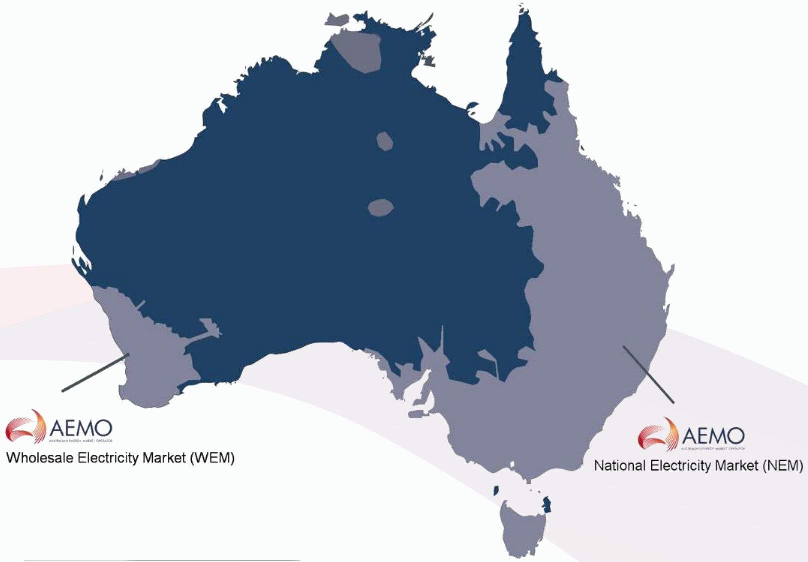
DER Integration

Addressing system security challenges in low load conditions

About AEMO



AEMO operates Australia's National Electricity Market and power grid in Australia's eastern and south-eastern seaboard, and the Wholesale Electricity Market and power grid in south-west WA.

Both markets supply more than 220 terawatt hours of electricity each year.

We also operate retail and wholesale gas markets across south-eastern Australia and Victoria's gas pipeline grid.

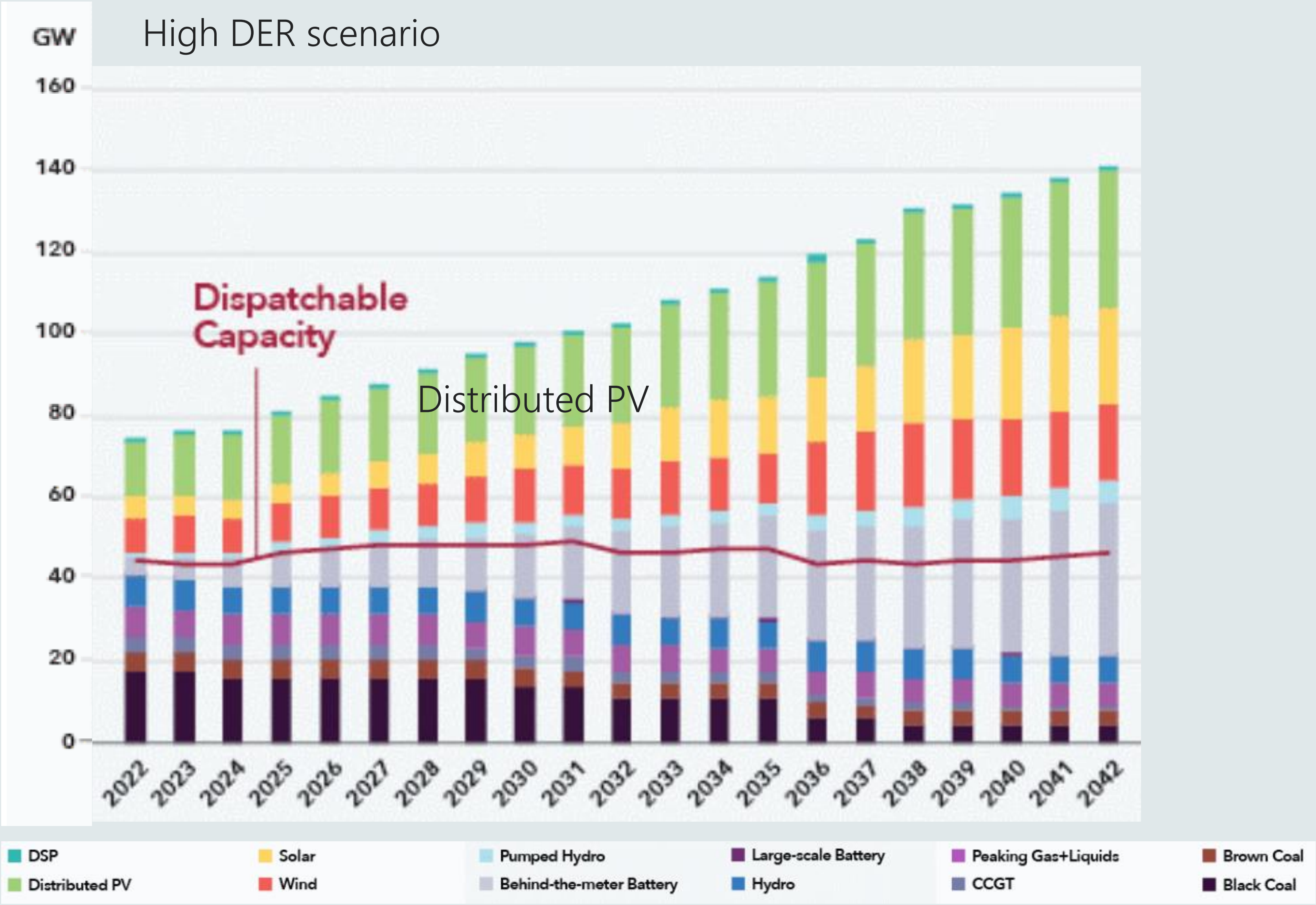
Collectively NEM & WEM traded over A$20 billion in the last financial year.

Ownership

40% Market participants

60% Governments of Australia

Resource development outlook



AEMO (12 Dec 2019) Draft 2020 Integrated System Plan, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/isp/2019/draft-2020-integrated-system-plan.pdf?la=en

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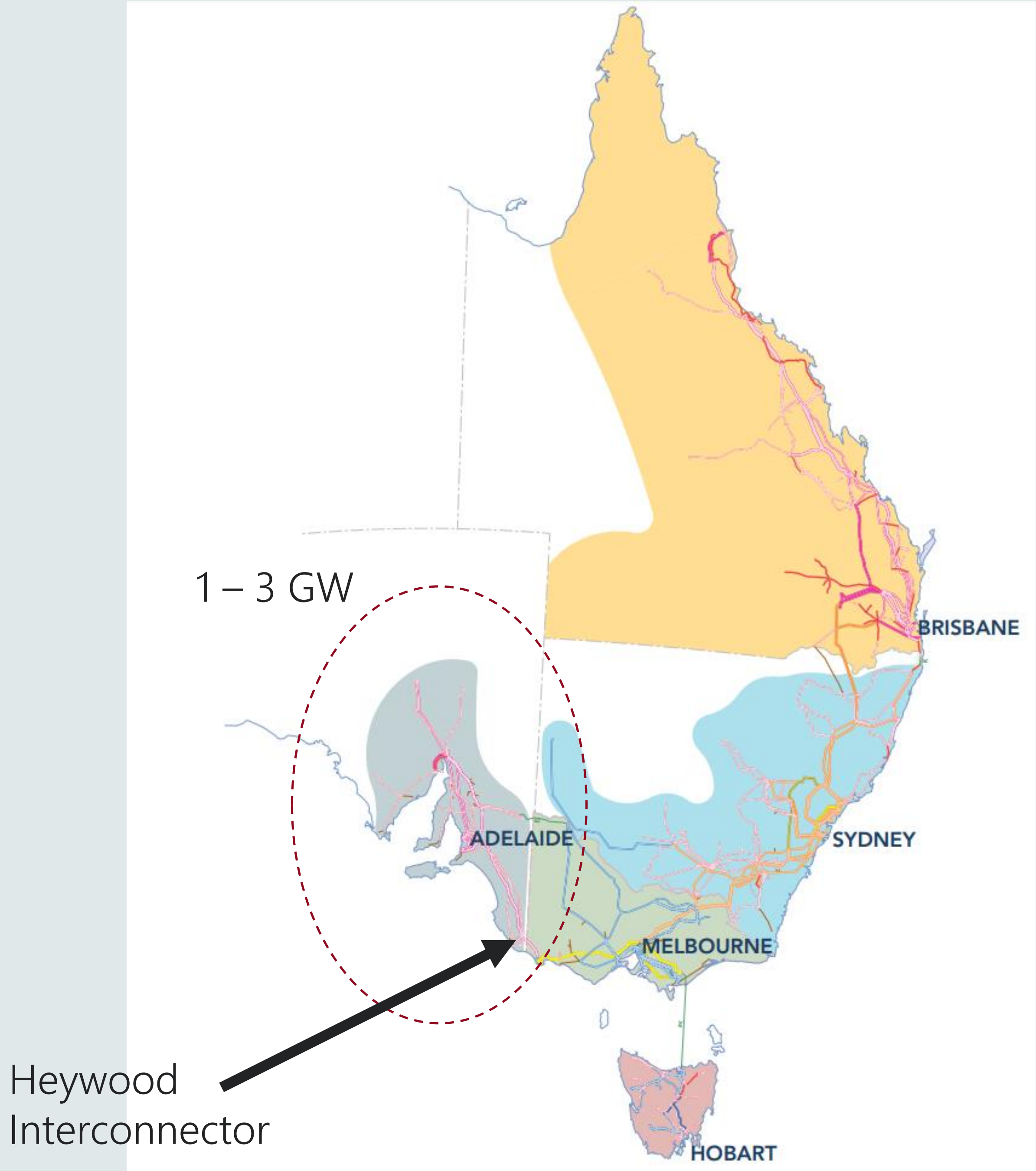
National Electricity Market (NEM)

~85% of electrical load in Australia



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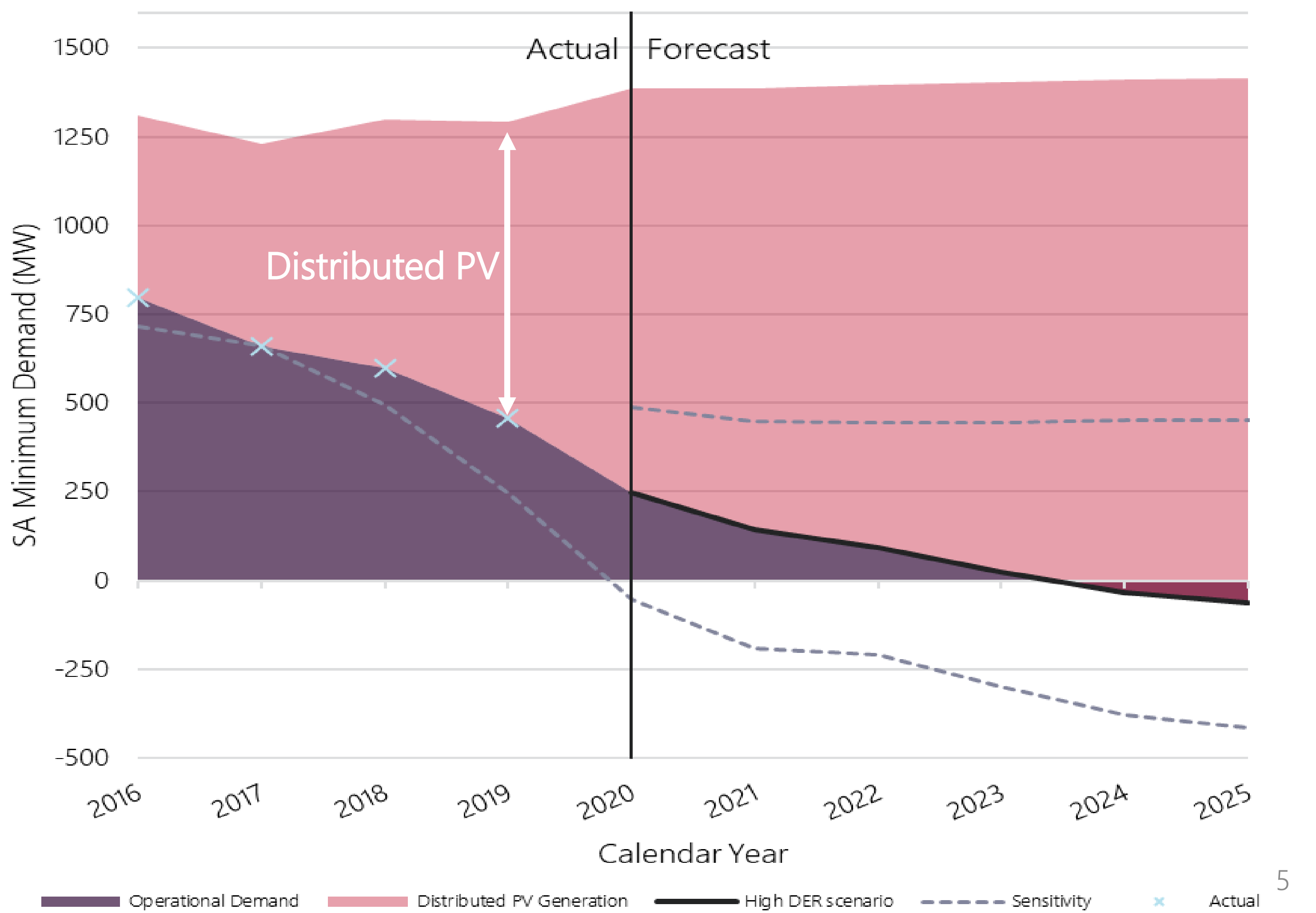
DER integration

- Within 1-3 years, operational demand in South Australia could become negative.
- When and what operational challenges may arise?
- What actions do we need to take now, to ensure we can operate a secure system?

Minimum operational demand in SA



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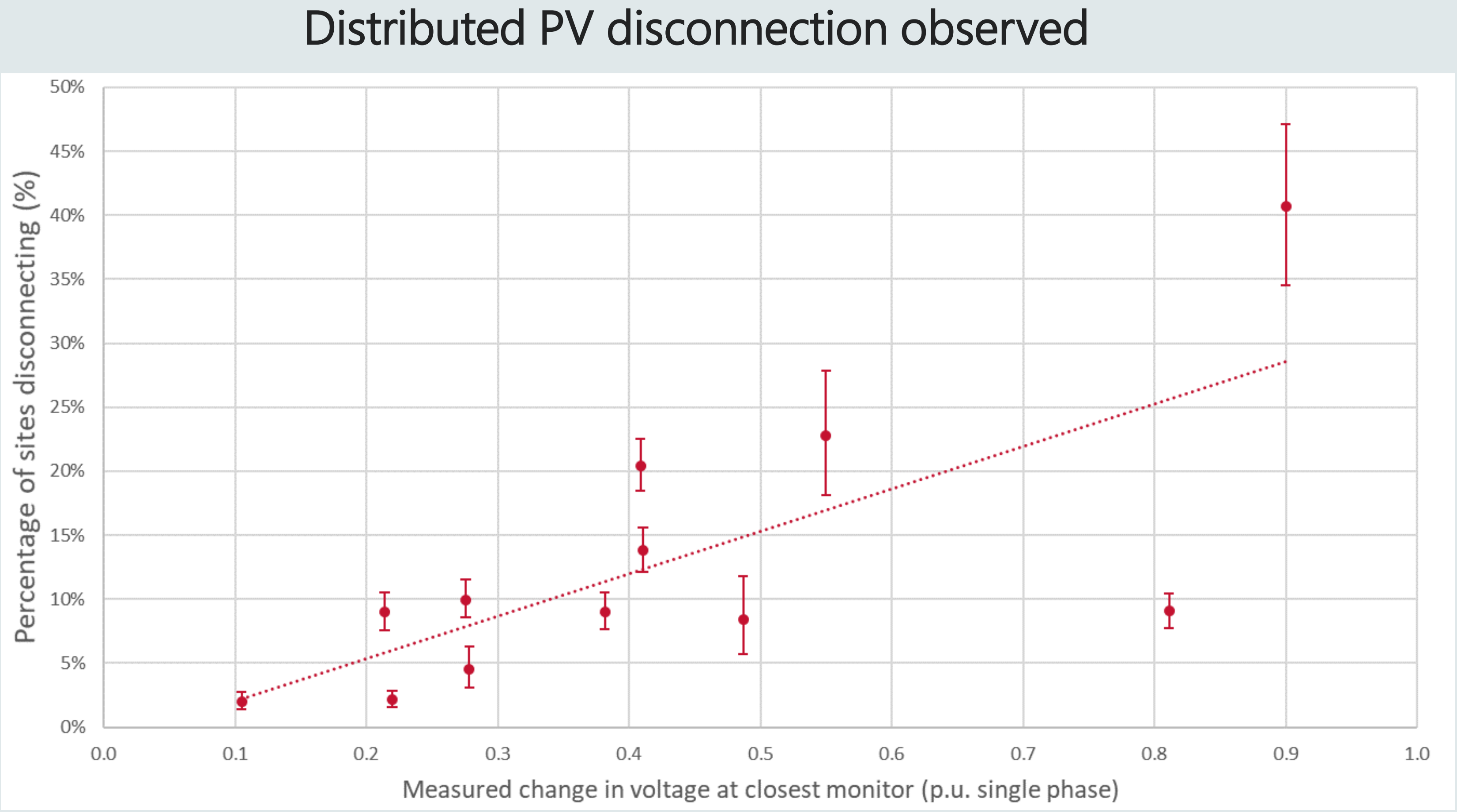
Preliminary findings

Challenges identified:

- Distributed PV disconnection
- Minimum load required to operate necessary units
- Under Frequency Load Shedding

Distributed PV disconnection

- Analysis of PV disconnection based upon data from individual inverters
- Verified by bench testing (ARENA project with UNSW)
- Used to calibrate PSS®E model of DER behaviour



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Distributed PV disconnection

- Severe but credible fault could cause significant disconnection of distributed PV
- Increases largest credible contingency
  - Added to largest generating unit
- When operating as an SA island:
  - Becomes almost impossible to maintain frequency >49 Hz when DER-load loss exceeds ~150 MW (operating in this realm in some periods already)
  - AEMO may no longer have the ability to operate SA in a secure state, if islanding occurs at times of high distributed PV generation
- Issues emerging in VIC/QLD soon

Maximum net PV disconnection

Most severe fault in most severe period

	Calendar year	Central scenario (90% POE)		
		SA	VIC	QLD
Historical	2019	110 (30-210)	-	0 (0-90)
Forecast	2020	170 (80-290)	0 (0-170)	0 (0-260)
	2021	*210 (130-330)*	20 (0-340)	20 (0-330)
	2022	*240 (160-370)*	170 (0-480)	80 (0-390)
	2023	*260 (180-390)*	*310 (90-670)*	*120 (0-440)*
	2024	*290 (200-420)*	*460 (230-790)*	*160 (0-490)*

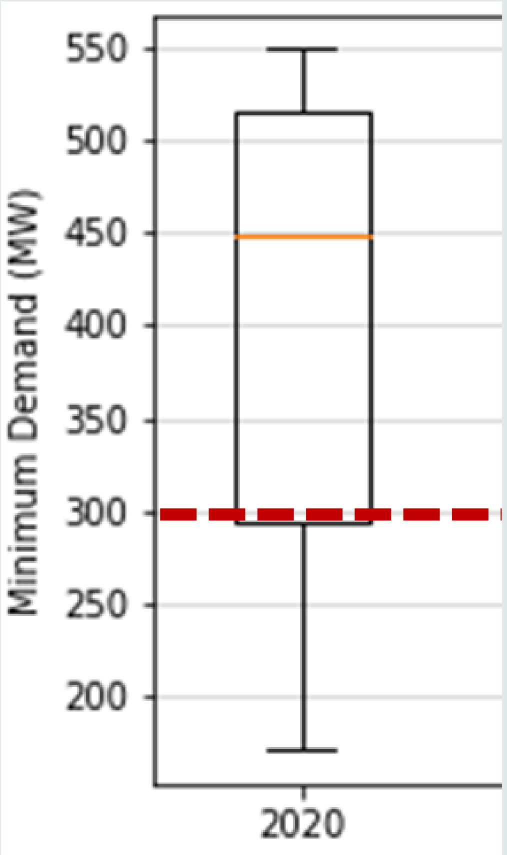
Measures to manage PV disconnection

1. Improve DER standards (AS4777)
2. Accelerated voltage ride-through test in SA
3. Improve compliance with standards
4. Collaborate with DNSPs on connection requirements
5. Project EnergyConnect (SA - NSW)
6. Network constraints

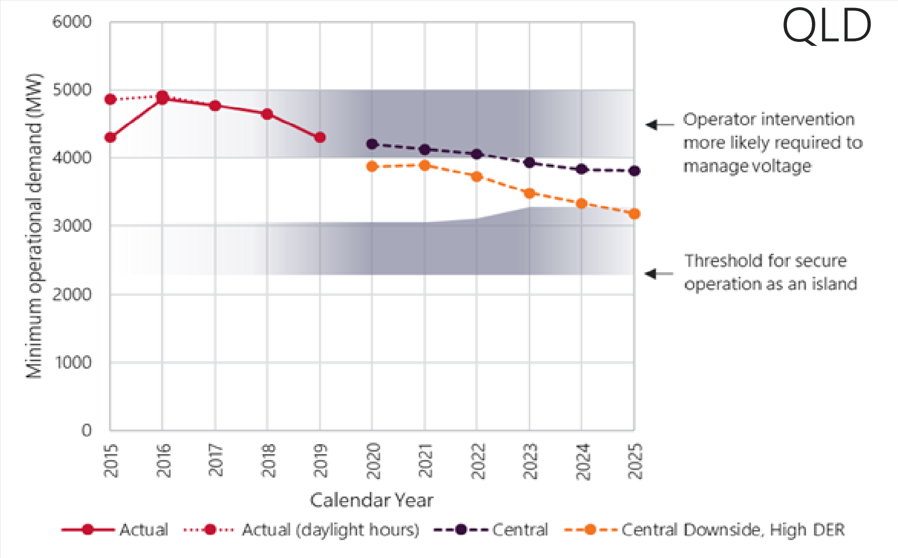
Minimum demand thresholds

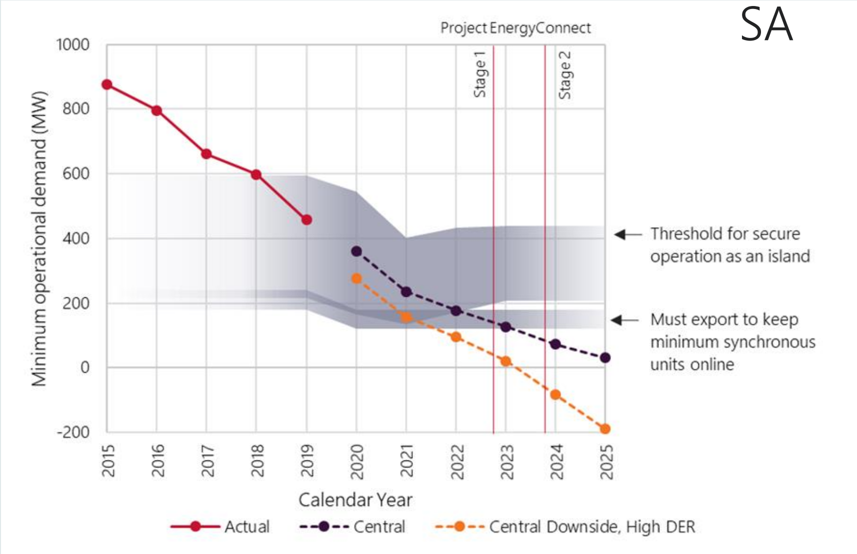
- **Islanded operation:** Need adequate load to operate necessary units for system strength, inertia, frequency control and voltage management
- Lowest operational demand experienced: 300 MW (October 2020)

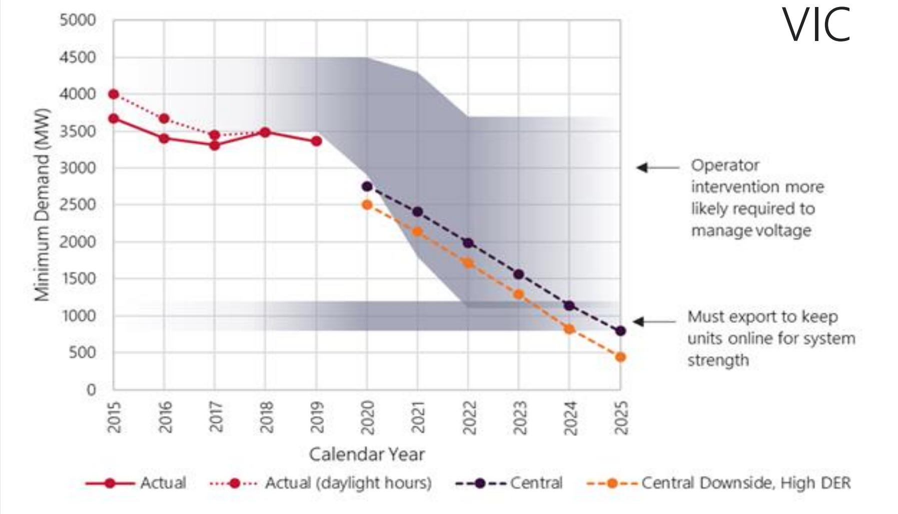
Minimum operational demand in SA

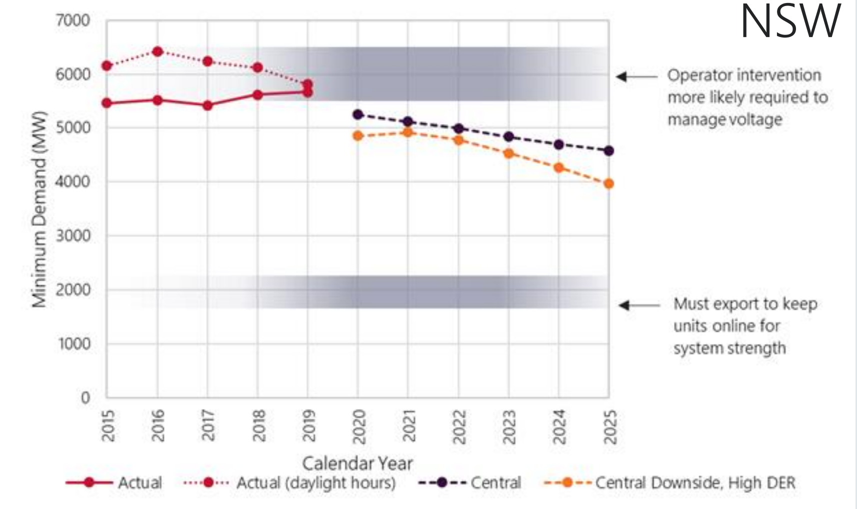


Minimum demand thresholds





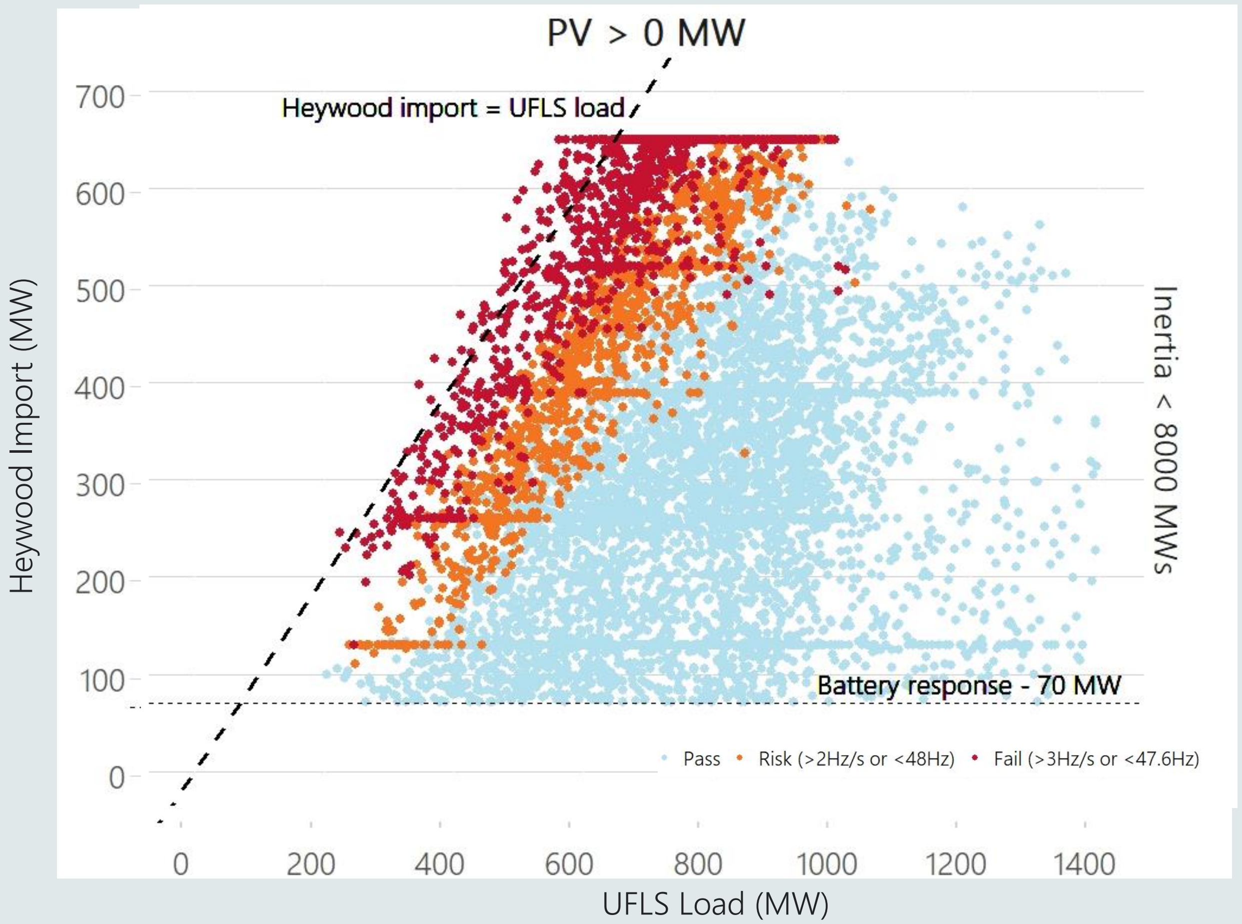




- Action required urgently in SA and VIC, and promptly in QLD
- NEM-wide adoption of disturbance ride-through capabilities and emergency PV shedding capabilities recommended
- Opportunities for stakeholders in providing services in DER aggregation, load shifting, storage, frequency control

Under Frequency Load Shedding

- UFLS is our "safety net", designed to arrest severe under-frequency events
  - Separation events
  - Multiple contingency events
- Involves controlled disconnection of load in less than a second
- Security challenges identified:
  1. Reducing net load
  2. Reverse flows
  3. Distributed PV disconnection
- Actions:
  - Increase UFLS load
  - Dynamic arming of UFLS relays
  - Heywood constraint
  - NER review



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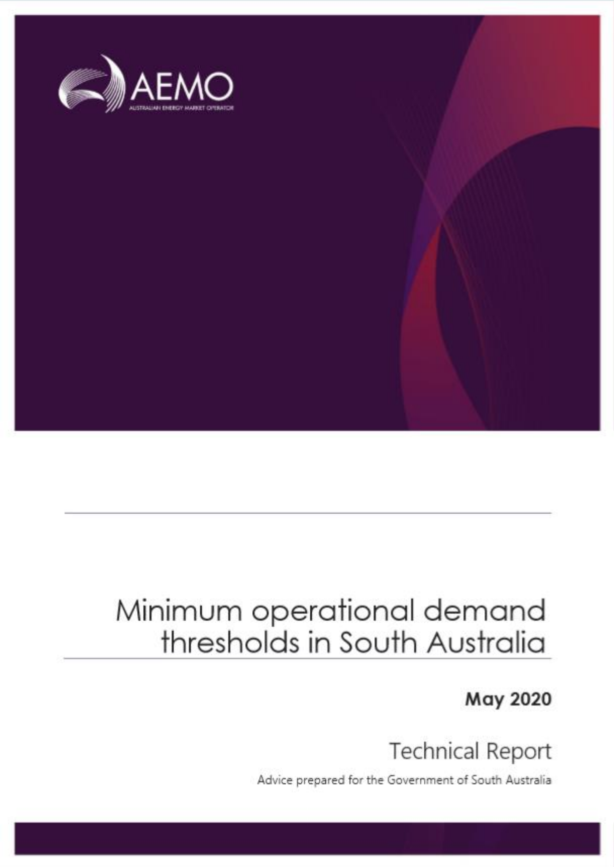
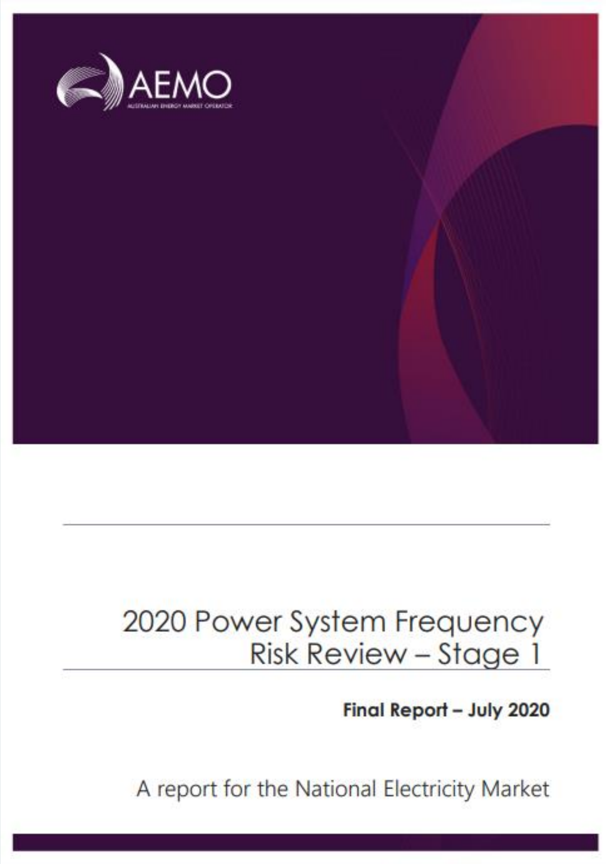
Next steps

- Collaboration with stakeholders on design and implementation of mitigation actions
- Analysis ongoing
- Continuing development of tools and data

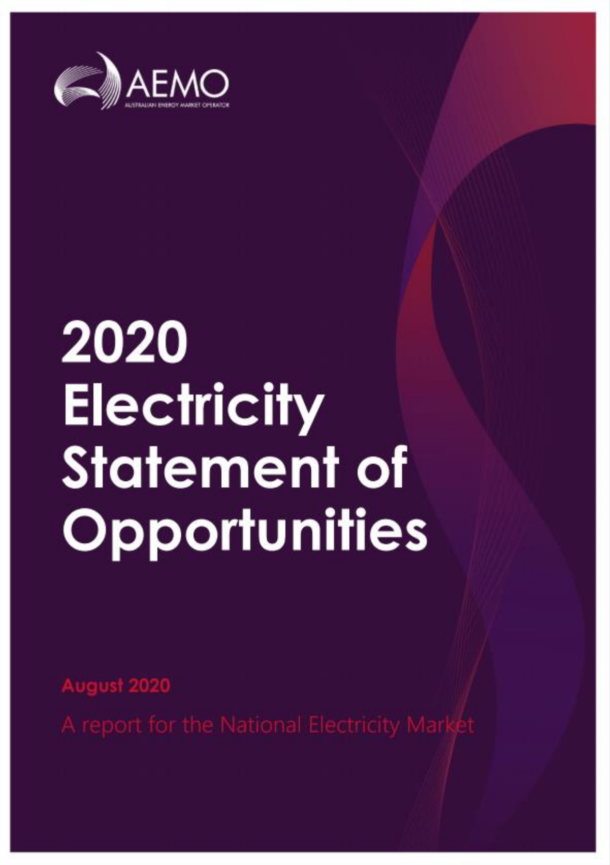
For further information:



https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/sa_advisory/2020/minimum-operational-demand-thresholds-in-south-australia-review.pdf?la=en



Appendix A, at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2020/psfrr/final-2020-power-system-frequency-risk-review-stage-1.pdf?la=en&hash=C1EA01AAC28C7DF0D4F69700B8FC439B



https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2020/2020-electricity-statement-of-opportunities.pdf?la=en&hash=85DC43733822F2B03B23518229C6F1B2

Accelerating Voltage ride-through capability

South Australian Requirements

Voltage Ride-Through Challenges

Issue

- Severe but credible fault could cause significant disconnection of distributed PV
- In SA, if islanding occurs during high PV generation we may not be able to operate SA in a secure state.
- Whilst there is a current review of AS/NZS4777.2 underway, the timing is insufficient.

Current AS/NZS4777.2:2015 requirements

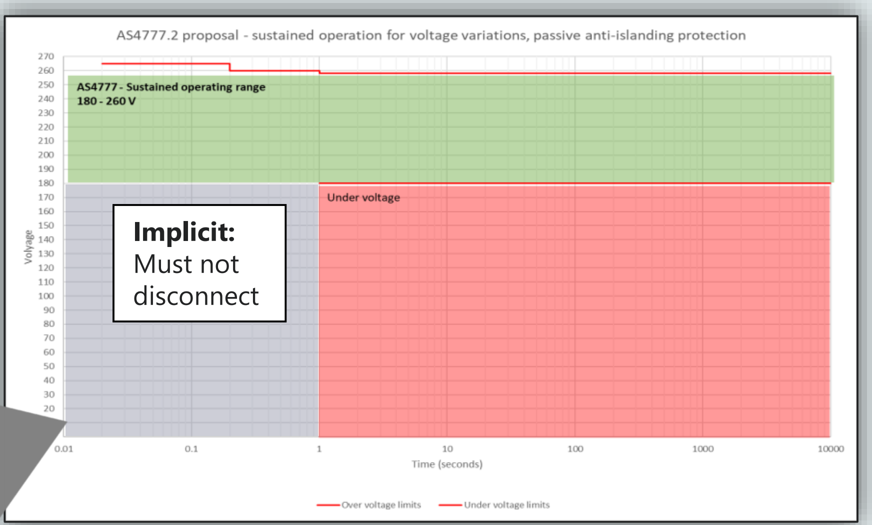
TABLE 13

PASSIVE ANTI-ISLANDING SET-POINT VALUES

Protective function	Protective function limit	Trip delay time	Maximum disconnection time
Undervoltage (V<)	180 V	1 s	2 s
Overvoltage 1 (V>)	260 V	1 s	2 s
Overvoltage 2 (V>>)	265 V	—	0.2 s
Under-frequency (F<)	47 Hz (Australia) 45 Hz (New Zealand)	1 s	2 s
Over-frequency (F>)	52 Hz	—	0.2 s

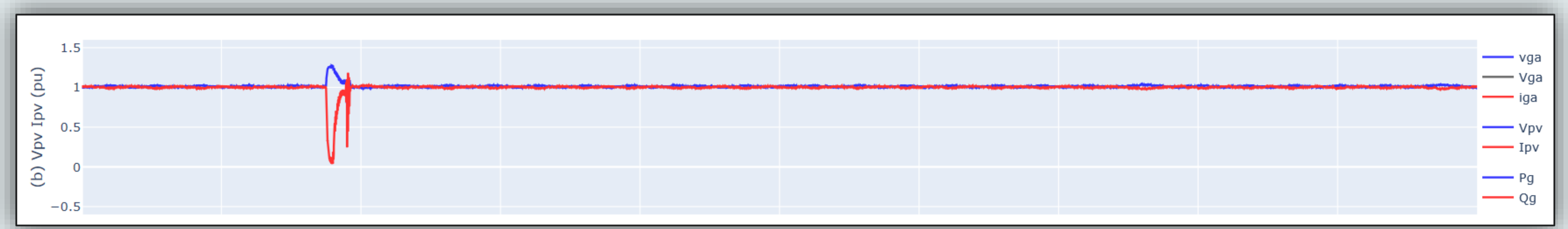
NOTE 1: When voltage falls below the undervoltage limit of Table 13 it is permissible to continue, reduce or stop the inverter output during the trip time delay and if voltage returns above the limit during the trip time delay period it may resume normal operation.

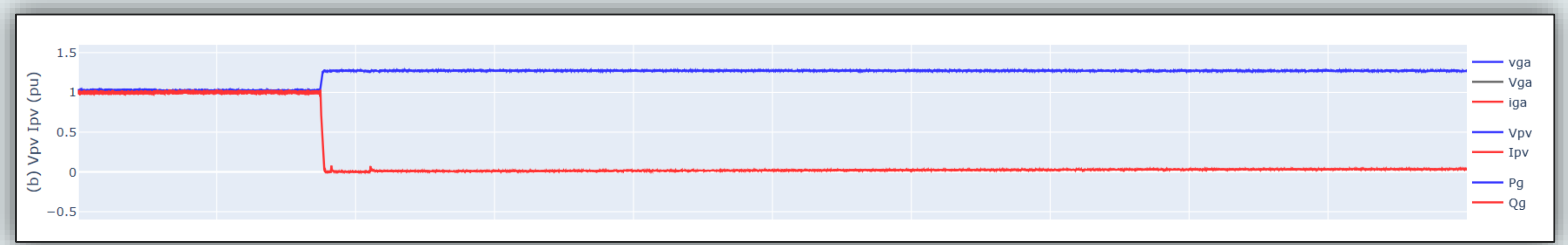
- The area in grey indicates where inverters are expected to stay connected based on AS/NZS 4777.2:2015 but has not been tested for.



Inverter Voltage Performance bench test

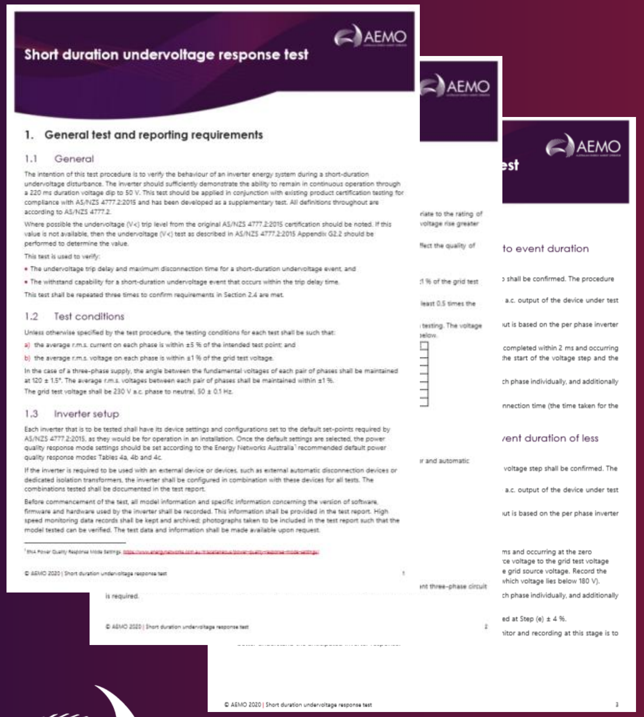
- Bench Testing has identified that 10 of 17 inverters that meet AS/NZS 4777.2:2015 requirements perform correctly during short duration undervoltage disturbances.





- Offers a solution – whereby we define a test that identifies the subset of inverters that already meet these requirements.
  - No development of existing inverters
  - Continued access to a wide-range of products

Working with industry to accelerate requirements


Short duration undervoltage response test

1. General test and reporting requirements

1.1 General

1.2 Test conditions

1.3 Inverter setup

- AEMO developed and consulted on a test procedure that would identify inverters that already demonstrate the preferred behaviour
- AEMO collaborated with industry including the local NSP (SAPN), industry bodies, OEMs, testing houses, SA Government to develop a suitable stop-gap measure that minimises the growing contingency size in SA.

AEMO publishes test report → SA Government develops regulation → Manufacturers provide assurance to SA Government. → Inverters are tested at an accredited lab → SA Government list compliant inverters.

- This process began on 28 September 2020 and compliant inverters are already listed and available.
- Pending timeframes, this option may be considered for the remainder of the NEM through a potential Rule Change that requires Minimum Technical Standards for Distributed Energy Resources.

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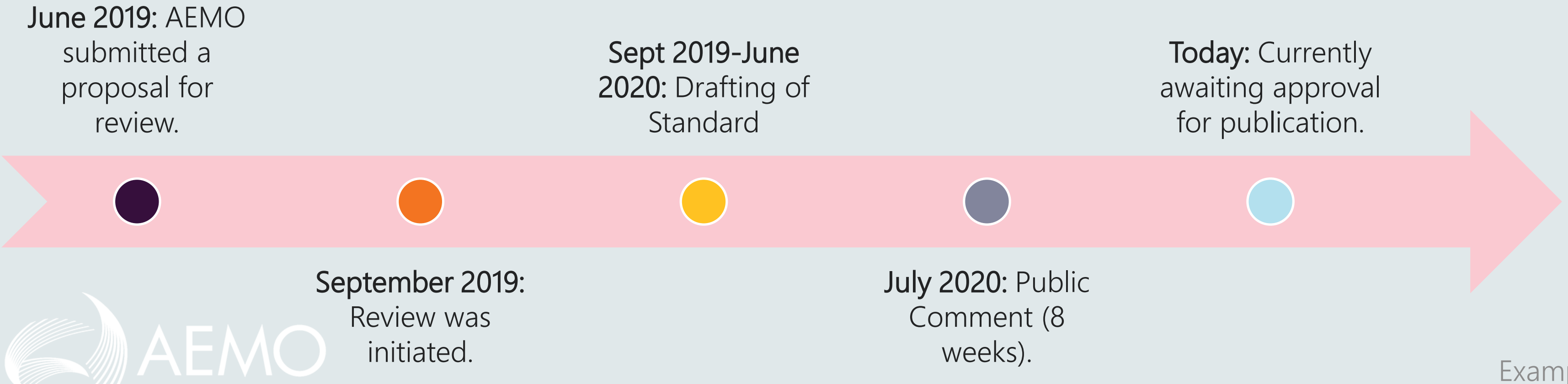
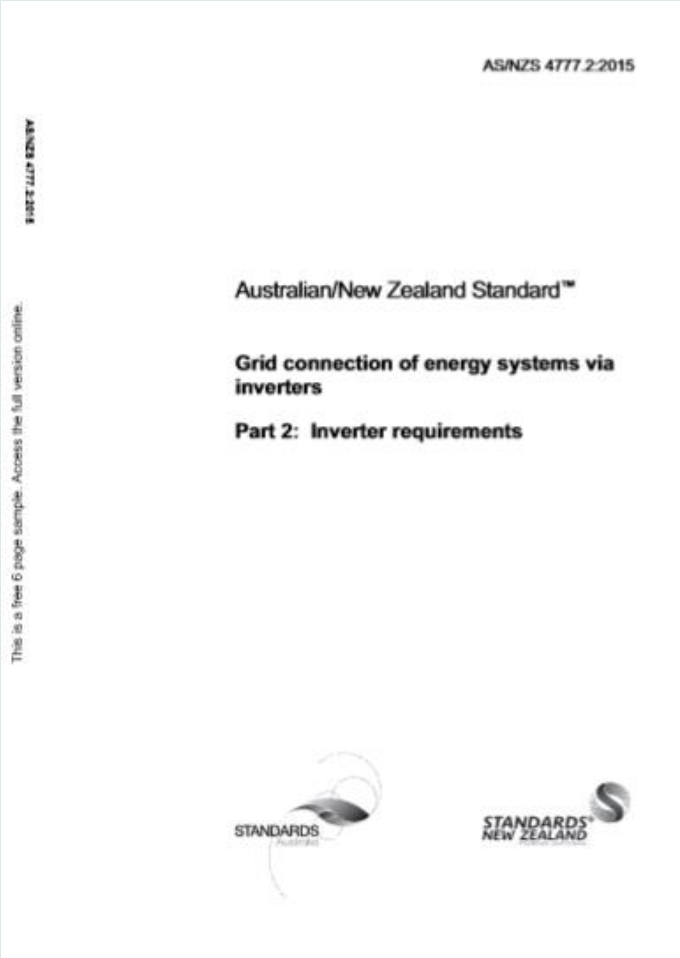
Revising AS/NZS4777.2

Australian Standards for Inverters

Scope and Review of the Standard

- AS/NZS4777.2 is the Australian and New Zealand Standard for the grid-connection of energy systems via inverters. Low-voltage connections only.
- Includes device specifications, functionality, compliance and performance testing for inverters
- The review objective was to align inverter responses with the needs of the power system.





AS/NZS 4777.2:2015

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Australian/New Zealand Standard™

Grid connection of energy systems via inverters

Part 2: Inverter requirements

STANDARDS Australia

STANDARDS NEW ZEALAND

Disturbance withstand capabilities

Proposed changes are intended to:

1. Ensure inverters have a minimum response during disturbances (provision of minimum requirements),

2. Provide immunity to transmission events while maintaining adequate protection from islanding for distribution networks,

3. Define clear zones of operation to provide clarity to manufacturers on the required behaviour and responses of inverters during system conditions.

TABLE 13

PASSIVE ANTI-ISLANDING SET-POINT VALUES

Protective function	Protective function limit	Trip delay time	Maximum disconnection time
Undervoltage (V<)	180 V	1 s	2 s
Overvoltage 1 (V>)	260 V	1 s	2 s
Overvoltage 2 (V>>)	265 V	—	0.2 s
Under-frequency (F<)	47 Hz (Australia) 45 Hz (New Zealand)	1 s	2 s
Over-frequency (F>)	52 Hz	—	0.2 s

Protective function	Protective function limit	Trip delay time	Maximum disconnection time
Undervoltage 2 (*V* <<)	70 V	1 s	2 s
Undervoltage 1 (*V* <)	180 V	10 s	11 s
Overvoltage 1 (*V* >)	265 V	1 s	2 s
Overvoltage 2 (*V* >>)	275 V	—	0.2 s

DRAFT

Voltage limits	Inverter response
> 260 V	Cease power generation
180 V to 260 V	Continuous operation
< 180 V	Cease power generation

DRAFT

	Region	Australia A	Australia B	Australia C	New Zealand
Under-frequency 1 (*F* <)	Protective function set point	47 Hz	47 Hz	45 Hz	45 Hz
	Trip delay time	1 s	1 s	5 s	1 s
	Maximum disconnection time	2 s	2 s	6 s	2 s
Over-frequency 2 (*F* >>)	Protective function set point	52 Hz	52 Hz	55 Hz	55 Hz
	Trip delay time	—	—	—	—
	Maximum disconnection time	0.2 s	0.2 s	0.2 s	0.2 s

DRAFT

Excerpts have been taken from the Public Draft version of AS/NZS4777.2 (available from 9 July 2020 to 10 September 2020). This draft is liable to alteration and is not regarded as an Australian/New Zealand Standard until the final issue.

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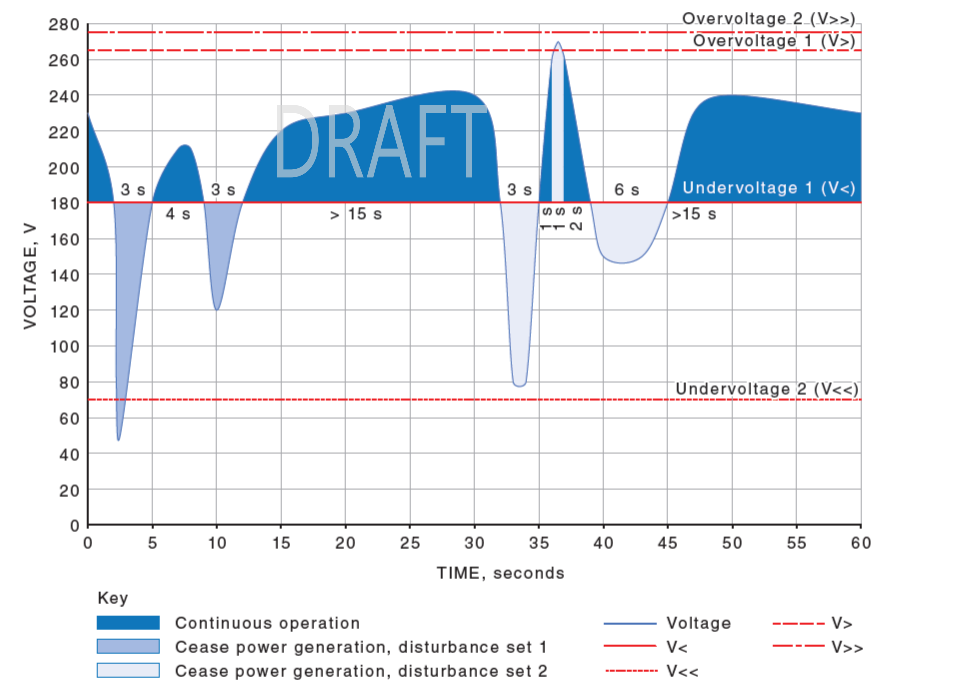
Disturbance withstand capabilities

Proposed changes are intended to:

- Align their expected response to disturbances (as much as possible) to large-scale generators and International Standards,
- Ensure inverters have a minimum response during disturbances (provision of minimum requirements)

Multiple Voltage Disturbances



Phase Angle Jumps

	Single-phase disturbance	Three-phase disturbance
Single-phase inverter	60°	—
Three-phase inverter	60°	20°

RoCoF

The inverter shall maintain continuous operation for frequency excursions with a rate of change of frequency (ROCOF) that do not exceed ±4.0 Hz/s for a duration of 0.25 s.

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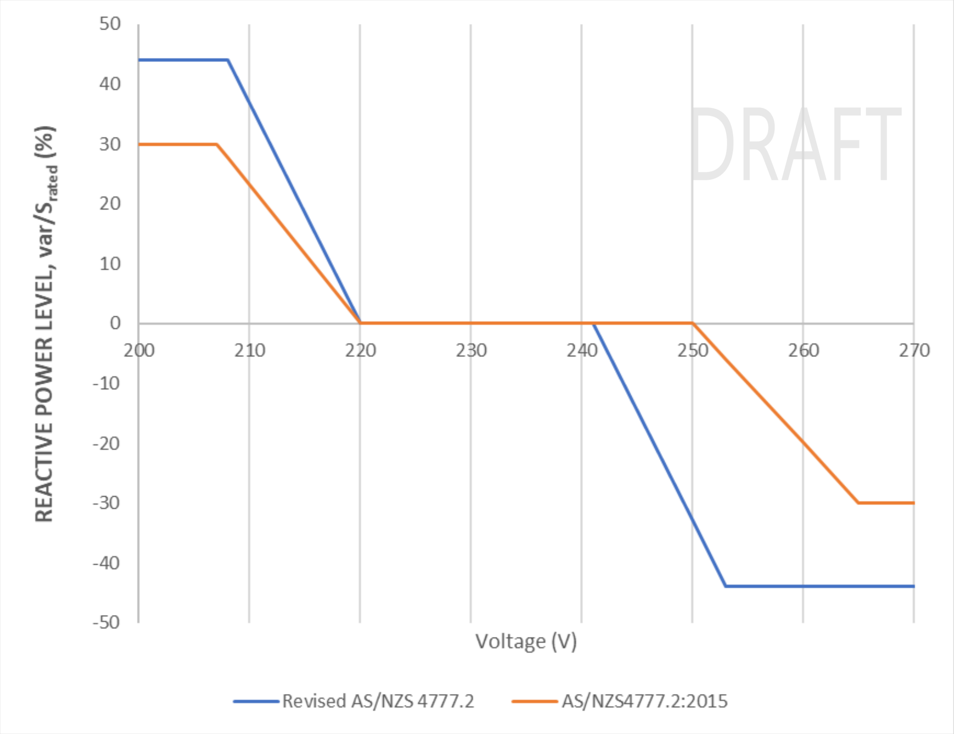
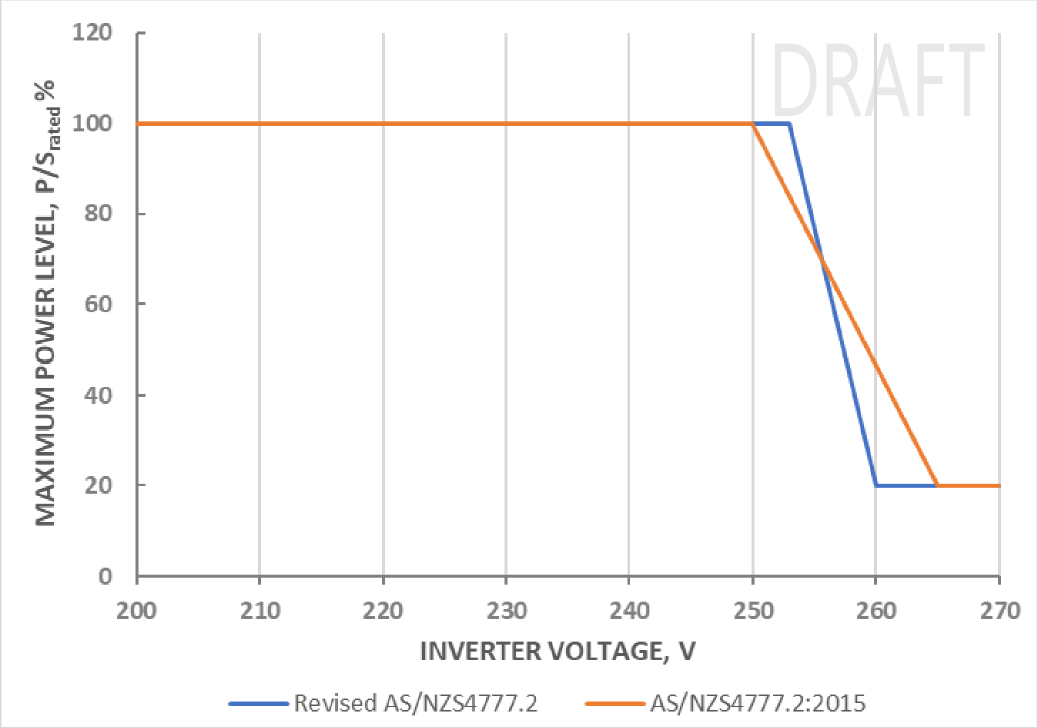
Power Quality Modes – Volt-var and Volt-watt

Proposed changes are intended to:

- Align expected response to International Standards (where applicable),
- Provide an autonomous response to local voltage management issues and maintain the grid within technical limits,
- Increase hosting capacity of distribution network feeders





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Over and Under Frequency Response

AS/NZS 4777.2:2015 already includes provision for inverters:

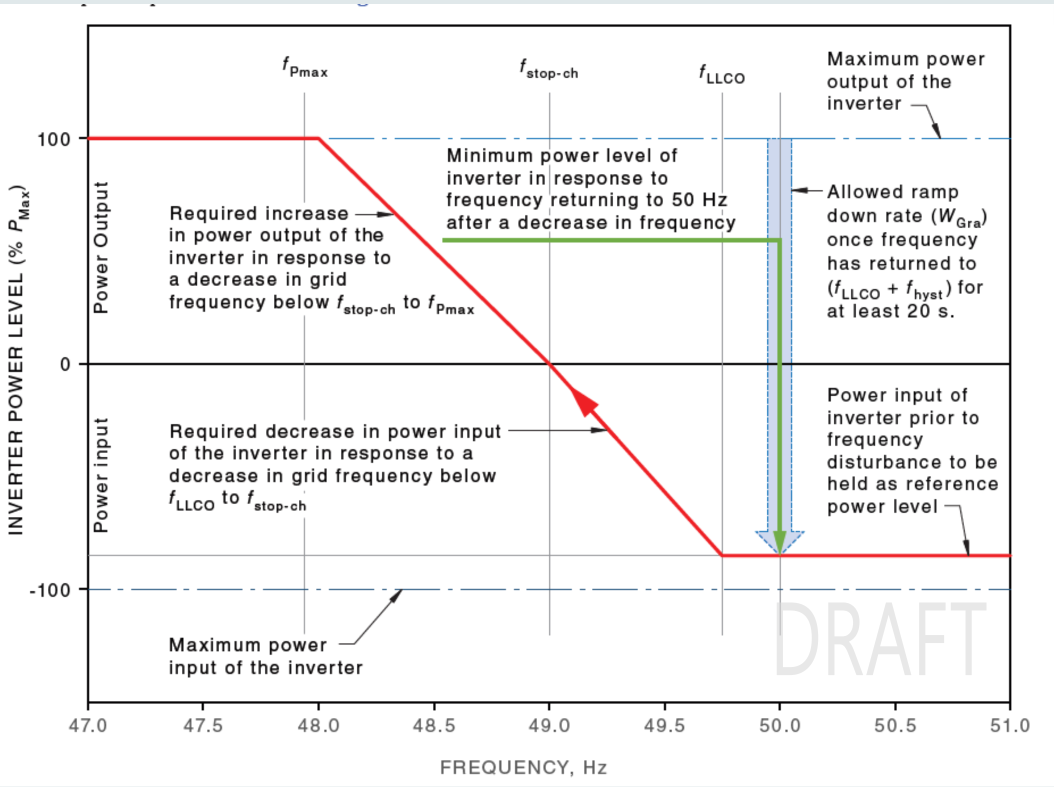
- to reduce output in response to an increase in frequency events
- with energy storage to reduce charging in the event of decrease in frequency events

Proposed changes such that inverters also:

- increase charging in response to increase in frequency events (very high frequency)
- increase output in response to decrease in frequency events for inverters that are curtailed
- increase discharging in response to decrease in frequency events (very low frequency)

Proposed changes are intended to:

To ensure that for contingency events that are outside the normal planning levels, all capable and connected plant responds in a way to ensure the situation is not exacerbated and is supported through the recovery and restoration process.



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Testing and Measurement Accuracy

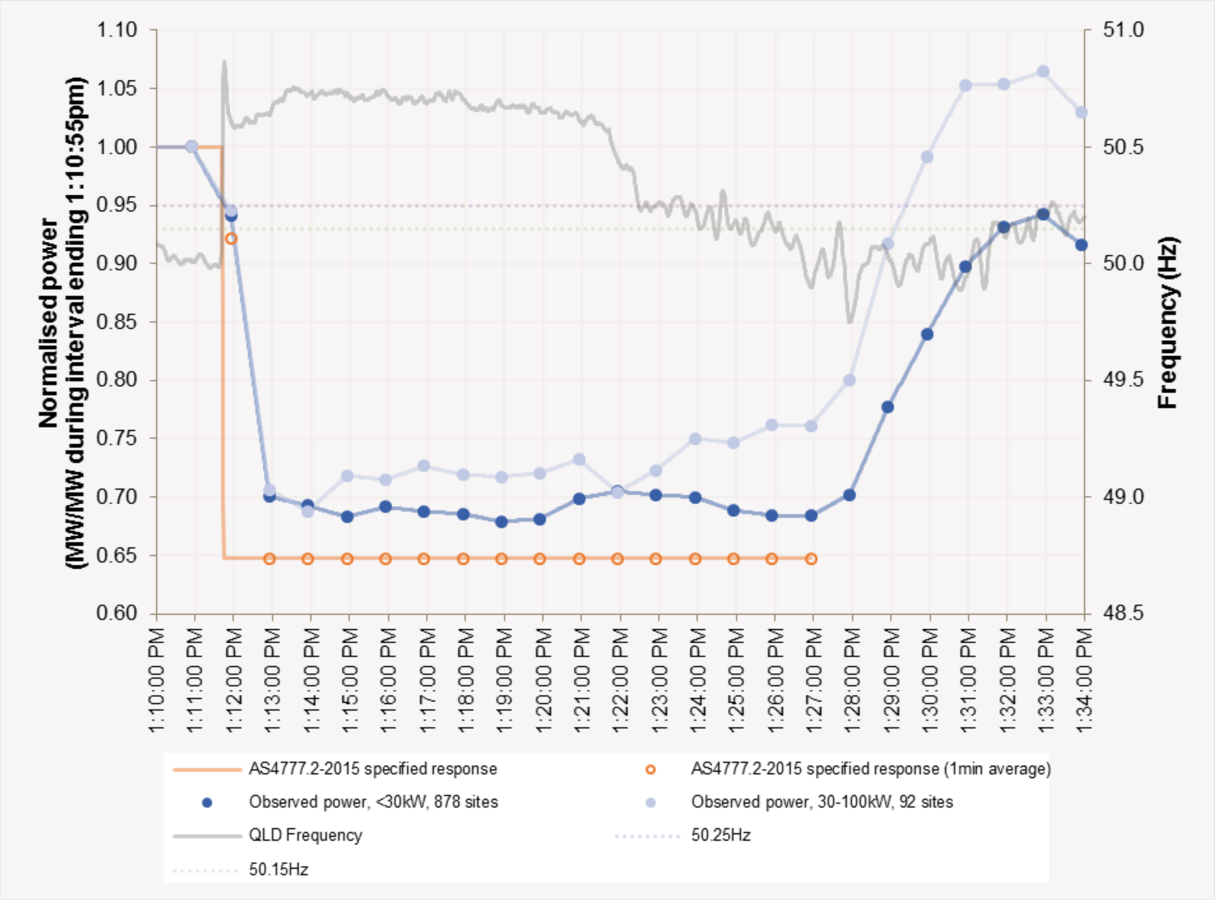
Proposed changes are intended to:

- Provide minimum requirements for system measurement and control (provides certainty to inverter response),
- Optimise DER responses so they do not cause control system instability,
- Provide degree of certainty to AEMO on the expected response of the DER generation fleet (to incorporate into our models).

Quantity	Measurement accuracy	Measurement time	Measurement range
Voltage	±1 % $V_{nominal}$	100 ms	0 to 280 V
Frequency	±10 mHz	100 ms	45 to 55 Hz
Active power	±4 % S_{rated}	200 ms	0 to 120 % S_{rated}
Reactive power	±4 % S_{rated}	200 ms	0 to ±120 % S_{rated}
Apparent power	±4 % S_{rated}	200 ms	0 to ±120 % S_{rated}
NOTE For the purposes of measurement accuracy, $V_{nominal}$ refers to 230 V of AS 60038.			

Excerpts have been taken from the Public Draft version of AS/NZS4777.2 (available from 9 July 2020 to 10 September 2020). This draft is liable to alteration and is not regarded as an Australian/New Zealand Standard until the final issue.

Separation event 25 Aug 2018:



Analysis by Naomi Stringer, UNSW Sydney
Data from Solar Analytics

Other related work

- Compliance
- Medium Voltage Connections
- Governance Review
- Minimum DER Technical Standards
- Interoperability

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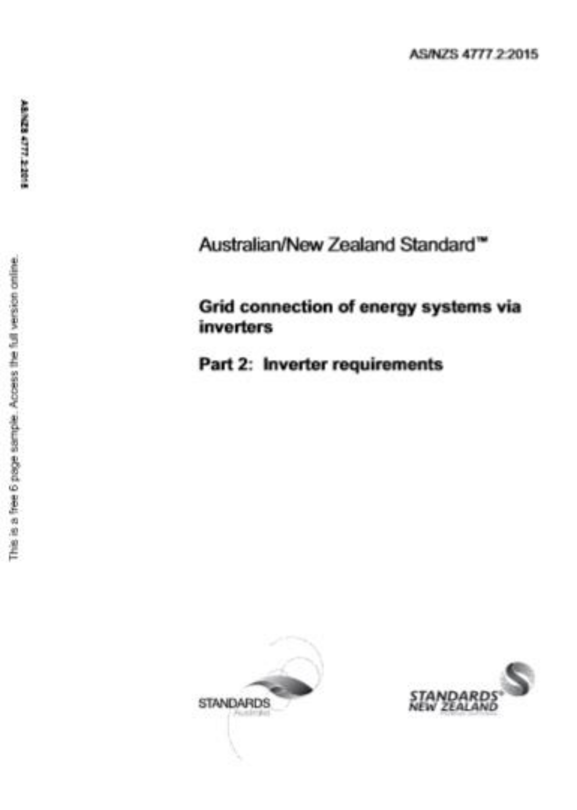
For Further Information



AS/NZS 4777.2:2015

Australian/New Zealand Standard™

Grid connection of energy systems via inverters

Part 2: Inverter requirements

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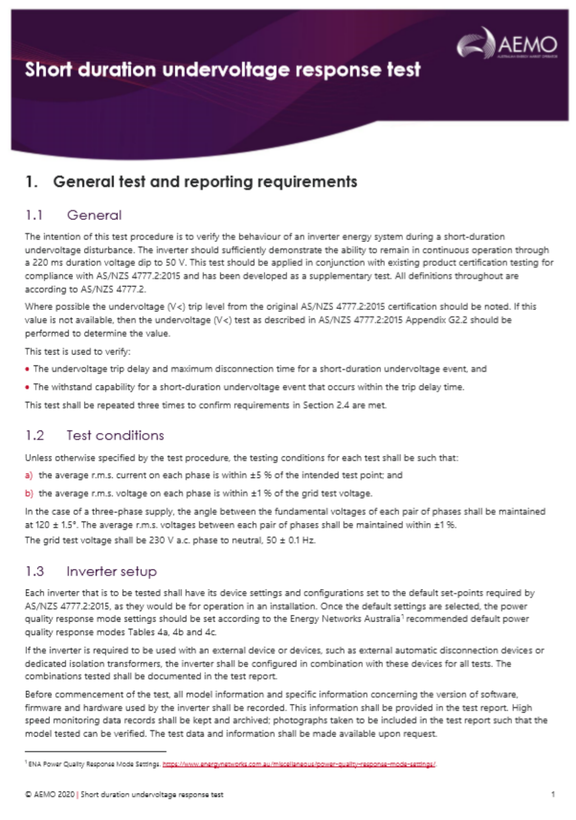
[AS/NZS4777.2 Review](#)



Short duration undervoltage response test

1. General test and reporting requirements

1.1 General

The intention of this test procedure is to verify the behaviour of an inverter energy system during a short-duration undervoltage disturbance. The inverter should sufficiently demonstrate the ability to remain in continuous operation through a 220 ms duration voltage dip to 50 V. This test should be applied in conjunction with existing product certification testing for compliance with AS/NZS 4777.2:2015 and has been developed as a supplementary test. All definitions throughout are according to AS/NZS 4777.2.

Where possible the undervoltage (V<) trip level from the original AS/NZS 4777.2:2015 certification should be noted. If this value is not available, then the undervoltage (V<) test as described in AS/NZS 4777.2:2015 Appendix G2.2 should be performed to determine the value.

This test is used to verify:

- The undervoltage trip delay and maximum disconnection time for a short-duration undervoltage event, and
- The withstand capability for a short-duration undervoltage event that occurs within the trip delay time.

This test shall be repeated three times to confirm requirements in Section 2.4 are met.

1.2 Test conditions

Unless otherwise specified by the test procedure, the testing conditions for each test shall be such that:

a) the average r.m.s. current on each phase is within ±5 % of the intended test point; and

b) the average r.m.s. voltage on each phase is within ±1 % of the grid test voltage.

In the case of a three-phase supply, the angle between the fundamental voltages of each pair of phases shall be maintained at 120 ± 1.5°. The average r.m.s. voltages between each pair of phases shall be maintained within ±1 %.
The grid test voltage shall be 230 V a.c. phase to neutral, 50 ± 0.1 Hz.

1.3 Inverter setup

Each inverter that is to be tested shall have its device settings and configurations set to the default set-points required by AS/NZS 4777.2:2015, as they would be for operation in an installation. Once the default settings are selected, the power quality response mode settings should be set according to the Energy Networks Australia[1] recommended default power quality response modes Tables 4a, 4b and 4c.

If the inverter is required to be used with an external device or devices, such as external automatic disconnection devices or dedicated isolation transformers, the inverter shall be configured in combination with these devices for all tests. The combinations tested shall be documented in the test report.

Before commencement of the test, all model information and specific information concerning the version of software, firmware and hardware used by the inverter shall be recorded. This information shall be provided in the test report. High speed monitoring data records shall be kept and archived; photographs taken to be included in the test report such that the model tested can be verified. The test data and information shall be made available upon request.

[1] ENA Power Quality Response Mode Settings. https://www.energynetworks.com.au/miscellaneous/power-quality-response-mode-settings/.

 1

[AEMO Short Duration Voltage Ride Through Test Procedure](#)

[SA Office of the Technical Regulator Voltage Ride Through Regulatory Changes](#)

[AEMC Minimum Technical Standards for DER](#)

[ESB DER Governance Review](#)

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