System Security Planning in Australia's Energy Transition

Mohammad Mohammadi
Future Energy Systems (FES) Group
Mohammad.Mohammadi@aemo.com.au

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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

AEMO and NEM

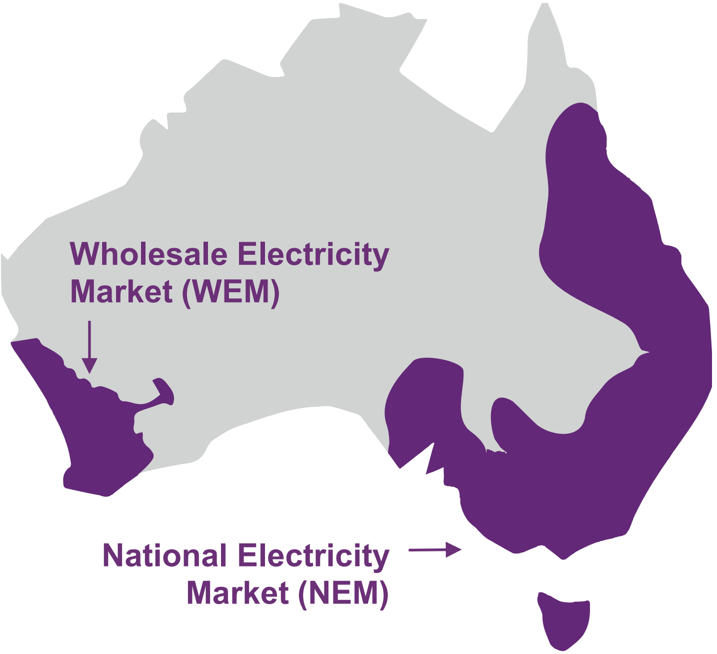
About AEMO

- 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.

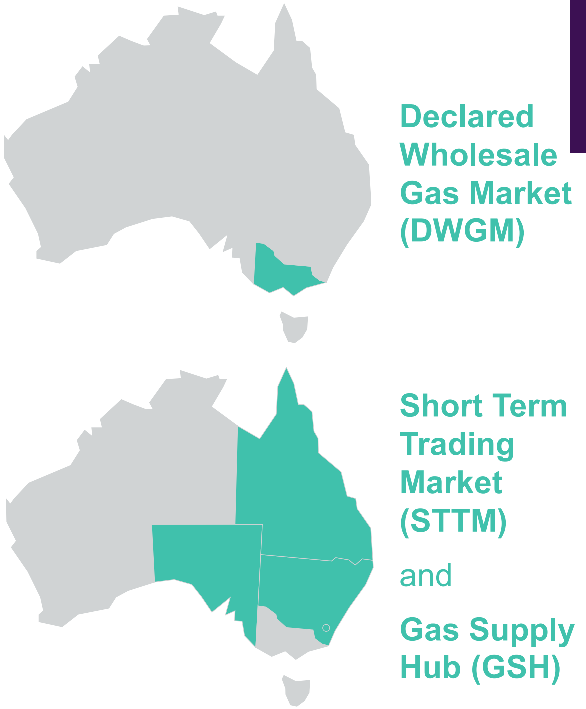
AEMO SERVICES

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

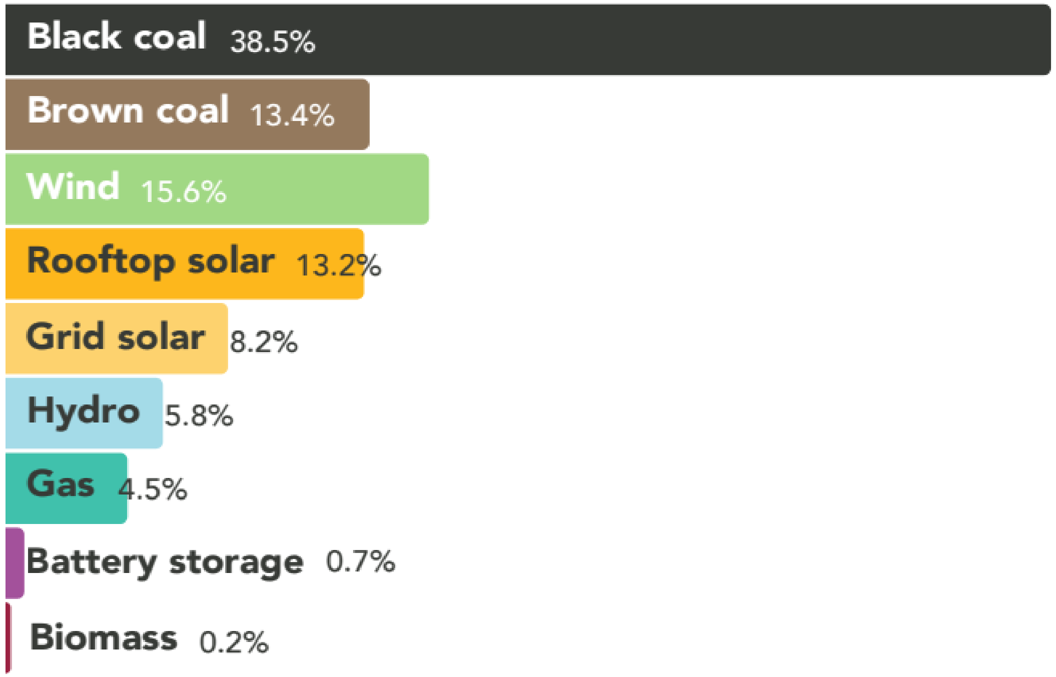


National Electricity Market (NEM)

- About **11 million** customers
- **650** registered market participants
- **100 GW** of total generation capacity
- **40,000 km** transmission lines
- **$25 billion** traded in FY25
- **200 TWh** supplied each year

Generation supply mix

By fuel type in 2025



NEM records

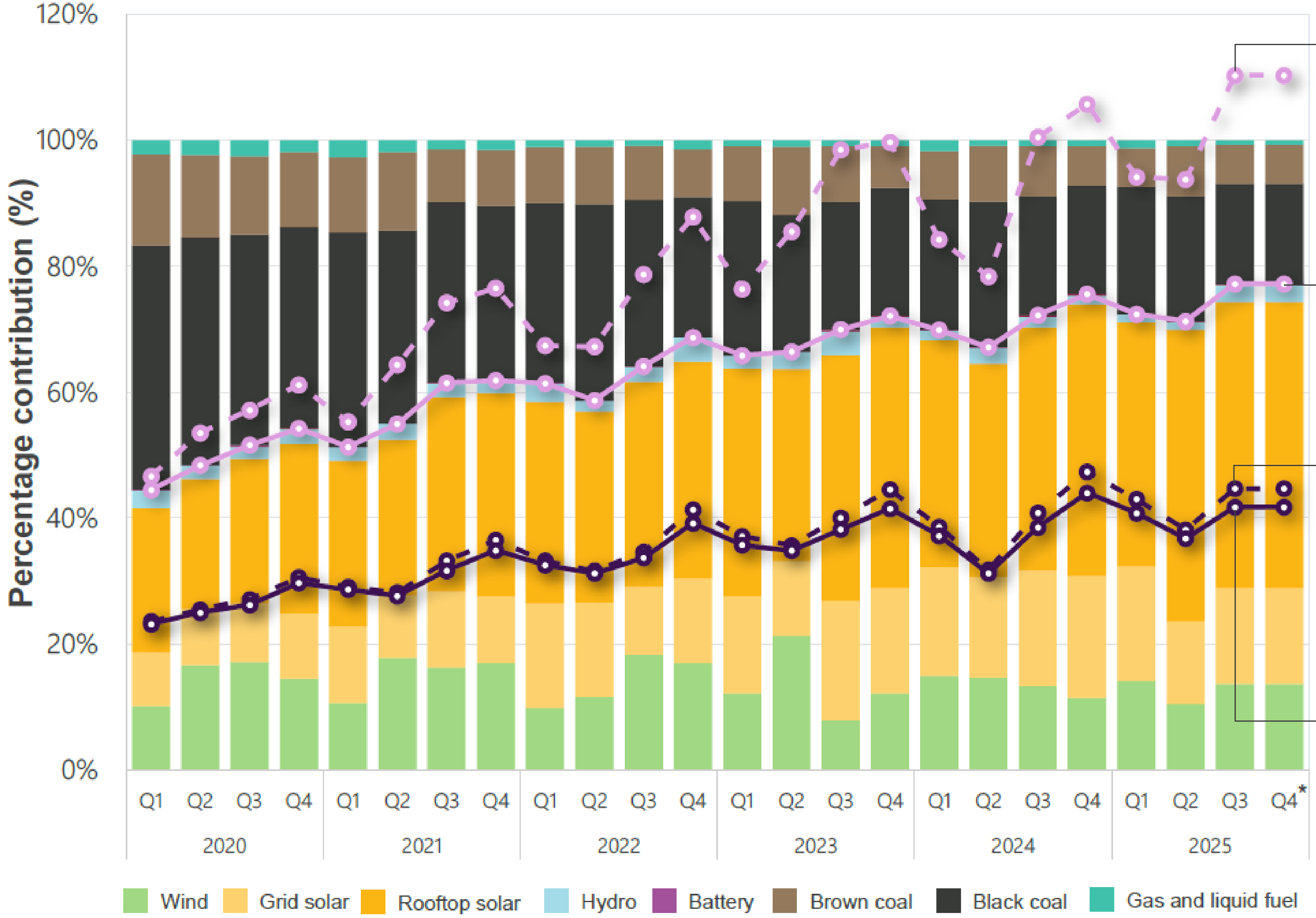
Maximum demand record: **35,796 MW** (29 Jan 2009)

Minimum demand record: **9,666 MW** (4 Oct 2025)

Driven by periods of high rooftop solar generation and mild temperatures, which reduce demand for energy from the grid.

Reference: NEM Fact Sheet

Renewables contribution in the NEM



Max. renewable potential
110%
(Q3 2025)
Maximum % of renewables available in any 30-min interval.

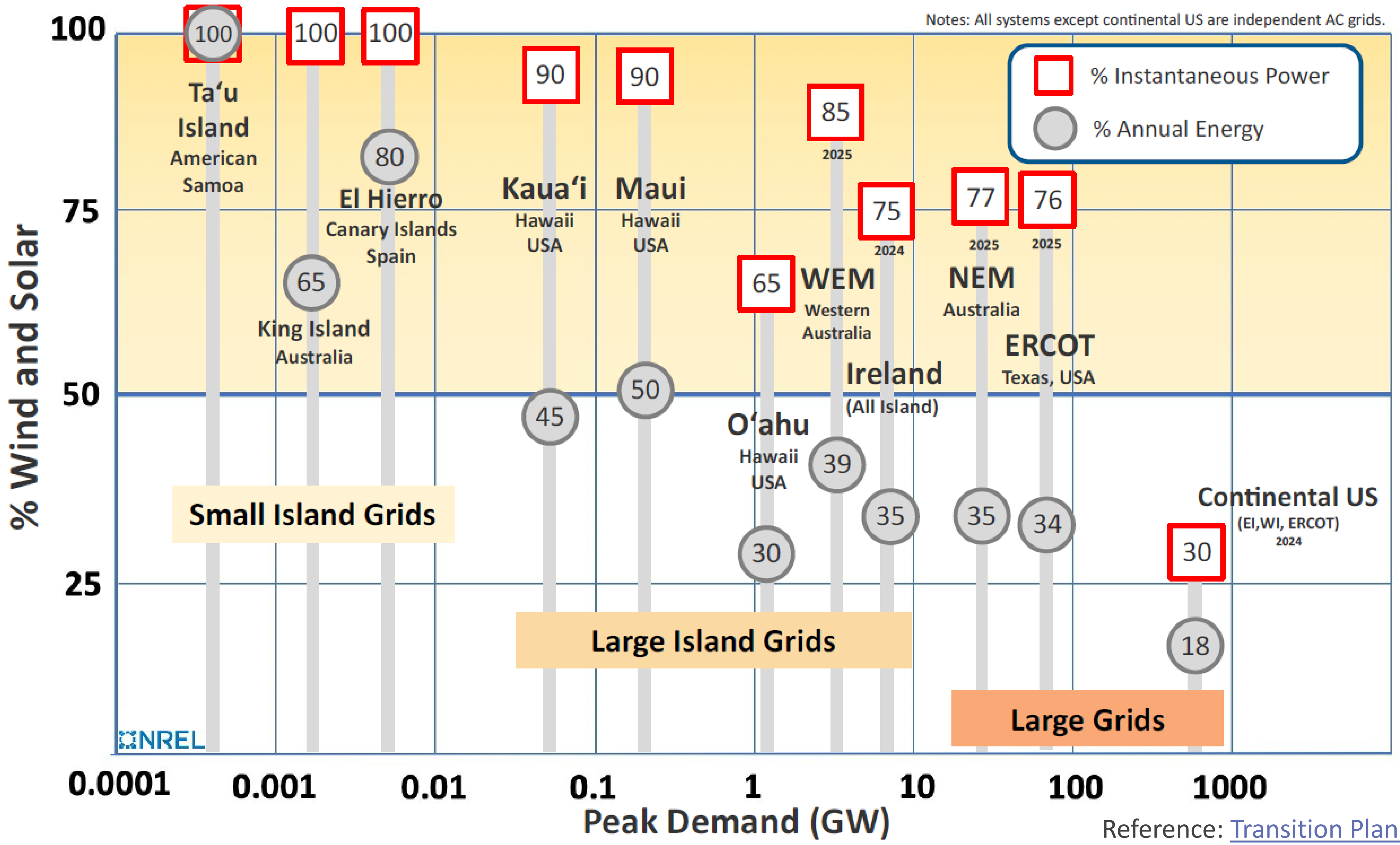
Max. renewable contribution
78%
(Q4 2025)
Maximum % of renewable generation actually dispatched in a 30-min interval.

Avg. renewable potential
47%
(Q3 2025)
Averaged total % of renewables available in that quarter.

Avg. renewable contribution
44%
(Q3 2025)
Averaged total % of electricity that renewables provided in that quarter.

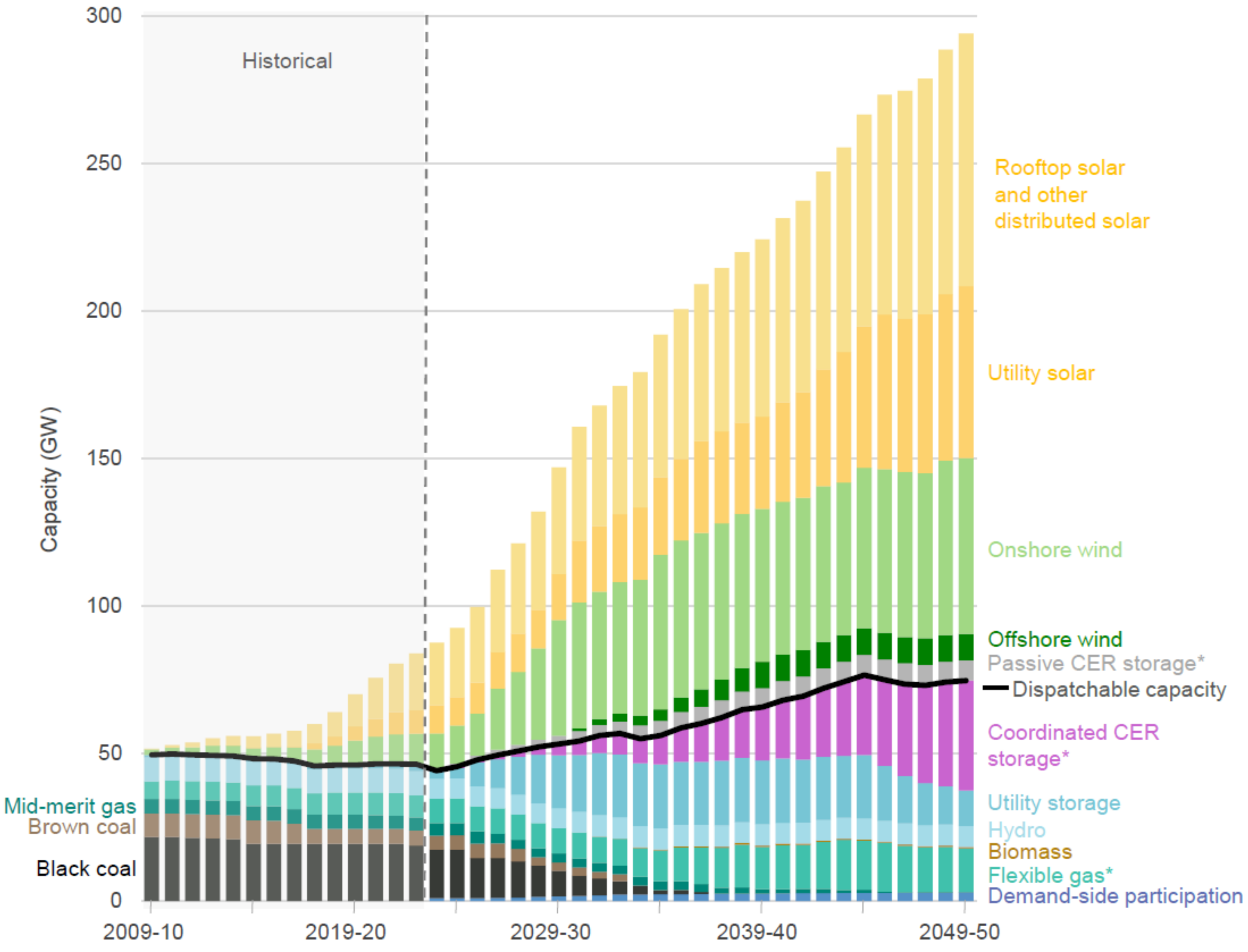
Reference: Transition Plan for System Security

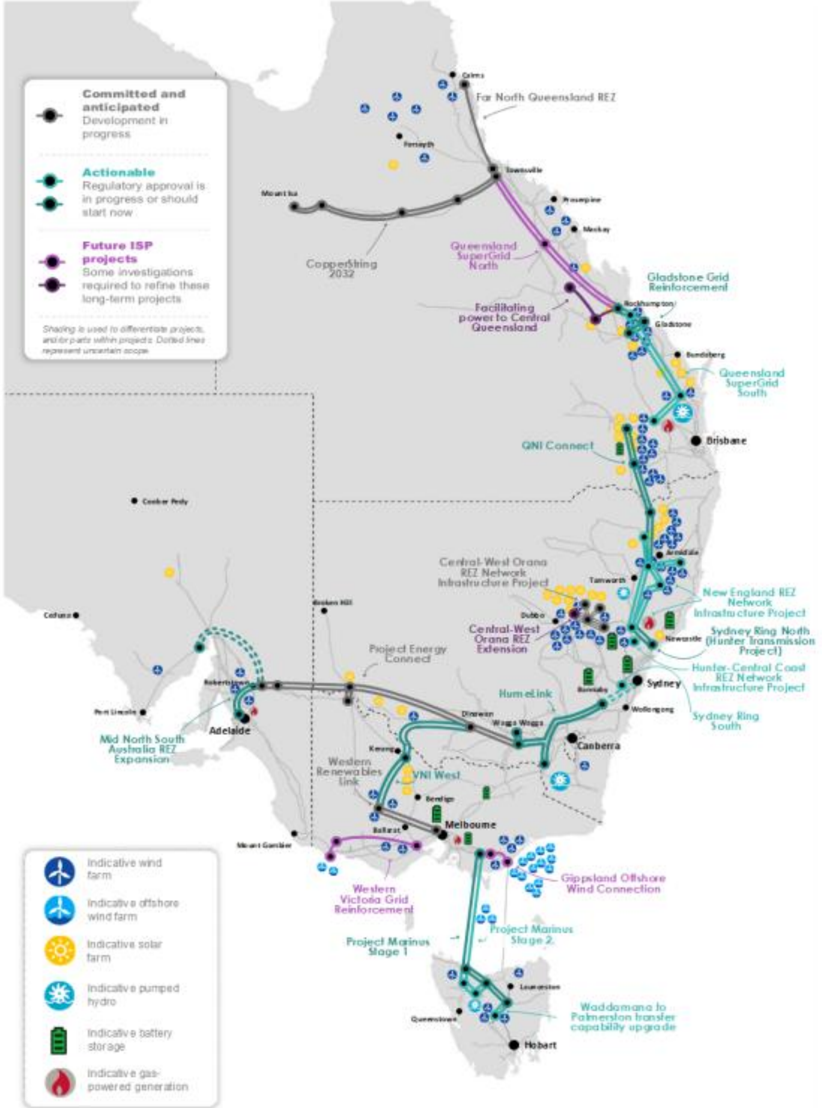
Record renewables contributions



Reference: Transition Plan for System Security

Integrated System Plan (ISP)





2024-integrated-system-plan-isp.pdf

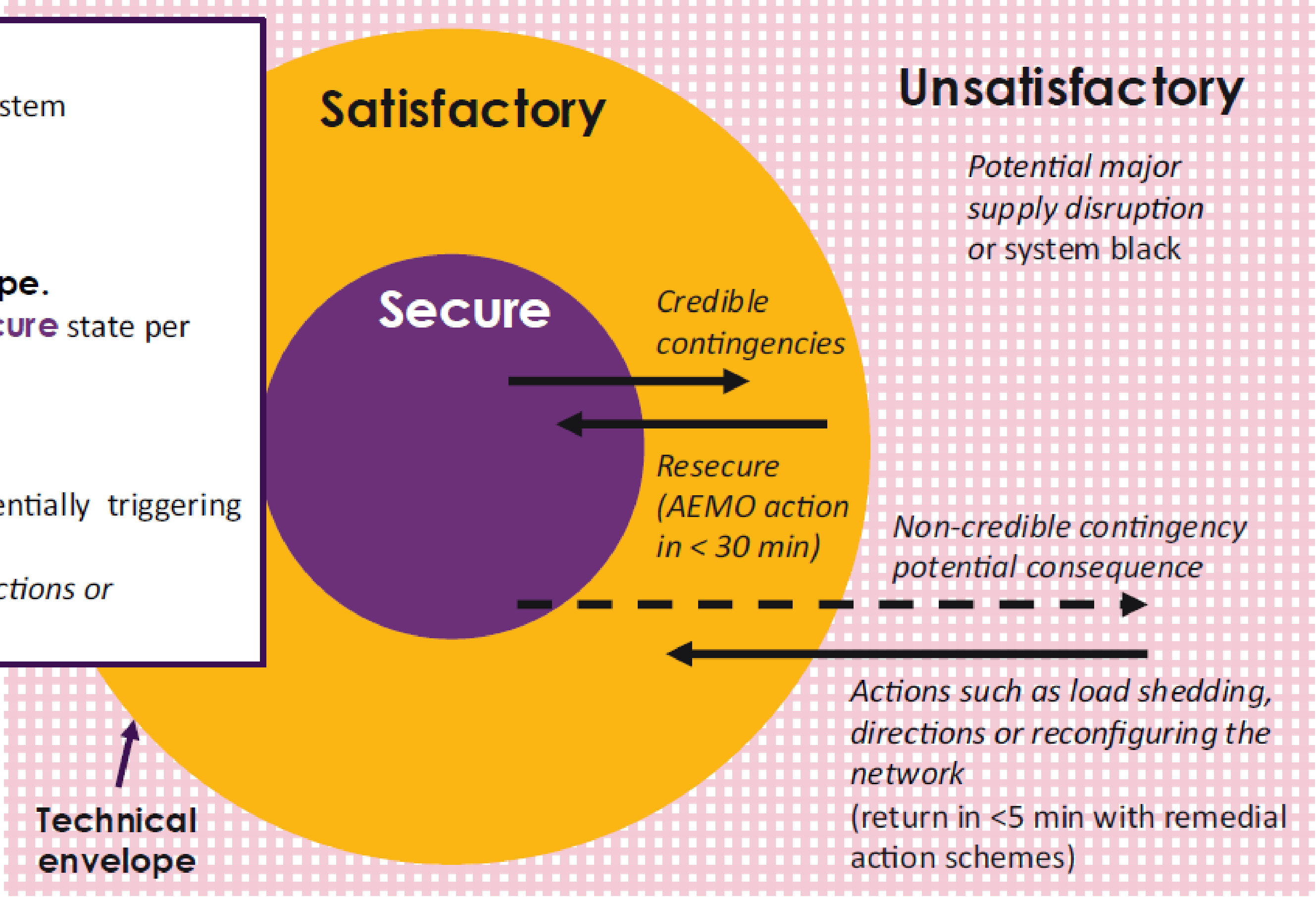
Power system security

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.*

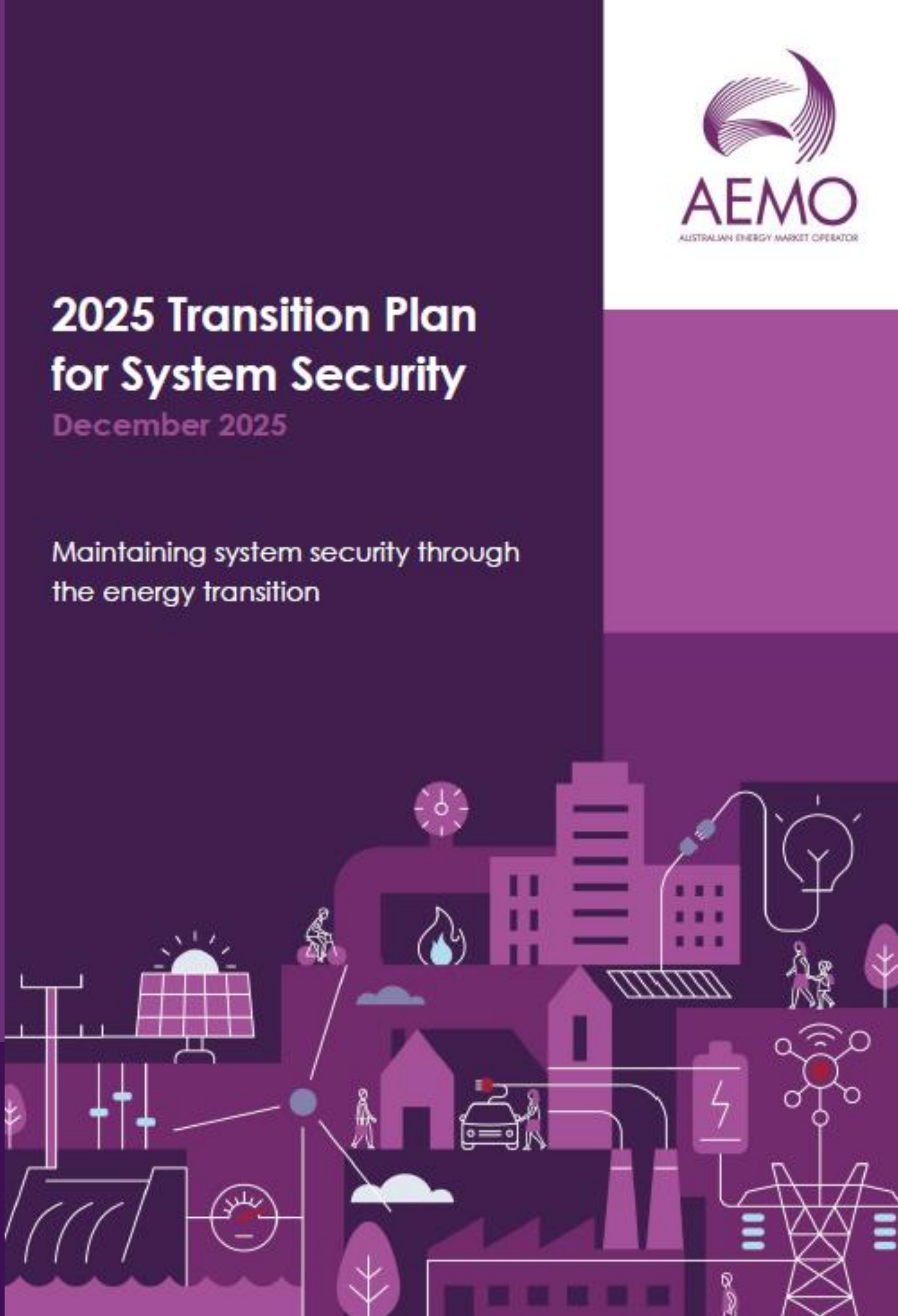


Security is a shared responsibility

	Technical requirements		Economic assessments		Operational delivery	
Frequency & inertia	**AEMC** Sets Primary Frequency Response (PFR) obligations.	**AEMO** Sets inertia requirements. Identifies gaps.	**AEMO** Procures frequency services through FCAS markets.	**TNSPs** For inertia, assess options to invest or procure from market participants. Generally, involves RIT-T.	**AEMO** Calculates FCAS reserve enablement through NEMDE, send signals to plant.	**TNSPs** Provide inertia from synchronous machines; synthetic inertia response from GFM.
	Reliability Panel Set Frequency Operating Standard (FOS).	**TNSPs** Internal studies of needs. Assess connections.		**AER** Assesses/reviews TNSP proposed/actual expenditure.	**Market Participants** Generators provide primary frequency control via governors and control systems (mandatory). Provide additional frequency control services (where enabled via FCAS).	**Market Participants** Where contracted by TNSP, provide inertia from synchronous machines; synthetic inertia response from GFM.
	AEMO Identifies Frequency Control Ancillary Services (FCAS) requirements and levels. Identifies PFR requirements. Assess connections.					

AEMC: Australian Energy Market Commission, **AEMO:** Australian Energy Market Operator
AER: Australian Energy Regulator, **TNSP:** Transmission Network Service Provider

System Security Transition Planning



AEMO's transition planning approach

Transition planning is an ongoing body of work that needs to be done to ensure readiness for every transition point.

Transition points are events that require material changes in the operational approach to managing system security.

Horizon 1	Horizon 2	Horizon 3
Operational planning to prepare for imminent transition points	Transition planning in the investment timeframe	Future system needs
0-2 years	2-10 years	10+ years

Example Transition Points

- **Major asset changes** such as coal power station retirement
- **Threshold events**, such as projected seasons where operational demand could drop below minimum levels
- **Operational changes** that could affect how security is maintained, such as reducing the number of synchronous generators required to be online in a region.

Summary of NEM transition points

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Horizon 1: 0-2 years
Operational timeframes with existing tools

Horizon 2: 2-10 years
Investment timeframes with planning frameworks

2025

SA 1 min sync generator (SA)
Successful reduction of minimum sync. generators to one, in Sept 2025

SA minimum system load (MSL) (SA)
Adequate options were available via directions to manage projected MSL periods.

Vic MSL (VIC)
Adequate options were available to manage forecast minimum demand periods via contracts and directions, though some scenarios could have required last resort mechanisms.

2026

Qld MSL (QLD)
Action required to ensure additional mechanisms are available to manage system security under certain (low probability) onerous system conditions.

NSW, SA, Vic MSL (NSW, SA, VIC)
Adequate options forecast to be available to manage minimum demand periods with the use of directions and transitional services where available. Last resort options may still need to called upon in certain (low probability) onerous system conditions.

2027

Eraring exit (NSW)
Assets flagged for system strength requirements are not scheduled to be operational before announced retirement date.

SA 0 min sync generators (SA)
Following Project EnergyConnect Stage 2 and evidence of secure operation, reduction to 0 min. sync. generators in SA is possible.

Qld first coal station potentially offline (QLD)
System strength and inertia shortfalls from market dispatch are possible but sufficient assets remain available for contract or direction if required.

2028

Yallourn exit (VIC)
Projects in pipeline to manage system strength and thermal limits. Procurement risks for system strength solutions means potential reliance on contracts or directions with limited available assets that could be impacted by gas adequacy.

Torrens Island B exit (SA)
Monitored potential transition point.

2029

Gladstone exit (QLD)
Powerlink actively progressing projects to resolve anticipated system security and reliability issues following scheduled retirement in 2029.

NSW second coal station potentially offline (NSW)
2028-29
System strength and inertia issues identified for Eraring retirement will be exacerbated. Little lead time for additional projects to be delivered.

2030-35

NSW third coal station potentially offline (NSW)
2031-32
Large pipeline of projects with sufficient lead times ahead of target dates to ensure on-time and in-full delivery.

Vic third coal station potentially offline (VIC)
2033-34
Security is contingent on planned assets being delivered ahead of coal decommitment.

Vic second coal station potentially offline (VIC)
2031-32
Additional solutions are required to ensure security given significantly higher reliance on remaining coal station

Continuing MSL and additional transition points (NEM)
MSL risks continue beyond 2027, with additional Horizon 2 transition points considered in further detail in Part B of the report.

Transition points are events that require material changes in the operational approach to managing system security. These utilise 2024 ISP Step Change projections, noting coal exit order is influenced by commercial drivers and asset condition. Additional points will be considered as required in future plans.

Industry readiness for transition point: Complete/ on track · Moderate readiness · Unresolved issues

Reference: Transition Plan for System Security

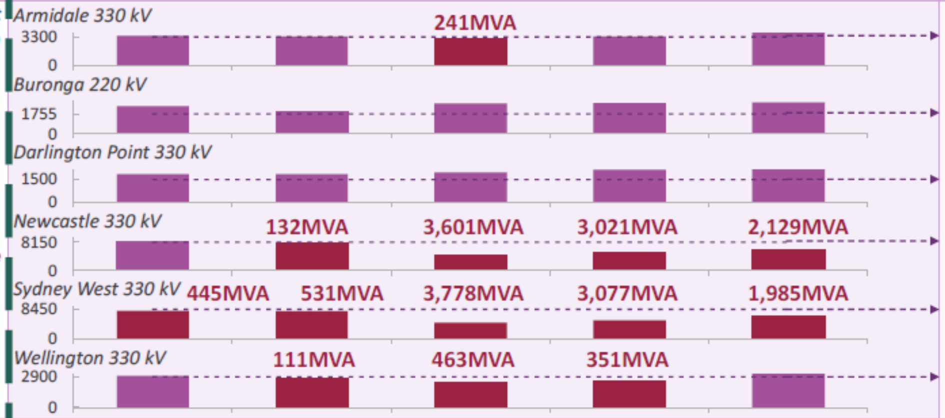
Regional plans: NSW

REGIONAL DEVELOPMENTS	Now	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34	2034-35
Synchronous generator capacity change *Annual capacity changes (MW)*		+750		-2,940	+1,100				-40	-4,035	
Committed and anticipated IBR *Annual capacity changes (MW)*		+3,804	+550	+2,367	+1,970	+919	*Future project details periodically evaluated in NEM generation information processes*				
IBR forecasts (*Sets efficient Sys. Strength level*) *Annual capacity changes (MW)*		+3,804	+550	+6,888	+8,276	+9,057	+2,297	+863	+4,113	+1,304	+3,984
Transmission augmentation[A, B]			HumeLink; PEC 2	Central-West Orana REZ; Hunter Central Coast REZ		Hunter Transmission Project	Sydney Ring South; VNI West	New England REZ Stage 1	QNI Connect		New England REZ Stage 2
Synchronous Condensers			PEC 2		System strength RIT-T; CWO REZ	→	System strength RIT-T	New England REZ	→ New England REZ		
Transition Points		NSW MSL	Eraring Power Station Exit		Coal potentially offline #2			Coal potentially offline #3			

- Committed/anticipated
- RIT-T in progress/actionable

AEMO'S CURRENT OUTLOOK	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34	2034-35
Assessment horizon	*NSCAS assessment (See Appendix 2)*					*Long term assessment*				

System strength – *nodal assessment* (minimum fault current in MVA)



Long-term, system strength requirements are managed by Transgrid through the RIT-T framework.

Transgrid's RIT-T is currently at the Project Assessment Conclusions Report phase, published in July 2025, and initial stages of procurement are underway. The New South Wales government has enabled acceleration of the first tranche of synchronous condensers from the preferred portfolio option, making portfolio 4 in the RIT-T now credible.

This portfolio option features the delivery of synchronous condensers in two tranches, and contracts with synchronous machines to manage system strength in the interim. System strength is expected to be further addressed by delivery of REZ synchronous condensers.

Inertia (MWs)

Inertia sub-network allocation to be met from Dec 2027

Low long-term risk due to Transgrid flywheel-equipped RIT-T synchronous condensers and IBR participation in frequency market, providing sufficient inertia and frequency support respectively.

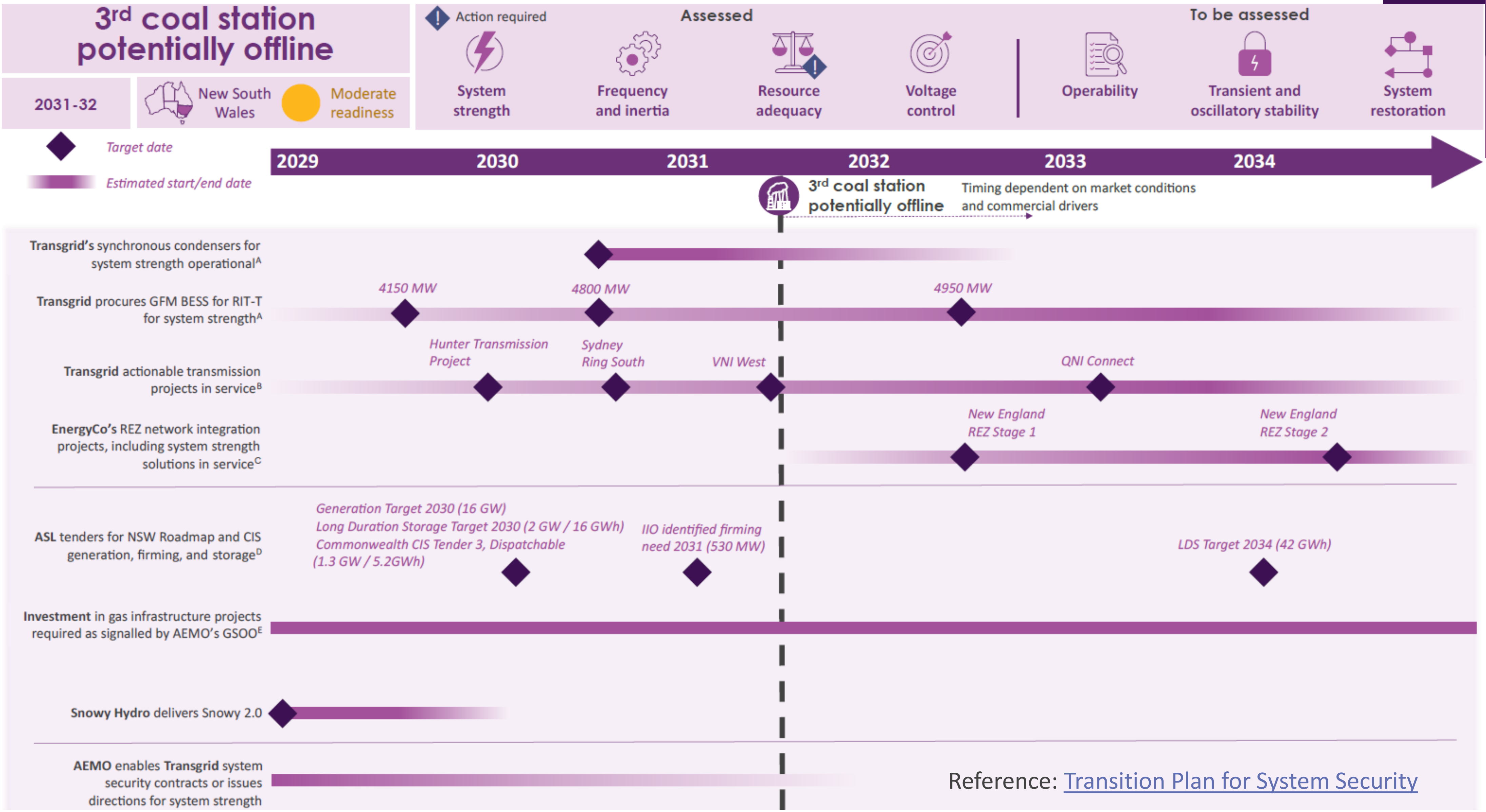
Thermal and voltage

No gaps declared, however emerging voltage/thermal risks are forecast with current pipeline of committed and anticipated projects. Delivery of actionable projects needed to address risk.

Reference: Transition Plan for System Security

------ Requirements | Available level | Deficit | NSCAS Gap

NSW with no-coal scenario



Reference: Transition Plan for System Security

Grid-Forming Technology

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Definitions

Grid-forming inverter

A grid-forming (GFM) inverter maintains a constant **internal voltage phasor** in a short time frame, with magnitude and angle set locally by the inverter, thereby allowing **immediate response** to a change in the external grid.

Grid-following inverters (GFL) Control system **synchronises** to the grid voltage waveform		Grid-forming inverters (GFM) Control system **sets its own** internal voltage waveform
Require a voltage signal from the grid. Shuts down if it loses this.		No reliance on grid voltage. Can operate with or without grid connection.
Limited possibilities for grid support. Can adjust power, but limited by speed & risk of interactions with other GFL.		Extensive possibilities for grid support. Very fast, intrinsic control of voltage waveform.
Most inverters in the NEM today are grid-following.		There are GW of GFM BESS planned for the NEM. These will provide inertia & system strength, with other services in development.

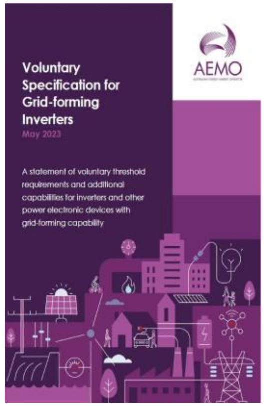
Reference: Voluntary Specification for Grid-forming Inverters.pdf

GFM journey

2021

White Paper
Application of Advanced Grid-scale Inverters in the NEM

2023

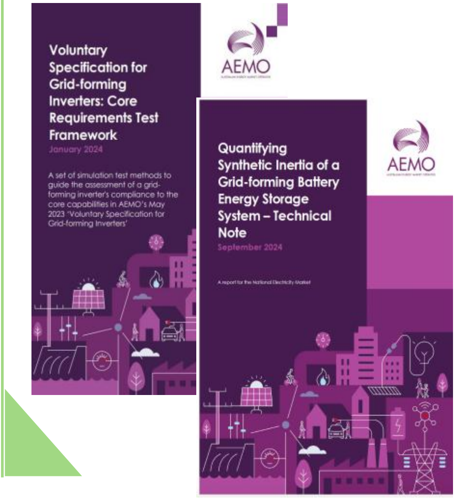


Voluntary Specification
Core and additional capabilities of GFMI

2024

Test Framework
GFMI core capabilities

Synthetic Inertia
Quantifying synthetic inertia of GFM BESS



2025

Synthetic Inertia
Key differences with synchronous inertia

GFM Fault Current
Adequacy of protection quality fault current from GFM

Performance Evaluation
Some GFM BESS projects for core capabilities

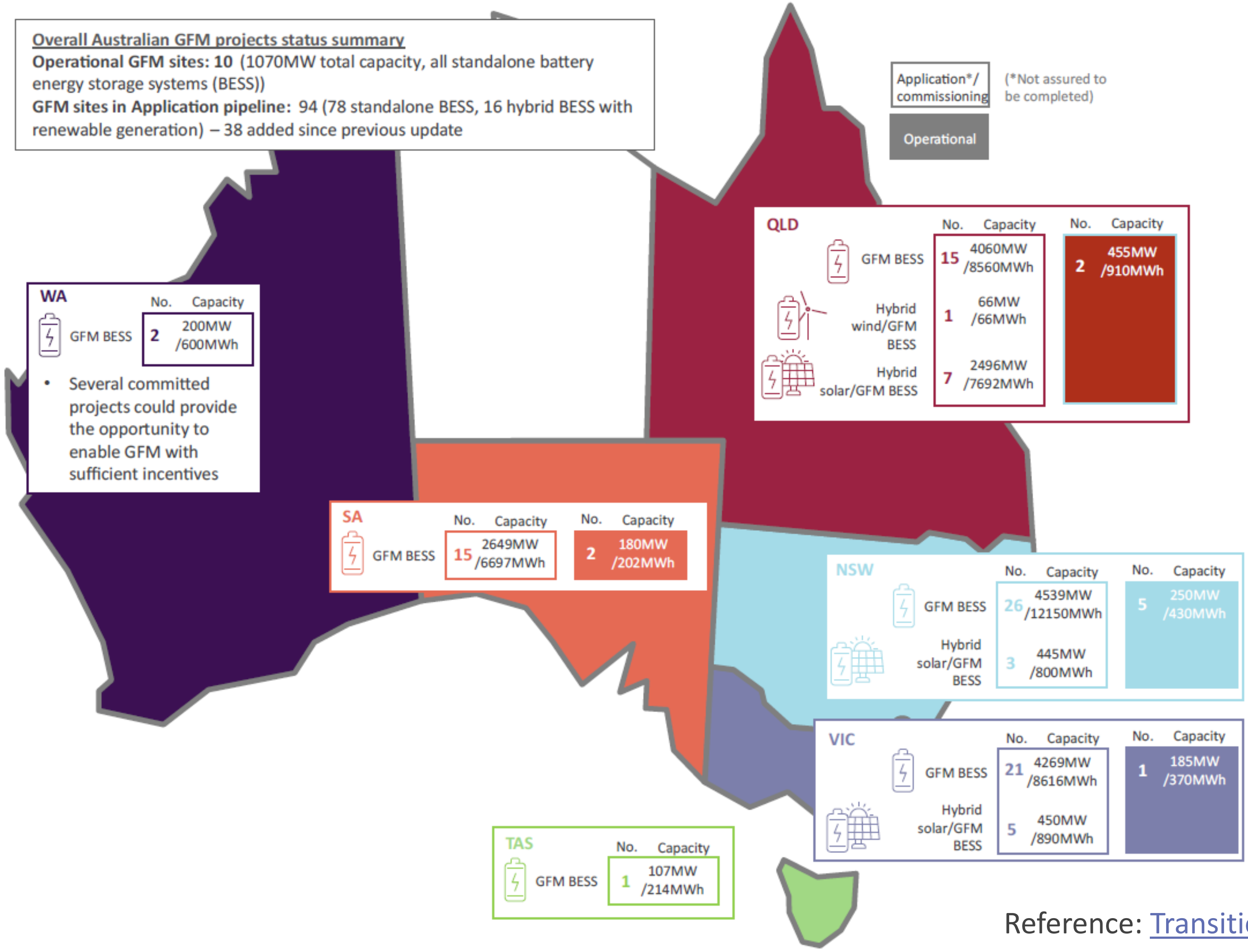
Stabilisation of GFL IBRs
Estimating the size of GFM BESS and comparison with Syncon

2026

OEM GFM Knowledge Sharing
Supporting active GFM projects
Learnings used to propose changes in Access Standards Review

GFM Access Standards Review
Develop grid-code for generator connections with GFM technology

GFM projects in the NEM and WEM



Reference: Transition Plan for System Security

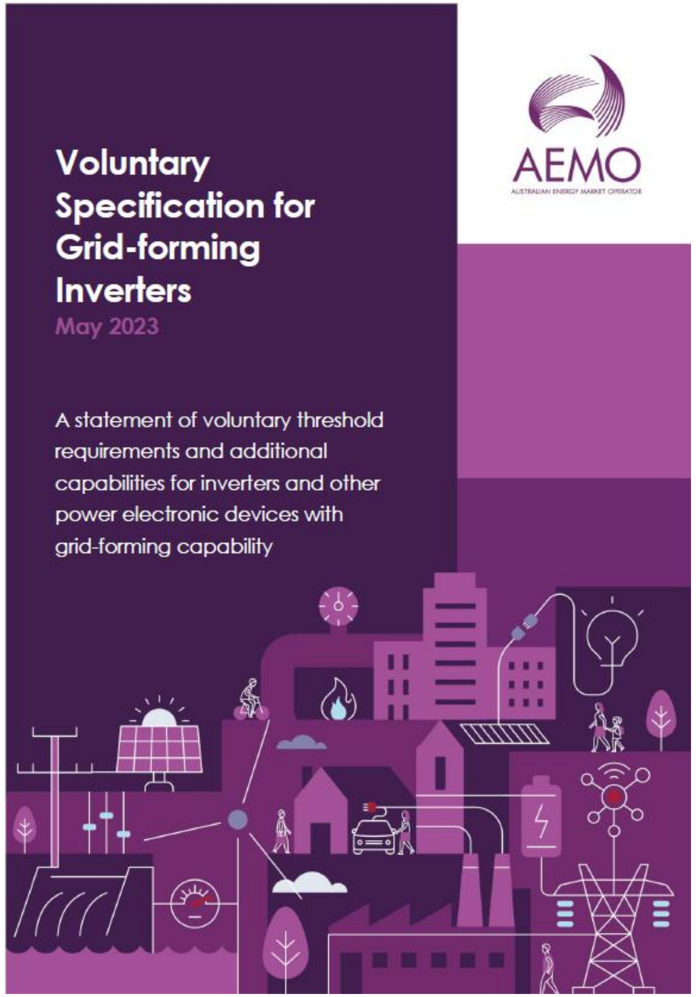
Grid-forming capabilities

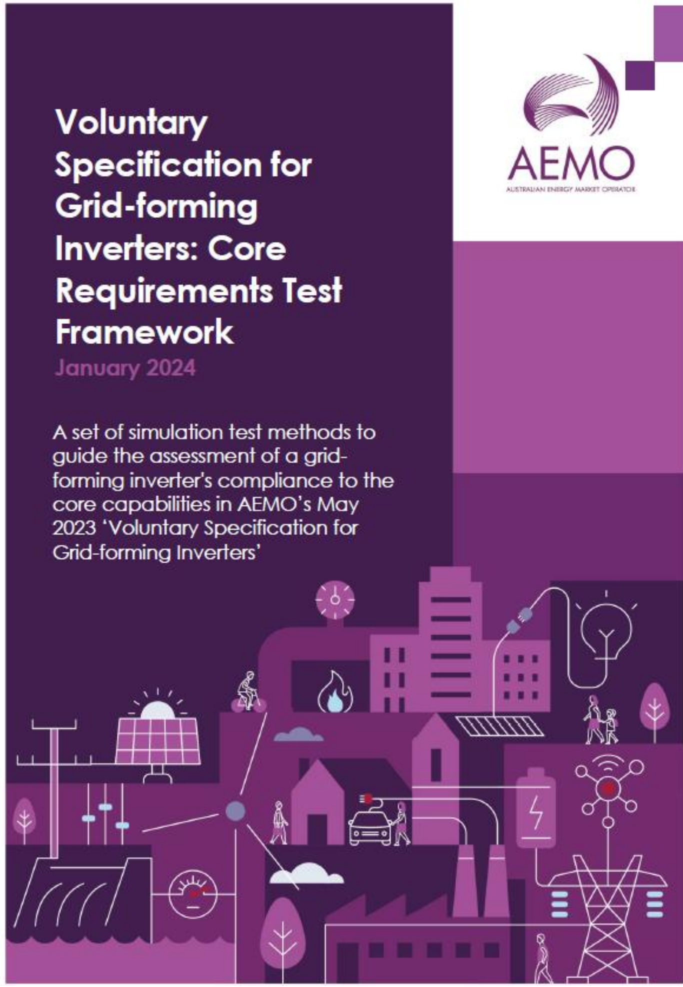
Core capabilities

- Voltage source behaviour
- Frequency domain response
- Inertial response
- Surviving the loss of last synchronous connection
- Weak grid operation and system strength support
- Oscillation damping capability

Additional capabilities

- Headroom and energy buffer
- Current capacity above continuous rating
- Black start capability
- Power quality improvements





References: Voluntary Specification for Grid-forming Inverters.pdf, Voluntary Specification for Grid forming Inverters: Core Requirements Test Framework.pdf

Seven Tests in GFM Test Framework

Test parameter	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Testbench	Testbench 2	Testbench 2	Testbench 2	Testbench 2	Testbench 1	Testbench 1	Testbench 1
Contingency /change	Loss of synchronous machine – discharging	Loss of synchronous machine – charging	Loss of synchronous machine – limits	Loss of synchronous machine – power balance	frequency ramp	SCR ramp down with fault	Angle step change
Network conditions	-	-	-	-	SCR 10 and X/R ratio 6	SCR 20 and X/R ratio 6	SCR 3 and X/R ratio 6
Test sequence	Run until the system is stable. Then trip the synchronous generator	Run until the system is stable. Then trip the synchronous generator	Run until the system is stable. Then trip the synchronous generator	Run until the system is stable. Then trip the synchronous generator	4 Hz/s frequency ramp up and ramp down with 5 seconds intervals	Applying 2 phase-to-ground fault before a progressive SCR step down to 10, 3, 2, 1.5, and 1.25	Dip the grid phase angle by 10, 30, and 60 degrees respectively
GFM plant 1 output	0.2 pu[A] discharging	0.5 pu[C] charging	0 pu[A]	0.5 pu[A] discharging	0.5 pu[A] discharging	1 pu[A] discharging	0.5 pu[A] discharging
GFM plant 2 (duplicate) output	0.2 pu[B] discharging	0.5 pu[D] charging	1 pu[B] discharging	0.5 pu[B] discharging	-	-	-
Load value	1 pu[A] and P.F. of 0.95	0.5 pu[C] and P.F. of 0.95	1 pu[A] and P.F. of 0.95	0.75 pu[A] and P.F. of 0.95	-	-	-

[A]P rated discharge of GFM plant 1, [B]P rated discharge of GFM plant 2,
[C]P rated charge of GFM plant 1, [D]P rated charge of GFM plant 2

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Summary of results

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GFM BESS performance appear to be improving with newer version of design and control parameters

Test ID	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Core Capability Reference	A,C,D,E,F				C,E	A,C,E,F	
Project 1	Fail	Fail	Fail	Fail	Pass	Fail	Fail
Project 2	Fail	Fail	Fail	Fail	Pass	Fail	Fail
Project 3	Pass	Pass	Pass	Pass	Pass	Pass	Pass*
Project 4	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Project 5	Pass	Pass	Pass	Pass	Pass	Fail	Pass*

Core Capability Reference	Description
A	Voltage source behaviour
B	Frequency domain response
C	Inertial response
D	Surviving the loss of last synchronous connection
E	Weak grid operation and system strength support
F	Oscillation damping capability

*Pass/fail indicated here does not mean failing an NER performance standard

Test 1 – 4: loss of the last synchronous machine

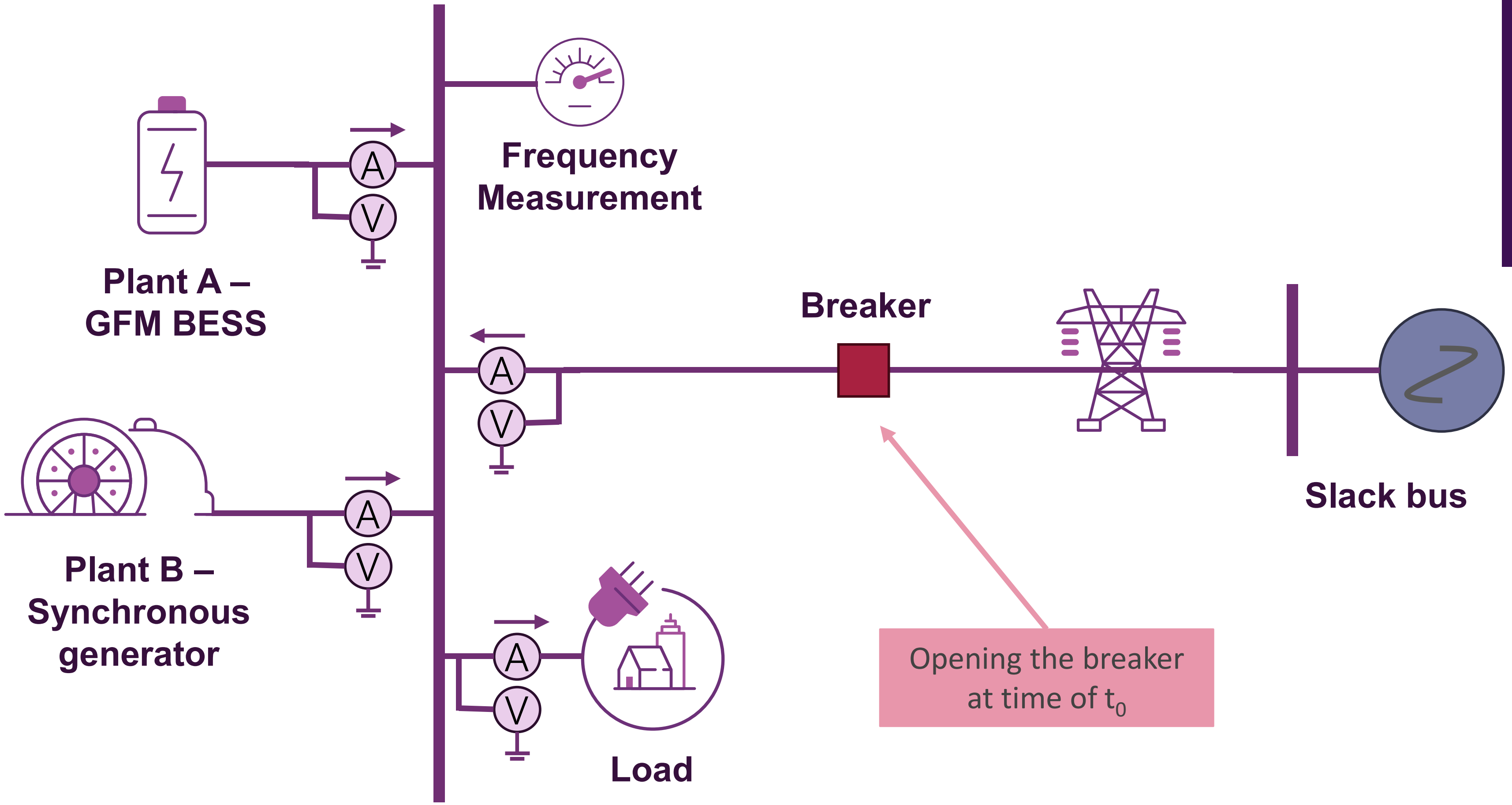
Test 5: RoCoF up and down | Test 6: SCR step change | Test 7: Angle step change

* Marginal pass

Reference: Transition Plan for System Security

Synthetic inertia quantification

- ✓ The inertia of Plant B is known
- ✓ The size of the Plant B is approx. twice as Plant A
- ✓ Frequency control loops are disabled
- ✓ Load is not sensitive to frequency and volage changes
- ✓ A steady state is achieved before breaker opening
- ✓ Amount/direction of the flow over Breaker can be adjusted using generation from A & B and load to achieve various operating points and desired under-frequency and over-frequency events.



Reference: [Quantifying Synthetic Inertia from GFM BESS]

Scenarios considered

Operating points

- 11 different operating points
- Charging and discharging modes
- Over and under-frequency events

+

Contingency size/RoCoF

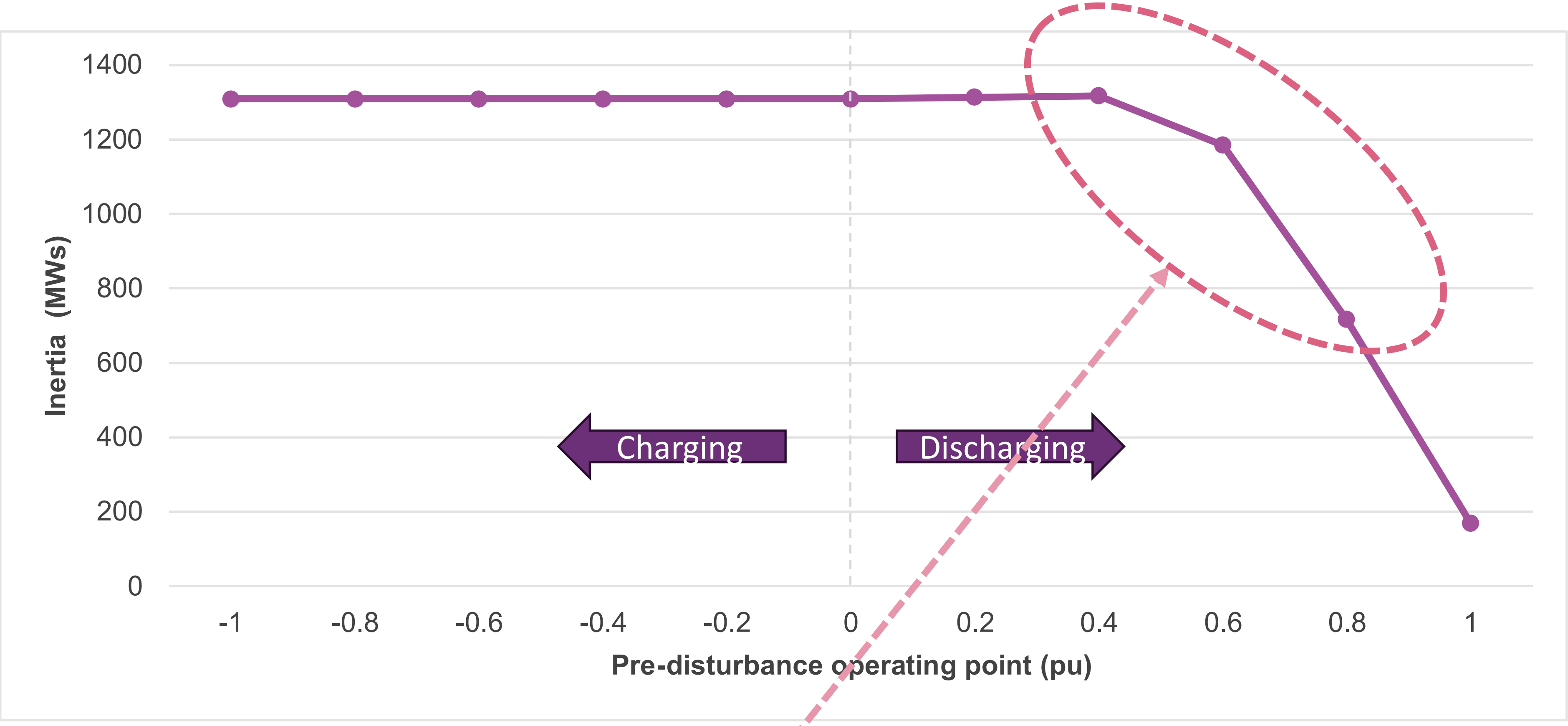
- 3 different contingency sizes resulting in different RoCoF values

Frequency control is disabled to avoid its confounding effect on the synthetic inertia quantification.

Two site-specific projects of similar size but different inertia settings and overload capabilities are considered.

1.Pre-disturbance operating point

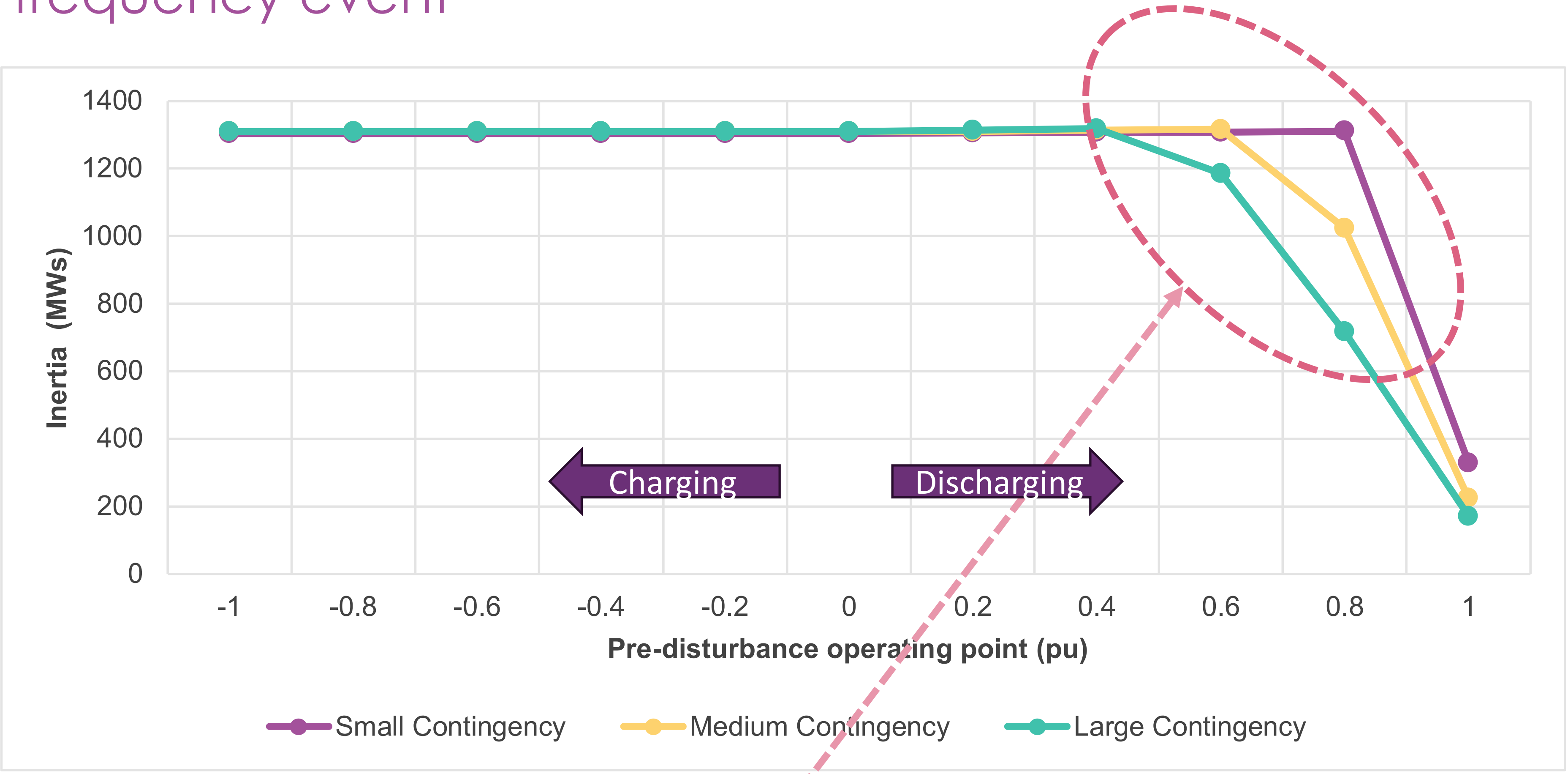
Under-frequency event



with an increase in pre-disturbance operating points in discharging mode, the synthetic inertial contribution of GFM BESS starts to decline

2.Contingency size/RoCoF

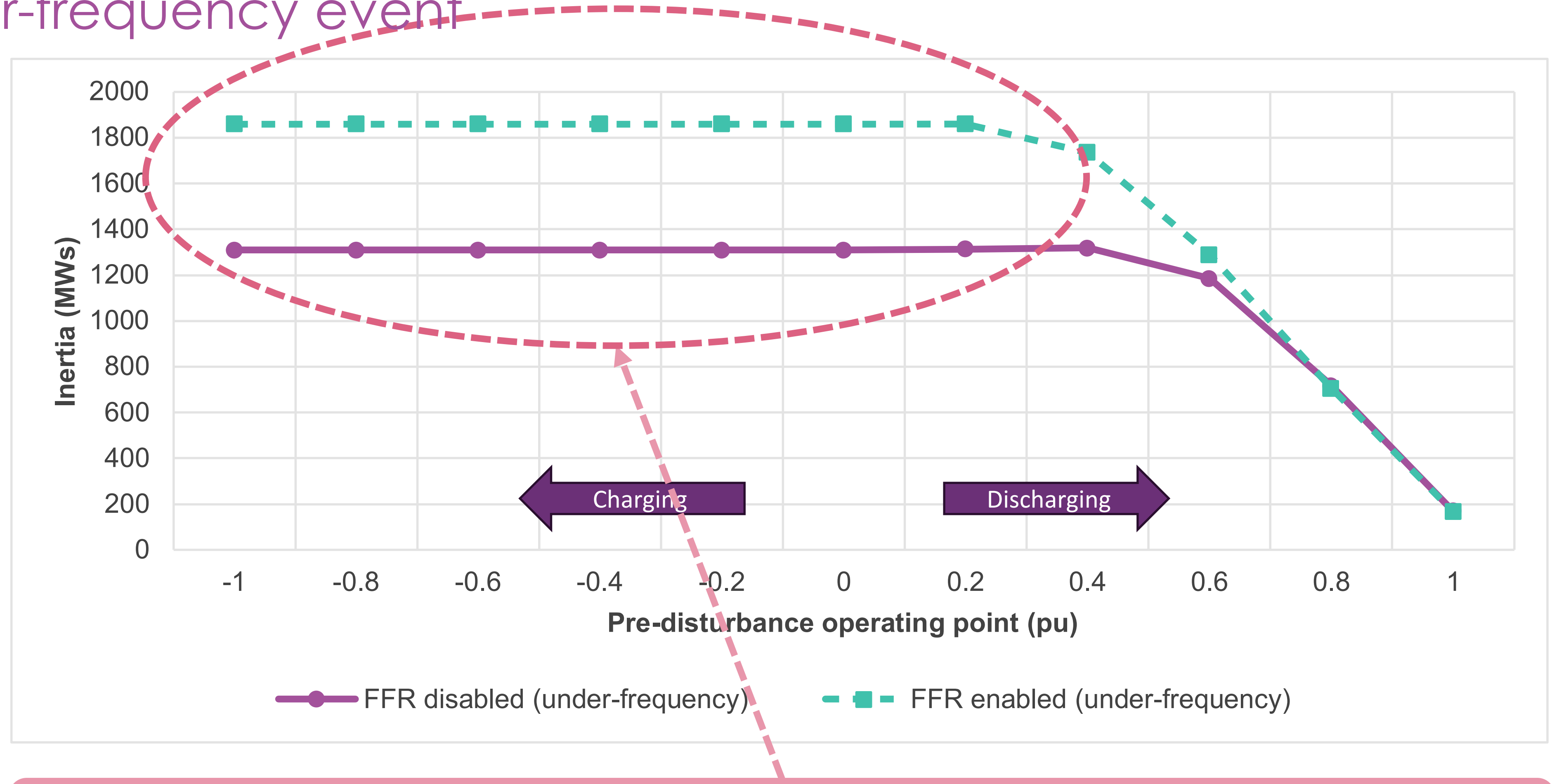
Under-frequency event



With increase in contingency size/RoCoF, inertia level starts to decline at lower operating points

3.Fast frequency response

Under-frequency event



The FFR has a confounding impact on the quantification of synthetic inertia provided by a GFM BESS particularly when pre-disturbance operating point is away from its active power limit

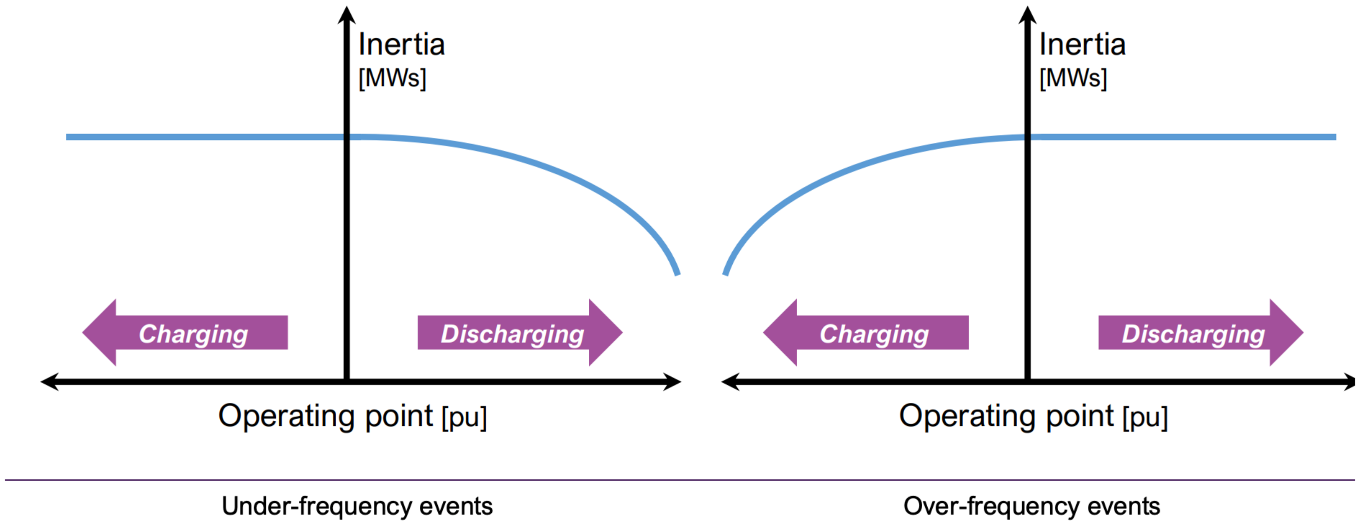
FFR: Fast frequency response

Synthetic inertia of GFM BESS

- **Synthetic inertia** of a GFM BESS **is likely to vary** depending on factors such as its operating point and contingency size/RoCoF.
- When GFM BESS is operating at **lower pre-disturbance operating points** (i.e. closer to zero active power), it would have **sufficient headroom** to provide synthetic inertial response.
- **A larger contingency** size in conjunction with **higher operating points** can increase the likelihood GFM BESS reaching its current limit, and thus **reducing the inertial contribution** from the GFM BESS.
- **Frequency control** (in particular FFR) can have **confounding impact** on the quantification of synthetic inertia provided by a GFM BESS. Therefore, when quantifying the synthetic inertia of GFM BESS, **FFR should be disabled** to calculate the **'bare-bone'** synthetic inertia.

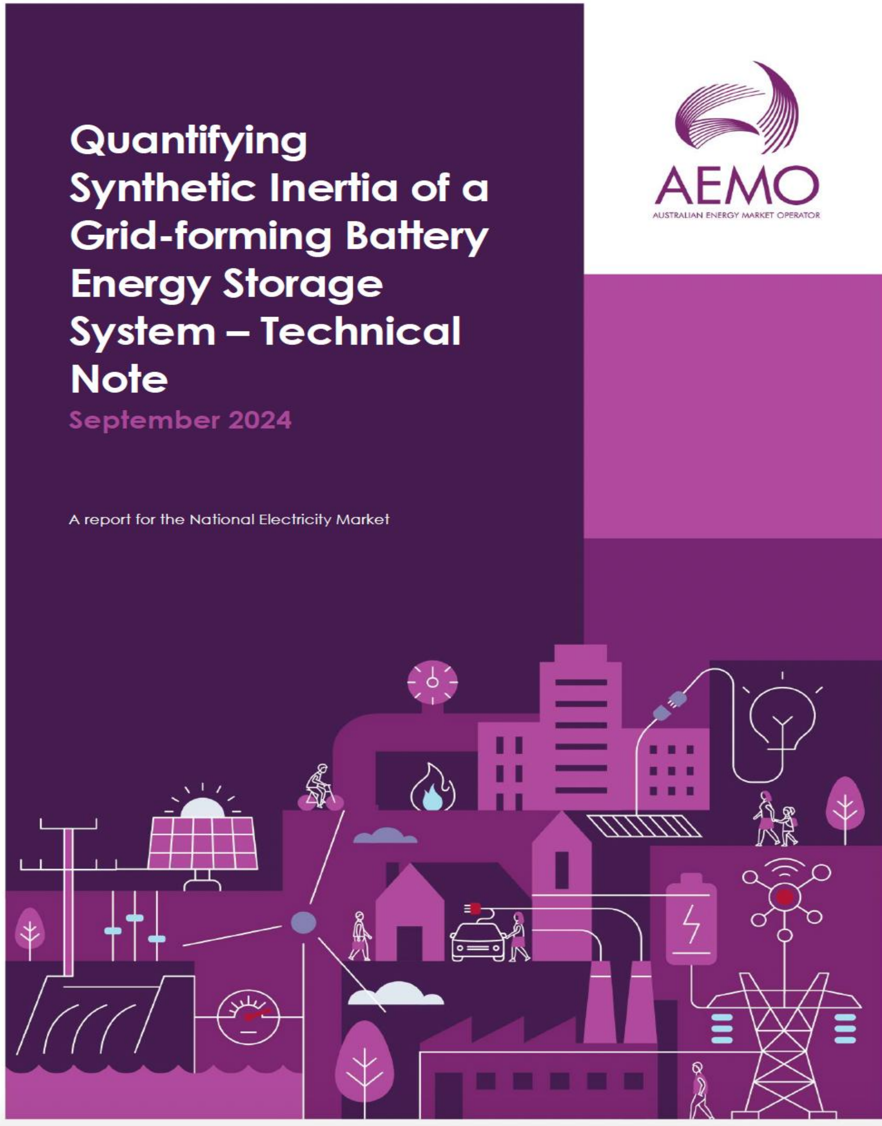
Synthetic inertia

A typical synthetic inertia capability curve for GFM BESS

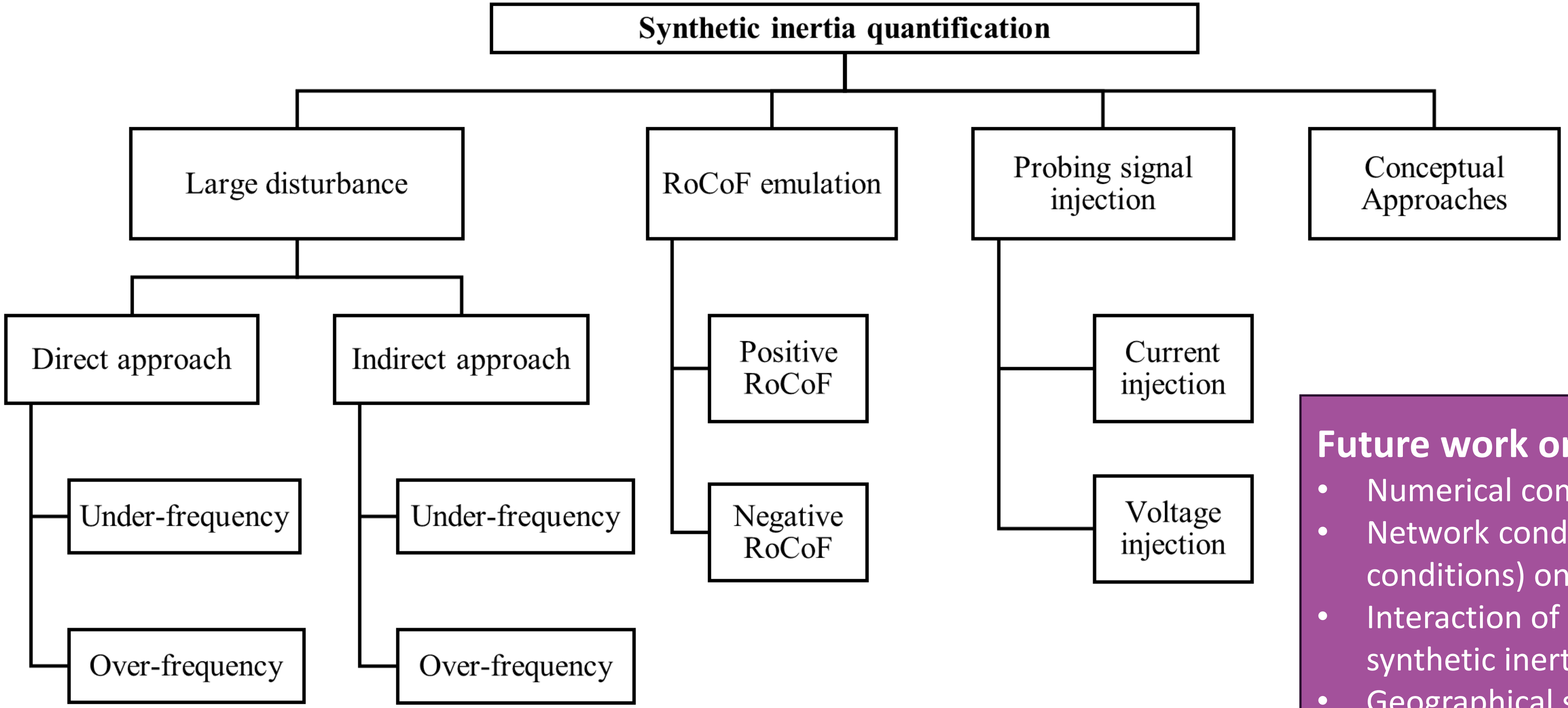


Unlike synchronous inertia, which is a physical property and a constant number, synthetic inertia is a control-driven response and may not be a constant value.

Reference: [Quantifying Synthetic Inertia from GFM BESS]



Classification of quantification methods



Future work on synthetic inertia

- Numerical comparison of existing methods
- Network conditions, (weak to strong grid conditions) on the synthetic inertia provision
- Interaction of adjacent IBRs while providing synthetic inertia
- Geographical spread of synthetic inertial response in the network
- The ratio of synchronous to synthetic inertia in the system

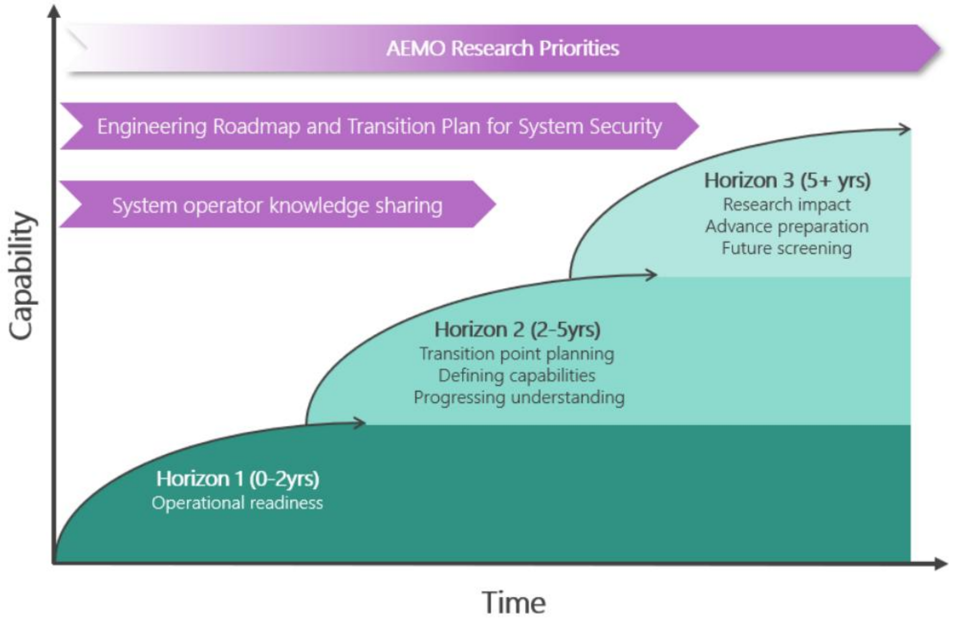
Reference: A Classification for Synthetic Inertia Quantification Methods with Practical Recommendations

Ongoing work on GFM

	2025	Forward plans
System strength – minimum fault level	**AEMO** commissioned 2 consultant reports **AEMO** survey of TNSP protection	**AEMO** studies and HIL testing (Eng Roadmap)
System strength – stable voltage waveform		**TNSP** multi-GW pipeline in RIT-Ts **AEMO** quantify contributions (Eng Roadmap)
Synthetic inertia	**AEMO** studies **AEMO** Inertia Network Services Specification	**TNSP** procurement as of 2 Dec 2025 (ISF)
System restart		**AEMO** Type 2 Transitional Service

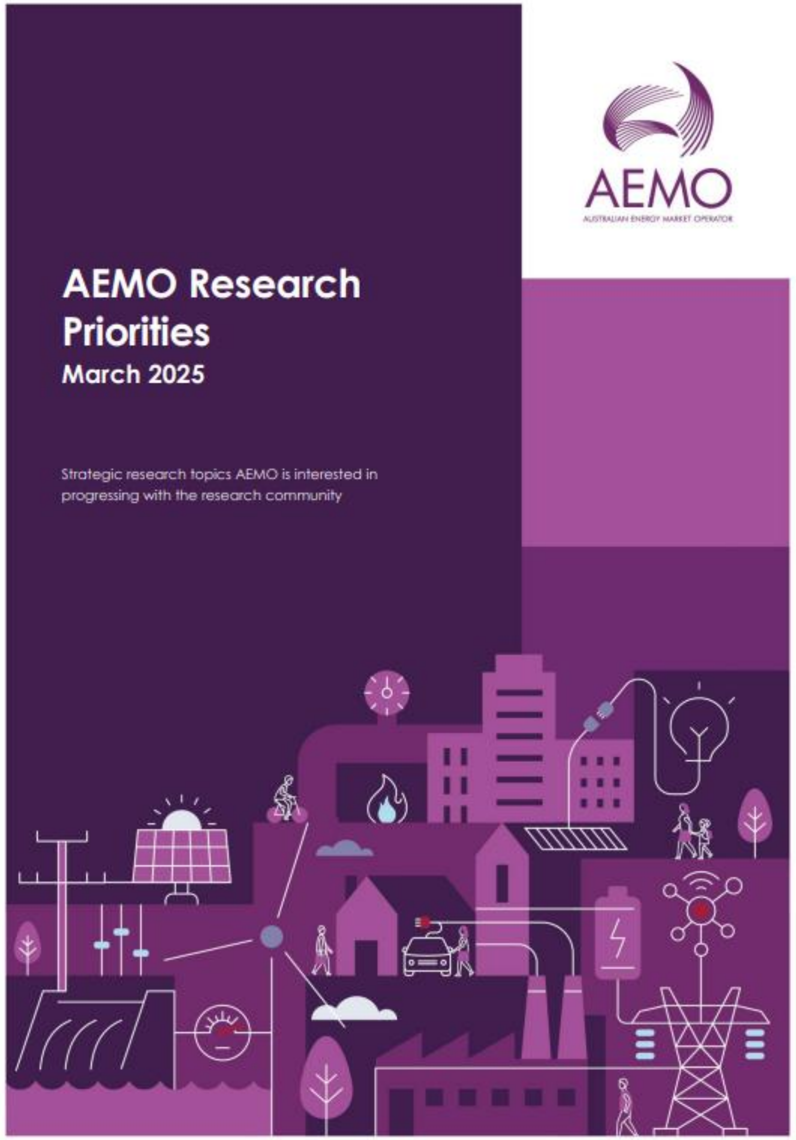
	2025	Forward plans
Standards	**AEMO** simulation tests against GFM Voluntary Specification	**AEMC** Access Standards Review
Trials	**AEMO** Statements of Need for Type 2 Transitional Services	Black start capability from inverter-based resources Zero synchronous generation trial Grid-forming inverter protection-quality fault current

AEMO Research Priorities



Knowledge partners

- Universities
- National Research Organisations
- Original equipment manufacturers
- International System Operators (ISON)
- Market bodies and participants
- Energy sector stakeholders



1. **Modelling major inverter-based loads (IBLs) and their performance in weak grid conditions.**
2. **Analysis and quantification of grid-forming (GFM) inverter capability to provide power system requirements.**
3. **Electromagnetic transient (EMT) and impedance scan tools and methodologies for planning, connections, and operational studies with an increasing share of inverter-based resources (IBR).**
4. **Coordinated storage from consumer energy resources (CER).**
5. **Management of energy in grids with high penetration of battery energy storage systems (BESS).**

Reference: AEMO Research Priorities

Summary

System security is a **shared** responsibility

AEMO | Market participants | Network Service Providers | Policy Makers | Regulators | Investors | Consumers | Research community

- ***Future-back*** *analysis to enhance understanding of the needs of a low-carbon power system.*
- ***Timely investments*** *are needed to decouple reliance on coal generators for system security – enabling the next phase of the energy transition.*

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