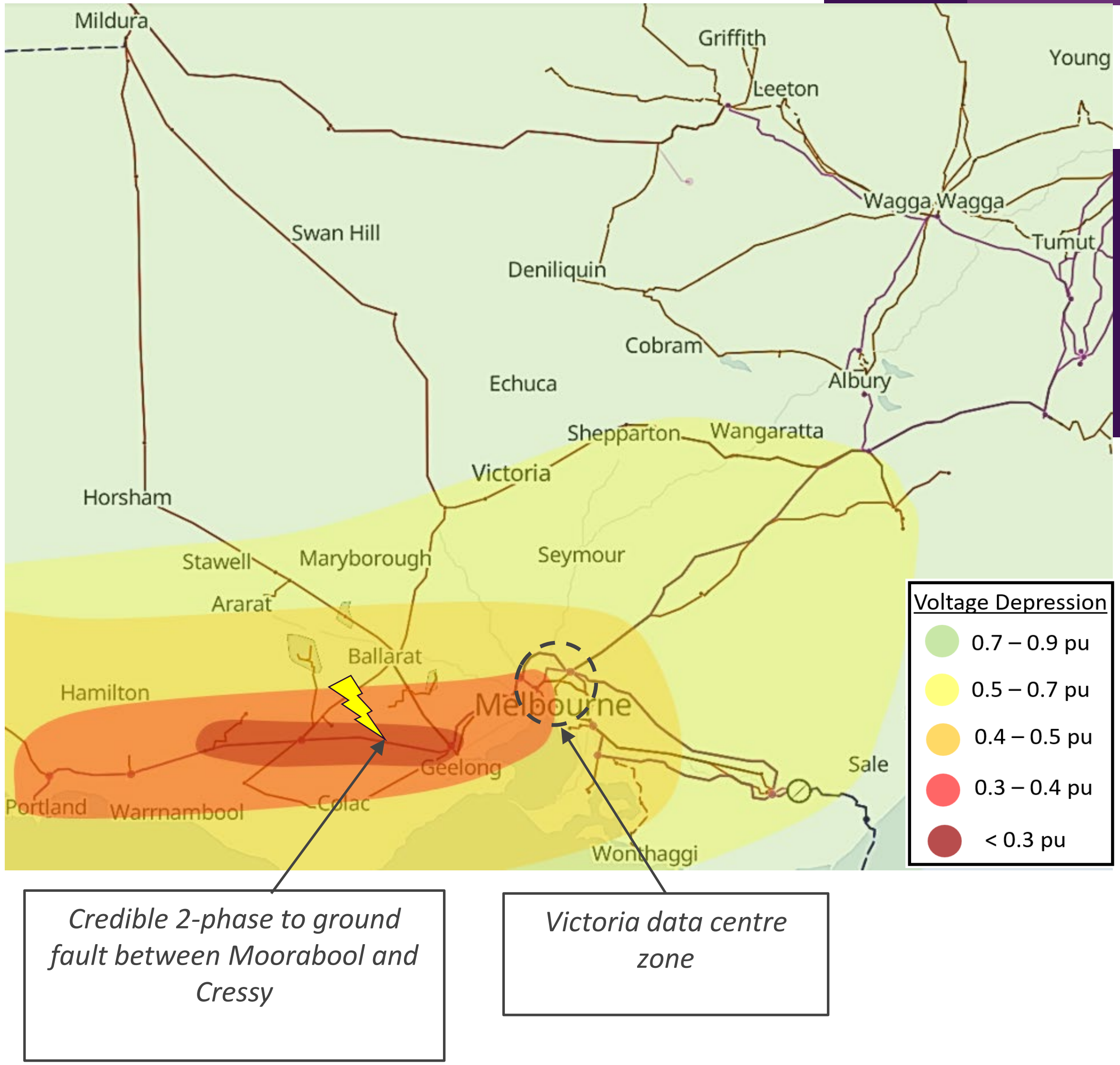
- **Jan 2023 - Apr 2026:**
  - 28 Loss Events (100-450 MW Load Loss)

Reference: Large Load Disturbance Performance

Increase in (load) contingency size

As per current ITIC standards, if the voltage drops below 0.7 pu for 20 ms, the data centre will trip.

- A single credible fault can **propagate** below 0.5 pu into the Melbourne data-centre zone.
- Without access standards, we could see credible load contingency sizes increasing significantly.
- The resilience issue is aggregate coincident response—not only individual site size.

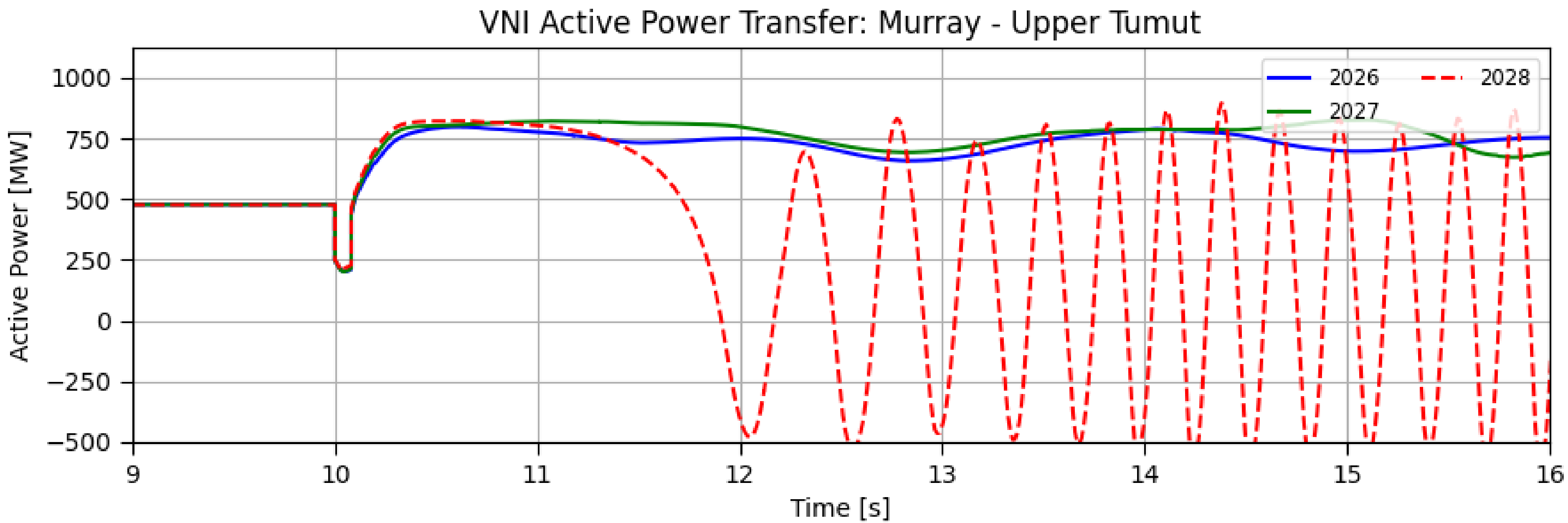


Reference: [2026 General Power System Risk Review]

ITIC: Information Technology Industry Council

Disconnection of IBLs can exceed network limits

Results for a credible fault and load continency in Victoria

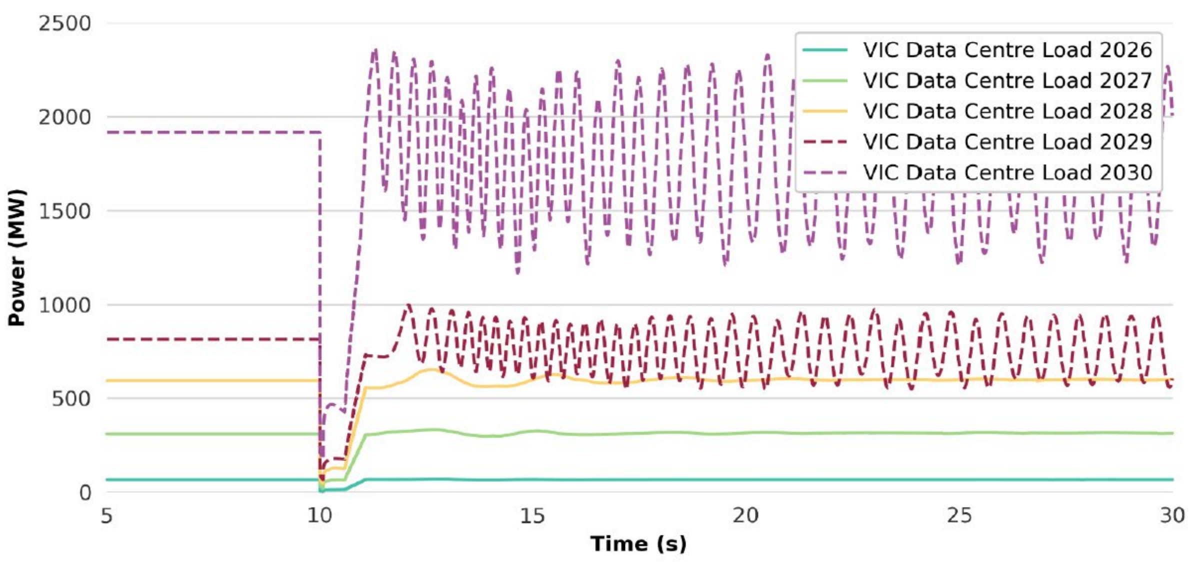


Without appropriate FRT performance, voltage collapse can occur due to sympathetic disconnection of IBLs

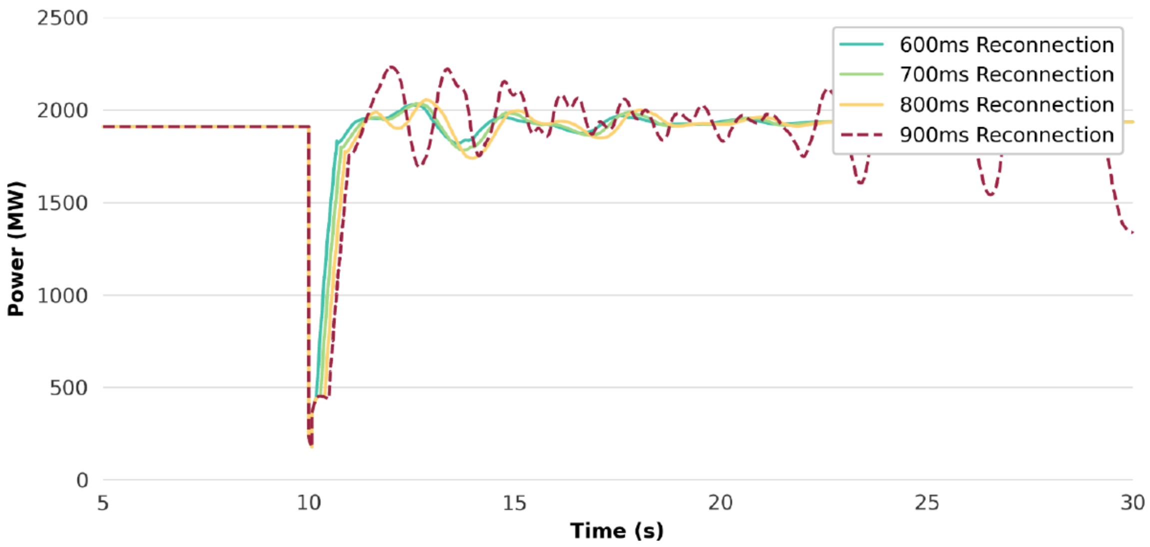
Reference: Improving the NEM access standards – Package 2

Active power recovery delays

Increasing data centre connections given a fixed active power recovery time (1s)



Increasing active power recovery time with a fixed size of data centre connections



Even with data centre voltage ride-through, speed of reconnection is important!

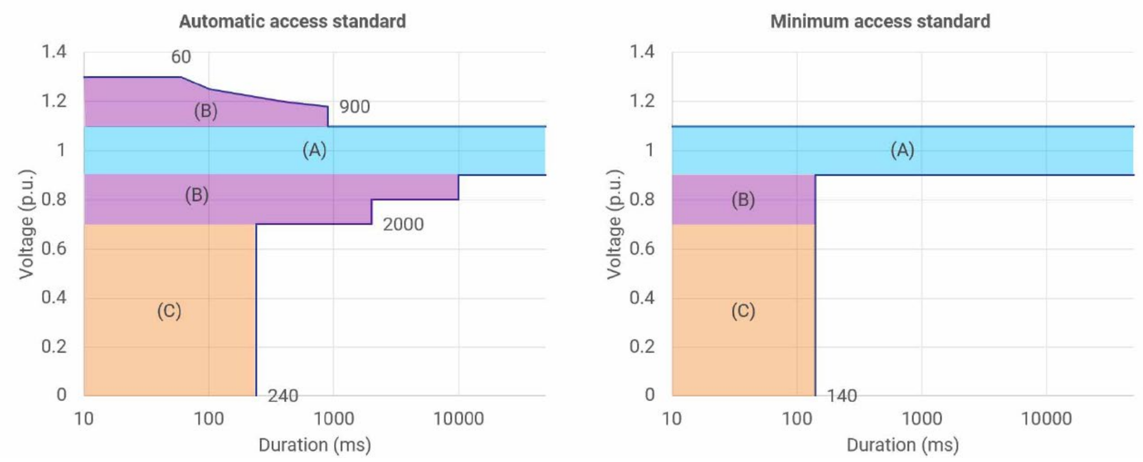
Reference: [2026 General Power System Risk Review]

Successful integration of IBLs requires continued resilience-oriented assessments

NOW

Access standards

- Fault ride-through requirements
- Active-power recovery performance



Reference: [Improving the NEM access standards – Package 2]

NEXT

Remaining operational gaps

- Rapid ramp rates
- Visibility and remote monitoring provision
- Enhancement of oscillation monitoring and detection
- Registration requirements for backup generation
- Short term forecasting
- Instructions/directions for system security or reliability
- Modelling capability

Summary

Resilience requires a portfolio of actions

- **Plan for resilience, not reliability alone:** prepare for high-impact, low-probability events by anticipating, absorbing, adapting and recovering.
- **Mitigate risks associated with increasing connection of inverter-based loads:** strengthen access standards and assess aggregate ride-through, recovery, ramping and monitoring risks, with continues monitoring of residual and emerging risks.

Enhanced Grid Resilience Towards Net Zero

Presentation at the Melbourne Energy Institute webinar

Dean Sharafi

19/08/2026

Why are we taking an interest in power system resiliency?

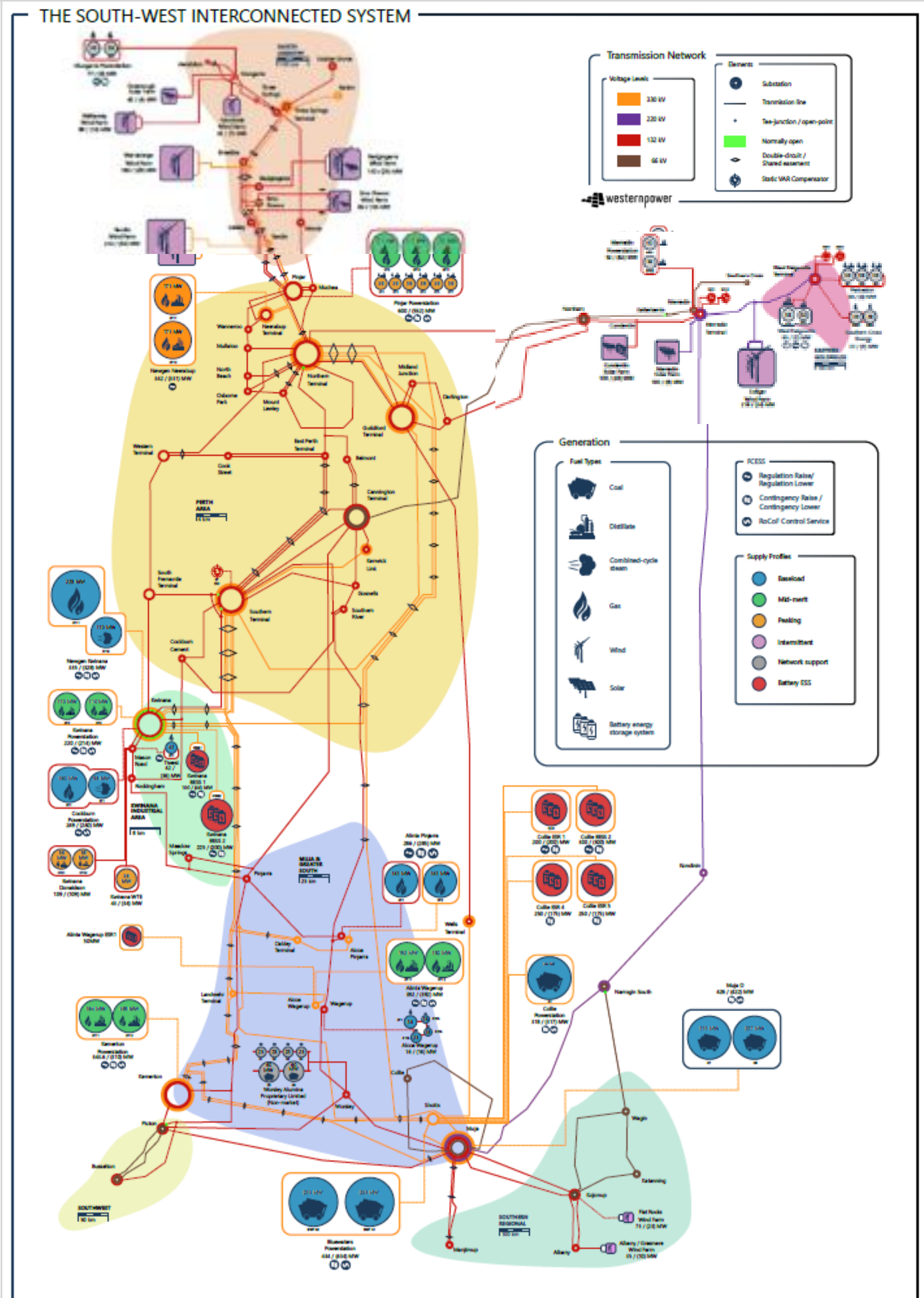
What are characteristics of a resilient grid?

- A resilient electricity grid is one that can anticipate, withstand, adapt to, and rapidly recover from high-impact, low-probability events (extreme weather, major outages, cyber or physical attacks), while continuing to supply essential services.

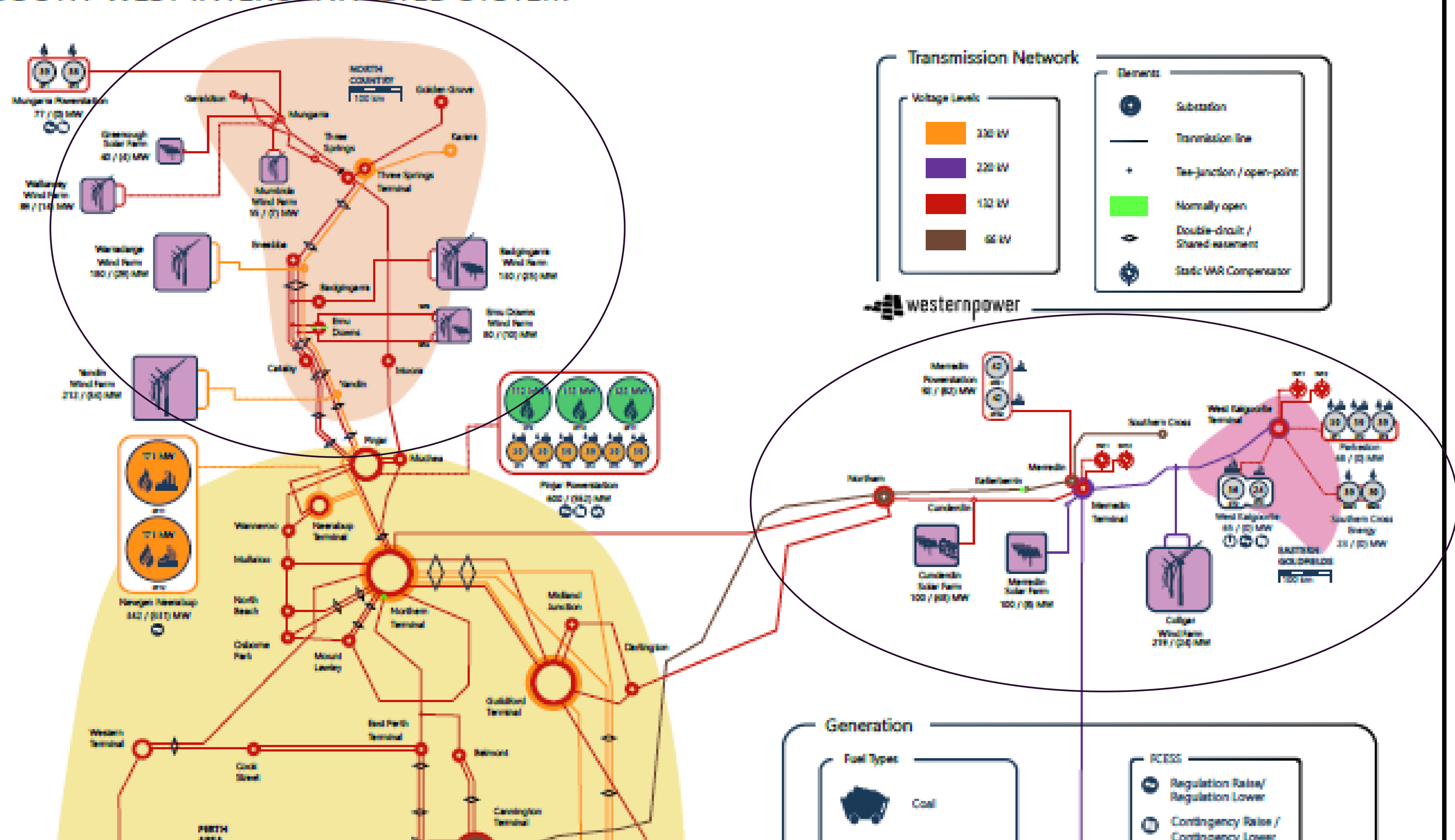
The South-West Interconnected System (SWIS)

Overview of SWIS Generation Mix

Gas-fired power: ~3.4–3.6 GW (spanning combined-cycle plants, open-cycle peaking units, and mid-merit turbines)
Black coal: ~1.2 GW (scheduled for full retirement by Synergy by 2030)
Wind & Large-scale Solar: ~1.3 GW combined utility-scale capacity
Rooftop Solar (Distributed): ~3 GW of cumulative capacity
Grid-scale Batteries: Over 1.3 GW of fast-response storage capacity



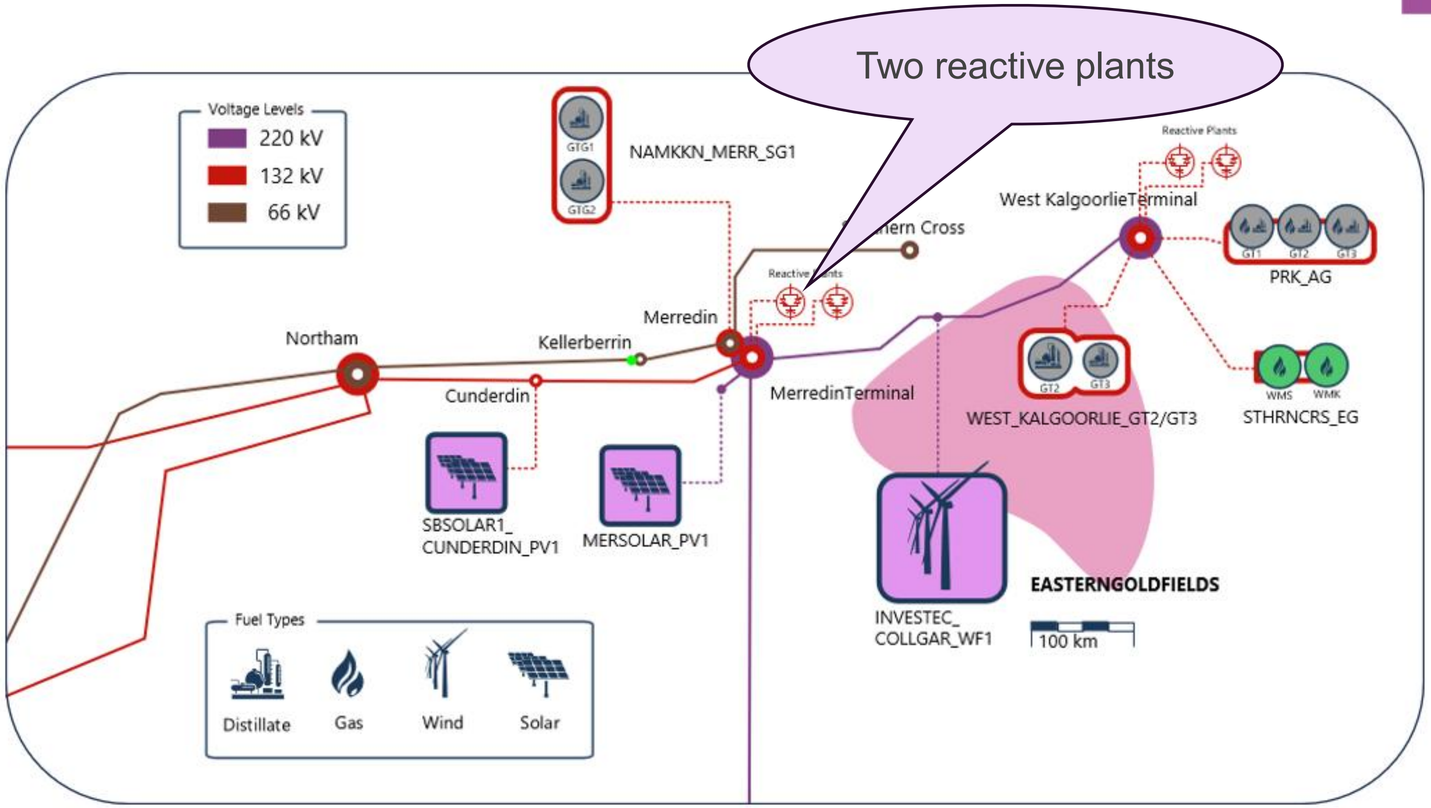
SOUTH-WEST INTERCONNECTED SYSTEM



Sub-Synchronous Oscillation

East Country network topology

- IBR penetration is relatively high in the region
- Two reactive plants are critical for regulating voltage



Sub-synchronous oscillation (SSO)

- Sub-synchronous oscillation (SSO) incident on 23 August 2024, in the East Country (EC) / Eastern Goldfields (EGF) areas where an undamped oscillatory behaviour (without any fault in the system) was identified by a protection relay at Merredin Terminal.
- This resulted in a disconnection of the 220-KV line, which left the EGF area with no power.

East Country Oscillations on 23 August 2024

Multiple voltage oscillations in EC on 23-08-2024

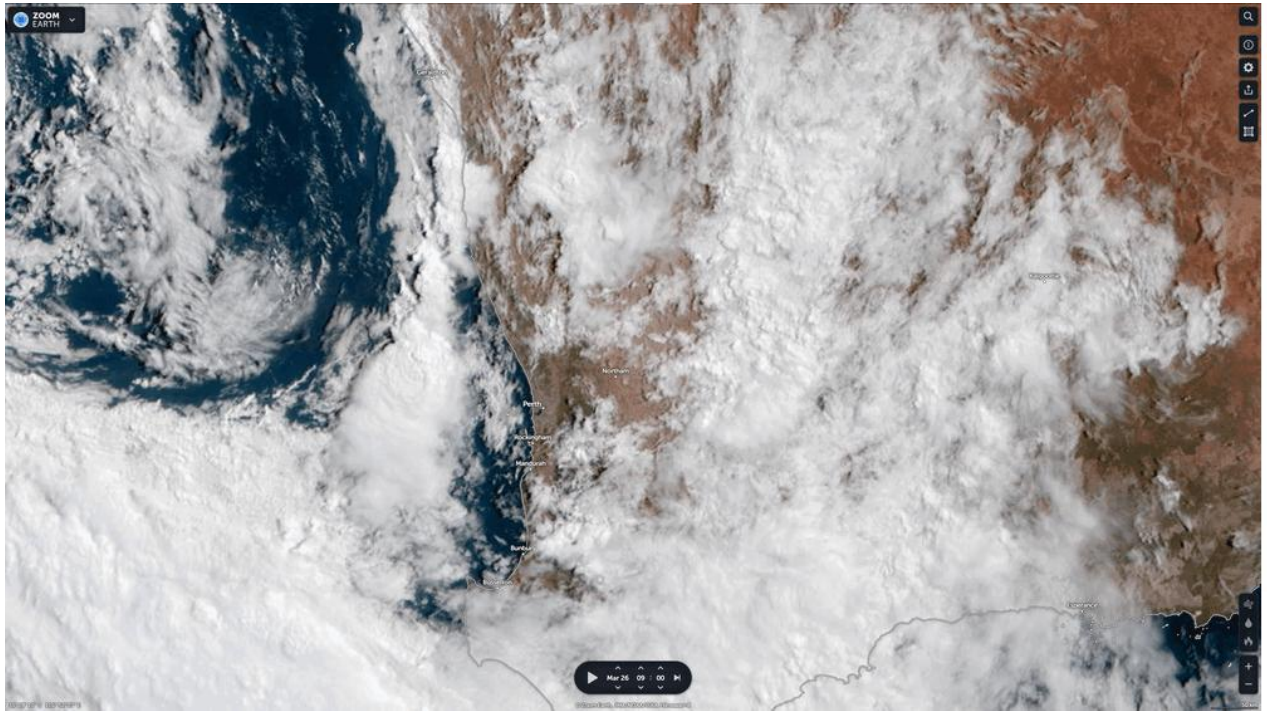
Limitations

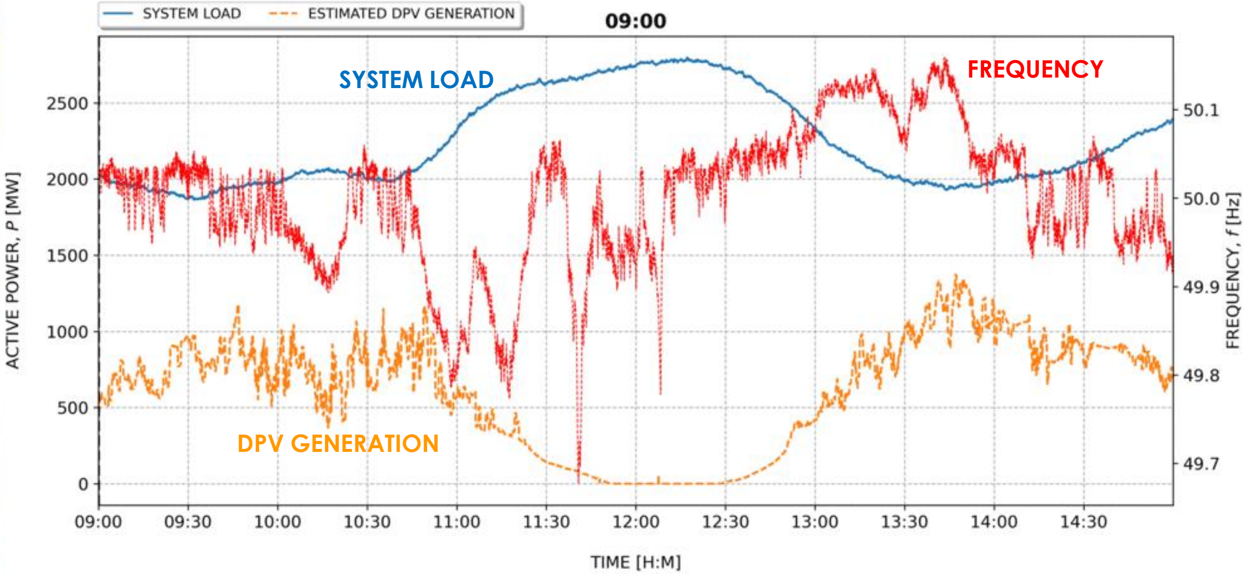
- Visibility gaps in oscillation detection and event awareness
  - No PMU data, no real-time visibility / operational decision-making
  - PMU coverage plays a key role in post-event analysis identifying source of oscillation in investigations.
- Modelling gaps - Lack of reliable EMT models from OEM
  - There is a regulatory limitation in EMT modelling of legacy generators.
  - Unable to replicate similar events in PSCAD modelling pose challenges to investigations.

Ramping Event

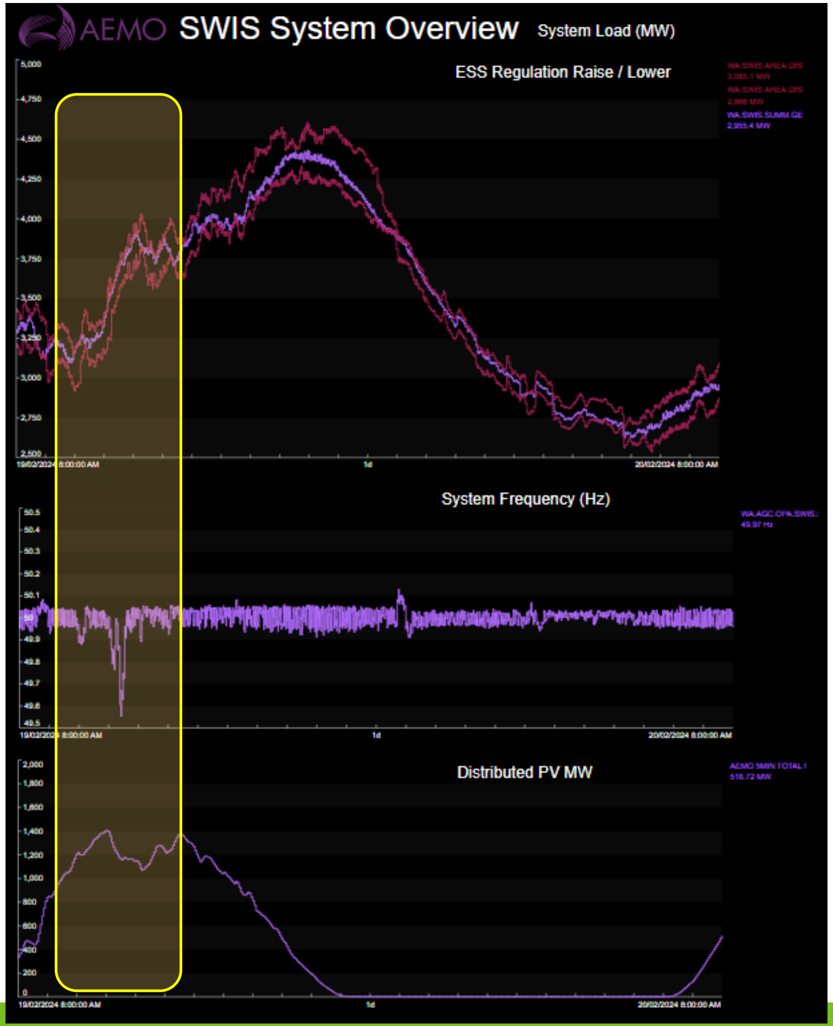
Ramping

Rapid real-time up and down movement in load due to uncontrollable and largely unpredictable weather events, such as cloud movement can result in large system load swing.

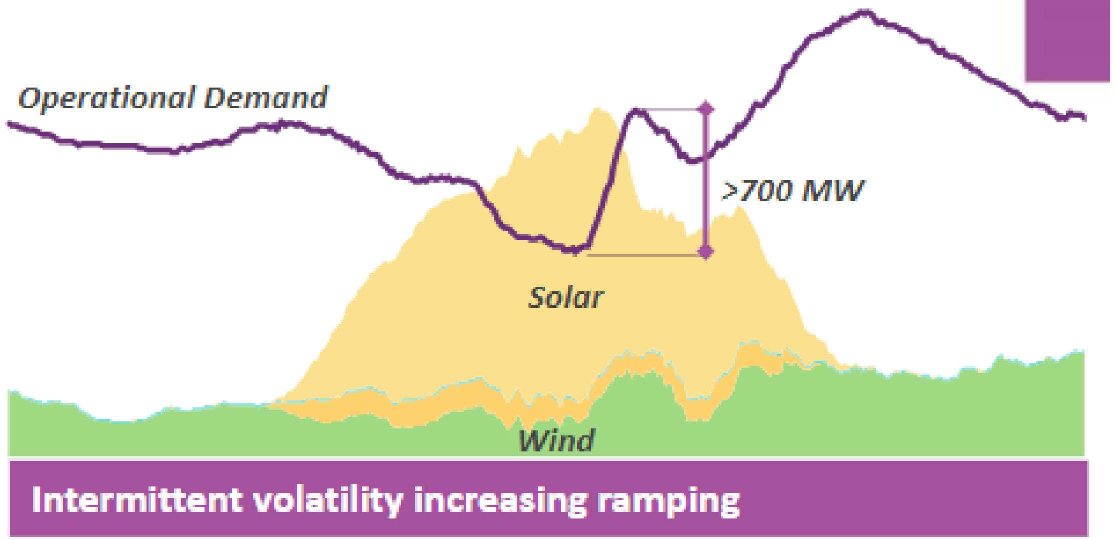




- **Ramping**
- **Or weather contingency?**



- Reduction in DER output due to cloud cover

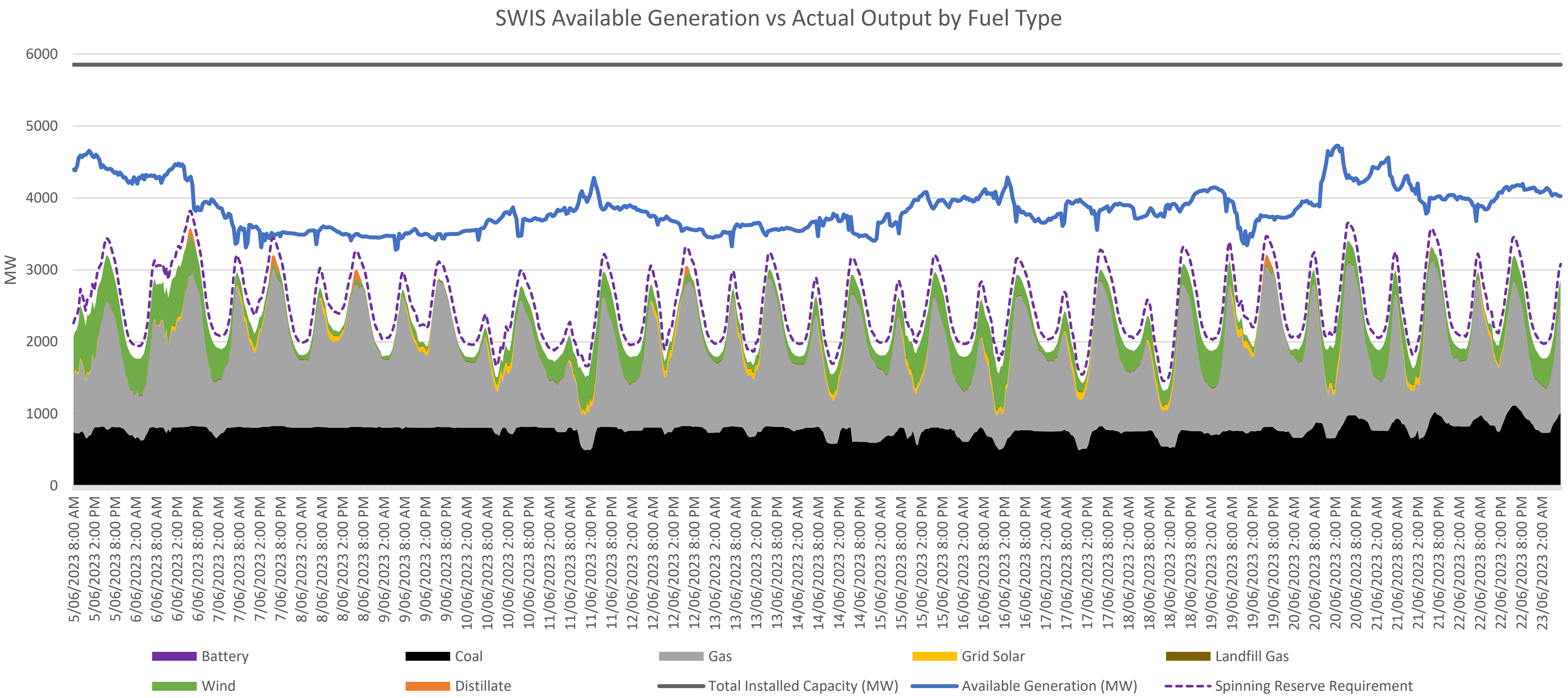


Renewable Drought

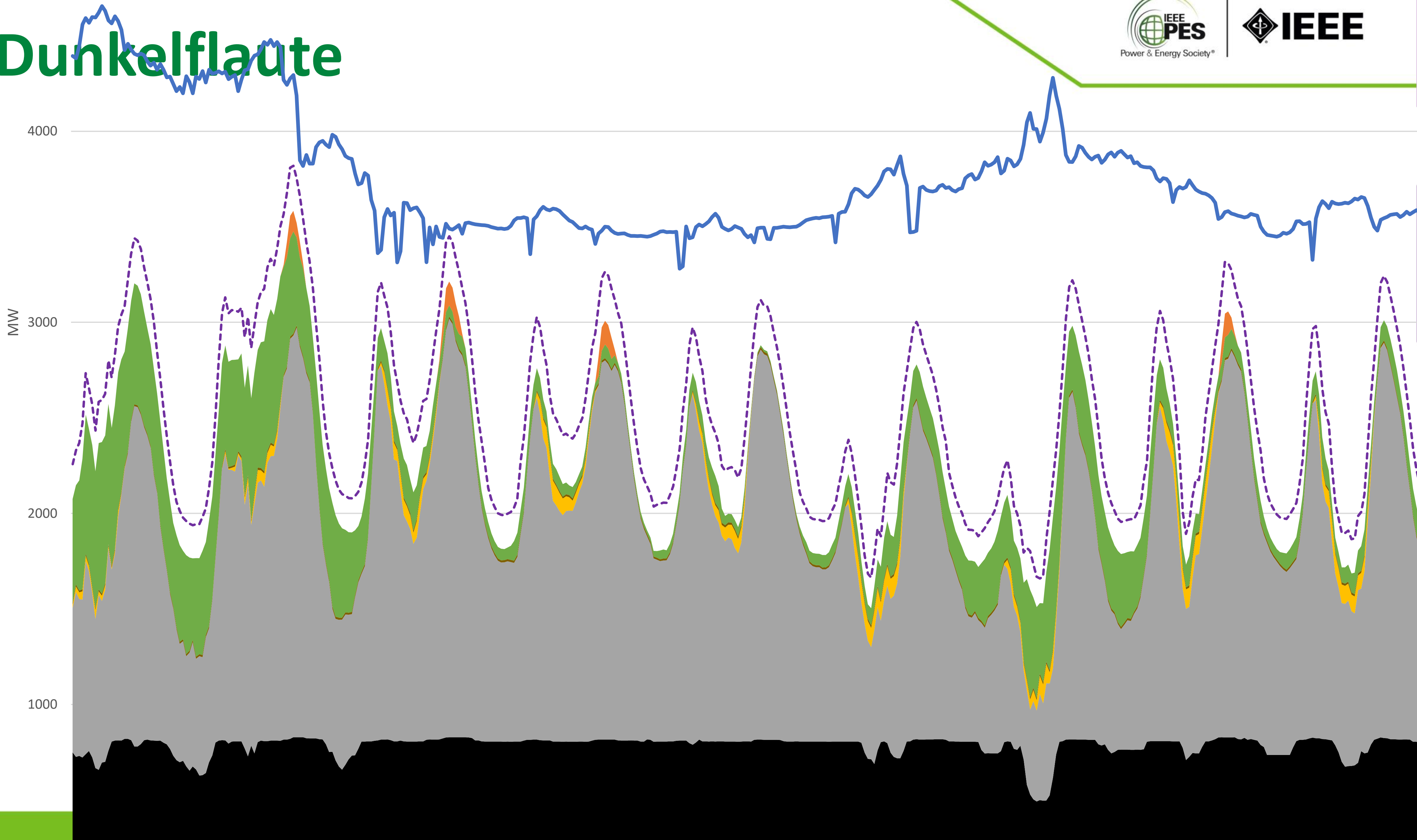
Dunkelflaute

- A prolonged, correlated weather-driven loss of wind and solar
- Key attributes:
  - Weather-driven, multi-day
  - Correlated across fleets
  - Often coincides with high demand (winter conditions)
  - Not a single contingency — a sustained system stress
- Root cause: resilience gap (insufficient depth/duration of firm supply)
- Outcome: reliability metric breach (USE, load shedding)

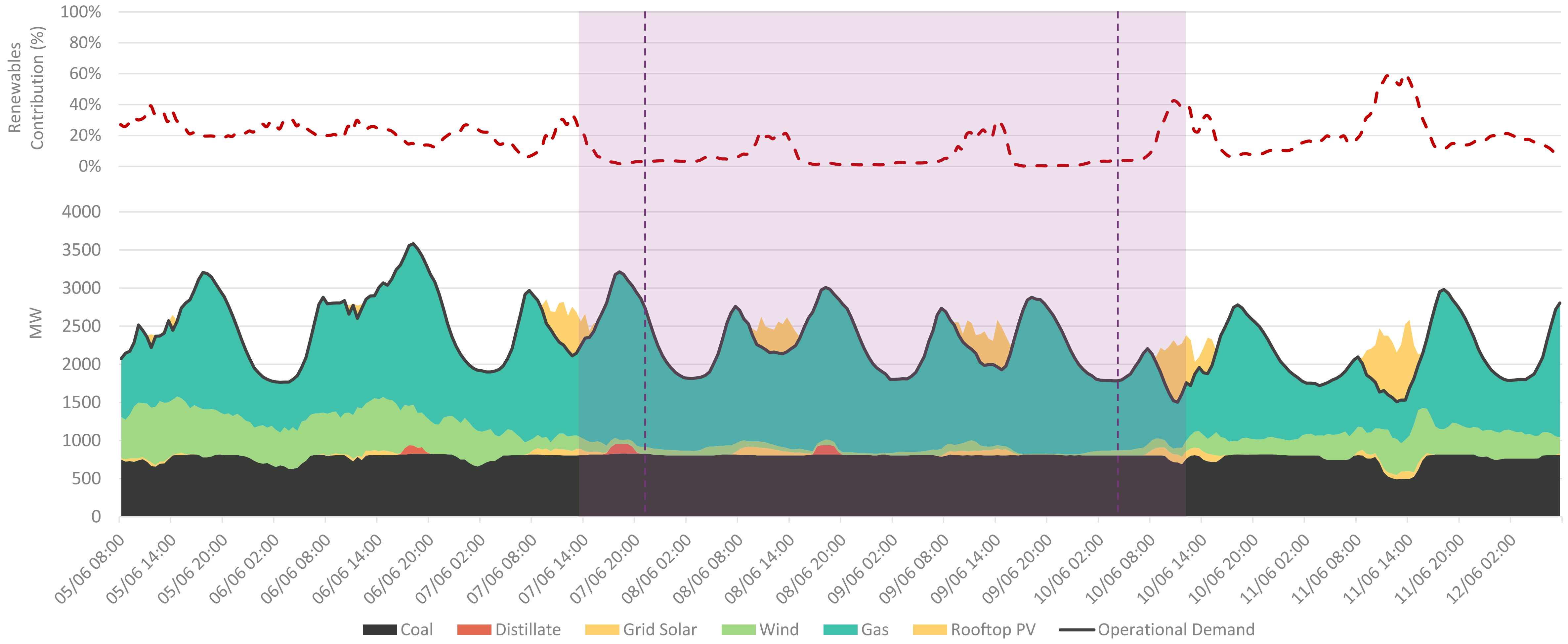
• Dunkelflaute



- **Dunkelflaute**



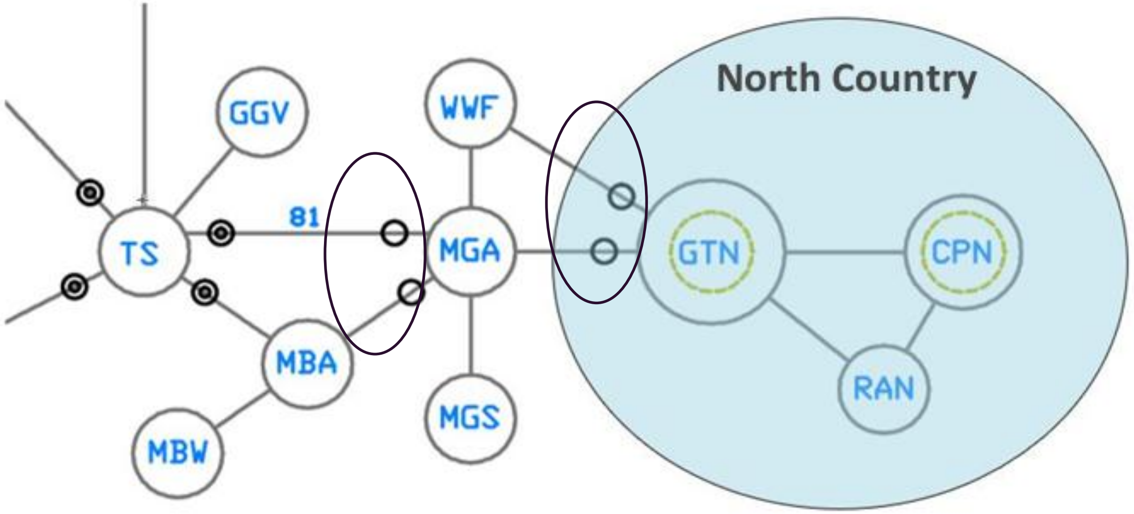
• Dunkelflaute



Cyclones and Bushfires

- In April 2021, a tropical cyclone caused widespread damage to transmission lines in North Country. As a result, the region was without power to all customers for a period of 3 days.
- In December 2025, a summer storm and bush fire event caused a separation event of the North Country.
- North Country was re-synchronised back to the SWIS after 5 days and 18 hours.

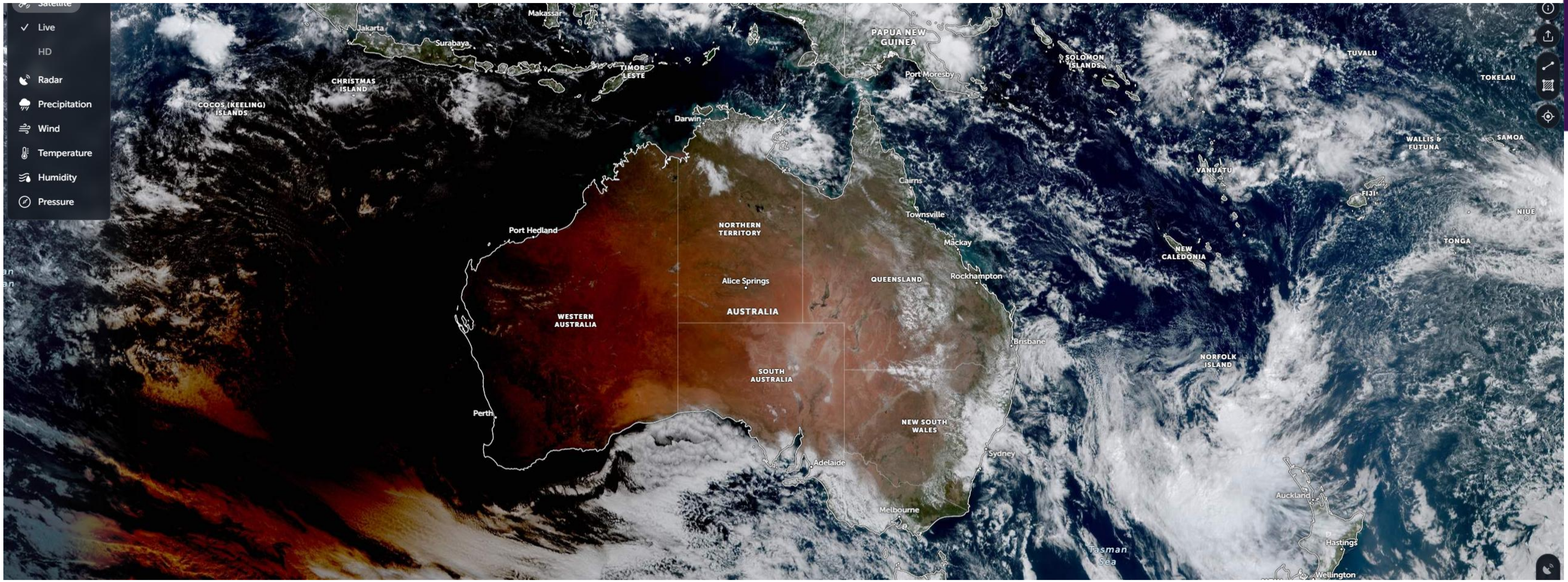
North Country



Resilience in Design

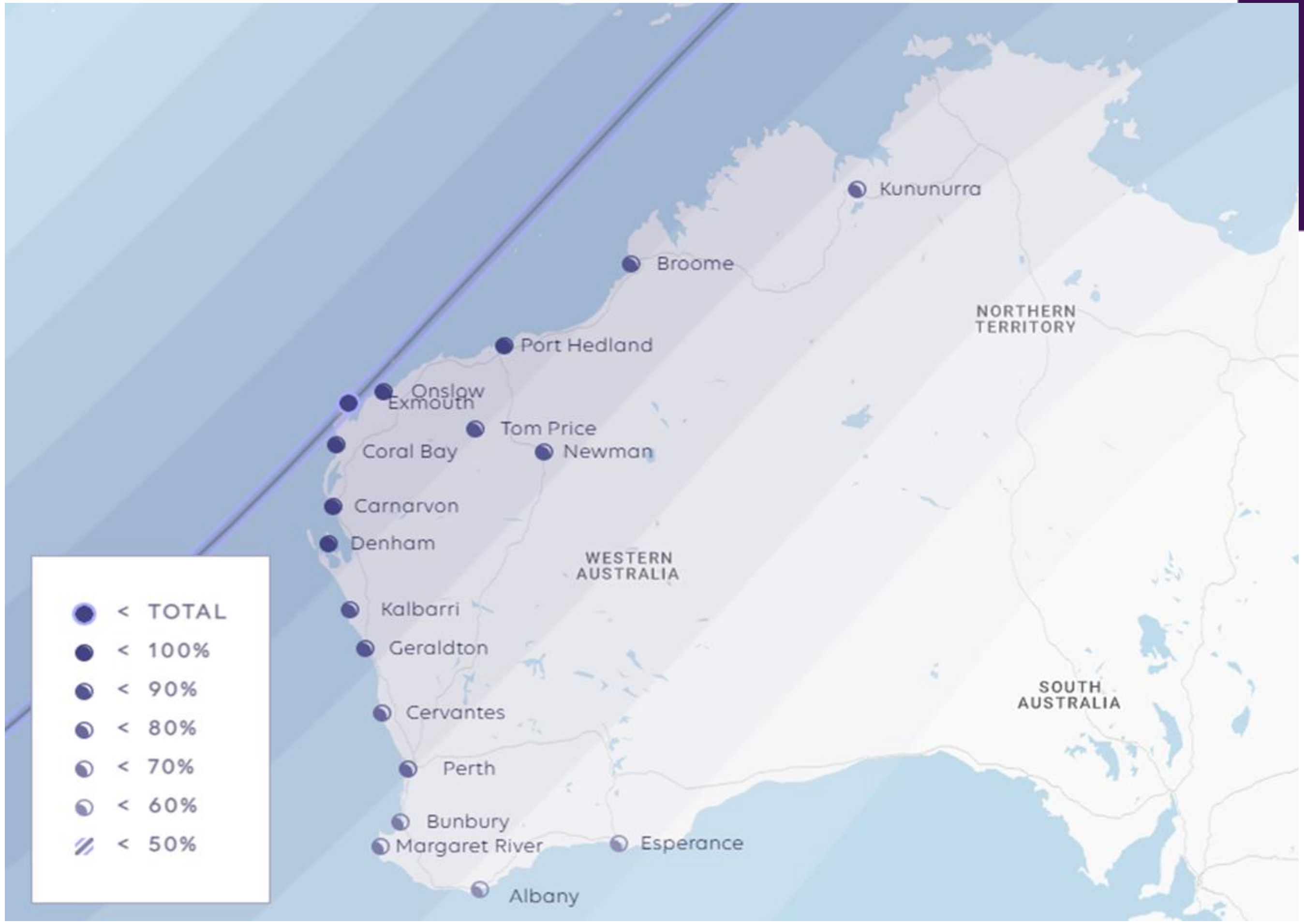
Storms damage transmission towers and cut supply to Goldfields customers in Jan 2024

Eclipse Overview, WA 20 April 2023

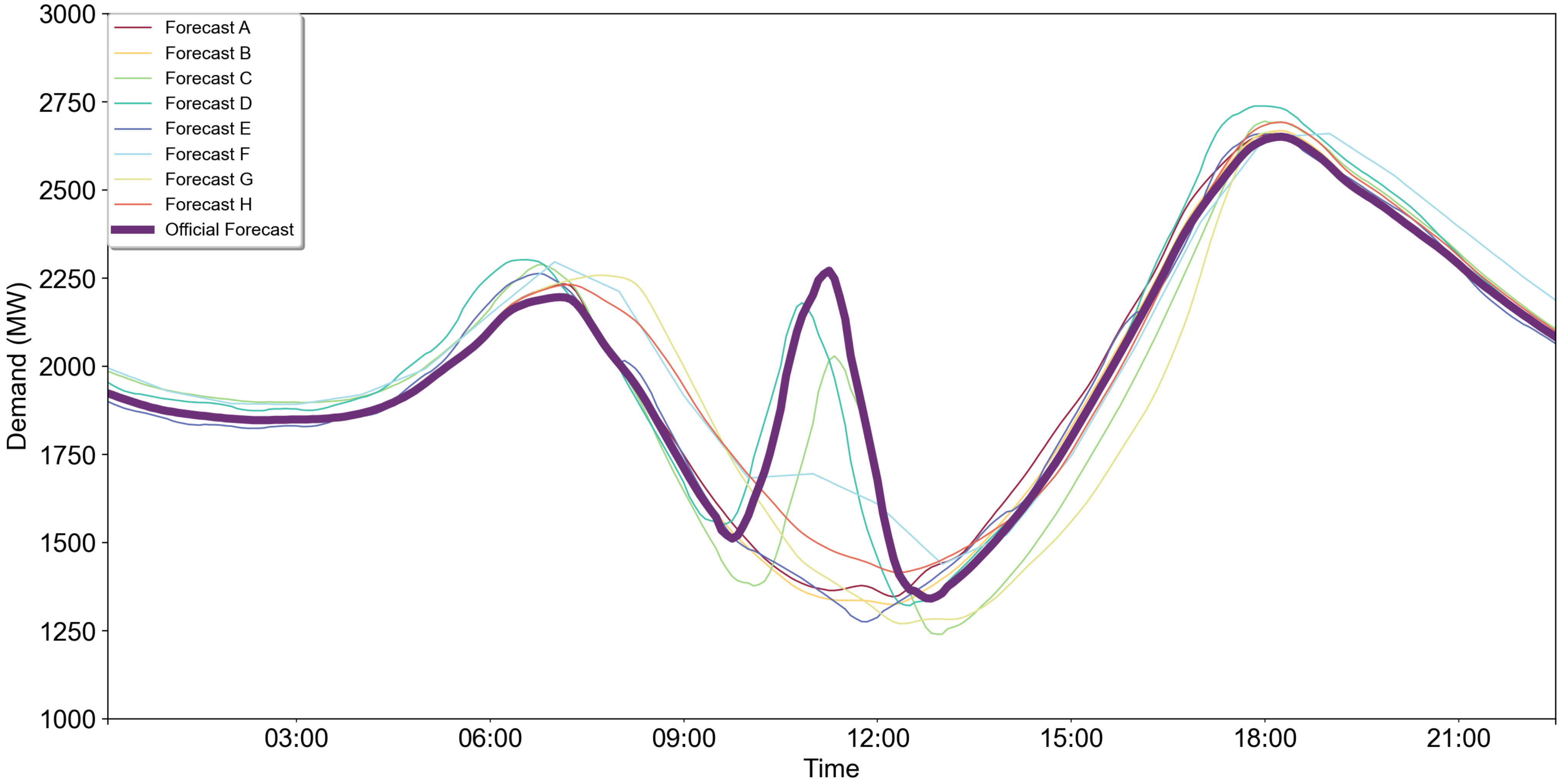


• Eclipse - Planning

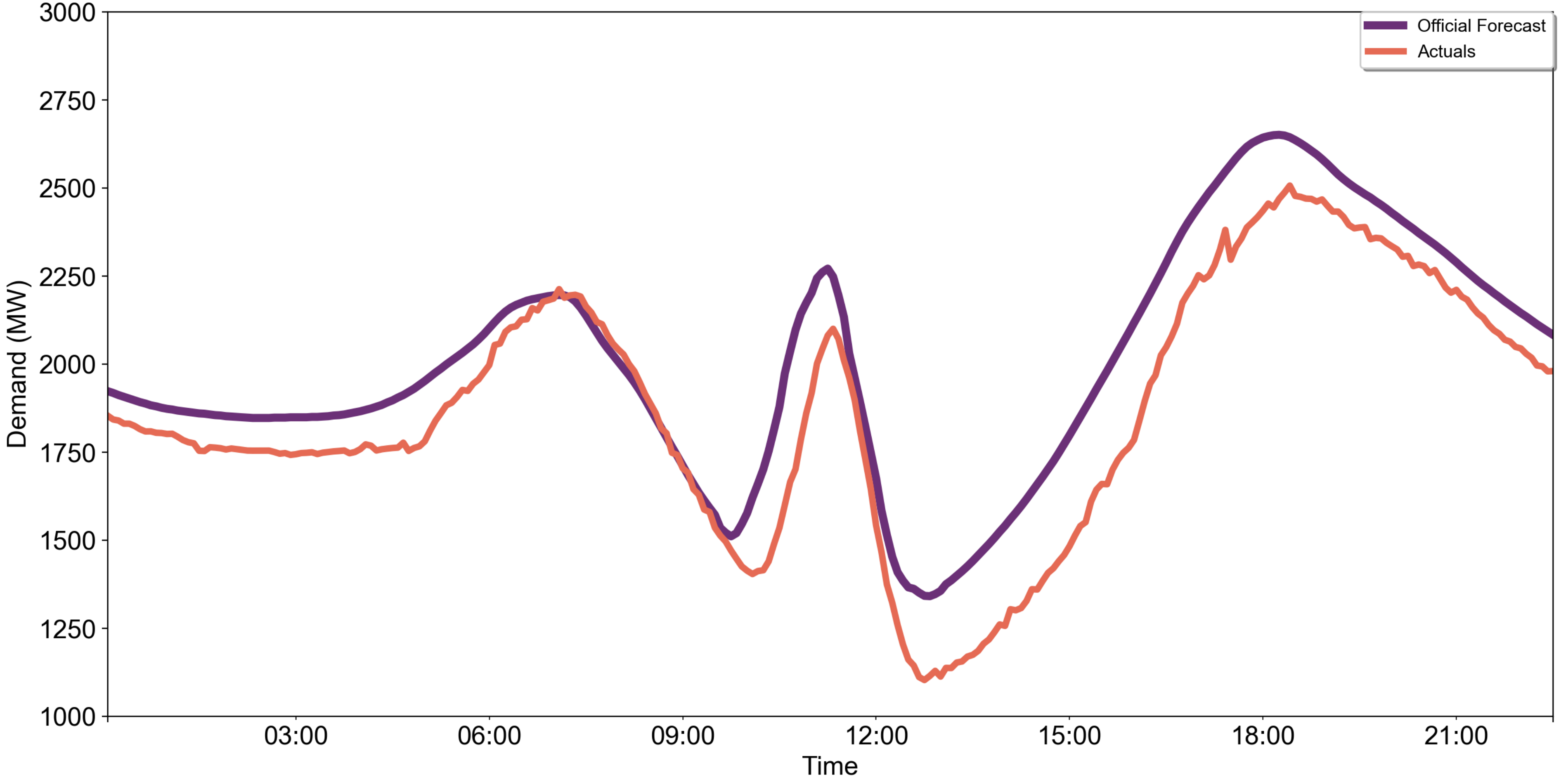
- Modeled the eclipse to simulate the impact on DER and consequently on demand.
- The SWIS was expected to experience on average 70% of the eclipse impact.



- **Eclipse forecast**
- **5:00 pm the day before**



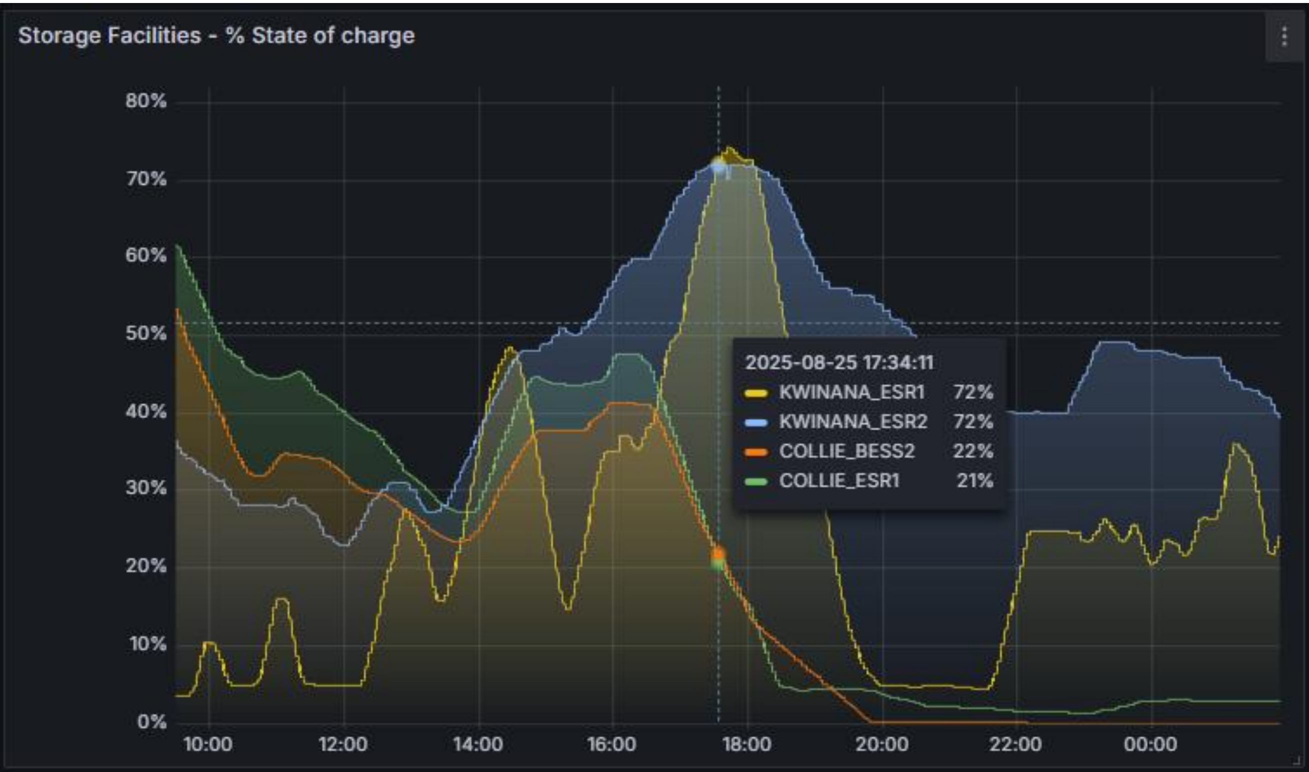
- **Eclipse actual vs forecast**
- **After the event**

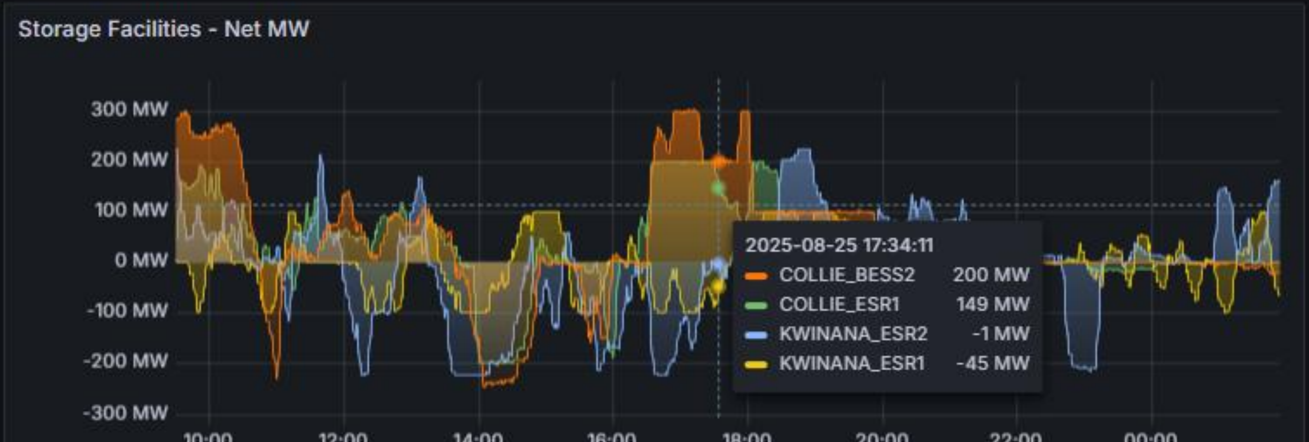


Resiliency and BESS

25 August 2025

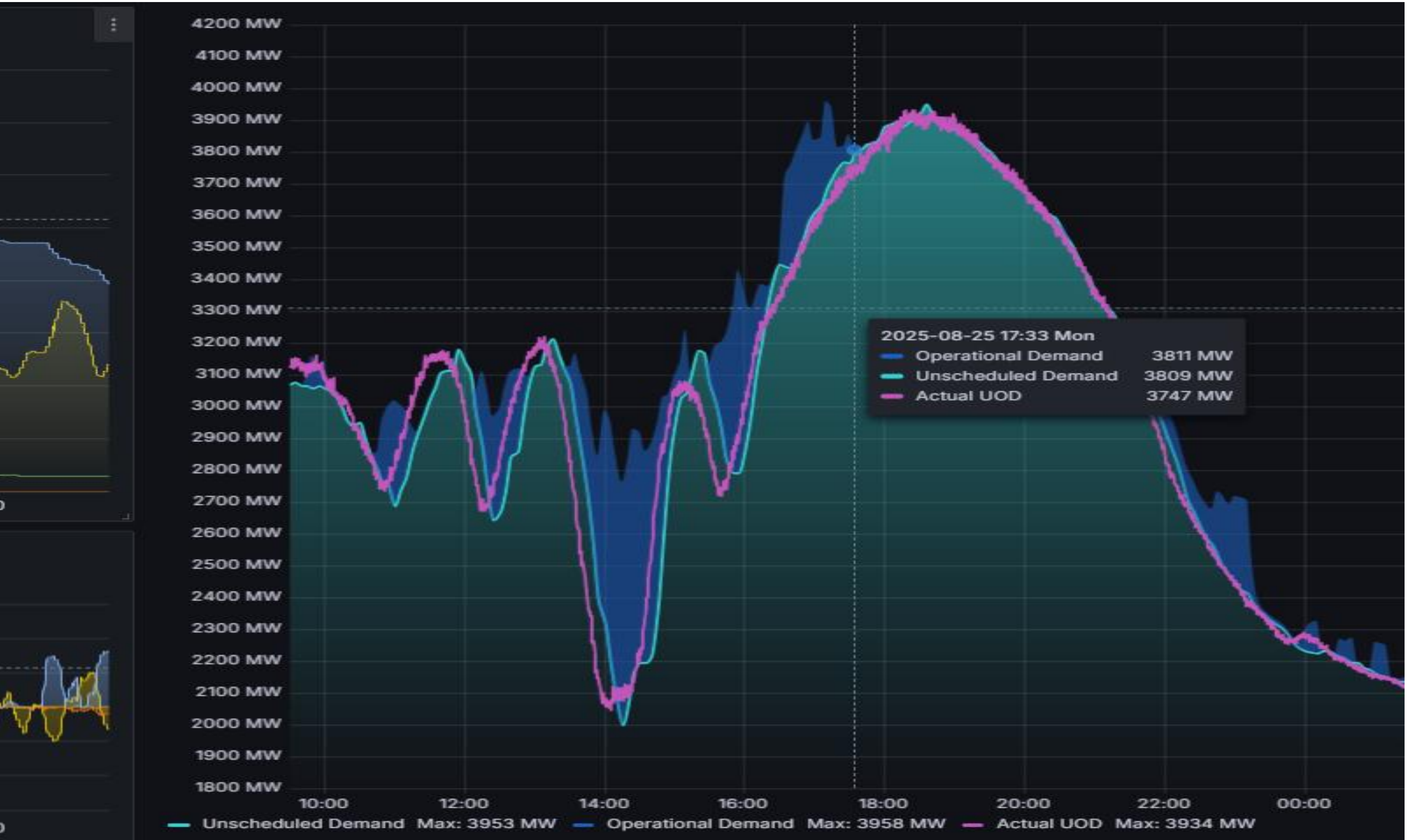
25 August 2025





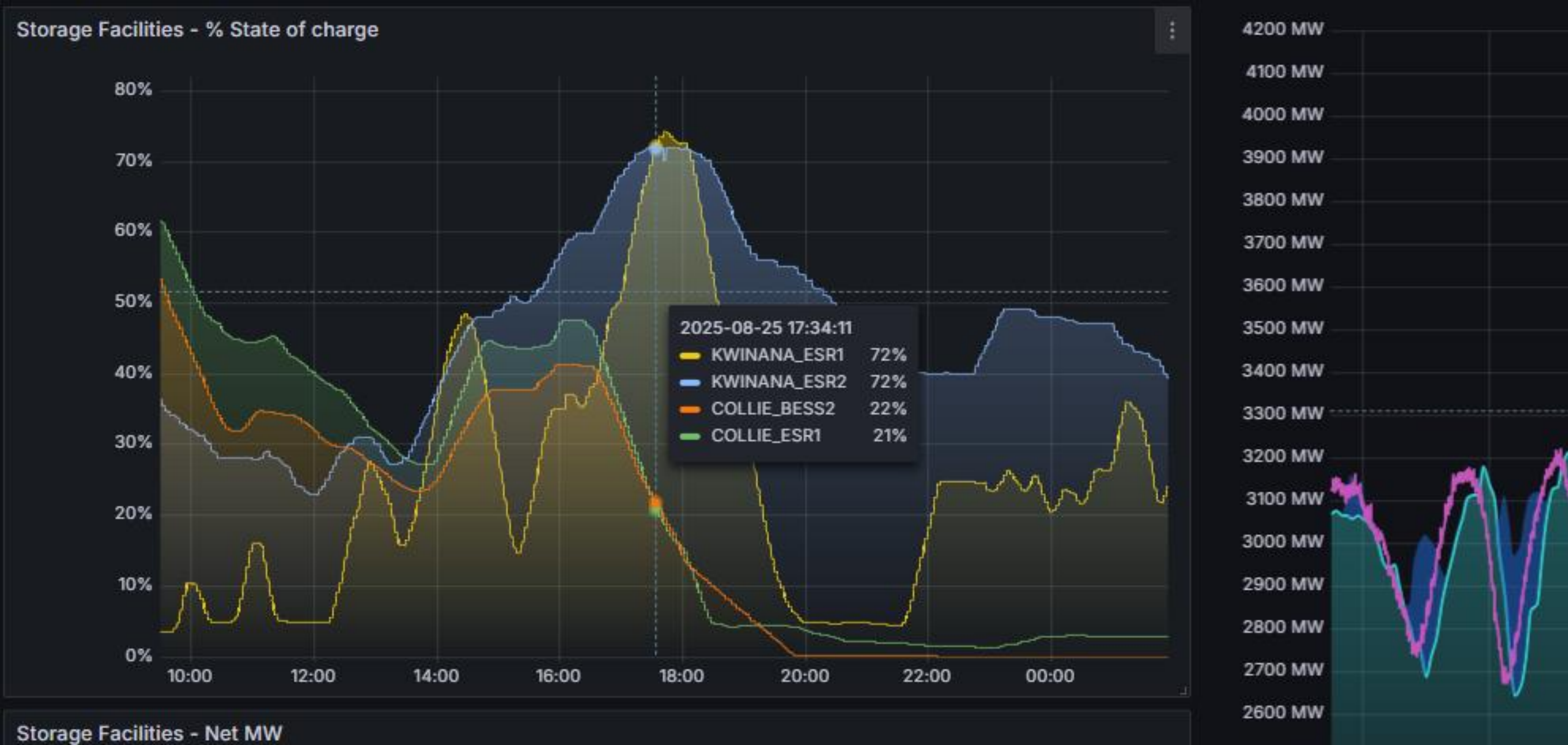
25 August 2025

25 August 2025



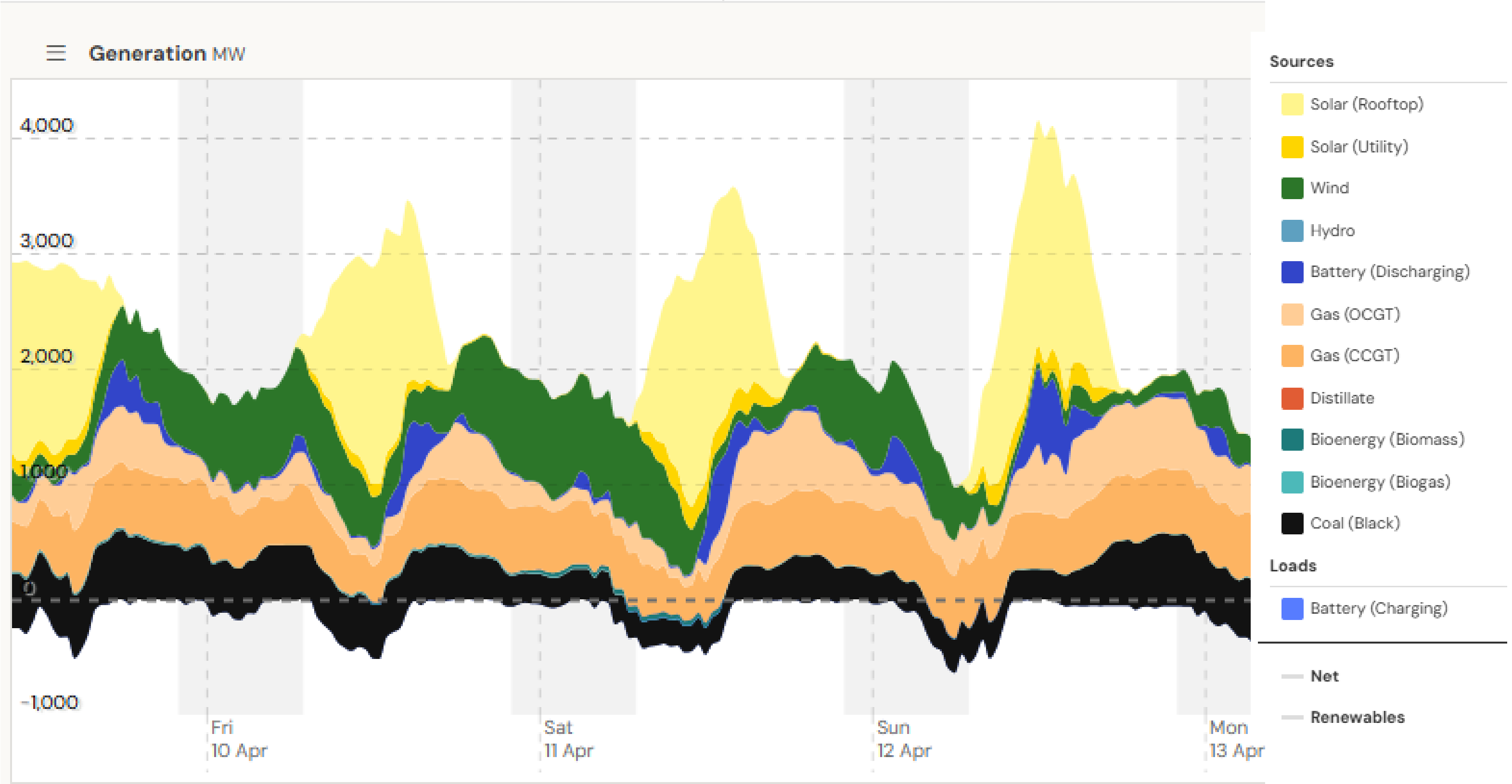
25 August 2025

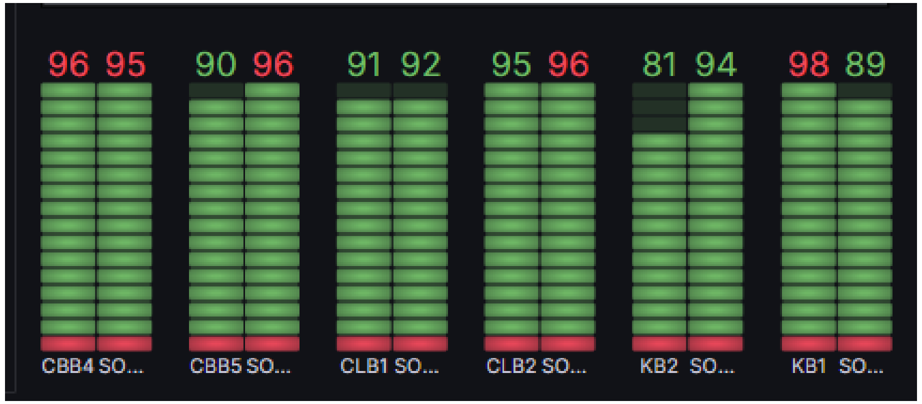
25 August 2025



25 August 2025

Resilience and Flexibility





Resilience as an outcome

Planning for Resilience

- Reliability incidents increasingly reflect weather related exposure rather than equipment failures.
- Reliability metrics alone are insufficient to characterise system robustness under extreme conditions.
- Resilience failures are economically and socially disproportionate to their frequency. As a result, systems that appear reliable on average may still be poorly prepared for high-impact events.
- Flexibility is the bridge between reliability and resilience.
- Resilience starts with planning.
- It involves a different design approach based on performance objectives.

Q & A

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