Compliance of Distributed Energy Resources with Technical Settings

April 2023

Compliance to AS/NZS4777.2

A technical report for Australia

Important notice

Purpose

The purpose of this report is to describe the current state of compliance of Distributed Energy Resources (DER) with technical settings, focussing on compliance of distributed photovoltaic (DPV) inverters with AS/NZS4777.2. The report outlines the potential implications of non-compliance with the technical standards and provides insights towards improving compliance. AEMO is seeking feedback on the data and analysis shared, and the recommendations proposed.

AEMO has prepared this report to meet our responsibility under clause 4.3.1 (n) of the National Electricity Rules (NER) to refer to Registered Participants as AEMO deems appropriate, information of which AEMO becomes aware in relation to significant risks to the power system where actions to achieve a resolution of those risks are outside the responsibility or control of AEMO.

This publication has been prepared by AEMO using data available and observations made at different times as indicated in the document, and other information available to AEMO as at December 2022.

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Much of the work outlined in this report was supported by funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Project MATCH (Monitoring and Analysis Toolbox for Compliance in a High DER future). The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Version control

Version	Release date	Changes
1	27/04/2023	Initial release

Executive summary

This report describes the state of compliance[1] of distributed energy resources (DER) with technical settings, and impacts of non-compliance, focussing on compliance of distributed photovoltaic (DPV) inverters to AS/NZS4777.2[2] in Australia. It aims to:

- Summarise evidence on the nature and scale of DER non-compliance;
- Highlight the importance and urgency of improving DER compliance; and
- Share insights that may inform improvements to governance frameworks for managing DER compliance.

In recognition of the complex challenges for DER compliance in Australia, this document does not attempt to propose definitive solutions. Instead, recognising the need for input from diverse stakeholders to solve this complex problem, this document aims to provide a strong foundation to support ongoing industry efforts to identify and implement solutions to improve DER compliance.

The information provided in this report is intended to support and complement the Australian Energy Market Commission's (AEMC) review into consumer energy resources technical standards[3].

Any stakeholders that are interested in collaborating with AEMO on matters related to compliance with technical standards or providing feedback on the data, analysis and insights outlined in this report please contact DERProgram@aemo.com.au.

Quantifying compliance

Evidence of DER compliance has been collected from a range of sources, with key findings to date summarised in Table 1. Numbers in red highlight the percentage of systems found to be non-compliant. Numbers in green highlight the percentage of systems found to be compliant.

Table 1 Quantifying compliance

Source	Details of investigation	Key findings
Laboratory testing of individual inverters	• Laboratory testing of individual DPV inverters to examine disturbance ride-through capabilities and confirm whether behaviour is consistent with what is defined in standards. • Tests conducted for 20 inverters developed against the AS/NZS4777.2:2015 standard and 12 inverters developed against the AS/NZS4777.2:2020 standard to date.	• When configured properly to the 2020 standard (AS/NZS4777.2:2020), all the tested inverters appear to be designed appropriately to deliver the required disturbance ride-through behaviours to support power system security. • Original Equipment Manufacturers (OEMs) appear to design their products to meet the requirements defined in the test procedures (outlined within the standard as a requirement for listing as an approved product). Where there are additional specifications in the body of the standard that are not specifically tested for in that process, compliance can be poor. • Many OEM products have complex menus and setup processes that can make it difficult for installers to set the inverter to the applicable standard.

[1] Throughout this report, the term 'compliance' is used to capture the technical settings requirements across the supply chain. This broad term is intended to encapsulate the requirements at manufacture to Standard, setting selection at install, and ongoing behaviour after install.

[2] AS/NZS4777.2 is a standard for the grid-connection of small-scale inverters. AEMO put forward a review to raise the performance requirements, with a major focus on improving the inverter's disturbance ride-through capabilities. The new Standard AS/NZS4777.2:2020 was published on 18 December 2020, and became mandatory for all new installations in Australia one year later.

[3] AEMC Review into consumer energy resources technical standards. Available at: https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards

Source	Details of investigation	Key findings
Clean Energy Regulator (CER) on-site audits	• On-site inspections by CER auditors conducted for 1-2% of DPV installations in the NEM, randomly selected from installations completed in the previous 12 months. • Technical settings were investigated in audits conducted in 2019 and 2020 (auditing systems installed one year prior), of systems installed across Australia against the applicable Standard at the time of install (the 2015 Standard).	• **55%** of inverters with visible settings had settings that were incorrect in some way. • Only **28%** of inverters with visible settings could be confirmed to have the correct settings applied. • The remaining 17% of inverters were partially correct or some settings were not visible. • For around half the inverters, the auditor was unable to confirm what settings were applied.
Post disturbance analysis of DER behaviours	• Post event analysis of the behaviour of individual DPV inverters in the field during power system disturbances, investigating whether behaviour is consistent with standards. • Analysis conducted for ~30 different disturbances occurring during 2018 to 2022 in all NEM and WEM regions, based on sample time-series data from thousands of individual inverters.	• When reconnecting to the grid following disconnection, **15-40%** of DPV systems installed under the 2015 standard did not display the required six-minute ramp rate limit to full capacity. • During over-frequency events, **30-50%** of DPV systems installed under the 2015 standard did not display the required over-frequency response. Only **30-50%** of systems are observed to display the required response. The remaining systems either partially respond, disconnect, or are already off at the time of the event. • These findings were consistent across all observed disturbance events, in all NEM and WEM regions.
Volt-VAr power quality assessments	• Assessing whether DPV inverters in the field are correctly delivering the Volt-VAr power quality function (adjusting reactive power as a function of local voltage) as defined in the relevant standard. This includes: – Extensive ongoing analysis by CitiPower/PowerCor/United Energy during 2019 to 2022 based on advanced metering infrastructure (AMI) data. – Analysis by SA Power Networks during 2022 based on AMI data. – Analysis by AEMO during 2022 based on Solar Analytics[4] data. – Analysis by Western Power in the SWIS during 2022 based on AMI data sampling.	• CitiPower/Powercor/United Energy (UE): – When Volt-VAr requirements were introduced in December 2019, compliance was initially measured at only **~10%.** – Compliance with Volt-VAr requirements has gradually increased to **~55-65%** by October 2022. – CitiPower/Powercor/UE have implemented a range of initiatives which have likely contributed to these improvements. These include working with selected OEMs to remotely rectify incorrect sites; updating their Model Standing Offer to ensure customer consent for settings updates and introducing commissioning checklists for installers; education programs for installers. • SA Power Networks (SAPN): – **~70%** of sites do not appear to perform the required Volt-VAr behaviour. – Some OEM products appear to perform better than others. The poorest performing OEM demonstrated **~3%** compliance. – Comparison with OEM polling of individual site settings shows Volt-VAr methods correctly identified 70% of non-compliant inverters. This provides a good starting point in identifying non-compliance, but cannot be relied on as the sole approach for detecting non-compliant installations. • AEMO and Project MATCH[5] analysis of Solar Analytics datasets: – **~70%** of sites do not appear to perform the required Volt-VAr behaviour. • Western Power (WP): – **~70%** of a sample of sites from one OEM were identified to not perform the required Volt-VAr behaviour.

[4] Solar Analytics is a software company that provides solar home energy management and data services. Data used for this report is derived from Solar Analytics monitoring devices designed and manufactured by internet of things (IoT) company Wattwatchers.

[5] Project MATCH is an ARENA funded collaboration between AEMO, UNSW Sydney and Solar Analytics seeking to establish a monitoring and analysis toolbox to better understand the behaviour of DER and implications for power system security. See https://www.ceem.unsw.edu.au/project-match

Source	Details of investigation	Key findings
Manufacturer (OEM) reporting of settings applied (remote polling)	• Some OEMs have remote visibility of the technical settings applied to their products in the field. • Ten OEMs supplied some kind of remote polling data to AEMO, with four OEMs supplying data on their entire internet connected fleet. • Data provided to AEMO represents in aggregate ~70% of the market share of new installations in Q1 2022.	• OEM polling data, weighted by market share, indicates that **~37%** of the fleet in the NEM installed in Q1 2022 were configured with the correct AS/NZS4777.2:2020 grid code at the time of installation. • Where settings were incorrect, the majority had the older 2015 standard applied. Approximately 5-7% of installations were set to various international grid codes. • Compliance rates differ significantly by OEM. The poorest performing OEM showed compliance of only **10%,** while the highest performing OEM showed compliance of almost **100%**. • Some OEMs can remotely update settings for inverters in the field. If OEMs voluntarily utilise this where already possible, compliance could be increased to **~45%** of new installations in the NEM. • To improve compliance in the field, ten OEMs (that represent ~70% of the installed fleet in Q1 2022) indicated to AEMO that they would voluntarily revise their product menus to remove legacy grid codes (removing the 2015 standard from the options presented to installers). If implemented, this could improve compliance to **~78%** of new installations, based on present market share estimates. • One OEM's polling data for Western Power sites for Q1 2022 sample indicates that only **23%** were correctly configured. The OEM remotely updated all residential legacy systems to the correct settings and now plans to do the same for legacy commercial systems. Additionally, from beginning of November 2022, a new firmware was made available, removing the 2015 standard grid codes.

The key insights from the body of evidence available at present are:

- When configured properly to the 2020 standard, most inverters appear to be designed appropriately to deliver the disturbance ride-through behaviours necessary to support power system security.
- In the field, compliance with technical settings is poor; a wide range of data sources **consistently indicate that less than half of systems installed are set correctly to the required standard**. This has been observed consistently in measures of compliance to specific settings within the 2015 standard, and also in compliance to the 2020 standard. This suggests significant deficiencies in governance frameworks for monitoring and enforcing compliance with technical settings in the field.
- OEMs have considerable influence over the compliance of their products in the field. Some major OEMs have the ability to remotely view and update settings for the majority of their fleet already installed and can easily and quickly implement changes to product menus (which assists with commissioning of systems yet to be installed). These changes allow them to already achieve close to 100% compliance of their products for new installations. Other OEMs have none of these remote capabilities, can have complex inverter setup processes, and compliance rates for their products can be as low as 3-10% in the field. There are no requirements at present for OEMs to have any of these capabilities[6], or to streamline design of their products to improve compliance in the field, or to engage with industry stakeholders to assist in monitoring and improving compliance of their fleet.
- Some DNSPs are already implementing significant programs of work to monitor and actively improve compliance in their networks. However various DNSPs have raised concerns as, whilst they recognise this issue as significant, they may not have sufficiently comprehensive governance

[6] There are also no requirements to meet any basic cybersecurity requirements.

frameworks to support and efficiently coordinate the required rectification actions to achieve and maintain high rates of compliance.

- In the absence of a clear definition for the roles and responsibilities around technical standards compliance (including monitoring, assessment and enforcement), and given the substantial risk to system security, AEMO has been leading industry engagement nationally on this issue. However, this is limited to voluntary contributions and cooperation. AEMO recognises that the lack of roles and responsibilities limit stakeholders' power to resolve non-compliance.

Implications of poor DER compliance

There is now considerable evidence that many DER products designed and tested to the older 2015 standard (AS/NZS4777.2:2015) can have poor disturbance ride-through characteristics, with up to half the DPV systems in a region being observed to disconnect (or "shake-off") in response to a power system fault[7]. Improved disturbance ride-through capabilities have now been defined in the 2020 standard (AS/NZS4777.2:2020), and preliminary laboratory testing to date suggests that DPV inverters designed and tested to this standard do demonstrate the required ride-through behaviours. The new 2020 standard became mandatory from 18 December 2021.

If compliance with the 2020 standard remains poor, there will be continuing growth in the amount of DPV installed with poor disturbance ride-through capabilities[8]. DPV shake-off can happen coincident with the trip of a large generating unit, increasing the size of credible contingences that must be managed to maintain power system security.

An increase in the size of the largest credible contingency has a series of flow on consequences:

- **Increasing procurement of frequency control services** – Larger contingency sizes increase the need for contingency Frequency Control Ancillary Services (FCAS), inertia and inertia support services such as Fast Frequency Response (FFR), which increases market costs[9]. This can become particularly problematic when attempting to operate parts of the grid that can island, such as South Australia or Queensland, where contingency sizes can rapidly exceed the total amount of frequency services available in the island. Similarly, in the WEM, during periods of high PV generation the Spinning Reserve Requirements (SRR) increase by 1 to 1.5 MW for every 10 MW of non-compliant DPV.
- **Increased need for DPV curtailment** – When operating a South Australia island, when all the other available options are exhausted, it can become necessary to direct network service providers (NSPs) to curtail DPV in order to maintain power system security. In the vast majority of cases at present this action is related to DPV contingency sizes that exceed manageable thresholds. If DPV continues to be installed with poor compliance, the amount of DPV that will need to be curtailed under these circumstances will continue to grow.
- **Reducing network stability limits** – NSPs advise AEMO of the limits of their network, including limits related to transient and voltage stability[10]. These limits aim to ensure that any single credible

[7] 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

[8] Three of the ten OEMs surveyed indicated that the 2020 Standard disturbance ride-through capabilities have been introduced through firmware updates, and therefore their products may demonstrate these behaviours even if when set to the 2015 standard. This is untested at this time. The other seven OEMs confirmed that inverters set to the 2015 standard, are expected to behave as per the 2015 standard.

[9] Referred to Spinning Reserve or Contingency Raise/Lower Essential System Services in the WEM. Rate of change of frequency or RoCoF Services are yet to be implemented in the WEM.

[10] For further explanation on stability limits, refer to AEMO's website, "Constraint Frequently Asked Questions", https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/congestion-information-resource/constraint-faq

contingency, (such as the sudden loss of a large-scale generating unit or single line trip), does not lead to instability. DPV tripping in response to a fault can exacerbate these credible contingency events, and therefore detrimentally affect stability limits. As such, major transmission lines and interconnectors can need to be constrained to lower levels during high DPV conditions, which has already impacted market outcomes by causing interconnectors to bind. The Heywood Interconnector export limit has already fallen to zero during some high DPV periods. Reducing network limits can result in increasing market costs, and could lead to an increased need for DPV curtailment as the only last resort measure available to prevent these stability limits from violating.

- **Reducing windows for planned network outages –** Network limits such as transient stability are often considerably reduced when there are network outages, and can be reduced even further under high DPV conditions due to DPV contingency impacts. When NSPs request to take network elements out of service for maintenance or necessary works, AEMO must assess those outages to confirm they will not lead to periods where there is a need for load shedding, last resort DPV curtailment, or other directions to maintain system security. This means that outages cannot be taken under some high and moderate DPV conditions. Often, network elements may need to be out of service for a period of consecutive days, so it can be challenging to find suitable windows for works to occur. This is already leading to almost entire seasons of the year where NSPs are unable to complete certain multi-day planned outages. This escalates risks of sudden unplanned outages associated with operating the network without the required maintenance and upgrade works being undertaken in a timely manner. If DPV compliance is not rapidly improved, opportunities for planned network outages to proceed will be significantly reduced.
- **Increased risks for non-credible contingencies –** Increasing DPV contingency sizes also escalates risks of cascading failure and system black associated with non-credible contingency events (such as a simultaneous trip of multiple lines or multiple generating units). Non-credible contingencies are typically expected to be managed by fast, autonomous emergency control schemes such as under frequency load shedding (UFLS). Poor DPV compliance can increase the size of the original contingency, and thereby exacerbate the inability of UFLS schemes to arrest a severe disturbance, compounding the risks of a system black event.
- **Other security implications** – AS/NZS4777.2:2020 also includes a range of other DPV behavioural specifications that are important to support power system security beyond disturbance ride-through capabilities, such as the frequency-watt response (which is important to assist in arresting severe frequency disturbances in periods with minimal scheduled/semi-scheduled generation operating). Poor compliance undermines delivery of these other critical functions.
- **DNSP implications** – AS/NZS4777.2:2020 also includes a wide range of requirements that are important for DNSP network performance and for improving DER hosting capacity of the network (such as Volt-VAr and volt-watt power quality modes). Poor compliance therefore also detrimentally affects distribution network performance, costs and hosting capacities.

AEMO's work to assess the implications of poor DPV disturbance ride-through capabilities is ongoing. Further quantification of these challenges will progressively come to light over time as AEMO and NSPs do the extensive work required to integrate DPV behaviour into all the existing operational processes to manage a system with high DPV.

At this time, it is clear that whilst the impacts of non-compliance are complex and multifaceted, this issue is already causing serious power system security challenges.

Poor disturbance ride-through of DER is identified as **the most serious and urgent barrier** to achieving successful, secure and reliable operation of the NEM and WEM with high levels of DER.

On this basis, AEMO recommends that industry efforts focus on improving compliance urgently, targeting **at least 90% compliance of new installations with AS/NZS4777.2:2020 by the end of 2023**, complemented by ongoing governance frameworks to maintain and further improve that level of compliance.

Potential solutions

Solutions need to be developed collaboratively, with input from the wide range of stakeholders who will have insight on the possible options available. This report aims to provide a foundation to inform ongoing efforts in this space.

AEMO has identified three areas of work that could help to improve DER compliance levels, summarised in Table 2. Further detail on each area is outlined below.

Table 2 Potential solutions to improve DER compliance

Option pathways		Details	Potential delivery pathway
1	**AS/NZS4777.2:2020 amendment**	• Amend AS/NZS4777.2:2020 to require that OEMs make only the current version of the Australian grid codes accessible from product commissioning menus for the installer.	AEMO has made a proposal to Standards Australia to amend the Standard. This has been approved as a formal project for the EL-042 Committee which has been initiated and is now underway.
2	**Immediate rectification actions**	• Industry collaboration to deliver a suite of immediate rectification actions, including strong engagement from DNSPs and OEMs. • Identify no-regrets actions that are achievable in the short-term within existing frameworks. • Target improving compliance for at least 90% of new installations to be set correctly to AS/NZS4777.2:2020 by December 2023.	• AEMO understands the AEMC Review into consumer energy resource technical standards[11] is considering options to progress activities with industry.
3	**Enduring governance frameworks**	• Implement clear frameworks that outline which parties are responsible for each of the aspects of DER compliance, including monitoring, assessment and enforcement. This should cover access to the tools, datasets and approved enforcement pathways to deliver these responsibilities while maintaining consumer protections. Where possible, this should consider nationally consistent frameworks across the NEM and WEM. • It is recommended that these frameworks are agreed and implemented as a matter of urgency.	• The AEMC Review is considering frameworks for the governance of technical standards. • AEMO notes that inverter compliance will need to encompass a broad range of parties across the supply chain, some of which currently exist outside of the NER (such as installers and OEMs) and may therefore sit outside the AEMC's jurisdiction. AEMO will continue to work with the AEMC on their Review, exploring the most appropriate pathways to address these compliance issues. • The Energy Policy WA (EPWA) review on DER Roles and Responsibilities and policy gap analysis encompasses monitoring and enforcement for inverter standards compliance.

[11] AEMC, Review into consumer energy resources technical standard. Available at: https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards

AS/NZS4777.2:2020 amendment

The quantitative analysis conducted to date indicates that the largest source of non-compliance is related to installer selection of the legacy 2015 grid codes during commissioning. Amendments that require OEMs to remove legacy Australian grid codes from product commissioning menus is an immediate action that could have a high impact to improve compliance. AEMO has already made a formal proposal to the Standards Australia EL-042 Committee and recommends that this proceeds to implementation as rapidly as possible through that process.

Opportunities for immediate rectification

Table 3 provides further detail on some immediate rectification actions that can be delivered under the existing regulatory frameworks, and merit consideration for industry collaboration. This list is a starting point only and is not intended to be exhaustive.

Table 3 Immediate rectification actions that could improve compliance

Key Parties	Potential actions
Original Equipment Manufacturers (OEMs)	• OEMs to explore opportunities to uplift their commissioning processes and remote capabilities across the board, while managing cybersecurity risks. • Ongoing collaboration with AEMO and DNSPs to develop processes to: – Provide data on compliance rates – Rectify non-compliant installations – Improve product design (such as removal of legacy grid codes)
Distribution Network Service Providers (DNSPs)	DNSPs to uplift their capabilities, to progress activities such as the following: • Mandatory close out process following installation to be linked to obligations (such as meter change-over, installer accreditation or other incentive schemes). • Update Model Standing Offer (MSO) to ensure customer consent to make remote changes to inverter settings (as achieved by Victorian DNSPs). • Implement processes to detect non-compliant installations through in-field analysis. • Work with OEMs to request remote updates to settings at sites where non-compliance is identified (while managing cybersecurity risks, firmware update failure, and other possible unintended consequences). • Coordinate and align DNSP actions to improve alignment, efficiency and effectiveness
All stakeholders (especially OEMs and DNSPs)	Other possible activities include: • Implement systems for remote reading and writing of DER inverter settings • Improvements to test lab reporting to ensure consistency • Improvements to product listing processes to incentivise preferred practices.
Clean Energy Regulatory (CER) and/or Energy Safety Regulators	Consider compliance and enforcement options for installer/electrician such as: • Ensure mandatory training to technical standards as a part of accreditation/licencing requirements, and • Incorporate technical standards into demerit point system to be incorporated from results of on-site audits.

Enduring governance frameworks

The Australian Energy Market Commission's (AEMC) review into consumer energy resources technical standards is considering the regulatory and market context for improving compliance. Some factors for consideration in the context of the development of enduring governance frameworks include:

Roles and Responsibilities

- **OEMs have considerable influence** over the rates of compliance of their products in the field. Options to create obligations or incentives for OEMs to design products that support high compliance rates in the field should be explored.
- **Some DNSPs are already demonstrating considerable innovation** around monitoring and improving compliance of DER connected to their networks. Further innovation is likely possible, but in AEMO's discussions with industry there was a significant lack of clarity and lack of consensus around the responsibilities of DNSPs (or in the case of the WEM, the retailer), and the tools that are realistically available to them. There are also likely to be benefits from coordinating and nationally aligning the approaches taken by DNSPs to enable consistency and efficiency.
- **Installer education and training** should be considered a complementary measure only, and is unlikely to achieve high rates of compliance if OEM product design is not improved to support installer selection of the correct grid codes.

Compliance activities to consider

- **Compliance monitoring and assessment** is a key function that needs roles and responsibilities clarified. This needs to include monitoring at the time of installation (allowing prompt rectification if non-compliance is detected), as well as ongoing monitoring over time (ensuring behaviour remains in alignment with requirements post installation). The tools and datasets available to support this function need to be clarified, ensuring they are accessible and of sufficient quality to the parties that need them.
- **Enforcement and rectification** is another reason why roles and responsibilities require clarification. Specific functions and the datasets to be applied for these purposes need to be designed and clearly articulated so that obligations can be legally enforced, and penalties applied if appropriate. These roles and responsibilities should also confer enforcement powers, provide a conflict resolution mechanism and include consumer protections.
- **Managing firmware updates and cybersecurity** needs to be considered. Many OEMs have the ability to remotely access the majority of their devices in the field and can change technical settings and control the inverter. This can fundamentally change the behaviour of the device so it no longer delivers the functions required in the applicable standards. There are no processes for managing these updates at present.
- **Penalties and incentives** should be considered to drive improvements in compliance, especially applying to parties that have considerable influence over implementation of programs of work that could deliver large improvements (such as OEMs and DNSPs). It needs to be considered where these penalties/incentives would be defined (in the NER, WEM Regulations or elsewhere?) and which party would monitor and enforce them.

Coverage of DER Technical Standards

- **The coverage of DER compliance frameworks** also needs consideration, particularly for new types of DER (such as electric vehicle chargers, which are identified as a critical gap in present frameworks) and medium voltage DER, and also considering whether the same compliance governance frameworks are also suitable for other types of technical behaviours aside from disturbance ride-through (such as interoperability and remote curtailment).
- **The national applicability of the framework** needs consideration. The AEMC governance review focuses on frameworks in the NEM, but there are elements of DER Technical Standards governance frameworks that are nationally led (such as the CER's Small-scale Renewable Energy Scheme

[SRES] accreditation), and many of these compliance challenges have been identified for other regions (including the WEM).

Ongoing work

AEMO has an ongoing program of work to investigate and improve compliance with technical standards. Any stakeholders that are interested in collaborating with AEMO on these initiatives or any others related to compliance with technical standards should contact DERProgram@aemo.com.au.

AEMO will proactively work as part of the AEMC's Review into customer energy resources technical standards to collaborate with industry on the various activities proposed within this document.

Collaborators and contributors

Much of the data and evidence noted in this report has been provided to AEMO on a voluntary basis, and AEMO would like to acknowledge the various contributors, particularly the ten OEMs who have contributed datasets and assistance, Solar Analytics, UNSW Sydney, CitiPower and Powercor, United Energy, SA Power Networks, the CER and funding from ARENA. In particular, this work was made possible due to the analysis undertaken through Project MATCH[12].

[12] See Project MATCH, at: https://arena.gov.au/projects/project-match/

Contents

Tables

Figures

Glossary

Term	Definition
2005 Standard	AS4777.3:2005 Australian Standard
2015 Standard	AS/NZS4777.2:2015 Australian Standard
2020 Standard	AS/NZS4777.2:2020 Australian Standard
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AMI	Advanced Metering
API	Application Programming Interface
ARENA	Australian Renewable Energy Agency
AS/NZS47777.2	Australian Standard – Grid Connection of energy systems via inverters: Inverter requirements. In this document this refers to either the 2015 or 2020 editions of the standard.
AS/NZS3000	Electrical installations (known as the Australian/New Zealand Wiring Rules)
BAU	Business as Usual
BESS	Battery Energy Storage System
BTM	Behind-the-meter
CEC	Clean Energy Council
CER	Clean Energy Regulator
CNAS	China National Accreditation Service
CPD	Continuing Professional Development
CSIP	Common Smart Inverter Profile
DAkkS	Deutsch Akkreditierungsstelle
DER	Distributed Energy Resources
DNSP	Distribution Network Service Provider
DPV	Distribution network-connected, Solar Photovoltaic
DRED	Demand Response Enabling Device
ENA	Energy Networks Association
EPWA	Energy Policy WA
ERA	Economic Regulatory Authority
ESB	Energy Security Board
ESM	Emergency Solar Management (WA)
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCAS	Frequency Control Ancillary Services
FFR	Fast Frequency Response
GOM	Generation outage management
GPS	Global Positioning System
GW	Gigawatt, a unit of active power
IEEE	Institute of Electrical and Electronics Engineers
ILAC MRA	International Laboratory Accreditation Corporation Mutual Recognition Agreement

Term	Definition
ISP	Integrated System Plan
JAS-ANZ	Joint Accreditation System of Australia and New Zealand
MDT	Minimum demand threshold
MSO	Model Standing Offer
MV	Medium Voltage
MW	Mega Watt, a unit of active power
NATA	National Association of Testing Authority
NEM	National Electricity Market
NER	National Electricity Rules
NMI	National Metering Identifier
NSP	Network Service Provider
OEM	Original Equipment Manufacturer
PTP	Permission to proceed
PV	Photovoltaic
RA	Relevant Agent
RMS	Root Mean Square
RoCoF	Rate of Change of Frequency
RTFS	Real Time Frequency Stability
SA	South Australia
SAPN	South Australian Power Networks
SCADA	Supervisory Control and Data Acquisition
SDP	Synergy Dispatch Plan
SRES	Small-scale Renewable Energy Scheme
SRR	Spinning Reserve Requirement
STC	Small-scale Technology Certificate
SWIS	South West Interconnected System
TNSP	Transmission Network Service Provider
UFLS	Under Frequency Load Shedding
UNSW	University of New South Wates
V2G	Vehicle-to-grid
VA	Mega Volt Amperes, a unit of apparent power
VNI	Victoria to New South Wales Interconnector
Volt-VAr	Response settings applied in the inverter that varies its reactive power output in response to the voltage at its grid-interactive port
Volt-Watt	Response settings applied in the inverter that varies its output power in response to the voltage at its grid-interactive port
VPP	Virtual Power Plant
WA	Western Australia
WEM	Wholesale Electricity Market

1 Background

Australia is experiencing world leading uptake of distributed energy resources (DER), particularly distributed photovoltaics (DPV)[13]. Continued growth of DER is projected as part of the generation mix into the future[14,15].

Large-scale generation (>5 MW) must demonstrate that they meet strict performance requirements when connecting to the power system. These performance requirements are defined in Chapter 5 of the National Electricity Rules (NER), and the Technical Rules in the WEM and include a detailed series of requirements for how generating units must perform during power system disturbances. These performance requirements are essential to support secure operation of the power system and avoid cascading failure events when disturbances occur. For example, a major contributing factor to the black system event in South Australia in 2016 was the inability of large-scale wind farm generation to ride-through the power system conditions occurring at the time[16]. The NER were amended[17] subsequent to that event to include new performance standards that now require large-scale generation connecting to the NEM to remain connected and ride-through these types of conditions.

DPV has already supplied up to 93% of demand at times in South Australia (16 October 2022), and this is expected to exceed 100% in some periods in the next year. For the NEM mainland[18], DPV has supplied up to 47% of generation in some periods (29 October 2022) and is forecast to reach 70-80% by 2025 or 2026[19]. Similarly, in the WEM, DPV has supplied up to 74%[20] of total underlying demand (16 October 2022) and is considered the key driver for consistently lowering minimum demand records in the region. To support secure operation of the future NEM and WEM regions, with the majority of generation supplied by distributed resources in some periods, it will be essential that these resources behave to a comparable standard to the large-scale generation resources which have supplied the majority of these grids in the past.

1.1 DER Technical Standards

Australian Standard AS/NZS4777.2 is the performance standard for grid-connected DER inverters across Australia. It defines the behaviours that inverter connected DER should demonstrate, based on

[13] AEMO, October 2019, Maintaining power system security with high penetrations of wind and solar generation International insights for Australia, available at: https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/future-energy-systems/2019/aemo-ris-international-review-oct-19.pdf?la=en

[14] AEMO, June 2022, 2022 Integrated System Plan available at: https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

[15] AEMO, June 2022, 2022 Wholesale Electricity Market (WEM) Electricity Statement of Opportunities, available at: 2022-wholesale-electricity-market-esoo.pdf (aemo.com.au)

[16] AEMO (March 2017) Black System South Australia 28 September 2016, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

[17] AEMC, October 2018, Generator technical performance standards Rule Change. Available at: https://www.aemc.gov.au/rule-changes/generator-technical-performance-standards

[18] The NEM mainland refers to the synchronous interconnected system of Queensland, New South Wales, Victoria and South Australia (excluding Tasmania, which is connected to the NEM via a DC link).

[19] AEMO (August 2021) Electricity Statement of Opportunities, https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2021/2021-nem-esoo.pdf?la=en

[20] AEMO, January 2023, Quarterly Energy Dynamics Q4 2022 available at: https://aemo.com.au/-/media/files/major-publications/qed/2022/qed-q4-2022.pdf?la=en#:~:text=The%20weighted%20average%20Balancing%20Price,prevalence%20of%20negative%20Balancing%20Prices.

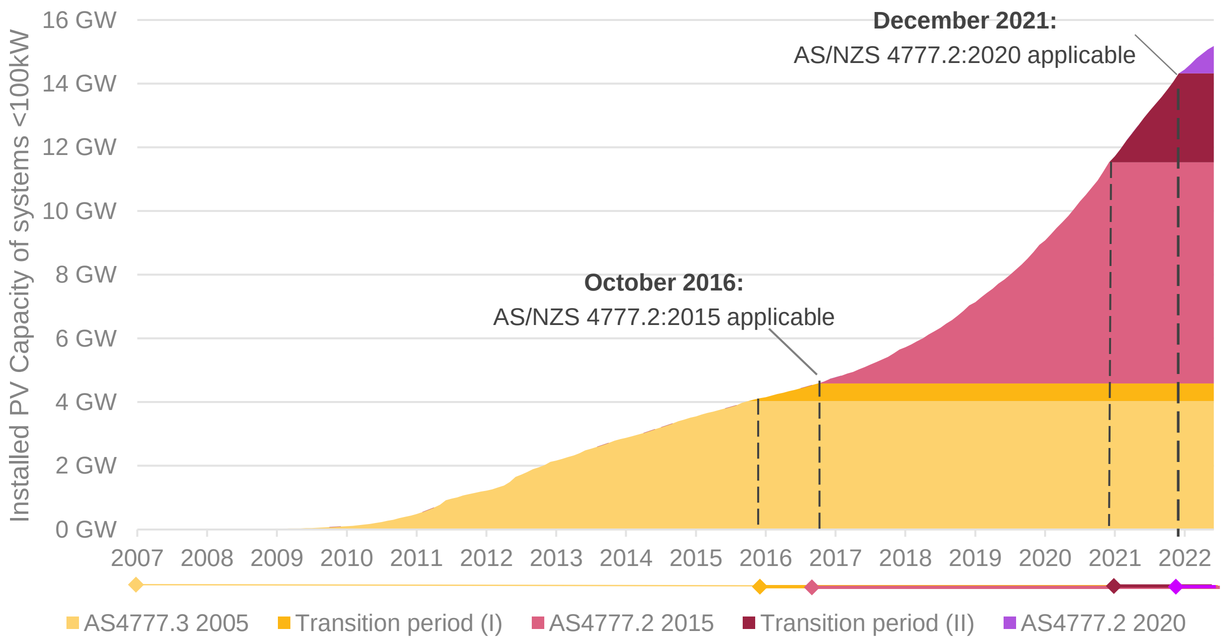
individual device measurements of system frequency and local voltage conditions. The Standard has had a number of iterations, summarised in Table 4.

Table 4 Australian Standards for DER inverters

Standard	Dates applicable
AS4777.3:2005 ("the 2005 Standard")	Applied to all inverters connected prior to Oct 2015
AS/NZS4777.2:2015 ("the 2015 Standard")	Published Oct 2015, mandatory from Oct 2016
AS/NZS4777.2:2020 ("the 2020 Standard")	Published 18 Dec 2020, mandatory from 18 Dec 2021

Figure 1 shows the proportion of DPV systems installed in the period while each standard applied. There is now ~15 GW total DPV capacity installed in the NEM and ~2.3 GW in the WEM. Around two thirds of this capacity were installed under the 2015 Standard, and there also remains a large proportion of inverters (~4-5 GW in the NEM) installed under the older 2005 Standard. Inverter installations are continuing at a rapid rate, meaning a significant proportion of inverters (~2.8 GW in the NEM) were installed between December 2020 and December 2021, during the "grace period" transition to the 2020 Standard. These inverters are assumed to have behaviour consistent with the older 2015 Standard, since most manufacturers had not yet completed the required testing and certification of inverters for the newer 2020 Standard until close to the end of the transition time period[21].

Figure 1 Installed capacity of DPV systems <100kW in the NEM and their applicable inverter standard



1.1.1 The 2020 Standard

The most recent changes to the AS/NZS4777.2 Standard had a major focus on improving the disturbance ride-through capabilities of distributed inverters. AEMO's analysis of power system disturbances during 2017 to 2021 showed that large quantities of DPV can disconnect in response to

[21] Based on the dates when inverters were added to the Clean Energy Council list of approved inverters, https://www.cleanenergycouncil.org.au/industry/products/inverters/approved-inverters

power system events[22,23], particularly in response to voltage disturbances and phase angle jumps. This can exacerbate contingency sizes, representing an increasing risk to power system security as DPV penetrations continue to grow.

To address the identified risks, and better support future operation with high levels of DER, recent updates to the Standard improved capabilities that are considered essential to enable the continued growth of DPV across Australia, including:

- **Disturbance ride-through performance –** More specific requirements regarding conditions in which inverters should stay connected and generating power or disconnect. This aims to better support system security, particularly during power system disturbances.
- **Measurement systems –** Improved accuracy and stability of measurement systems used in inverters, to improve the reliability of performance characteristics.
- **Power quality modes –** Optimisation and coordination of parameters to maximise the value of the capabilities offered with "smart" inverters. This aims to provide improved power quality to customers and grid support functions for networks, allowing increased hosting capacity of DER on distribution feeders and in turn allowing more customers to install DER.

The revised Standard was published on 18 December 2020, as AS/NZS4777.2:2020 ("the 2020 Standard") and became mandatory one year later for all new grid-connected inverters connected at low voltage.

Complementing the review of the Standard, the Australian Energy Market Commission (AEMC) also undertook a rule change establishing a framework to set minimum technical standards for DER within the National Electricity Rules (NER). The new rule amended the NER to require all new or replacement DER to be compliant with the DER Technical Standards (which include AS/NZS4777.2:2020)[24]. In the WEM, equivalent requirements were established by Western Power as the local DNSP[25].

Critical to the effectiveness of this new standard is ensuring that all new DER installations are compliant and performing as anticipated.

1.2 DER Compliance frameworks

1.2.1 Processes and parties involved

Figure 2 shows a simplified view of the processes that apply at present to manage compliance of DPV inverters installed in the NEM and WEM. There are three broad phases:

- **Product design and accreditation –** The process by which the required performance of products is defined, designed, and confirmed, prior to the products being sold in Australian markets.
- **Installation and connection** – The processes that manage the installation and connection products to the distribution network.

[22] AEMO (April 2019) Technical integration of Distributed Energy Resources, https://aemo.com.au/-/media/files/electricity/nem/der/2019/operations/technical-integration-of-der-report.pdf?la=en&hash=65EAE8BA3C64216F760B16535CE2D3ED

[23] 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

[24] AEMC (25 February 2021), Technical Standards for distributed energy resources, https://www.aemc.gov.au/rule-changes/technical-standards-distributed-energy-resources

[25] Western Power, 30 November 2021, Transition requirements for new standards AS/NZS4777.2:2020, https://www.westernpower.com.au/industry/industry-news/transition-requirements-for-new-standards-asnzs-477722020/

- **Post-installation checks** – The processes by which distributed inverter installations are checked after installation, to confirm they comply with required standards, and implement any rectifications required.

Figure 2 Simplified DPV compliance frameworks and process

	Product design and accreditation	Installation and connection	Post-installation checks
Standards Australia	Define Standards		
OEMs	Design and manufacture products to meet Standard		Voluntary: Some OEMs can remotely view settings
Accredited Testing Lab	Test products against the Standard test regime		
JAS-ANZ Certifier	Review test reports to issue a Certificate of Suitability		
Clean Energy Council	Review test reports, maintain list of approved products that meet standards	Accredits solar installers as required under the SRES	May de-list products if reported breaches to certification requirements are verified
Electrical Safety Authority		Licenses electricians to state-based electrical safety	
Installer and/or Retailer		Design and install systems	
DNSP		Approves connection application	
Customer		Commissions installer/retailer for work, applies for network connection with DNSP, applies for STCs	
Clean Energy Regulator		Approves and issues STCs	Audit of sample of sites to confirm STCs

The key actors in the process are as follows:

- **Standards Australia:** Defines technical standards for distributed inverters (based on extensive consultation with industry stakeholders, including OEMs, DNSPs and AEMO). These standards include a series of specific laboratory tests that must be demonstrated.
- **Original Equipment Manufacturer (OEM):** Design and manufacture products that meet the required standards, and pass the necessary tests defined in the standards.
- **Accredited inverter testing laboratories:** Engaged by OEMs to conduct the tests required in the relevant standard, to confirm the inverter delivers the required behaviours in those tests. The test laboratory must be approved by an accreditation body that is a signatory to the International Laboratory Accreditation Corporation (ILAC) Mutual Recognition agreement (MRA), allowing test reports from other accredited laboratories to be recognised and accepted. This includes accreditation bodies such as the National Association of Testing Authorities (NATA), China National Accreditation Service (CNAS) and Deutsch Akkreditierungsstelle (DAkkS).
- **Joint Accreditation System of Australia and New Zealand (JAS-ANZ):** Test reports issued by an ILAC MRA accredited testing laboratory is reviewed by a JAS-ANZ certifier who will issue a Certificate of Suitability to certify the inverter to the required Australia or New Zealand standard.

- **Clean Energy Council (CEC):**
  - Reviews test reports provided by OEMs to confirm necessary requirements are met and adds product to list of approved inverters[26].
  - Manage the accreditation of installers via the CEC's own accreditation scheme[27], confirming they have appropriate training and that they pursue Continuing Professional Development (CPD).
- **State-based electrical safety authority:** Licenses electricians, ensuring that any electrical work is carried out to minimum safety specifications.
- **Customer:** Engages an installer via a solar retailer and selects a preferred product. The customer also engages with an electricity retailer to include solar as part of their plan and initiating access to a feed-in-tariff and meter change-over. Where the installation is applicable under the SRES scheme, the customer can apply to the CER for small scale technology certificates (STCs) via an agent (or installer). In the WEM, the customer can apply for Synergy's (state owned retailer) buyback schemes directly or via its installer/solar retailer.
- **Installer:** An installer is engaged by the customer (and/or their solar retailer) to proceed with the installation, the installer applies for a connection application to the local DNSP, once approved the installer installs and commissions the product to the applicable technical and compliance requirements. An installer must be licensed by the relevant state-based electrical safety authority. Where an installation is applicable for SRES (and/or some state jurisdictional schemes) the installer is required to be accredited by the CEC.
- **Distribution Network Service Provider (DNSP):** Reviews connection applications and provides approval for new connections. This process is largely automatic for most DNSPs at present, with minimal checking. In the WEM, this is achieved via the customer's retailer, Synergy. For systems greater than 30kVa, the DNSP may undertake additional audits to confirm that the system meets technical requirements, this may include confirmation of technical standards.
- **Clean Energy Regulator (CER):** For installations that are eligible for the federal incentive program, the Small-scale Renewable Energy scheme (SRES), the CER administers STCs, and conducts selective audits to confirm compliant installs.

There are many parties involved in this process. Notably, the compliance monitoring, enforcement and rectification processes after installation are minimal. Additionally, many of these processes do not necessarily capture technical standards compliance, and instead focus only on electrical installation safety consistent with local regulatory requirements.

1.2.2 Governance frameworks

The existing regulatory governance frameworks for requiring DER compliance applicable in the NEM are summarised below. These define who is responsible for the various aspects of compliance, the penalties if compliance is not adequate, and levers available for rectification.

[26] Noting that the CER is currently undertaking work as part of the Rooftop Solar Sector Review, to determine whether to make changes to the solar panel and inverter product listing. This is a primary focus for the CER in Q1 2023, with interim requirements specifying that the CEC continue to publish the SRES solar panel and inverter product lists. Further details available here: https://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target/rooftop-solar-sector-review/phase-2-changes-to-the-small-scale-renewable-energy-scheme

[27] Noting that the CER is currently undertaking work as part of the Rooftop Solar Sector Review, to determine whether to make changes to the operator and the administration of the current installer accreditation scheme. This is a primary focus for the CER in Q1 2023, with interim requirements specifying that the CEC continue with their current accreditation scheme. Further details available here: https://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target/rooftop-solar-sector-review/phase-2-changes-to-the-small-scale-renewable-energy-scheme

Table 5 Existing governance frameworks for DER compliance

Framework	Administered by	Compliance lever	Comments
DNSP Technical Standards. **For the NEM, specifications are required under the National Electricity Rules (NER).** **For the WEM, DNSP implements own technical standards**	DNSPs require their own technical standards for new embedded generation connections. From December 2020 the NER includes requirements for NEM DNSPs to reference AS/NZS4777.2 as part of the model standing offer (MSO) of basic connection services. The WA DNSP has separately required AS/NZS4777.2 as part of its connection standards. This applies to new or replacement embedded generators. The AER approves the DNSP's MSO, which forms a contractual relationship between the individual customer and the DNSP.	The DNSP, as party to that contract, can seek remedial action from the customer and/or disconnect the customer's micro EG connection. The AER has no role in enforcing compliance with the provisions of that contract.	The DNSPs have indicated that their mechanisms to manage compliance are 'heavy-handed' and penalise customers excessively rather than directly influencing the party responsible for the non-compliance. DNSPs indicated that in many cases if they apply rectification requirements to the customer, the installer will then charge the customer for rectification.
	DNSP requirements on OEMs Victorian DNSPs have updated their MSOs allowing the DNSP to request changes to inverter settings by the manufacturer if non-compliance is identified.	This allows rectification of sites after non-compliance is identified. This is likely only practical at sites where the OEM can remotely communicate with the inverter (however remote communication is not required).	This change was to make it explicit that DNSPs can make changes to settings at customer sites, as some manufacturers raised concerns with their power to make changes on behalf of the customer.
State based Electrical Safety Requirements	Jurisdictional technical regulators have oversight of state-based electrical work. Requirements to meet AS/NZS4777.2 by jurisdictional regulators apply in all Australian jurisdictions, although exact specifications may differ such as specification of Wiring Rules in AS/NZS3000 (which reference the AS/NZS4777 series) or in reference to the local DNSP requirements (which now require AS/NZS4777.2 in their MSO).	Electrical safety requirements apply to the licencing of electricians to undertake electrical work in the relevant state.	From AEMO's discussions with industry stakeholders, it appears this requirement is perceived to only apply to the electrical safety of an installation and does not extend to technical settings requirements.
State based incentive schemes	Some jurisdictional incentive schemes such as the Victorian Solar Homes require AS/NZS4777.2 compliance as an eligibility criteria for various rebates and subsidies.	Requirements are generally applied to installers authorised to deliver installations under the scheme.	This is not applicable in all Australian regions, is not required for all installations, and is finite in duration.
Small scale Renewable Energy Scheme (SRES) **via Small-scale Technology Certificates (STCs)**	Clean Energy Regulator (CER) administers the Renewable Energy (Electricity) Regulations 2001[28], which requires that to be eligible for STCs the DER system must be compliant to AS/NZS 4777.2. Currently the Clean Energy Council (CEC) administers the accreditation scheme for installations.	The CEC manages installer accreditation for SRES. They apply a demerit system, which escalates from rectification, probations, suspensions and cancellations of accreditation of installers to the scheme. The CEC also manages the process of listing approved products that meet the requirements of SRES. The CER manages an inspection program under the Regulations to help monitor compliance with these requirements.	To date this function has been primarily focused on electrical safety and applicability to the SRES scheme. To extend the scheme to consider technical settings compliance would require improved certainty in the integrity of data sources and an uplift in resources. The CER is currently pursuing actions as part of their Integrity review, which may impact elements of the scheme including accreditation. See Section 4.2.3 for further details.

[28] Renewable Energy (Electricity) Regulations 2001, Statutory Rules No.2 2001 made under the Renewable Energy (Electricity) Act 2000. Compilation No. 80, Registered: 21 December 2022. https://www.legislation.gov.au/Details/F2022C01231

While AS/NZS4777 is noted as a requirement in a range of different regulatory instruments applicable to new installations in the NEM, there appears to be a lack of clarity and a lack of consensus among industry stakeholders around which parties are responsible for implementing and enforcing these requirements, and what levers and penalties they have available to them to enact these roles.

There are currently a number of reviews underway seeking to clarify the roles and responsibilities with relation to DER technical standards, including the AEMC Review into consumer energy resources technical standards, and the CER's Integrity Review. These are discussed in further detail in Section 4.2.

2 Quantifying compliance

This section summarises the various sources of evidence available regarding the proportion of inverters installed that are compliant with the AS/NZS4777.2 Standard.

2.1 Laboratory bench testing

Researchers at UNSW, in an ARENA-funded collaboration with AEMO, have performed laboratory bench testing of individual inverters[29], to investigate potential risks related to the performance of DPV inverters.

The project included undertaking a suite of tests to confirm the behaviour of both AS/NZS4777.2:2015 and AS/NZS4777.2:2020 compliant inverters, off the shelf, to perform the requirements within their respective standards. Key findings are summarised in Table 6.

Table 6 Summary of bench testing compliance responses

Standard	Parameter	Total tested	Response
AS/NZS4777.2:2015	Over-voltage disconnection	20	17 correctly disconnected 2 performed power curtailment 1 rode-through
	Under-frequency ride-through	20	15 rode through 5 disconnected
	Over-frequency power reduction response (not a specified test in the Standard)	20	12 performed power reduction 8 disconnected
	Reconnection response	20	20 reconnect correctly
	Volt-VAr response curve (step decrease 1pu to 0.9pu)	20	20 follow Volt-VAr curve
AS/NZS4777.2:2020	Under-voltage sag	12	12 compliant to standard specifications
	Under-frequency	12	12 compliant to standard specifications
	Over-frequency	12	12 compliant to standard specifications
	Voltage-phase angle jump	12	12 compliant to standard specifications

The bench testing confirms that most inverters (and in the case of the 2020 Standard, all inverters tested to date) perform as per the standard test compliance requirements, when they are configured correctly to the relevant standard.

The testing process also demonstrated that compliance is reduced where the standard includes specifications but there are no formal tests to support the requirement. For example, the 2015 Standard includes specified trip delay times[30], suggesting that inverters should not disconnect earlier than these requirements. Trip delay times are specified for both voltage and frequency passive anti-islanding protections setpoints[31]. However, no formal test is specified in this standard as a pre-requisite for listing as an approved product. When tested in the UNSW project, around 40% of the inverters under the 2015

[29] UNSW Sydney, School of Electrical Engineering and Telecommunications, Addressing Barriers to Efficient Renewable Integration project, ARENA project website, at https://arena.gov.au/projects/addressing-barriers-efficient-renewable-integration/

[30] AS/NZS4777.2:2015, 7.4 – Voltage and frequency limits (passive anti-islanding protection)

[31] AS/NZS4777.2:2015, Table 13 – Passive anti-islanding set-point values

Standard disconnected or curtailed only returning after 6-7mins, for voltage sags with a duration less than the specified trip delay times[32].

Considerable work was undertaken during the review of the 2020 Standard to address some of these gaps in the testing specifications. Continued assessment is ongoing.

2.1.1 Observations on inverter commissioning

Through this project, the researchers at UNSW purchased inverters "off the shelf" and had to set up and configure each of the inverters to the required settings. This work provided insights on the commissioning process undertaken by installers. Insights for inverters under the 2020 Standard included:

- Only one of the inverters had a default setting "out of the box" to automatically configure to the applicable 2020 Standard and Australia A (by default).
- Five inverters had complex menus and processes required for setup, before they could be configured to the correct setting. The process required initiative from the person setting up the inverter, to select the correct standard, with the 2020 Standard (and regional options i.e. Australia A/B/C) often located further down the grid code standard selection list than the 2015 selection, requiring time and patience.
- One inverter required download of new firmware, multiple phone calls to the manufacturer's customer support and a long and difficult process before it could be set to the correct standard. It is anticipated that very few installers (if any) would be likely to engage in this process during the commissioning of an inverter, so the selection of an incorrect and more accessible grid code is more likely.

2.1.2 Observations on test reports

As part of the CEC's inverter product listing process, manufacturers provide test reports against the suite of tests required to meet AS/NZS4777.2, and the CEC undertakes a desktop study to approve the product listing. While details of the test reports are confidential, anecdotal reports have provided insights on repeated challenges, and issues that have been identified, highlighting some areas of improvement with the existing process, which include:

- Inconsistency between test laboratories reporting on the same tests. This includes details of:
  - Testing regime: the level of detail that test laboratories provide on the test regime is inconsistent. This makes it challenging to confirm whether the test was performed as specified and consistently, as it is often left to the interpretation of the testing lab.
  - Testing results: testing laboratories provide test results in different formats and in some cases provide minimal detail with only a simple pass/fail deemed by the testing laboratory. Therefore, it is difficult to confirm where the same criteria have been used to determine the status.
  - Charts and tables: Any additional information that the testing laboratories provide as part of reporting differs between test laboratories and even test reports. This can include inconsistent charts, such as different units or parameters used on charts making it difficult to compare between reports.

[32] UNSW, Addressing barriers to efficient renewable integration http://pvinverters.ee.unsw.edu.au/Summary

- Frequent errors identified in the test reports for AS/NZS4777.2 that leads to unacceptable test reports and delays in listing include:
  - Testing laboratories not following the instructions as prescribed by the Standard, or inconsistent testing practices between laboratories to perform the same test, particularly where there is reference to other related standards.
  - Testing of the suite of systems that are covered by test reports, including different testing requirements needed between single inverters and multiple inverter combinations, and where a test report covers a series of inverters that are identical in hardware construction, but the output power is derated by software.
  - Interpretation of elements of the test report (such as measurement accuracy performance), specifically where insufficient detail is provided on the test undertaken.

This highlights the importance of the interpretation of the standards by the test laboratories, and the need for the Standard to appropriately define the requirements of the test reports. Further, it is noted that following the rejection or advice provided by the CEC during the test report review process, it is unclear whether the testing laboratories are carrying out re-testing to provide a revised test report or if they have simply edited the report to satisfy the issues identified.

Potential improvements include standardising the test report form through JAS-ANZ, including standardised reporting format, test details and structure. This would ensure that all test laboratories are reporting requirements consistently.

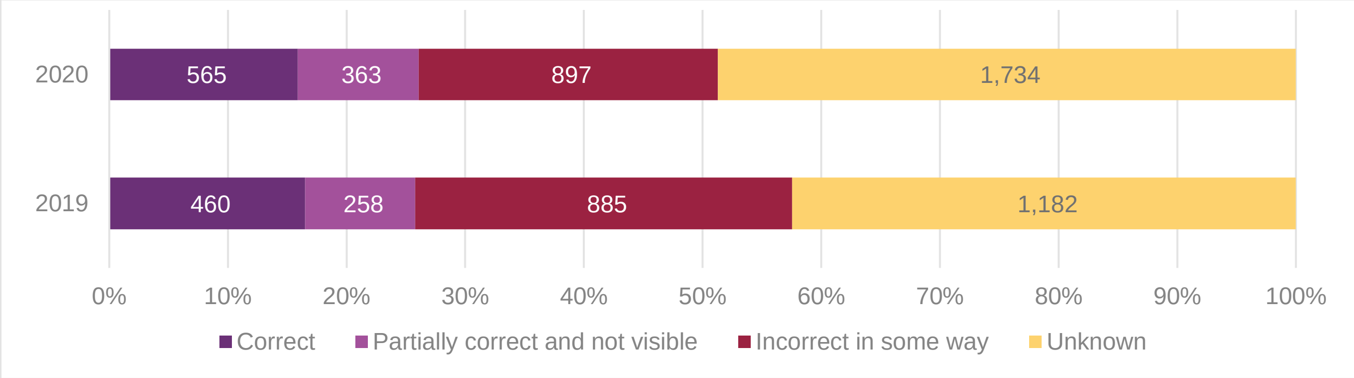
2.2 CER Audits

The Clean Energy Regulator (CER) undertakes an inspection program as part of its administration of the Small-scale Renewable Energy Scheme (SRES)[33]. Under this program, inspectors physically visit a "statistically significant" number of total DPV installations (approximately 1-2%) where STCs have been created. Installations are selected randomly from those completed in the previous 12 months and on a rolling basis.

Figure 3 shows the audit results for whether inverters were set correctly to AS/NZS4777.2:2015, for inverters installed during 2019 and 2020. For around half the inverters, the auditor was unable to confirm what settings and/or Standard were applied. Of the visible inverter settings, it shows that only ~28% of inverters could be confirmed to have the full suite of correct settings applied and 45-55% of inverters had settings applied that were confirmed incorrect in some way. The 2015 Standard had commenced 3-4 years prior to the time of installation of these inverters (noting there is a one-year lag on audits following the installation), and despite this there was still evidence of inverters installed to the preceding 2005 Standard.

[33] Available at: http://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Agents-and-installers/Small-scale-Renewable-Energy-Scheme-inspections.

Figure 3 Results of CER Audits in 2019 and 2020 (inverters configured to AS/NZS4777.2:2015)



For systems audited in 2020, of those that had visible settings that were incorrect, approximately half had incorrectly configured grid protection settings (e.g. maximum 10-minute average voltage), and half had incorrectly configured power quality response mode settings (e.g. Volt-Watt or Volt-VAr). A small subset of these had an incorrectly set power ramp rate limit.

Where there were incorrect inverter settings, approximately 6-8% of the whole fleet (or 10-15% of the visible fleet) were set to an international or "default" grid-code, that was not to an Australian setting. The most common incorrect grid code selected was the German 50Hz Standard, which is assumed to be due to an incorrect understanding by installers opting for the local grid frequency, or selecting the first option on the menu, or the menu being set up so that the first option is selected by default. In some cases, it appears as though the installer has not commissioned the inverter at all, where no grid setting has been selected and factory defaults are operating.

2.2.1 Unknown settings

In the past, CER audits have focused primarily on electrical safety and confirming the site has correctly applied for STCs. The confirmation of technical settings was only added as an audit requirement in September 2020. The CER has indicated that since introduction of the technical settings within the checklist, they have also undertaken efforts to improve the collection of data by the auditors. However, over time there has not been any noticeable improvement of settings classified as "Unknown" which includes both instances where there is no inspector entry and leaving the field as blank or the settings fields are not visible by the auditor. It is possible that some may not be visible for a range of reasons including password protection and accessibility of the interface.

2.3 Disturbance analysis

AEMO has analysed the behaviour of DPV inverters from about 30 different power system disturbances occurring between 2017 and 2022 in the NEM, based on generation data from a sample of thousands of individual inverters[34]. Full findings are elaborated in AEMO's detailed report[35] (Chapter 4, Standard conformance) and in relevant incident reports. Table 7 summarises findings on compliance to defined technical settings from AS/NZS4777.2:2015, indicating that under different scenarios 15-50% of inverters do not appear to deliver the performance behaviours as required in the relevant standard.

[34] Work conducted under Project MATCH, ARENA funded collaboration between AEMO, UNSW Sydney and Solar Analytics, https://www.ceem.unsw.edu.au/project-match

[35] 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

Table 7 Compliance findings from disturbance analysis

Standard Capability	Impact on power system security	Compliance finding
Over-frequency response	Response is needed to assist in arresting frequency rise. Important for power system security for this to occur in a controlled and predictable manner.	• During over-frequency events, 30-50% of DPV systems installed under the 2015 Standard did not display the required over-frequency response. • Only 30-50% of systems are observed to display the required response. • The remaining systems either partially respond, disconnect, or are already off at the time of the event. • This has been observed consistently in six different over-frequency events occurring in South Australia, Queensland and Victoria.
Reconnection profile	Predictability of this profile is important during reconnection of load blocks with large amounts of DPV.	• When reconnecting to the grid following disconnection, 15-40% of DPV systems installed under the 2015 standard did not display the required six-minute ramp rate limit to full capacity. • This has been observed consistently when assessed in five different disturbances occurring in Queensland, South Australia, New South Wales and Victoria.

These behaviours were performed correctly by most inverters tested in the UNSW bench testing project[36], when they were configured correctly to the 2015 Standard. This indicates that the non-compliance observed in the field is likely related to the inverters having incorrect standard or settings applied.

2.4 Volt-VAr power quality assessments

The 2015 and 2020 Standards require that DPV inverters deliver a "Volt-VAr" response, adjusting reactive power delivered as a function of local voltage measured by the inverter. Correct delivery of this function assists distribution network voltage management, and thereby increases the DPV hosting capacity of the distribution network.

The following historical background provides context for the analysis described below:

- The Volt-VAr specification was introduced in the 2015 Standard, however at the time the mode was disabled by default. Following this each DNSP developed their own individual specifications for delivery of this response, and required these settings to be enabled through their connection standards. Volt-VAr requirements were therefore rolled-out independently by each DNSP, with their own unique settings and timeframes.
- To apply the Volt-VAr requirements, additional intervention was typically required by an installer during the commissioning process to adhere to the individual DNSP requirements. Over time, many manufacturers developed unique DNSP grid code selection options as part of their menus.
- The 2020 Standard now requires that Volt-VAr is enabled by default, with standardised values adopted across all NEM mainland regions (Australia A), the WEM (Australia B) and Tasmania and regional WA (Australia C).

Analysis of various data sources to quantify the observed performance of the required Volt-VAr settings in the field is described below.

[36] Noting that tests applied differed to the compliance tests defined in the Standard. For the reconnection test, all inverters demonstrated a 60-second delay before reconnection, and the majority performed a 6-min power ramp-rate limit. For the over-frequency response, the inverters that remained connected all performed an over-frequency response.

2.4.1 Victorian DNSPs

CitiPower, Powercor and United Energy introduced Volt-VAr requirements in December 2019. Since this date, they have been undertaking assessments based on individual customer advanced metering infrastructure (AMI) data to quantify compliance.

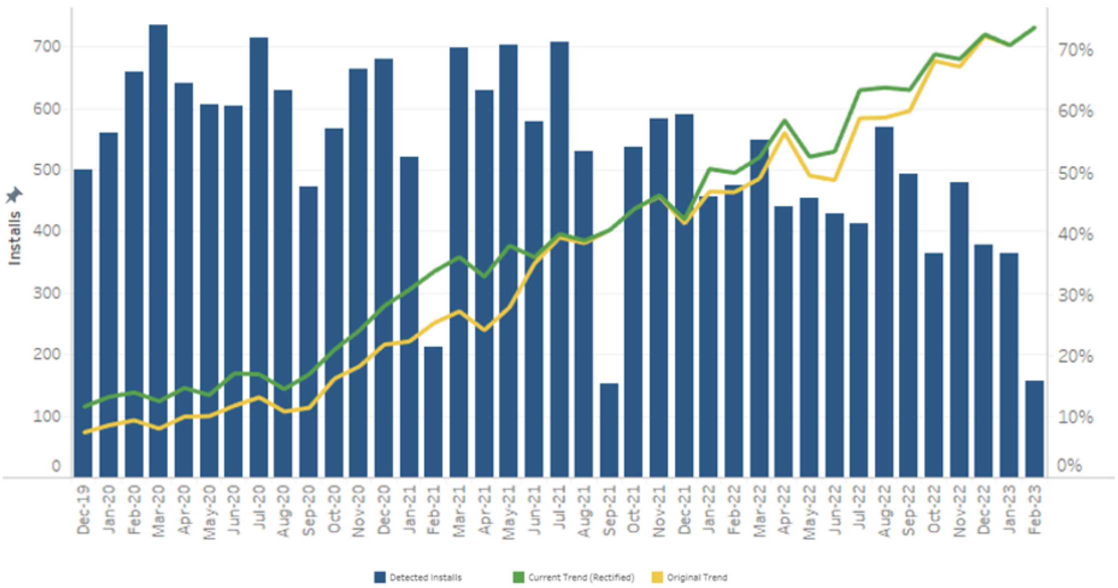
The approach involves identifying customer sites with PV installed recently, identifying periods where those sites experienced trigger voltage levels and should have been demonstrating a Volt-VAr response, and then comparing the reactive power response from the inverter with what was expected based on the applicable Volt-VAr requirements. If the response was detected to be at least 50% of what was expected, the site was deemed to be likely to have the correct Volt-VAr settings enabled.

CitiPower, Powercor and United Energy have reported on this analysis in multiple submissions to the AEMC review of governance of DER[37,38], and have shared further details with AEMO. A summary is provided here for reference (with their permission).

Figure 4 and Figure 5 show the compliance rates over time for CitiPower, Powercor and United Energy, respectively. Both charts show that when Volt-VAr requirements were introduced in December 2019, compliance was initially measured at only ~10%. This had gradually increased to around 65-75% by February 2023.

The yellow trend line in Figure 4 and Figure 5 illustrates the initial inverter compliance rate at the time of installation while the green trend line shows the current compliance rate after remote rectification works were conducted. Remote rectification works have increased Volt-VAr application for approximately 5-10% of installs in a month.

Figure 4 Citipower and Powercor monthly Volt-VAr compliance assessment



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[37] CitiPower Powercor, United Energy submission to Initiation of distributed energy resources technical standards ERC0319. October 2021, available at: https://www.aemc.gov.au/sites/default/files/documents/211007_submission_by_citipower_powercor_and_united_energy.pdf

[38] CitiPower Powercor, United Energy submission to Draft Determination of distributed energy resources technical standards ERC0319. February 2022, available at: https://www.aemc.gov.au/sites/default/files/2022-02/220203_submission_from_citipower_powercor_and_united_energy_0.pdf

Figure 5 United Energy monthly Volt-VAr compliance assessment

A number of initiatives have been introduced over this time period, as summarised in Table 8.

Table 8 Initiatives to improve compliance in Victoria

Initiative	Details	Appliable period	Notes
Education programs	DNSPs provided education programs, information sessions and training initiatives to build the capacity of the sector.	During 2020	Steady improvement in compliance observed during this period.
OEM menus	Many OEMs updated product menus, providing pre-set DNSP selection options. This allows installers to select options by DNSP, rather than entering individual settings.	Progressively applied	Likely contributor to improvements.
2020 Standard	The 2020 standard introduced default “Australia A” setting for all inverters connecting to the NEM mainland.	Mandatory from Dec 2021	Noticeable increase in compliance to Volt-VAr requirements in United Energy’s network, but not observed in CitiPower and Powercor datasets.
Remote rectification	Worked with top 5 manufacturers to remotely adjust settings	Since February 2021	Enacted rectification of systems once non-compliance was identified, is evident by the green line in Figure 4 and Figure 5, which represents the current trend (rectified).
Direct customer engagement	Develop solar pre-approval checklists, information pack, automatic reassessments and direct advice to residential, commercial and industrial customers highlighting importance of inverter settings	Since February 2021	Likely contributor to improvements.
Updates to MSO	Updated model standing offer (MSO)[39] to ensure customer consent to make remote changes to inverter settings (via the OEM).	March 2022	Improvements through remote rectification made achievable through this change, is evident by the green line in Figure 4 and Figure 5, which represents the current trend (rectified).

[39] CitiPower, Powercor, and United Energy Model Standing offer for basic connection services for retail customers who are micro embedded generators. March 2022. See Clause 39. Available at: https://media.powercor.com.au/wp-content/uploads/2022/04/04172452/CPPALUE-MSO-for-EG-version-3-AER-approved13317322.1.pdf

Initiative	Details	Appliable period	Notes
Commissioning checklists	CitiPower, Powercor and United Energy introduced mandatory commissioning sheets at the point of installation, which are validated prior to the meter change-over. Further discussed below.	Introduced Oct 2022	Noticeable "up-tick" in compliance in October 2022 in both datasets. Ongoing monitoring in progress to confirm general trend of improvement.

Breakdown of non-compliance by installer

CitiPower and Powercor have confirmed that their datasets indicate that non-compliance is widespread across many installers. Based on a sample of 43,500 new solar PV systems installed since December 2019 in CitiPower and Powercor networks[40], the Volt-VAr assessment indicated that 80% (34,779) were non-compliant. A total of 991 installers were responsible for these installations (with varying levels of compliance with inverter settings). 441 installers were responsible for 28,463 solar installations (65% of the total undertaken) and were assessed as being between 70% and 90% non-compliant. A further 263 (26%) were responsible for a small number of installations (834) with none of their installations found to be compliant.

This demonstrates that non-compliance is widespread and not limited to a small set of installers .

Remote rectification

Victorian DNSPs updated their model standing offer (MSO) to require customers to provide explicit informed consent for the DNSP to make changes to inverter settings (via the manufacturer, where remote communication is available).

To implement the new MSO requirement, CitiPower, Powercor and United Energy worked with the top five non-compliant manufacturers to remotely correct settings for existing non-compliances, identified through serial numbers reported in connection applications. Through this activity, between June 2021 and December 2022, they have been able to remotely rectify over 4,300 sites. For systems rectified, the OEM provides confirmation of sites that have been successfully communicated to the DNSPs. This change in settings is then subsequently corroborated through Volt-VAr assessments, confirming that the site is corrected (as evident in the rectified trend observed in Figure 4 and Figure 5. This work highlights that there has been approximately a 5-10% overall compliance improvement per month from rectifications.

For one manufacturer, only 24% of sites identified to be non-compliant in the CitiPower and Powercor network could be rectified, and only 32% in the United Energy network. This was due to the manufacturer's inability to communicate with the devices, suggesting that remote communication to devices is unreliable and is often not retained where required for commissioning.

This analysis highlights that non-compliance at the installation has been a long and persistent problem. Activities such as training and education are important, however more active engagement such as commissioning sheets by the DNSPs appear to have the good potential to help improve compliance.

[40] Citipower, Powercor, United Energy Submission to AEMC ERC0319 Draft determination – Governance of distributed energy resources technical standards. Available at: https://www.aemc.gov.au/sites/default/files/2022-02/220203_submission_from_citipower_powercor_and_united_energy_0.pdf

Commissioning datasheets

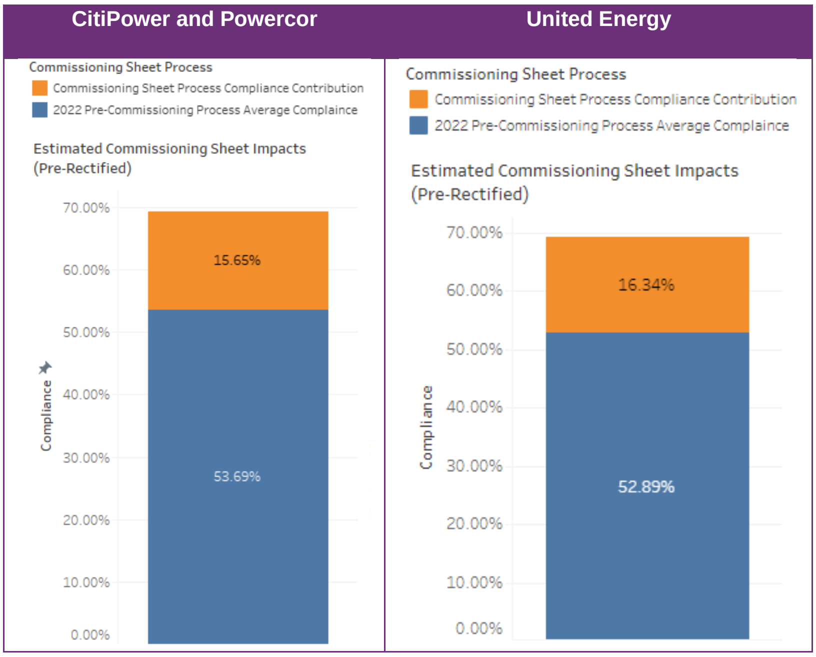
Some of the Victorian DNSPs have developed commissioning sheets for DER connections which require the installer to provide confirmation that the correct technical device settings are in place at the time of commissioning[41,42]. This requirement was introduced by CitiPower, Powercor and United Energy from 1 October 2022.

After the installer installs and commissions the system, they are required to provide a commissioning sheet to the DNSP (including a declaration of requirements). The sheet involves a confirmation that the correct technical settings are applied (i.e. AS/NZS 4777.2:2020 - Australia A). This is provided to the DNSP along with other documentation such as the alteration request and Certificate of Electrical Safety. Once reviewed and validated, the DNSP updates the meter configuration with the customer's retailer, thus allowing the household to export and receive a feed-in tariff. This is currently achieved manually however options are being pursued to automate this in the future.

The commissioning sheet process places responsibility on the installer to ensure that compliance is achieved at the point of installation before customer handover via the meter-change.

Figure 6 shows the pre-commissioning average compliance between February 2022 and September 2022 (in blue) and the additional improved compliance on average since the introduction of the commissioning sheet process between October 2022 and February 2023 (in orange). This shows that this additional step has improved compliance by 15-16% on average in both the CitiPower, Powercor and United Energy Networks. This is further supported in Figure 4 and Figure 5, which both show the highest single month jump in compliance improvement to Volt-VAr settings between September and October 2022. Compliance monitoring is ongoing as more installers become aware of the new requirements.

Figure 6 Commissioning sheet review process and outcomes



[41] Citipower Powercor, 2022. Smart Inverter settings. https://www.powercor.com.au/industry-partners/connections/solar-connections/smart-inverter-settings/

[42] United Energy, 2022. Smart inverter settings. https://www.unitedenergy.com.au/partners/solar-installers/smart-inverter-settings/

The datasheet commissioning process suggests that high-levels of Volt-VAr compliance can be maintained through point-of-installation awareness along with targeted incentives (i.e. export limits). This measure has proven to be a practical approach for DNSPs to address non-compliances.

As part of the process, the DNSPs have also nominated a list of preferred inverters, that have been identified to have a high-level of installation compliance. This nomination by a DNSP provides an additional incentive for OEMs to improve their compliance levels.

2.4.2 SA Power Networks

SA Power Networks (SAPN) has also undertaken an assessment of Volt-VAr compliance in their network, using net meter data from AMI meters. The sites analysed were commissioned in the most recent period when the 2020 standard applied and assessed against the new 2020 standard “Australia A” requirements.

From a sample of 572 NMIs over the period of 7 April 2022 to 14 April 2022, SAPN identified:

- 72% (411) of installations did not appear to perform the required Volt-VAr behaviour.
- Some manufacturers appear to perform better than others. The poorest performing manufacturer demonstrated ~97% non-compliance[43].
- Sites were determined to be non-compliant even when assessed against SAPN’s previous Volt-VAr settings, indicating this is not solely a result of installers not selecting the recently introduced 2020 Standard during commissioning.

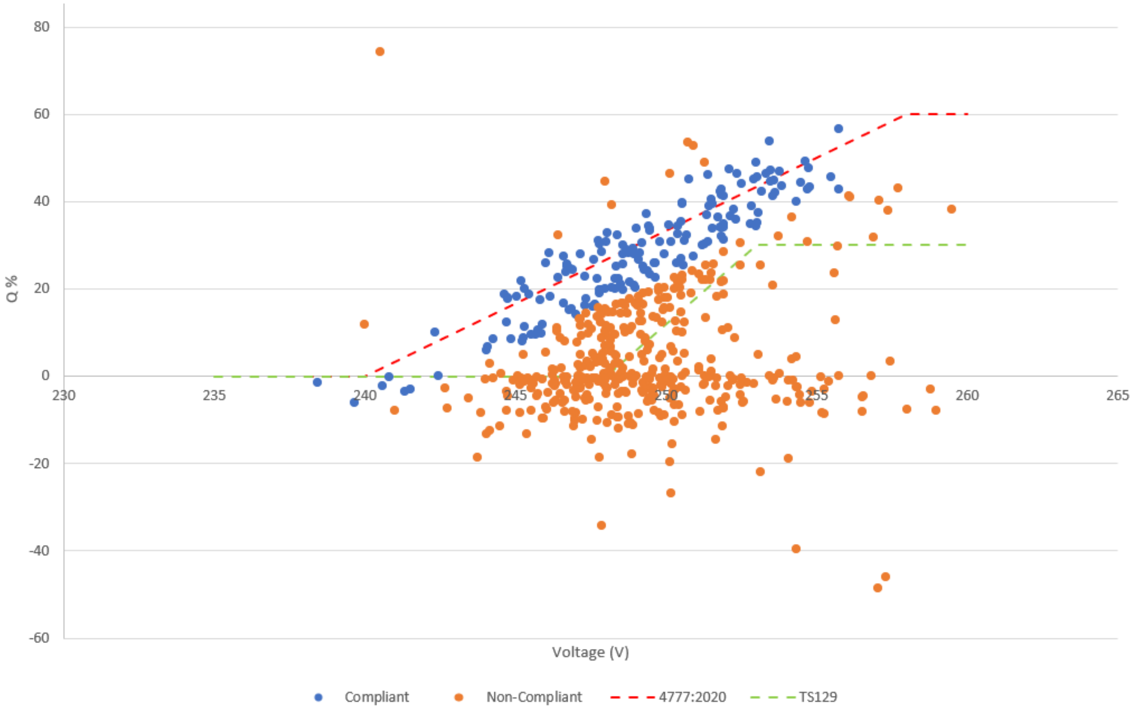
An illustrative example is provided in Figure 7. The red dashed line indicates the ideal reactive power response of the inverter, as a function of local voltage measurements (horizontal axis), based on the specifications in the 2020 Standard - Australia A. The dots indicate measured instantaneous responses of individual inverters in SAPN’s network in selected five-minute intervals in April 2022. Sites delivering within ±10% of the ideal response are considered compliant (shown in blue). Sites outside of this range, particularly those delivering minimal reactive power response (far below the dashed red line) are identified as non-compliant. The ideal response based on SAPN’s previous Volt-VAr settings (applied under the 2015 standard) and defined in their Technical Standard (introduced in 2017) for small embedded generator connections less than 10 kW (TS129)[44] is shown in the green dashed line.

As part of SAPN’s compliance program initiative, SAPN is considering the replacement of their current manual detection of Volt-VAr compliance with an automatic detection of non-compliant inverter operation through time series data.

[43] SAPN has subsequently worked with this manufacturer, where serial numbers were available in the DER Register, and they have remotely updated 50% of sites.

[44] SA Power Networks, 6 Jul 2021, Technical Standard TS129 Small embedded generator connections technical requirements – capacity not exceeding 30kVa. Available at: https://www.sapowernetworks.com.au/public/download.jsp?id=318532

Figure 7 SAPN measurements of Volt-VAr response compliance (measurements in April 2022 of sites installed since 18 December 2021)



Comparison with manufacturer polling data

For the specific sites assessed by SAPN for Volt-VAr compliance, 151 sites were identified where the relevant product manufacturer had remote visibility of the settings applied to those inverters. AEMO requested this data from these manufacturers, for comparison. This allowed AEMO to assess the effectiveness of the Volt-VAr method for identifying inverters with incorrect settings applied[45].

The number of inverters in each combination of compliance labels is summarised in Table 9.

Table 9 Comparison of compliance assessment methods

<table>
<tr><th colspan="2"></th><th colspan="2">DNSP AMI Volt-VAr assessment</th></tr>
<tr><th colspan="2"></th><th>2020 Compliant</th><th>Non-2020 Compliant</th></tr>
<tr><td rowspan="2">OEM remote surveying label*</td><td>2020 Compliant</td><td>20</td><td>15</td></tr>
<tr><td>Non-2020 Compliant</td><td>35</td><td>81</td></tr>
<tr><td colspan="4">* Note: OEM remote surveying refers to the ability for some OEMs to remotely access and view the settings applied to their products in the field. This capability is further discussed in Section 2.5.</td></tr>
</table>

Of the 151 sites, 20 were identified as performing Volt-VAr correctly and confirmed by the OEM as having correct settings applied. A further 81 sites were identified as not performing Volt-VAr correctly and confirmed by the OEM to have incorrect settings applied.

[45] Work conducted under Project MATCH, an ARENA funded collaboration between AEMO, UNSW Sydney and Solar Analytics, https://www.ceem.unsw.edu.au/project-match

If it is assumed that the OEM reported compliance classifications are perfectly accurate, this comparison suggests that the DNSPs Volt-VAr compliance assessments are reasonably accurate. The Volt-VAr approach:

- Correctly identified 81 of the manufacturers reported non-compliant inverters (~70% of non-compliant inverters correctly identified); and
- Correctly identified 20 of the manufacturers reported compliant inverters (~56% of compliant inverters correctly identified).

For the sites with a mismatch between the two datasets:

- For the 35 sites where the OEM indicated the inverter was non-compliant, but the Volt-VAr assessment indicated it was compliant, the site may have had the 2015 grid code applied with the Volt-VAr settings included. The Volt-VAr assessment approach also includes a degree of leniency to allow for measurement uncertainty. This indicates that the Volt-VAr method cannot be relied on as the only source of detecting non-compliant installations (approximately 30% of non-compliant installations were not detected by this method).
- For the 15 sites where the OEM indicated the site was correctly installed with the 2020 Standard settings, but the AMI assessment indicated the site was not delivering the Volt-VAr response correctly, these sites need further investigation. This could be related to multiple inverters at the site (possibly installed under different standards), or other unique case-by-case conditions at the site. This indicates that these datasets may not be sufficient on their own as a basis for application of penalties for non-compliant installations (for example). They can only be used as a preliminary indication of possible non-compliance, requiring further investigation.

These findings indicate that the Volt-VAr assessment method can be used to automatically detect non-compliant DPV installations with reasonable levels of accuracy (~70% of non-compliant identifications). This provides a good starting point for DNSPs to identify non-compliances and may serve as a means to select key sites to begin addressing issues. However, the method cannot be relied on as the sole approach for detecting non-compliant installations. As part of SAPN's broader compliance program, they are intending to enhance the detection method used in this methodology and operationalise these improved requirements in 2023.

2.4.3 Solar Analytics dataset assessment

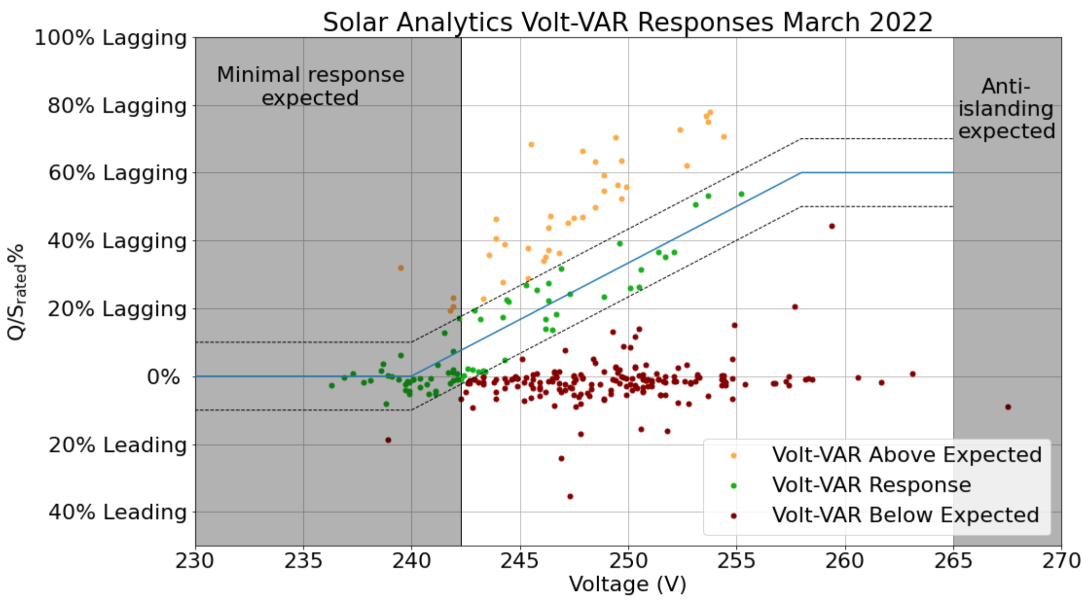
Solar Analytics provides a solar monitoring service to customers, collecting data and analysing generation from a customer's DPV system so that any performance issues can be identified and rectified in a timely manner. They have long term datasets on generation from thousands of DPV systems across the NEM, from a wide range of different manufacturers' products. AEMO has been collaborating with Solar Analytics and researchers at UNSW since 2017 on ARENA funded projects to analyse these datasets and provide insights on DPV behaviour[46].

Data from 244 DPV sites, installed after 18 December 2021, across all NEM mainland regions, was assessed for Volt-VAr response on a clear sky day in March 2022. Solar Analytics voltage and reactive power data of each site was used to determine whether the inverter response to local voltage conditions was consistent with Volt-VAr specifications as part of AS/NZS4777.2:2020. Further details on the methodology are described in Appendix A1.

[46] Work conducted under Project MATCH, an ARENA funded collaboration between AEMO, UNSW Sydney and Solar Analytics, https://www.ceem.unsw.edu.au/project-match

Results are shown in Figure 8. Sites were deemed non-compliant if their reactive power delivery was more than 10% below the response specified in the 2020 Standard - Australia A, illustrated by the blue line. In this dataset, 72% of sites did not exhibit a significant Volt-VAr response consistent with the local voltage conditions experienced, shown in red in Figure 8. A further 14% of sites (shown in orange) responded more aggressively to the conditions than required. This may be explained by factors such as a higher than anticipated voltage rises between the measurement point and the inverter.

Figure 8 Solar Analytics Volt-VAr response March 2022



These findings are generally consistent with the assessments performed by the Victorian DNSPs and by SAPN, highlighting that non-compliance is pervasive and consistently observed across all the available datasets.

2.4.4 General observations on Volt-VAr approaches

Analysis to date indicates that the Volt-VAr assessment method provides a useful method of remotely detecting non-compliant DPV installations with reasonable levels of accuracy. This provides a good starting point for identifying non-compliances.

The following limitations of this method are noted:

- Detection of non-compliance is not perfect with current data sources. Available evidence suggests ~30% of non-compliant sites may not be identified, and some sites can be identified as non-compliant via this method even where correct settings have been applied, such as where there are multiple installations at a connection point. It should only serve as an initial screening mechanism to identify sites for further investigation and should not be relied on as the sole method for identifying non-compliance.
- Outside of Victoria, DNSPs do not have free access to all AMI data. DNSPs have reported difficulties accessing the necessary datasets within reasonable cost thresholds or can only access subsets of data (which may introduce biases).
- In most cases, AMI installations are not configured to separately measure the DPV and site load and provide only a net measurement of the two for the site. Analysis of the net site behaviour may

exacerbate inaccuracies in this method. The South Australian technical regulator[47] has introduced requirements from 28 September 2022 for AMI meter configuration to separately measure and control an electricity generating plant and controllable load from the essential load, allowing for DPV to be separately metered. However, the analysis in SA has been undertaken on net metering due to the cost of procurement and availability of data.

- At present, high voltages are experienced periodically in most parts of most networks, allowing incidental identification of time periods where inverters should be delivering a measurable Volt-VAr response. In future, with improvements to DNSP voltage management, and with increased Volt-VAr rollout, incidences of significant high voltages could be expected to decrease. This may mean that many sites cannot be screened via this method. CitiPower and Powercor are exploring whether they may temporarily deliberately elevate voltages on some feeders for a period to screen inverters connected in those locations.
- Assessing performance of Volt-VAr functions is only an indicator of general compliance and does not directly confirm compliance with other requirements of the standard, such as disturbance ride-through capabilities. These are critical for system security.

These factors mean that while Volt-VAr assessments may provide a useful tool in the near term, DNSPs will likely need other complementary methods to monitor and rectify compliance in the longer term.

2.5 Manufacturer Reporting

Some inverter OEMs have remote visibility of the settings applied to their products in the field.

2.5.1 Analysis approach

This analysis was conducted in collaboration with UNSW Sydney under an ARENA funded project (Project MATCH)[48]. One of the aims of the project is to identify new datasets and approaches for quantifying DER compliance.

AEMO and UNSW contacted a number of OEMs to request data on the technical settings applied to their systems installed in the four months since the introduction of the 2020 Standard (this standard became mandatory from 18 December 2021). AEMO approached the 13 OEMs with largest market share for recent installations. These OEMs are estimated to represent in aggregate about 95% of the DPV fleet installed in the relevant period.

Ten OEMs supplied some kind of data for their fleet, with four OEMs able to survey their entire internet-connected fleet since the introduction of the 2020 Standard. The other six OEMs required lists of inverter serial numbers to undertake targeted polling. To facilitate this process, AEMO extracted serial numbers for recently installed inverters from each OEM from only the NEM DER Register[49] (maintained by AEMO and based on data supplied by DNSPs). The DER Register data was found to have significant shortcomings[50]; only a subset of installations have correct serial numbers recorded and the volume of serial numbers for some installations is excessive (e.g. micro-inverters). From a basic screening of the DER Register, it was identified that at least 12% are clearly invalid (such as blank, N/A,

[47] Government of South Australia Department for Energy and Mining, Technical Regulator Guideline. Available at: https://www.energymining.sa.gov.au/__data/assets/pdf_file/0005/671972/Technical-Regulator-Guideline-Smart-Meter-Minimum-Technical-Standard.pdf

[48] https://www.ceem.unsw.edu.au/project-match

[49] https://aemo.com.au/en/energy-systems/electricity/der-register

[50] Potential options to address shortcomings include increase automation of data inputs and improved facilitation of serial number ranges.

or dummy serial numbers i.e. 123456). Additionally, when serial numbers have been provided to OEMs they reported that 15-25% were considered invalid by the OEM. AEMO provided the subset of correct serial numbers to the relevant OEMs and conducted analysis on compliance rates within this sample set. Where sample sets were used, they were assumed to be unbiased, and extrapolated to the entire fleet for each OEM.

In total, some kind of data was extracted from OEMs remote polling to assess compliance rates for around 70% of all Q1 2022 installations.

2.5.2 Compliance estimates at time of installation

Combining all the information supplied by OEMs from remote inverter surveying, scaled by market share estimates compiled from datasets maintained by the Clean Energy Regulator (CER), it is **estimated that only 37% of the fleet in the NEM installed in Q1 2022 was configured with the correct AS/NZS4777.2:2020 grid code at the time of installation**[51]. This is consistent with the estimates of non-compliance quantified via other measures (outlined in sections above).

Where settings were incorrect, the majority had the 2015 Standard applied. Approximately 5-7% of installations were set to various international grid codes.

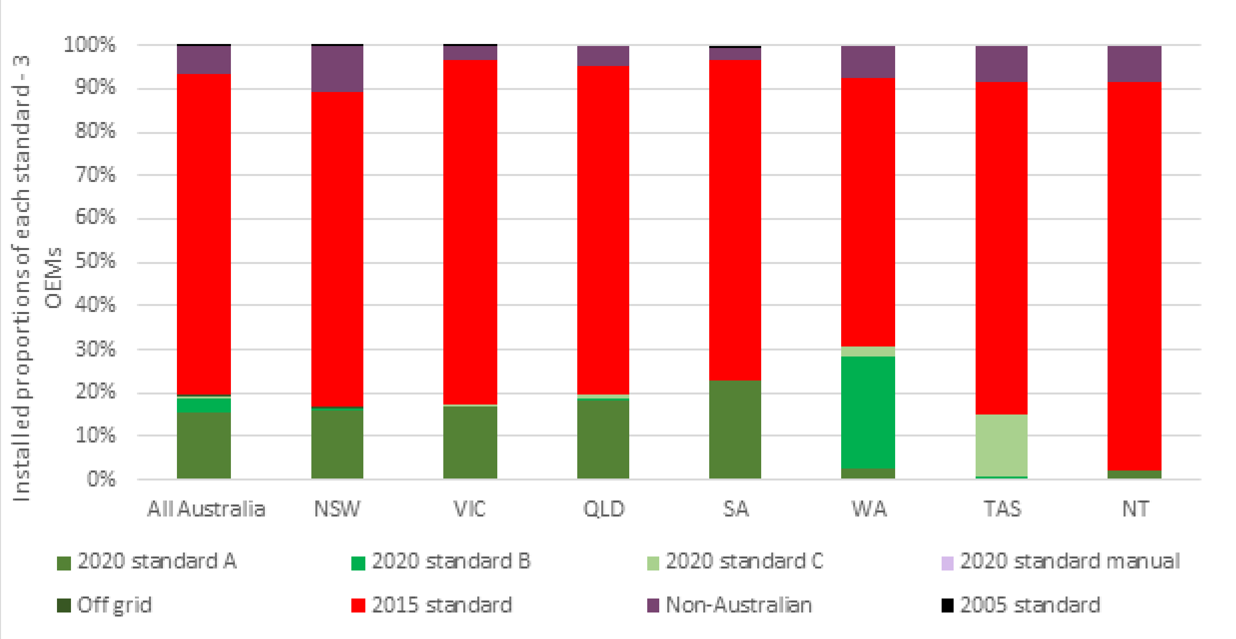
Nature of the incorrect settings

Figure 9 shows the settings that were applied to inverters at the point of installation, aggregated by region. This is based on data for three OEMs that provided relatively large datasets that included regional information, so that compliance with the regional requirements of Australia A/B/C could be properly assessed. Findings include:

- All regions show similar rates of non-compliance. States with mandatory requirements for emergency backstop curtailment capability (SA and WA) might indicate slightly higher rates of compliance to the new standard, but otherwise non-compliance appears equally pervasive in all regions.
- The majority of non-compliant installations have been set to the 2015 Standard. There is also a non-negligible proportion (5-10%, depending on the region) that have been set to various international standards.
- Most of the installations that were correctly set to the 2020 Standard have also been set to the correct regional standard (Australia A for NSW/VIC/QLD/SA, Australia B for the South West Interconnected System (SWIS), and Australia C for TAS and regional WA).

[51] Market share is based on the number of installations recorded for each OEM, as opposed to the number of inverters, to avoid over-representing microinverter technology.

Figure 9 Variations in compliance rate at installation, 3 OEMs (Q1 2022)

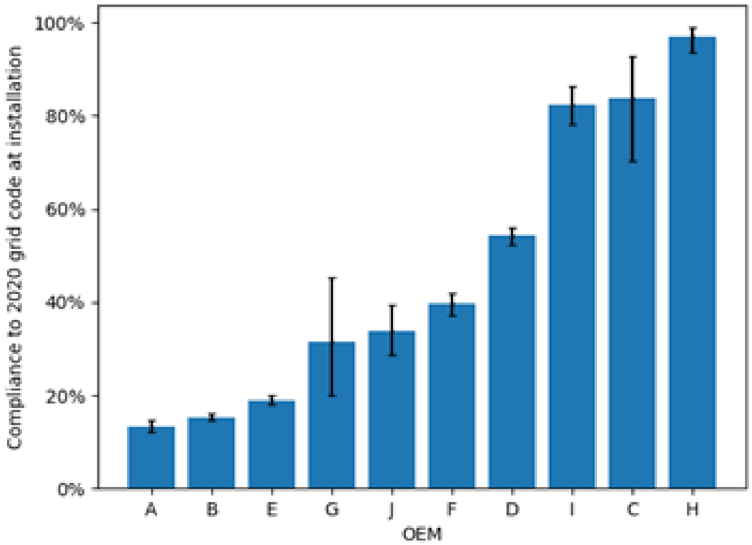


AEMO discussed these findings with the relevant OEMs. The OEMs confirmed that almost all had retained the 2015 Standards in their menu options. It appears that installers are preferencing selection of these older standards during the commissioning process.

Differences in compliance by OEM

Compliance rates were found to differ significantly by OEM. Figure 10 shows estimated compliance rates to the 2020 Standard at the time of installation for the 10 OEMs which provided remote polling data. The poorest OEM showed compliance of only 10%, while the highest performing OEM showed compliance of almost 100%.

Figure 10 Compliance rates to the 2020 Standard (Q1 2022 installs)



Confidence intervals are indicated based on the size of the sample dataset available for analysis. Confidence intervals are based on a 95% Clopper-Pearson approach. Some OEMs were able to remotely poll significantly more inverters than others, leading to differences in confidence between the aggregate compliance rate for each OEM.

AEMO surveyed OEMs about their menu options and installation processes. The OEMs with poorer performance for compliance in the field were generally found to have installation processes that required installers to scroll through long menus to find the correct standard, with many older standards and international standards presented as options (up to 130 in some instances). Some menus are "one-directional", so if the installer missed the option they may need to scroll through the entire list. In contrast, the OEMs with the best compliance performance in the field were generally found to have processes that encourage or require installer selection of the correct 2020 Standard, such as:

- Clear defaults to the 2020 Standard (appearing at the top of the menu, or error messages where an older standard is selected, or products are shipped with the applicable standard as default); or
- Older standards removed or hidden from the available options (installers are only presented with the default standard that is applicable at the time of installation) or
- Requirements that the inverter is internet connected for the commissioning process (so that available options in the menu can be determined by the location of the installation).

This suggests that OEMs have significant influence over compliance of their products when installed in the field, depending on how their products are designed.

2.5.3 Remote updates of inverters

Four OEMs indicated that they have the capability to remotely update their inverters in the field to the compliant 2020 grid code. The proportion of each OEM's inverters that can be remotely updated depends on:

- The proportion of their fleet with internet connectivity. This ranges from as low as 15% of their fleet for one OEM, to as high as almost 100% for another OEM.
- Some OEMs require a list of serial numbers to update. AEMO extracted serial numbers from the DER Register where possible, but this dataset was found to be incomplete and error prone. It appears that in most cases, this data must be entered manually by the installer. For the OEMs that required serial numbers, AEMO found that 15-25% of installations had incorrect serial numbers recorded in the DER Register.

Where possible, the OEMs that have the capability have remotely updated their inverters in the field to the correct standard. Based on information provided by these OEMs, it is estimated that the proportion of inverters set to the correct 2020 Standard could be increased from a market share weighted total of 37% in the NEM at the time of installation to a **total of approximately 45% in the NEM following remote updates** (implemented progressively during Q2 2022, for installations in Q1 2022).

The capability to remotely update inverters (including settings, firmware and grid codes) is a voluntary option established by the OEM, there are currently no technical specifications or cybersecurity considerations defined.

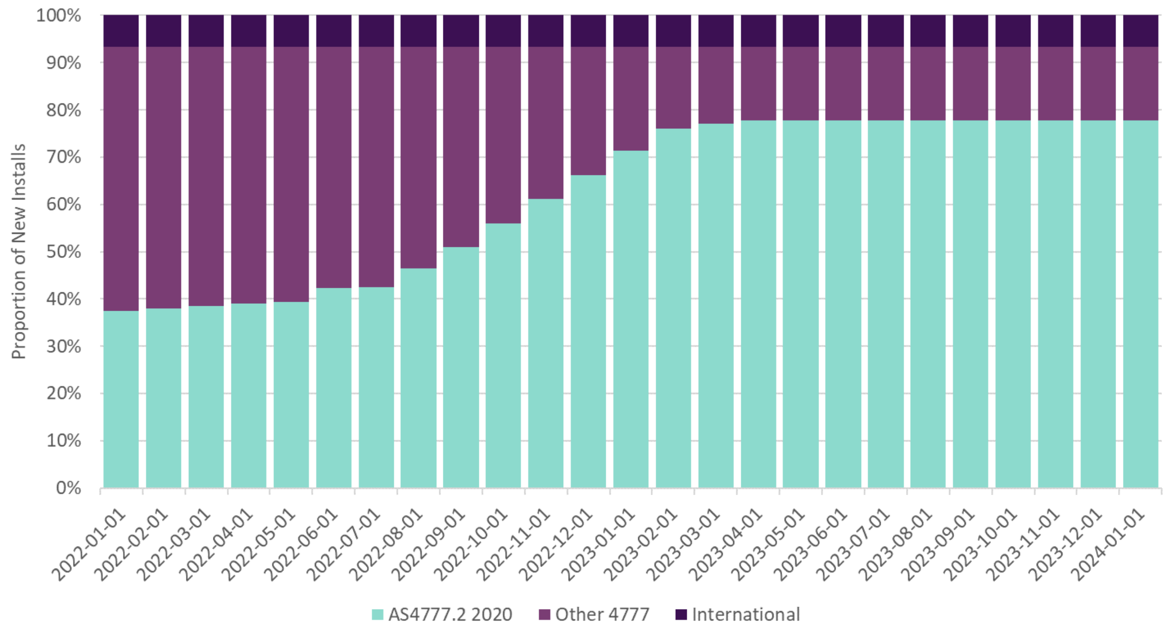
2.5.4 Revision of product menus

AEMO discussed the above findings with OEMs. To improve compliance in the field, ten OEMs indicated that they would voluntarily revise their product menus to remove legacy grid codes (specifically including removing the 2015 Standard from the options presented to installers). Since the incorrect selection of the 2015 Standard was the main source of non-compliance observed, it is expected that the removal of the 2015 Standard from the options available to installers should significantly improve overall compliance rates. It is expected that this change will have no effect on the 5-7% of installations that were incorrectly set to international standards.

One OEM was able to almost immediately update their inverter commissioning menu (achieved via changes to their app configuration, which was possible because their devices require internet connectivity for commissioning) to remove legacy grid code options for selection. Following this change in May 2022, this OEM identified an immediate and significant improvement from 50% compliance in Q1 to 100% of installations correctly set to the 2020 Standard.

The ten OEMs that engaged with AEMO indicated that they would implement these changes to their product menus as per the OEM indicated timeframes, which were reported to occur progressively between June 2022 and March 2023. The time taken to revise menus and for this to be saturated through the manufacturer fleet, was assumed based on manufacturer reporting, where unreported it was assumed that there is an average seven-month lag in the supply chain. Based on these timing estimates, a forward estimate of possible improvements in total compliance (following OEM remote updating where feasible) is shown in Figure 11.

Figure 11 Forward estimates of monthly compliance to the AS/NZS4777.2:2020 grid code



Assumptions include:

- The market share of installs in Q1 2022 is carried forward through the forecast period.
- When an OEM updates their product menus to remove the 2015 Standard options, all installations that were previously under the 2015 Standard will thereafter be under the 2020 Standard.
- Where an OEM can remotely update the settings on their products, this has been done.
- Where an OEM has not indicated they will update their product menus, the present installation rates from Q1 2022 are assumed to persist.
- Where an OEM has not provided data, the estimated average manufacturer compliance rate of 37% is assumed.

This indicates that the proportion of new inverter installations set to the correct 2020 Standard could be increased from a market share weighted total of 45% in the NEM (including remote updates where feasible) to **a total of approximately 78% by mid-2023 if all OEMs that have indicated they will voluntarily update their product menus do so on their proposed timelines.** Similar proportional increases are expected to be seen across other regions in Australia, including the WEM.

AEMO is continuing to work with OEMs to confirm these settings updates have been made as proposed, and that this is resulting in the anticipated improvements in compliance.

At present, these actions by OEMs to improve compliance are entirely voluntary. Some OEMs with significant market share have indicated unwillingness to implement these changes unless required to do so. At present there is no governance framework to require these actions by OEMs.

The above estimates are based on AEMO's extensive engagement with the ten OEMs with the largest market shares for new installations at present, however this may vary between regions and may change over time. This improvement represents only a short-term measure based on information as of Q1 2022. As new OEMs enter the market and grow in market share, they will require similar engagement to ensure their products are designed correctly and deliveri the necessary capabilities. At present AEMO is taking leadership to engage with OEMs on these issues, because non-compliance represents a major security issue if not rapidly addressed. Current governance frameworks do not define which party should be leading this engagement with OEMs, or the required governance arrangements for OEMs and installers.

2.5.5 Disturbance ride-through capabilities

Three OEMs indicated that they have incorporated the new disturbance withstand capabilities specified in the 2020 Standard (specifically ride-through of RoCoF, phase angle jumps and voltage disturbances) through the *firmware* of the device, rather than through the grid code setting (selected by the installer). This means that although an inverter may have been configured incorrectly to the 2015 Standard at the point of installation, if the firmware has been updated to the latest version, the disturbance ride-through functionality specified in the 2020 Standard may still be delivered.

Three of the ten OEMs surveyed reported a design of this type. The remaining seven OEMs surveyed by AEMO confirmed that if the device is set to the incorrect 2015 grid code, it should be expected to deliver disturbance ride-through capabilities consistent with the older 2015 Standard.

Based on the Q1 2022 market share values and OEM datasets, accounting for these self-reports, it is estimated that a total of **~70% of new installations[52] may deliver the necessary disturbance ride-through behaviour**, even though a proportion of these may be non-compliant to the grid code.

Further work is required to confirm the required behaviour, as this is based on OEM self-reporting inferred from OEM firmware and grid code rollout and has not been tested with the specific configurations that are applied in the field.

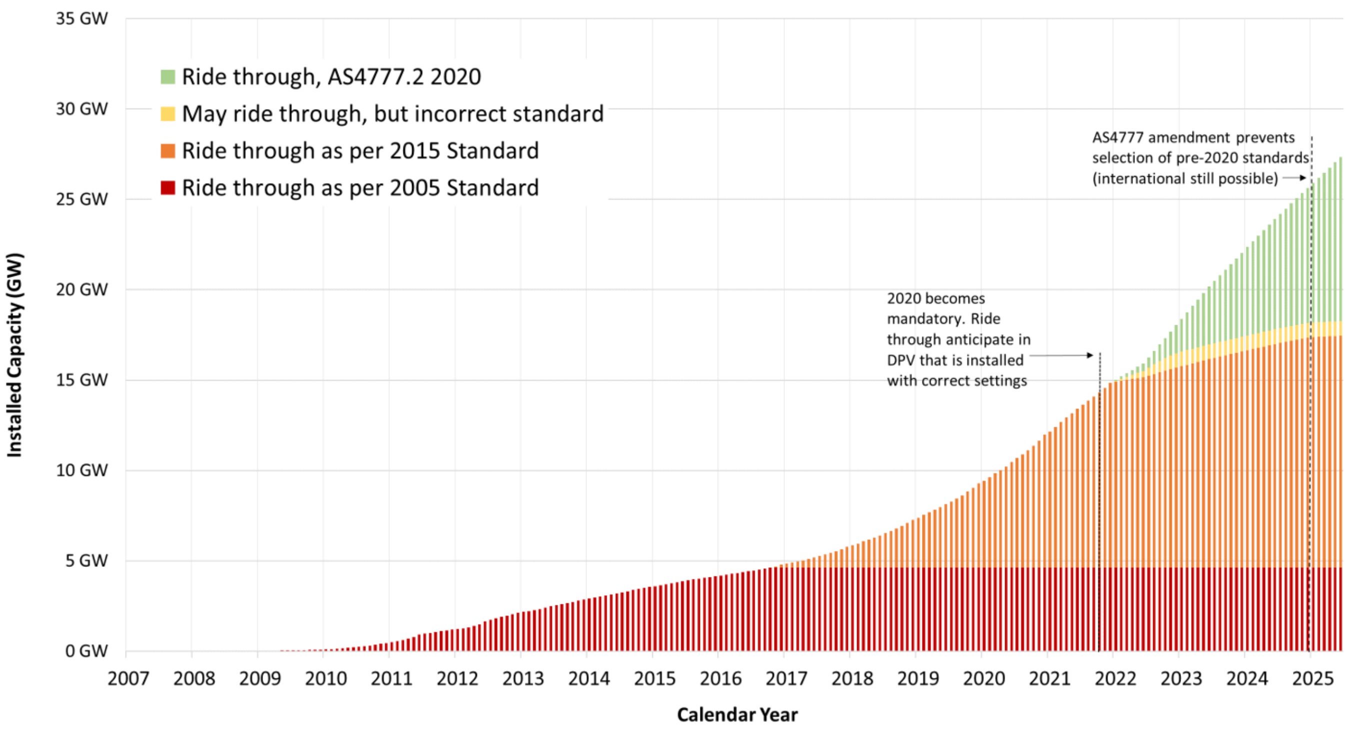
Assuming this self-reported behaviour is correct, and that the above noted updates by OEMs are all implemented as per their proposed timelines (see Section 2.5.3 and Section 2.5.4), an estimate of the proportion of the total DPV fleet installed in the NEM that is expected to deliver the required disturbance ride-through behaviours is shown in Figure 12. All DPV installed prior to 2022 are assumed to show ride-through behaviours consistent with observations for inverters under the 2005 and 2015 Standards as applicable, as observed in field disturbances and bench testing[53]. In any particular disturbance, some proportion of inverters installed under the 2015 Standard will ride-through, depending on the individual conditions they are exposed to. AEMO's power system models that represent these ride-through behaviours have been calibrated based on these observations[54].

[52] This includes OEMs that have undertaken remote updates to correct inverters to the 2020 Standard, and remove legacy grid codes.

[53] 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

[54] AEMO (November 2022) PSS®E 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

Figure 12 Ride-through capabilities of the installed DPV fleet in the NEM (historical and future)



Forecast growth of DPV installed capacity is based on the 2022 ISP Strong Electrification Scenario. OEM market share values from Q1 2022 have been assumed to the end of the forecast period.

2.5.6 Comparison with DER Register

Table 11 shows a comparison of the Standard grid code identified from the OEM reported data and the manual data input in the DER Register at time of install. This analysis matched serial numbers between OEM data and that listed in the DER Register of installations in Q1 2022, providing comparison of the standard reported for a sample size of over 1000. This highlights that only 7% were reported as 2020 compliant in both the DER Register and matched with the OEM reporting. It also shows that in over 50% of cases the reported Standard in the DER Register is not aligned with that identified by the OEM. This highlights that reporting in the DER Register may not be representative of inverters in the field, and may be a consequence of relying on installers to manually input data into a separate form, and auto-populated data fields.

Table 10 Comparison of DER Register and OEM reported compliance

		OEM Reported Compliance	
		2020 Compliant	Non-2020 Compliant
DER Register	2020 Compliant	6.8%	43.0%
	Non-2020 Compliant	9.6%	40.6%

Some NSPs have identified that their installer data entry portals have not been updated to facilitate the correct entry of the site information (for example the 2020 Standard option is unavailable in drop down menus) and also identified points of missing data. Work is underway to correct these portals and information and should facilitate an improvement in the data quality in the DER Register.

2.5.7 Summary of compliance findings

A summary of compliance findings based on OEM datasets is provided in Table 11.

Table 11 Proportion of inverters installed in the NEM

Parameter	Percentage of new installations (%)	Notes
Inverters installed Q1 2022 with the correct AS/NZS4777.2:2020 option selected at the time of commissioning.	37%	Based on datasets from ten major inverter OEMs collectively representing more than 70% of new installations.
Total proportion of Q1 2022 installs that can be set correctly to AS/NZS4777.2:2020 if OEMs update inverters utilising remote update capabilities.	45%	Four OEMs stated that they have the capability and are willing to voluntarily remotely update existing installed inverters to the 2020 Standard. Only a limited proportion of their inverters will be able to be remotely changed (depending on the proportion that is internet connected, and possibly relying on provision of product serial numbers).
PROJECTION: Total proportion of inverters installed in mid-2023 set correctly to AS/NZS4777.2:2020 if OEMs update product menus as voluntarily indicated, and voluntarily apply remote updates where feasible.	78%	Ten OEMs have indicated they will voluntarily implement changes to product menus to remove older AS/NZS4777 standards, this will assist in improving the grid code selected for new installations.
Total proportion of Q1 2022 installs that might perform disturbance ride-through behaviours aligned with the 2020 Standard (based on unconfirmed self-reporting by OEMs).	70%	Three OEMs have indicated that their inverters may still perform ride-through behaviours even if the incorrect grid code is selected, as this functionality has been implemented through firmware changes. Further work is required to confirm the behaviour as this has not been tested.
PROJECTION: Total proportion of inverters installed in mid-2023 that will perform ride-through behaviours as per the 2020 Standard (based on preliminary self-reporting by OEMs) if OEMs voluntarily update product menus as indicated, and voluntarily apply remote updates where feasible.	80%	Assumes OEM market shares remain as per Q1 2022.

The above estimates highlight the significant influence that OEMs have over the compliance rates of their products in the field, depending on how they design their products, the capabilities they implement in their products, and how they present the commissioning process to installers.

Achieving the above improvements to compliance rates has required AEMO to undertake significant ad-hoc engagement with OEMs and is reliant on OEMs voluntarily undertaking the actions required. This process will require ongoing maintenance and strong engagement to ensure actions are being undertaken as stated and to include new OEMs in these processes (especially as they increase in market share). To date, AEMO has taken leadership in this process because poor AS/NZS4777.2:2020 compliance was identified by AEMO as a significant risk to power system security and immediate action was required to highlight this risk and implement rapid improvement measures. The relevant legal and governance frameworks require clarification and improvement, particularly around which parties should be taking responsibility for ensuring compliance with the relevant standards in the field, and the levers, datasets and tools available to them to do so.

2.5.8 Summary of OEM capabilities

To complete the analysis summarised in the previous sections, AEMO contacted the largest 14 OEMs to request information on their capabilities, based on market share in Q1 2022. Of the 14 that AEMO contacted, 10 responded with the requested information. Table 12 summarises these findings for completeness and ease of reference.

This survey indicates that a number of large OEMs already have relatively sophisticated capabilities which assist considerably in improving compliance of their products in the field. However, there is a great deal of variability in OEM capabilities. At present, to AEMO's knowledge, there is no requirement for OEMs to have any of these capabilities, or to be actively involved or engage with AEMO, DNSPs, the CEC, the CER or any other parties in the monitoring or improvement of compliance of their inverters in the field.

Table 12 Summary of self-reported OEM capabilities

Capability	OEM self-reported capabilities	Notes
Ability to remotely survey fleet settings.	• 4/10 – Can view settings for entire interconnected fleet. • 5/10 – Can view settings for individual sites if inverter serial numbers are provided and site is internet connected. • 1/10 – Could not view settings on any installed systems at all.	
Ability to remotely update inverter settings.	• 3/10 – Able to remotely update inverter settings across entire internet connected fleet en masse. • 3/10 – Able to remotely update settings where serial numbers are provided and sites are internet connected. • 4/10 – Could not make any remote updates to settings.	
Implementation of inverter disturbance ride-through capabilities defined in the 2020 Standard.	• 7/10 – Disturbance ride-through requirements are associated with inverter settings. • 3/10 – Disturbance ride-through requirements are embedded in the firmware (may demonstrate ride-through behaviours regardless of grid code settings).	No accredited testing has been performed to confirm that inverters with the updated firmware perform disturbance ride-through as reported, but some older grid code settings are reported to perform the ride-through requirements as specified in the 2020 Standard.
Inclusion of international settings in product menu options at time of commissioning.	• 9/10 – International settings are included in menus. • 1/10 – Only provide Australian products in the Australian market, with no international settings available to installers.	Some OEMs report being able to limit options through GPS through the installer commissioning app.
Internet connectivity.	• Some OEMs report internet connectivity close to 100%. • Other OEMS indicate ~60% internet connectivity.	Reporting of internet connectivity is challenging as some OEMs are unclear of the proportion of actual fleet installed. Where possible, serial numbers were provided however these had various shortcomings and could not provide completeness of the fleet.
Lead times to make changes to product menu settings.	• Some OEMs report being able to make updates to menu settings in 10 minutes. • Some OEMs report that it will take up to two years to make changes to product menus.	Reporting of lead-time for the roll-out of changes that require alterations at the point of manufacture is challenging as visibility of the supply chain of stock is limited for manufacturers once products are shipped and provided to distributors.

2.6 Solar Curtailment Compliance

2.6.1 South Australia Relevant Agent

From 28 September 2020, the SA Government introduced mandatory requirements on all new embedded generation installations in South Australia, requiring that all new and replacement systems appoint a relevant agent that has the capability to remotely control the embedded generation output, with a minimum capability to connect and disconnect. One of the reasons that this capability was implemented, was to manage the risk of DPV contingencies (which would be reduced if compliance to the 2020 Standard were assured).

When disconnection is required to maintain system security, SA Power Networks will contact the relevant agents with a disconnection requirement. The relevant agents will then meet the requirement. The type of response differs between different relevant agents and technology types, with some limiting DPV to zero export and curtailing generation, and some disconnecting generation.

Through monthly testing of relevant agents (which includes a variety of technology providers and OEMs) an understanding of the ability for systems to perform remote communication has been developed. As of April 2022, it was identified that approximately 30% of systems were non-compliant to the relevant agent requirements, as they did not have active remote communication available and were uncontrollable. Further analysis is also underway to investigate compliance rates of relevant agents during the South Australia separation and subsequent island operation during 12-19 November 2022, where DPV curtailment approaches were applied; key findings will be outlined separately in an incident report[55].

To address these arising challenges, SA Power Networks has established a DER Compliance Program to improve performance to both the relevant agent requirements, as well as to AS/NZS4777.2 settings and flexible export registration (which improves hosting capacity through the application of export control).

The compliance program features a series of project cycles (iterations) to develop:

- the technical capability to identify DER non-compliances;
- methods to communicate them to relevant parties; and
- systems to enforce consequences.

In the first iteration of the compliance program, SA Power Networks is developing the capability to automatically detect when a DER installation should have been closed-out via its SmartInstall commissioning process. This will enable the ability to notify solar retailers and/or installers when the reporting is outstanding (as it differs to behaviour), and therefore prevents future embedded network applications continuing where non-compliances exceed a threshold.

2.6.2 WA Emergency Solar Management (ESM)

From 14 February 2022, the WA Government[56] introduced requirements for all new and upgraded solar systems with an inverter capacity of up to 5 kW to be capable of being remotely turned off in an extreme minimum operational demand event. By assessing the response from one major technology provider, it was identified that from 300 sites 20% were non-compliant due to the lack of NMI data provided during the commissioning process (which is required for a successful ESM registration). For systems that are correctly registered, it is anticipated that 80% to 90% will be online and available to perform the requested response.

[55] AEMO, Power System Operating Incident Reports, https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports/power-system-operating-incident-reports

[56] Government of Western Australia, Emergency Solar Management, available at: https://www.wa.gov.au/organisation/energy-policy-wa/emergency-solar-management

As the national average for residential systems is now over 5 kW, there are discussions to possibly extend ESM to larger and upgraded systems in WA.

2.7 Summary

The key insights from the body of evidence available to AEMO at present are:

- When configured properly to the 2020 Standard, most inverters appear to be designed appropriately to deliver the specified disturbance ride-through behaviours.
- In the field, compliance with AS/NZS4777.2 is poor; a wide range of data sources consistently indicates that **less than half of systems installed are set correctly to the required standard**. This has been observed consistently in measures of compliance to the 2015 Standard, and also in compliance to the 2020 Standard.
- OEMs have considerable influence over the compliance of their products in the field. Some major OEMs have the ability to remotely view and update settings for the majority of their fleet and can easily and quickly implement changes to product menus. These changes allow them to achieve close to 100% compliance of their products in the field. Other OEMs have none of these capabilities, and compliance rates can be as low as 10% in the field. There are no requirements at present for OEMs to have any of these capabilities[57] or to engage with industry stakeholders to assist in monitoring and improving compliance of their fleet.
- DNSPs have some existing frameworks to support delivery of compliance management functions, particularly through their connection agreements with customers. The tools, datasets and pathways that are available to DNSPs to compel and enforce compliance need review, particularly where the capability to remedy action lies on the customer, or other parties that may not consistently cooperate on a voluntary basis.
- It is important to manage compliance at the point of installation. Connectivity drop off following installation makes it increasingly difficult to rectify compliance later, even for more advanced OEMs that have remote update capabilities.
- Gaps have been identified in the existing audit and inspections programs with regards to technical standards.

[57] There are also no requirements to meet any basic cybersecurity requirements.

3 Implications of poor compliance

AEMO's work to assess and quantify the implications of poor compliance is ongoing. A brief qualitative summary is provided here, and further insights will be provided to the industry as this work progresses.

The importance of generator performance requirements

As a condition of connecting to the grid, large-scale scheduled and semi-scheduled generators must demonstrate that they meet a wide range of technical requirements (defined in Chapter 5 and clause 5.2.5 of Schedule 5.2 of the National Electricity Rules (NER)). These detailed and extensive requirements are well understood to be crucial for secure and stable power system operation. They ensure that generators perform as required to support the grid.

DER now represents a considerable and growing proportion of NEM generation, with DPV already supplying almost half the generation on the NEM mainland[58] and more than 74% of WEM in some periods in 2022, which is projected to grow to 70-80% of NEM generation in some periods by 2025 or 2026. This means that, to maintain stable and secure power system operation, DER (in aggregate) must now meet comparable technical performance requirements to those which apply to scheduled and semi-scheduled generators.

One of the most important performance requirements is that generators can ride-through (not disconnect or "shake-off") when power system disturbances occur. For example, poor disturbance ride-through capabilities for a significant proportion of large-scale generation was a key contributing factor to the South Australian system black event in 2016[59]. This was soon followed by improved ride-through requirements being defined in the NER.

Disturbance ride-through performance of DER

There is now considerable evidence that DER designed and tested to the 2015 Standard (AS/NZS4777.2:2015) has poor disturbance ride-through characteristics, with up to half the DPV systems in a region being observed to disconnect (or "shake-off") in response to a power system fault[60]. Improved ride-through capabilities have now been defined in the 2020 Standard (AS/NZS4777.2:2020), and preliminary laboratory testing to date suggests that inverters designed and tested to this Standard demonstrate the required behaviours (although further field observations are required). The new 2020 Standard became mandatory for systems installed after 18 December 2021.

If the installation of inverters compliant only with the 2015 Standard (and not with the new 2020 Standard) continues, the amount of DPV with poor disturbance ride-through capabilities[61] will continue to grow. DPV shake-off can happen coincident with the trip of a large generating unit, thus increasing

[58] The NEM mainland refers to the synchronous interconnected system of Queensland, New South Wales, Victoria and South Australia (excluding Tasmania, which is connected to the NEM via a DC link).

[59] AEMO (March 2017) Black System South Australia 28 September 2016, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

[60] 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

[61] Three of the ten OEMs surveyed have indicated that the disturbance ride-through capabilities required in the 2020 Standard have been introduced through firmware updates, and therefore their products may demonstrate the necessary ride-through behaviours even if they are set to the 2015 Standard. This is untested at this time. The other seven OEMs surveyed have confirmed that if their inverters are set to the 2015 Standard, they are expected to behave as per the 2015 Standard.

the size of the largest credible contingency that AEMO must manage in order to maintain power system security.

An increase in the size of the largest credible contingency has a series of flow on consequences:

- **Increased requirements for frequency control services** – Larger contingency sizes require higher amounts of contingency Frequency Control Ancillary Services (FCAS), inertia and inertia support services such as Fast Frequency Response (FFR), which must be procured.
- **Increased need for DPV curtailment –** When operating islanded regions, after all the other available options have been exhausted, AEMO may direct network service providers (NSPs) to curtail DPV in order to maintain power system security. In the vast majority of cases this action is related to DPV contingency sizes that exceed manageable thresholds.
- **Reducing network stability limits –** NSPs advise AEMO of the limits of their network, including limits related to transient and voltage stability. These limits aim to ensure that any single credible contingency will not lead to instability. DPV tripping in response to a fault can detrimentally affect stability limits, resulting in flows on major transmission lines and interconnectors needing to be constrained to lower levels during high DPV conditions. This in turn could increase market costs, and by late 2024 could lead to an increased need for DPV curtailment as the only last resort measure available, when these limits violate.
- **Reducing windows for planned network outages** – When NSPs request to take network elements out of service for maintenance or necessary works, AEMO must assess whether those outages will occur during or cause periods where there is a need for load shedding, last resort DPV curtailment, or other directions by AEMO to maintain system security. Outages must now be avoided under some high and moderate DPV conditions to avoid a need for such last resort DPV curtailment actions to manage DPV contingency sizes. Often, network elements may need to be out of service for a period of consecutive days, which means that it can be challenging to find suitable windows for works to occur. This is already leading to almost entire seasons of the year where NSPs are unable to complete certain multi-day planned outages. This escalates the risk of sudden unplanned network outages occurring because required maintenance and upgrade works could not be being undertaken in a timely manner.
- **Increased risks for non-credible contingencies** – Increasing DPV contingency sizes also escalates risks of cascading failure and system black associated with non-credible contingency events (such as loss of a double circuit interconnector or a trip of multiple generating units). These types of contingencies are typically expected to be managed by emergency control schemes such as under frequency load shedding (UFLS). Poor DPV inverter compliance can increase the size of the original contingency, thereby exacerbating the inability of UFLS schemes to arrest a severe disturbance and increasing the risk of a black system event occurring.
- **Other security implications** – AS/NZS4777.2:2020 includes a range of other behavioural specifications that are important to support power system security beyond disturbance ride-through capabilities, such as the frequency-watt response (which is important to assist in arresting severe frequency disturbances, especially in periods with few scheduled/semi-scheduled units operating). Poor compliance compromises the delivery of these other important functions.
- **DNSP network implications** – AS/NZS4777.2:2020 also includes a wide range of requirements that are important for DNSP network performance and for improving DER hosting capacity of the network (such as Volt-VAr and volt-watt power quality modes). Poor compliance therefore also detrimentally affects distribution network performance, costs and hosting capacities.

AEMO's work to assess the implications of poor DPV disturbance ride-through capabilities is ongoing, and further quantification of these challenges will progressively come to light over time as AEMO and NSPs do the work required to integrate DPV behaviour into all the existing operational processes.

The impacts are complex and multifaceted, and are already leading to considerable challenges.

Poor disturbance ride-through of DER is identified as **the most serious and urgent barrier** to achieving successful, secure and reliable operation of the NEM with high levels of DER.

On this basis, AEMO recommends that industry efforts should urgently focus on improving compliance, targeting **at least 90% compliance with AS/NZS4777.2:2020 by the end of 2023**, complemented by ongoing governance frameworks to maintain and further improve that level of compliance.

Case studies are provided in the sections below, providing further detail and quantitative analysis in some of these areas where available.

3.1 Growth in DPV contingency sizes over time

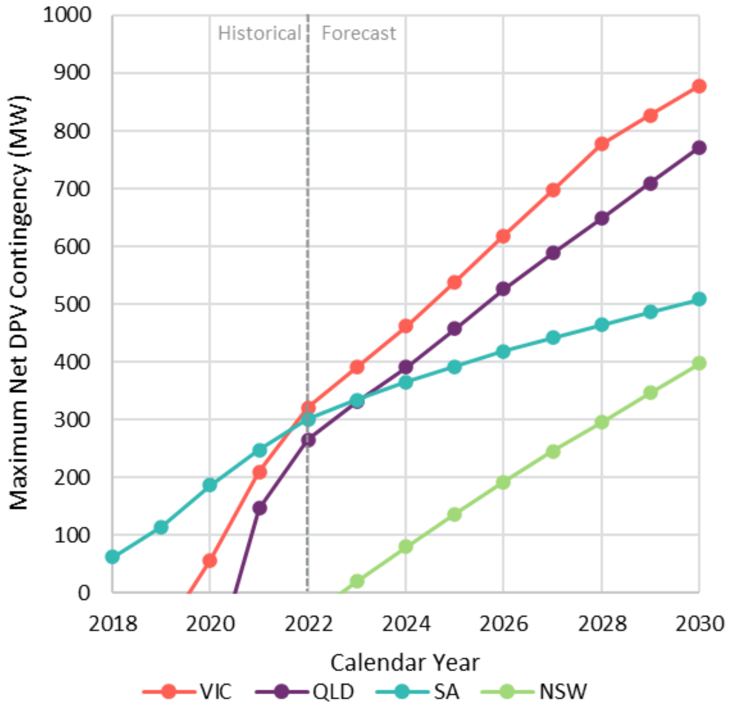
Figure 13 shows a projection of the maximum potential net contingency due to DPV shake-off in response to a severe but credible fault. This estimate is based on:

- DPV growth forecast in the Integrated System Plan (ISP) Step Change[62] scenario.
- the percentage of load and DPV shake-off that could occur associated with a severe fault at a range of possible locations in the network in each region, studied in an RMS model applying DPV and load models validated against historical disturbances[63]. These models have an approximate uncertainty margin of ±30% of the contingency size and are in continuing development.
- the present compliance rates continuing unchanged (assuming ~50% of new installations are not compliant with the 2020 Standard and continue to demonstrate disturbance ride-through characteristics aligned with the older 2015 Standard). As outlined in Section 2, a wide range of measures of compliance indicate that less than half of DPV systems are being installed under the correct and current standard. Measures are being explored by some OEMs and some DNSPs to improve compliance, and a few OEMs report that their inverters may demonstrate ride-through behaviour even if they are installed under the incorrect standard. However, these measures are unconfirmed at present, being undertaken on a voluntary and self-reported basis only, and actions are only being undertaken by selected OEMs and a small number of DNSPs. Until these measures are implemented across most of the NEM and by most OEMs, and further robust evidence is available to confirm successful application of these measures, AEMO will need to manage power system security on the basis of the present evidence available. This evidence indicates an approximate compliance rate of no more than 50% of new installations behaving according to the disturbance ride-through characteristics in the 2020 Standard.

[62] AEMO, 2022 Integrated System Plan (ISP). Available at: https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp

[63] AEMO (November 2022) PSS®E 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

Figure 13 Maximum Net DPV Contingency Risk by region



Assumes DPV growth from the ISP Step Change scenario, the 2022 weather reference year, and a 50% new-install compliance rate. Contingency sizes account for load shake-off, with the net (DPV shake-off minus load shake-off) values shown.

Figure 13 shows that if half of the new DPV installed in the NEM continues to have disturbance ride-through capabilities consistent with the older 2015 Standard, the size of the DPV contingency risk is forecast to continue growing in all NEM Mainland regions, reaching more than ~600 MW by 2026, and almost ~900 MW in 2030.

These DPV contingency sizes would be added to the largest credible contingency (typically associated with the largest generating unit online). At times of high DPV generation, most scheduled and semi-scheduled units will be dispatched at low levels. If it is assumed that the largest relevant scheduled unit is dispatched at ~300 MW at this time, this would lead to a total generation contingency risk of ~900 MW by 2026 and ~1200 MW by 2030. This represents a quadrupling of typical generation contingency risk sizes in high DPV generation periods.

Based on the Step Change scenario in the ISP, approximately 700 MW of DPV will be installed in Victoria each year. If half of this new DPV installed capacity continues to have disturbance ride-through capabilities consistent with the older 2015 Standard, this will lead to an increase in maximum credible NEM-wide contingency sizes of ~80 MW each year, every year, until compliance rates are improved.

3.2 Implications for NEM FCAS requirements

In 2022, the average size of the largest credible generation contingency risk (based on dispatch levels of scheduled/semi-scheduled units and Basslink flows, and not accounting for DPV contingency risk) was 670 MW, with a maximum of 730 MW and a minimum of 330 MW. Scheduled and semi-scheduled unit dispatch levels are generally lower in periods with high DPV generation due to low operational demand. This means that the DPV contingency can increase FCAS requirements in the middle of the day. This will lead to increases in costs associated with enabling FCAS in those periods.

3.2.1 Case Study: NEM FCAS requirements

As a case study example, consider a recent NEM-intact (system normal) period where a Loy Yang B unit was online at 335 MW, close to its minimum stable load. The largest credible generation contingency risk during this period (not accounting for DPV continency risk) was 350 MW (set by a different unit), and the R6 FCAS requirement (not accounting for DPV contingency risk) was 286 MW (less than the contingency size due to load relief).

Preliminary studies (in progress at present) indicate that a credible fault leading to a trip of a Loy Yang B unit could simultaneously lead to ~30% of DPV and ~11% of underlying load in Victoria suddenly disconnecting from the power system[64].

Based on these preliminary studies, Table 13 gives an indication of the total contingency sizes in this dispatch interval, both for a recent historical dispatch interval, and a near future period (based on projections in the ISP Step Change scenario) if the unit trip and DPV trip are both accounted for.

Table 13 Example dispatch period: NEM FCAS requirements

	Recent historical period (1300 hrs 18/12/22)	Near future period (2025) (if half of new DPV installed continues to have poor disturbance ride-through capabilities)
Loy Yang B unit dispatch	335 MW	335 MW
DPV generation (MW)	2,957 MW	4,409 MW
Underlying load (MW)	5,152 MW	5,152 MW
Total contingency contribution from DPV and load (MW)	320 MW	538 MW
Total contingency size including DPV and load (MW)	655 MW	873 MW

As shown in Table 13, the total largest credible contingency size in high DPV periods could increase to ~870 MW by 2025. This would increase requirements for all contingency FCAS services, including the new very fast FCAS service[65].

In the NEM, there are a relatively large number of generating units registered to provide raise FCAS (a total of ~5,000 MW registered). However, only a small proportion of this capacity will be available in any particular period, since units must be operating and (if synchronous) dispatched above their minimum generation level to offer FCAS capability. This is especially the case in periods of low operational demand where there will likely be very few scheduled units operating. This means that initially DPV shake-off will act to increase FCAS and energy market costs, but over time it will likely have an increasing influence over dispatch, and eventually there may be difficulties maintaining sufficient frequency control services.

In addition to the increased direct FCAS procurement costs, increasing FCAS requirements could increase energy costs, due to the co-optimisation of energy and FCAS markets. For example, high prices can be observed during periods where South Australia is operating as an island during high DPV

[64] Examples of similar disturbances (used to validate PSS®E models) are outlined in the report: AEMO (November 2022) PSS®E 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

[65] AEMO, Amendment of the Market Ancillary Service Specification (MASS) – Very Fast FCAS, https://aemo.com.au/consultations/current-and-closed-consultations/amendment-of-the-mass-very-fast-fcas#:~:text=On%2015%20July%202021%2C%20the,to%20control%20power%20system%20frequency.

generation periods (such as on Thursday 17 November 2022 when energy prices exceeded $500/MWh around midday).

3.3 SA Island frequency control management

AEMO's analysis indicates that approximately 32% of the DPV and 13% of the underlying load in South Australia could trip in response to the most severe credible fault event, in conjunction with a trip of a Pelican Point unit or a Torrens Island unit[66,67].

During island operation, the amount of raise contingency FCAS available is limited to only that registered in South Australia and is particularly restricted in periods with low operational demand when few scheduled units are operating.

The amount of inertia available in South Australia can also be very low in periods with low levels of operational demand, which often leads to fast frequency response (FFR)[68] being the main limiting factor for provision of adequate frequency control in the South Australian island. For these reasons, AEMO's present operating procedures for operating a South Australian island in periods with high levels of DPV generating require that:

- FFR providers (primarily the large Battery Energy Storage Systems (BESS) in South Australia) are constrained to dispatch levels close to 0 MW such that their available FFR headroom and footroom is maximised.
- The total contingency size in the South Australia island is maintained at no more than ~200 MW. This requires that:
  - units connected to the 275kV metro-area network in South Australia are maintained at dispatch levels below 110 MW[69].
  - The contingency associated with DPV shake-off is maintained at less than ~80 MW. This often requires that total South Australia DPV generation levels are actively managed, such as in the recent South Australian island period[70].

These procedures will be updated following commissioning of new plant in South Australia and following introduction of the very fast FCAS market in late 2023[71].

Based on the Step Change scenario in the ISP, approximately 200 – 300 MW of DPV will be installed in South Australia each year until 2030. If half of this new DPV installed capacity continues to have

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[66] 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

[67] AEMO (November 2022) PSS®E 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

[68] This is being formally introduced as a new very fast FCAS services from late 2023. It is already operationally important in South Australia, and FFR availability levels are already accounted for in operating procedures under island operation conditions.

[69] During the recent period of SA island operation (12-19 November 2022), a temporary operating procedure was applied on two days (17 Nov and 19 Nov) due to extremely high DPV conditions. This procedure required that Pelican Point was offline, and constrained the Torrens Island B units to approximately 70 MW, which increased the allowable DPV contingency size to 110MW. This temporary operating procedure was applied so that the limited amount of DPV curtailment capability available would suffice to maintain contingency sizes within secure limits. This procedure results in a highly constrained system which can lead to other issues under some conditions, such as lack of reserve, and therefore is not applied as the standard operating procedure.

[70] AEMO (November 2022) Preliminary Report – Trip of South East – Tailem Bend 275kV lines on 12 November 2022, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2022/preliminary-report--trip-of-south-east-tailem-bend.pdf?la=en

[71] AEMO, Amendment of the Market Ancillary Service Specification (MASS) – Very Fast FCAS, https://aemo.com.au/consultations/current-and-closed-consultations/amendment-of-the-mass-very-fast-fcas#:~:text=On%2015%20July%202021%2C%20the,to%20control%20power%20system%20frequency.

disturbance ride-through capabilities consistent with the older 2015 Standard, there will be a continuing increase in contingency sizes of ~30 MW each year, every year (if present DPV installation rates continue), until compliance rates are improved.

Managing to simultaneously deliver all the power system requirements including adequate frequency control in a South Australian island is already highly complex and very constrained in some high DPV periods.

3.4 DPV curtailment

As noted above, when operating a South Australian island, the contingency associated with DPV tripping must be maintained at less than ~80 MW. This often requires that total DPV generation levels in South Australia are curtailed.

For example, following a recent non-credible separation event on 12 November 2022[72], South Australia was operating as an island for approximately a week under very high DPV generation conditions with DPV generation forecast with a maximum capacity factor of 71% (1,600 MW of DPV generation) on 17 November[73]. After all other available options were implemented to maintain the system in a secure operating state, to reduce the credible contingency size to secure limits, AEMO issued an clause 4.8.9[74] instruction to ElectraNet on every day between 13 to 17 November 2022 (inclusive) and on 19 November 2022 to maintain DPV generation to a level that would maintain the DPV contingency risk to secure levels.

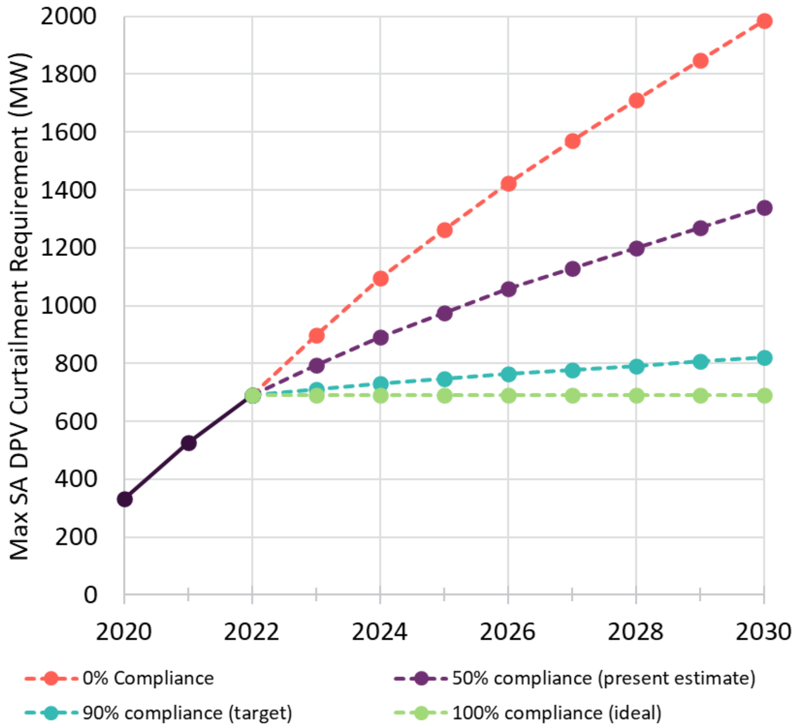
During this event, it was necessary to curtail more than 400 MW of DPV to maintain DPV contingency sizes within necessary thresholds. Based on the present resources available, this will grow by approximately 100 MW per year if present DPV installation rates and compliance levels continue. This means that if the same circumstances occur in late 2023, and the present compliance rates continue, it would be necessary to curtail ~500 MW of DPV to maintain system security. Figure 14 gives an indication of the year-on-year growth in the maximum amount of DPV curtailment that would be required in South Australia (on the highest curtailment requirement day), if South Australia is operating as an island, based on the present operating procedures. The purple line indicates the maximum DPV curtailment requirement if half of new installations have ride-through capabilities consistent with the older 2015 Standard. As a comparison, lines are also shown for the growth in maximum DPV curtailment required if all new DPV installations are non-compliant (assumed to have ride-through capabilities consistent with the older 2015 Standard), or all compliant (assumed to have ride-through capabilities consistent with the new 2020 Standard).

[72] AEMO (November 2022) Preliminary Report – Trip of South East – Tailem Bend 275kV lines on 12 November 2022, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2022/preliminary-report--trip-of-south-east-tailem-bend.pdf?la=en

[73] This is close to the maximum estimated SA DPV generation in 2022, which was 1,650 MW, with a capacity factor of 72%.

[74] Under Clause 4.8.9 of the National Electricity Rules AEMO may require a registered participant to do any act or thing if AEMO is satisfied that it is necessary to do so to maintain or re-establish the power system to a secure operating stage, a satisfactory operating state, or a reliable operating state

Figure 14 Maximum DPV curtailment required in South Australia to manage DPV contingency



Based on present operating procedures. These procedures will be reviewed following commissioning of new entrants such as the 250 MW AGL Torrens Island grid-scale battery. Compliance rates indicate compliance with the 2020 Standard, assuming non-compliant installations have disturbance ride-through capabilities consistent with the 2015 Standard.

Alternatively, new sources of fast frequency control are required to manage the growing DPV contingency related to non-compliance, the installation of ~30 MW of new BESS each year is required, ongoing, until compliance rates are addressed (and this capacity would need to be reserved in these periods to make sufficient headroom available). When commissioned, the 250 MW AGL Torrens Island grid-scale battery (and any other large-scale batteries in the development pipeline) will assist by providing additional fast frequency response, and operating procedures will be updated accordingly to reflect the increased ability to manage larger contingency events in the South Australian island. With continuing growth in DPV contingency sizes, this and the existing BESS will continue to need to be dispatched at close to 0 MW during South Australian island periods with high DPV generation to maintain their full ability to deliver frequency control.

At present, DPV curtailment is only possible in South Australia and Western Australia (with Queensland introducing some requirements for larger DPV systems installed after February 2023).

Management of DPV contingency sizes is the primary reason that DPV curtailment is required at present.

3.5 Reducing network stability limits

TNSPs must advise AEMO of network limits. AEMO implements these limits in the form of constraint equations, which influence market dispatch.

One form of network limits are transient stability limits, which aim to ensure the network remains stable following any credible contingency. Stability risks are often mitigated by limiting pre-fault flows across a cutset (such as an interconnector). DPV shake-off either side of the cutset could cause post-fault flows to breach these limits, thus pre-fault flows may need to be constrained to account for DPV shake-off. This means that the network may need to be more heavily constrained to meet the required security outcomes. All stability limits relating to credible contingency events in the vicinity of DPV generation centres must be reviewed to determine when and how they may be affected by poor DPV disturbance ride-through behaviours.

To facilitate the studies required, AEMO has invested considerable resources developing and validating Root Mean Square (RMS) models that represent the disturbance ride-though behaviours of DPV in the NEM at present[75]. These models are based on field measurements and bench testing to calibrate the conditions under which a proportion of aggregated DPV connected behind a transmission bus is likely to disconnect[76]. The models were released for operational use in late November 2022 and are now being applied by AEMO and TNSPs to review the impact of DPV shake-off behaviours on stability limits. This work is in progress; some preliminary insights are outlined below.

These limited case studies provide some evidence that DPV shake-off behaviours are already affecting system limits, and indicate that further continued growth in DPV contingency sizes is likely to lead to increasingly complex and problematic outcomes.

3.5.1 Case Study: South Australia system normal limits

ElectraNet has provided AEMO with advice relating to stability limits on the Heywood Interconnector which incorporate the impacts of DPV shake-off. These limits already result in some periods where South Australia must export to Victoria via the Heywood Interconnector under system normal conditions (i.e., Victoria must import from South Australia via the Heywood Interconnector). This will interact with Victoria's ability to export to other regions.

3.5.2 Case Study: South Australia with outages (credible risk of separation)

ElectraNet has also provided AEMO with advice relating to various network outages that lead to South Australia being at credible risk of separation, accounting for DPV shake-off risk. Typically, limits associated with network outages are significantly reduced compared with system normal limits (when all network elements are in service). The exact limit depends on exactly which network element is out of service, the dispatch levels of scheduled and semi-scheduled units in South Australia, subregional demand levels, and the amount of DPV generation.

Sometimes, network elements suddenly fail leading to an unplanned (forced) outage. Under these conditions, AEMO will invoke the necessary constraints relating to the specific outage, and the NEM dispatch engine will adjust dispatch accordingly to meet that reduced interconnector limit. If the interconnector limit violates, and all other options are exhausted, it may be necessary for AEMO to issue an NER Clause 4.8.9 instruction to ElectraNet to maintain DPV generation to a level that maintains the DPV contingency risk to secure levels.

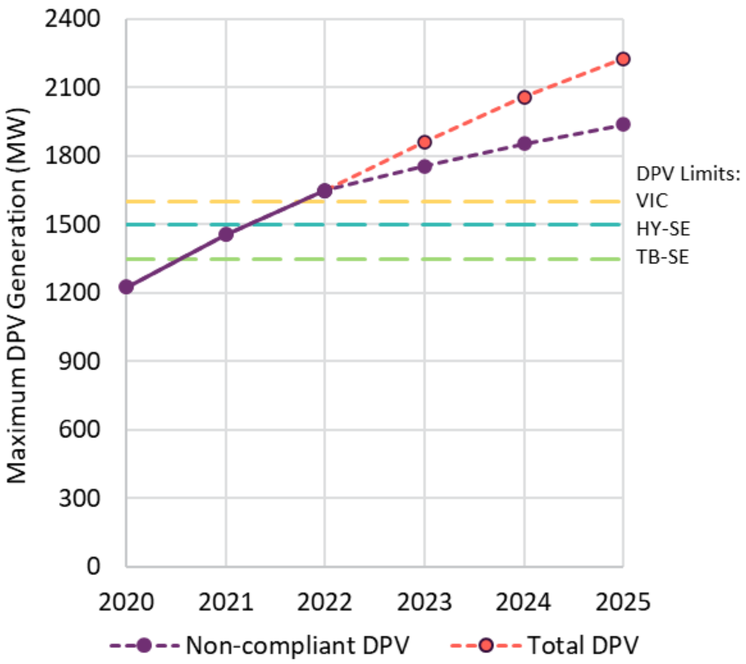
Figure 15 shows the maximum level of non-compliant DPV generation that can be managed in South Australia before DPV curtailment is required as a last resort to maintain power system security, with various network outages. The red line shows projected maximum total DPV generation in South

[75] AEMO (November 2022) PSS®E 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

[76] 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

Australia. The purple line shows projected maximum non-compliant DPV (if half of new installations are non-compliant). Outages of a Tailem Bend to South East (TB-SE) 275 kV line are the most onerous, and require that non-compliant DPV generation is limited to below approximately 1,350 MW (assuming all existing DPV has ride-through behaviour aligned with the older 2015 Standard). This DPV generation limit can be further reduced if other network elements, such as the Black Range series capacitors, are unavailable. DPV generation already far exceeds this level in many periods. The maximum DPV generation in South Australia in 2022 was 1,650 MW, growing by 150-220 MW each year.

Figure 15 Maximum DPV thresholds in South Australia for various network outages



VIC: Outage of any line in the VIC 500kV network between Heywood and Moorabool with Black Range capacitors bypassed.
HY-SE: Outage of a Heywood to South East 275 kV line with Black Range capacitors in service.
TB-SE: Outage of a Tailem Bend to South East 275 kV line with Black Range capacitors in service.

If there is continuing growth in DPV contingency sizes, an increasing amount of DPV will need to be curtailed in these outage conditions. In contrast, if there is confidence that new DPV installations have the required ride-through capabilities (compliant with the 2020 Standard), it would be possible to allow those DPV installations to continue operating uninterrupted under these conditions (because they are not contributing to the power system risk).

3.6 Reducing windows for planned outages

Section 3.5.2 above outlines the impacts of DPV contingency risk on stability limits associated with network outages. This has impacts on dispatch when there are unplanned (forced) outages, discussed above. It also has implications for the windows of time available for TNSPs to take planned outages, to undertake necessary maintenance works or implement planned upgrades.

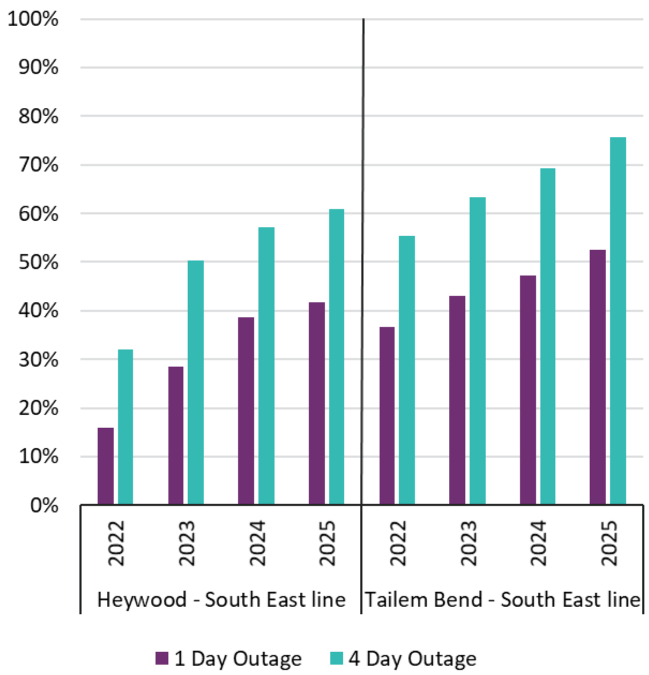
AEMO cannot allow an outage permission to proceed (PTP) if the outage would lead to an elevated risk of load shedding[77], last resort DPV curtailment, or other interventions in order to maintain power system security.

Often, once an outage has commenced, the necessary works can take several consecutive days to complete, and it may not be possible to recall the outage and return the lines to service if unforeseen circumstances arise. This means that a multiple day window of low DPV generation may be required for an outage to proceed.

3.6.1 Case Study: South Australia with planned outages

Figure 16 shows an estimate of the proportion of the year where AEMO would need to revoke permission to proceed for a planned outage of the Heywood - South East line, or the Tailem Bend-South East line, if the outage needed to extend for one full day (purple) or needed to extend for four full days (turquoise). By 2025, if present compliance rates continue, the DPV contingency risk alone would prevent four-day outages of the Heywood to South East line for more than 60% of the year. For the Tailem Bend to South East line, four-day outages would not be possible for more than 75% of the year due to the DPV contingency risk. Other PTP requirements, such as reserve levels and system strength, must also be met, further increasing the proportion of the year where such outages would not be possible. The available windows for these outages will continue to reduce over time if the DPV contingency risk continues to grow.

Figure 16 Proportion of year that outage cannot proceed due to DPV contingency risk



Shows proportion of year where DPV generation is expected to exceed the PTP threshold during the outage period for two outages:

- 1 x Heywood to South East 275 kV line (the Heywood Interconnector). Indicative PTP threshold used = 1,400 MW
- 1 x South East to Tailem Bend 275 kV line (the next line west of the Heywood Interconnector). Indicative PTP threshold used = 1,250 MW

[77] AEMO would revoke PTP for an outage if reserve levels are forecast below the Lack of Reserve 2 (LOR2) trigger level.

Reducing windows for planned outages is already problematic and has been a major cause for concern for AEMO and NSPs (ElectraNet and AusNet) during 2022. Significant resourcing in the operational planning teams at both AEMO and the NSPs has been dedicated to working out how to allow outages to proceed in a timely manner, while maintaining system security and avoiding customer impacts.

TNSPs need to take planned outages in a timely manner to conduct necessary maintenance, and if this maintenance needs to be delayed it puts the network at elevated risk of failures and unplanned outages. These risks also increase the costs of conducting such maintenance (for example, if a planned outage that would ideally take a number of days must be re-organised such that it can be returned to service for a part of each day, or recalled at short notice if required). These increased costs are ultimately borne by consumers.

Managing uncertainty

Even if all PTP requirements are satisfied, these conditions are difficult to forecast more than a week in advance. TNSPs and generators usually need to book in equipment and contractors further in advance than this. In the past, TNSPs used to be able to reliably schedule outages for the shoulder season. Now, these increasing complexities mean that these outages must increasingly be booked in opportunistically. Outages are often cancelled at the last minute, and then must be rescheduled (possibly through multiple iterations until the outage can proceed).

Throughout this time, equipment and personnel can be waiting on the ground. This can significantly increase the cost of maintenance works. Alternatively, favourable conditions may suddenly arise, but there is not sufficient time to mobilise the necessary equipment and personnel. Many of the remaining periods indicated in Figure 16 as viable for an outage to proceed may not be viable in practice, if that period could not be forecast accurately with sufficient lead time.

These challenges can lead to TNSPs scheduling planned outages only in certain limited seasonal windows where the necessary specific conditions are more likely to arise. This might lead to delays in maintenance or upgrades of up to a year.

Delaying maintenance, or delaying upgrade works that would lead to market benefits and/or increased system security, for up to a year, is clearly far from ideal as it likely will increase overall costs and risks associated with power system operation.

3.7 Increased risks for non-credible contingencies

In addition to affecting credible contingency events, DPV tripping affects non-credible contingency events. AEMO does not typically apply network constraints or procure FCAS to manage the consequences of non-credible events (unless they are declared as a protected event). It is generally assumed that non-credible contingency events will be adequately managed via emergency frequency control schemes such as under-frequency load shedding (UFLS).

AEMO's studies indicate that the ability of UFLS to adequately manage non-credible contingencies has been significantly deteriorated by DPV[78]. Contributing factors include:

- Decrease in net load on the feeders that are shed via UFLS;

[78] AEMO (July 2022) Power System Frequency Risk Review, Section 3.3, https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psfrr/2022-final-report---power-system-frequency-risk-review.pdf?la=en

- Increasing incidences of reverse power flows on UFLS feeders (meaning that tripping the feeder on its original UFLS settings will result in exacerbation of the contingency event, rather than helping to correct it); and
- Tripping of DPV on the inverter settings, increasing the contingency size (due to poor disturbance ride-through capabilities).

AEMO's studies indicate that the trip of DPV is a major contributing factor to failure scenarios where UFLS is inadequate to arrest the frequency decline.

3.7.1 Case Study: DPV tripping in South Australia separation event

A case study example of a period where DPV tripping exacerbates a non-credible contingency is shown in Figure 17. A non-credible South Australia separation at the Heywood Interconnector has been modelled.

The original scenario outcome (based on an Integrated System Plan dispatch outcome for 2022 in the Step Change scenario) with ~1.4 GW of DPV generating in South Australia is shown in black, compared against an equivalent hypothetical counterfactual case with 0 MW of DPV generating (in grey), to illustrate the effects of DPV.

In the black scenario (with original DPV levels) frequency falls below 47.6Hz, which trips the last UFLS bands (containing the most sensitive loads) and is considered a fail scenario based on the acceptance criteria applied for these studies (likely to lead to cascading failure and a black system). The poor result is significantly exacerbated by the trip of approximately 100 MW of DPV based on inverter settings (illustrated by the acceleration of the black frequency trace at point B). This scenario could be considerably worse if there was also a voltage disturbance or phase angle jump associated with the initial separation event, exacerbating the original contingency (not modelled in this scenario).

In the counterfactual scenario without DPV (grey), frequency arrests just below 49Hz. The trip of UFLS successfully arrests frequency decline. This demonstrates the considerable influence of the behaviour of DPV (in this case, due to both inverter ride-through and also deterioration of UFLS capability).

Figure 17 Low UFLS load period (13:30, spring 2022)

<table>
<tr><th></th><th>Operational demand (MW)</th><th>UFLS load (MW)</th><th>Inertia (MWs)</th><th>DPV generation (MW)</th><th>Imports at Heywood (MW)</th><th>Synchronous generator dispatch</th></tr>
<tr><td>Original scenario</td><td>400</td><td>251</td><td rowspan="2">4,400</td><td>1,371</td><td rowspan="2">224</td><td rowspan="2">None</td></tr>
<tr><td>No DPV, counterfactual</td><td>1,771</td><td>1,513</td><td>0</td></tr>
</table>

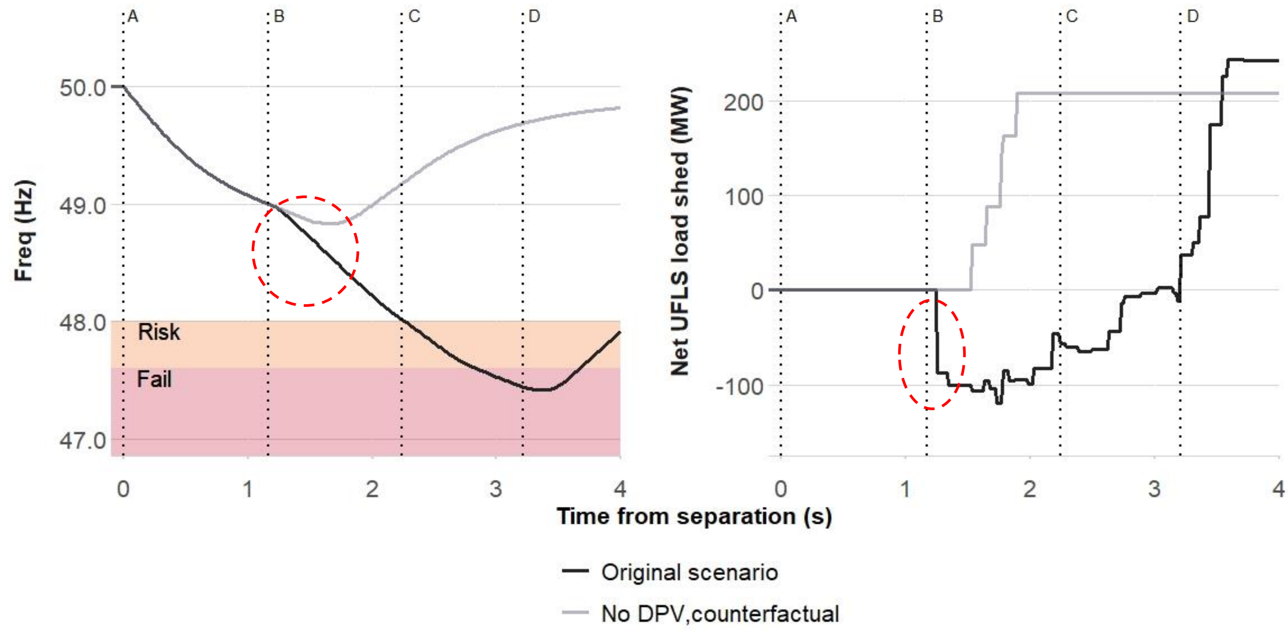


Table 14 Key events in case study: Low UFLS load period (13:30, spring 2022)

	Time from separation	Event	Notes
A	0s	Separation at the Heywood Interconnector	• RoCoF following separation is approximately -1 Hz/s (300 ms average). • Rapid active power injection from generators providing fast frequency response. (FFR) assists in arresting the frequency decline.
B	1.17s	Black scenario: Frequency reaches 49Hz and ~100 MW of DPV disconnects (with a 80ms delay)	• ~100 MW of DPV disconnects on inverter under-frequency settings (shown as step down in right panel). • This leads to a significant acceleration of frequency decline.
C	2.24s	Black scenario: Reverse UFLS operation	• Frequency decline is further exacerbated by "reverse" UFLS operation. • UFLS relays disconnect circuits when under-frequency thresholds are reached, but the net UFLS load value "steps" down due to the trip of UFLS bands in reverse flow, which accelerates frequency decline.
D	3.21s	Black scenario: Trip of positive UFLS load on 47.6Hz band	• Arrests frequency, but frequency is well below 48Hz, far outside of typical power system operation ranges. • The loads in these last UFLS bands are considered highly sensitive.

This case study demonstrates the influence that DPV tripping can have on the outcomes of non-credible contingency events.

3.7.2 Case Study: 25 May 2021

On 25 May 2021, there was a trip of multiple generators and high voltage transmission lines in Queensland following an initial event at CS Energy's Callide C Power Station, leading to under-frequency load shedding and temporary synchronous separation between Queensland and New South Wales. At the time of this disturbance, DPV was estimated to be generating a total of 1,367 MW in Queensland, and 1,290 MW in New South Wales. In response to this event, it is estimated that 11% of the DPV in Queensland and 6% of the DPV in New South Wales disconnected in response to the disturbance due to poor inverter disturbance ride-through behaviours[79]. This exacerbated the size of the contingency, and increased the amount of UFLS required to arrest the disturbance.

This case study indicates that non-credible contingencies have already occurred where DPV shake-off was increasing risks.

3.8 Implications of non-compliance in Western Australia

Late in 2020, AEMO expedited work in the SWIS to better understand the scale and impact of DPV disconnection following power system disturbances. This was considered critical for the region as it is an isolated multi-gigawatt scale grid, that has no interconnections to other transmission systems, and similarly high penetrations of DPV as the NEM.

It was identified that DPV disconnection following the loss of the largest contingency in the region was sufficiently large that AEMO sought Economic Regulatory Authority (ERA) approval to increase the Spinning Reserve Requirements[80] (SRR) during periods of high DPV, incurring additional costs. It was understood that upon the commencement of the revised 2020 Standard that DPV tripping contingency sizes would not increase proportionally to installation rates, and the SRR was only procured for the estimated capacity up to the time that the new 2020 Standard became mandatory (18 December 2021).

A high-level overview of the BAU (Business as Usual) planning and operational impacts for managing system security considering the compliance levels and consequent DPV disconnection rates is shown in Figure 18, with descriptions of actions in Table 15.

[79] AEMO (October 2021) Trip of multiple generators and lines in Central Queensland and associated under-frequency load shedding on 25 May 2021, Section 3.3, https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/trip-of-multiple-generators-and-lines-in-qld-and-associated-under-frequency-load-shedding.pdf

[80] Note this is referred to as frequency contingency raise services in relation to the NEM.

Figure 18 WA BAU impacts of compliance

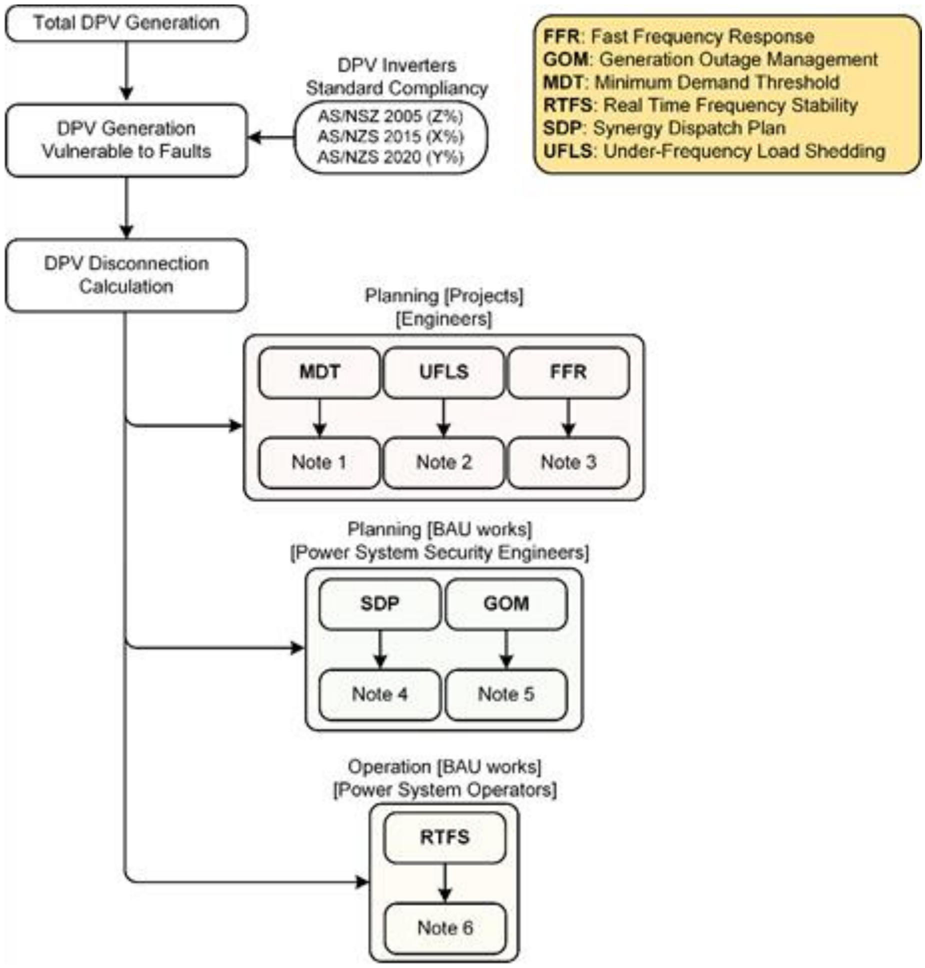


Table 15 WA impacts of compliance details

Item	Description
Planning Horizon	
Note 1	The MDT values will be required to be re-assessed as the DPV disconnection rates increases resulting in higher MDT values, which will increase the possibility of triggering ESM to ensure System Security.
Note 2	The studies carried out as part of WA DER Roadmap[81] Action #10 (UFLS Works Packages 3A and 3C) will be impacted.
Note 3	The analysis being carried out on the FFR services will be impacted (e.g., enablement duration, enablement quantity, etc.).
Note 4	The tools used by the Power System Security / Planning Engineers for carrying out the day-ahead dispatch plan will require to be modified to reflect the impact of greater DPV disconnections as higher spinning reserve ancillary services (or contingency reserve) will be required.
Note 5	Assessing outages for some of the Synergy units that are crucial for MDT days will be impacted as there is a finite number of dispatch combinations for MDT values, which should be planned well in advance.
Operational Horizon	
Note 6	Controllers will have to provision greater spinning reserve ancillary services (or even reducing the largest contingency size) to maintain Frequency Stability in real time due to the risk of greater DPV disconnections.

[81] WA Government, DER Roadmap, available at: https://www.wa.gov.au/government/publications/der-roadmap

Where the ride-through behaviour has not been revised to the latest 2020 Standard, and is instead consistent with the 2015 Standard, additional SRR will be required. It is estimated that for every 10 MW of non-compliant DPV added to the network, the SRR will increase by 1 to 1.5 MW during high PV intervals depending upon other generation present in the network at the time.

If this increase in SRR requires the dispatch of another unit to meet requirements, then this will result in a cost borne by consumers (via Synergy, the State's only electricity retailer for non-contestable customers in the SWIS). As system load decreases, the likelihood of AEMO having to dispatch out of merit to meet SRR increases, resulting in other higher costs. The higher SRR due to non-compliant DPV will result in this occurring more often and at higher system loads. Further, following the new WEM[82] commencement in October 2023 it is not clear what price point contingency services will reach, but unnecessarily increasing demand for this service will likely increase the costs for all consumers in the WEM.

3.9 DNSP implications

This report focuses on the implications of poor compliance which are relevant to AEMO's areas of responsibility, with a particular focus on system security. However, DNSPs have also highlighted that non-compliance with technical standards will have implications for their networks, particularly in relation to their voltage performance requirements in accordance with AS 61000.3.100[83]. Specifically, settings such as Volt-VAr, volt-watt and over voltage settings defined in AS/NZS4777 are critical for solar hosting capacity, network safety, and efficient operational and capital expenditure. Poor management of any of these can trigger an increase in customer complaints.

3.10 Customer impacts

In addition to addressing the issues noted above, improved DER compliance will ultimately benefit customers by reducing power system costs, and ensuring the power system can be operated in a stable and secure manner throughout periods when large amounts of DER are operating. Having technically compliant DER will minimise the need for active curtailment of customer DER systems, allowing them to operate unconstrained for a larger proportion of the time than they do currently.

Improving compliance also increases distribution network hosting capacity, allowing more consumers to install DER and should help to improve distribution voltage management (thus reducing costs arising from network upgrades and management of power quality issues).

[82] See AEMO WEM Reform Implementation Update at: https://aemo.com.au/initiatives/major-programs/wem-reform-program/latest-news/wem-reform-implementation-update

[83] See CitiPower PowerCor, United Energy Submission to AEMC's Draft determination: Governance of distributed energy resources technical standards (ERC0319). Available at: https://www.aemc.gov.au/sites/default/files/2022-02/220203_submission_from_citipower_powercor_and_united_energy_0.pdf

4 Addressing DER non-compliance

This report aims to summarise the evidence of DER non-compliance collected to date, to provide clear guidance on the nature, importance and urgency of the associated problems, and provide a strong foundation for industry collaboration on solutions to those problems. Solutions need to be developed collaboratively, with input from the wide range of stakeholders who will have insight into the possible options available. This report aims to provide a foundation to start that process.

4.1 Summary of work underway and opportunities

AEMO proposes three areas of work to improve DER compliance, summarised in Table 16.

Table 16 Summary of actions and opportunities to improve DER compliance

Option pathways		Details	Potential delivery pathway
1	**AS/NZS4777.2:2020 amendment**	• Amend AS/NZS4777.2:2020 to require that OEMs make only the current version of the Australian grid codes accessible from product commissioning menus for the installer.	• AEMO has made a proposal to Standards Australia to amend the 2020 Standard, this has been approved as a formal project for the EL-042 Committee which has been initiated and is now underway.
2	**Immediate rectification actions**	• Industry collaboration to deliver a suite of immediate rectification actions, including strong engagement from DNSPs and OEMs. • Identify no-regrets actions that are achievable in the short-term within existing frameworks. • Target improving compliance to at least 90% of new installations set correctly to AS/NZS4777.2:2020 by December 2023.	• AEMO understands the AEMC Review into consumer energy resources technical standards[84] is considering options to progress activities with industry.
3	**Enduring governance frameworks**	• Implement clear frameworks that outline which parties are responsible for each of the aspects of DER compliance, monitoring, assessment and enforcement. This should cover access to the tools, datasets and approved enforcement pathways to deliver these responsibilities while maintaining consumer protections. Where possible, this should consider nationally consistent frameworks across the NEM and WEM. • It is recommended that these frameworks are agreed as a matter of urgency.	• The AEMC Review is considering frameworks for the governance of technical standards. • AEMO notes that inverter compliance will need to encompass a broad range of parties across the supply chain, some of which currently exist outside of the NER (such as installers and OEMs) and may therefore sit outside the AEMC's jurisdiction. AEMO looks forward to continuing to work with the AEMC on their Review and exploring the most appropriate pathway to address these compliance issues. • Energy Policy WA (EPWA) review on DER Roles and Responsibilities and policy gap analysis encompasses monitoring and enforcement for inverter standards compliance.

Further detail on each area is outlined in the sections below.

[84] AEMC, Review into consumer energy resources technical standard. Available at: https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards

4.2 Work underway

4.2.1 Amendment to AS/NZS4777.2:2020

AEMO is currently pursuing an amendment to the 2020 Standard seeking to require that manufacturers remove legacy Australian grid codes. This is currently with the Standards Australia EL-042 Committee.

The proposed change to the 2020 Standard would require that when an inverter is tested for compliance with the 2020 Standard by an accredited testing laboratory, the tests performed would require confirmation that the legacy grid codes are not present. The test report produced would be reviewed as a condition of being listed as an "Approved product" for sale in Australian markets.

As presented in Section 2.5.4, the evidence available suggests that a significant contributor to non-compliance with the 2020 Standard is the retention of legacy grid codes on DER inverters (see Section 2.5.2), and therefore this being selected at point of install. If legacy grid codes are removed, compliance rates are expected to improve considerably and immediately. Some OEMs have agreed to do this voluntarily, but there is no requirement for them to do so, and no governance frameworks to monitor or enforce any changes. Some major OEMs have not agreed to make these changes voluntarily. The proposed amendment to AS/NZS4777.2:2020 creates a pathway to require and enforce removal of legacy grid codes for all products sold in Australian markets.

It is worth noting, that while changes to standards are a sensible pathway to address these challenges at the device level, the timeframes are relatively long given the uptake we have seen of DER and the urgency in which these issues can arise. Time is required to review and amend standards, with further time required for OEMs to make changes, retest and for supply to be made available across Australia.

International grid codes

Most OEMs providing products in Australia serve a global market and have indicated that they need to retain international grid codes in the menu options available at the time of commissioning.

The evidence available to date indicates that only a relatively small proportion (5-7% of inverters installed in Q1 2022) are being set to a non-Australian grid code setting (see Section 2.5.2 and Section 2.1.2). This suggests that a significant proportion of non-compliance can be addressed by removal of legacy Australian grid codes, even if international grid codes are retained. However, it does not represent a complete solution and some level of non-compliance is likely to persist.

Some OEMs have more sophisticated commissioning processes that address this issue. For example, it is possible to utilise GPS to geo-locate (via the installer's phone and commissioning app) an inverter at the time of commissioning and ensure that limited grid code options are listed and the correct one more likely to be applied.

Warranty replacements

Some stakeholders have raised concerns about the ability of installers to deliver warranty replacements if legacy grid codes are removed from product menus. This relates to a very small proportion of installations and can likely be handled via alterations to the specifications for "like-for-like" warranty replacements. The changes could involve requiring that settings on replacement products meet the latest relevant technical standards (which is already required in some networks) or OEMs incorporating capabilities to maintain older standards but ensure these are not visible for selection without additional commissioning processes, such as the installer requesting a remote firmware change from the OEM.

4.2.2 AEMC Review into consumer energy resources technical standards

The AEMC is currently undertaking a review of the implementation of the existing obligations in the NER[85] that require compliance with AS/NZS4777.2. The review is focussing on compliance and enforcement issues associated with the implementation of existing DER technical standards, as well as the regulatory and market context for improving compliance.

The review intends to work actively with the Energy Security Board (ESB) and the ARENA Distributed Energy Integration Program, to support work on CER technical standards that may already be underway.

This report highlights that technical standards non-compliance has been identified as an issue across NEM and in other regions including the WEM, and that parties operating outside the NEM and WEM are relevant and have influence across the supply chain. Consideration will need to be given to a broader context of DER governance for parties that are operating outside the NER and WEM Rules, such as other frameworks that are nationally led. Many of these compliance challenges have been identified for other regions and functions. See Section 5 for further details of considerations identified for enduring frameworks for the governance of DER technical standards.

4.2.3 The CER's Integrity Review

Following the CER's Integrity Review of the Rooftop Solar PV Sector, the Australian Government supported all their review recommendations and allocated $19.2 million of funding to the CER to effectively implement the recommendations[86]. These include:

- Tightening SRES eligibility on inverter manufacturers by requiring serial number ranges. The CER have already received data for 76% of inverter models.
- The CER to take on new functions and increased compliance monitoring and enforcement activities through new powers to declare non-compliant installers, and inverter models ineligible to participate in the SRES.
- Amending regulations to give the CER powers to approve an installer accreditation scheme.
- Enhancing the functionality of the CER's business systems to support greater use of technology solutions that will reduce regulatory burden for industry while improving compliance.

Some of these actions may assist in improving compliance. However, the scope of the review only relates to the SRES scheme (confirming that installations generate the credits that they should), and none are specifically targeted at improving compliance with technical standards.

It may be possible for the CER to require compliance with additional technical standard requirements as part of these changes (for example, by the CEC including requirements around technical standards in their rules for installer accreditation and inverter manufacturer eligibility), but AEMO understands that this is not an area of focus at present.

At this time, it appears that the AEMC Review into consumer energy resources technical standards is a more suitable avenue for implementing the necessary improvements to enduring (beyond the lifetime of

[85] AEMC, Review into consumer energy resources technical standard. Available at: https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards

[86] Clean Energy Regulator, Integrity Review of the Rooftop solar PV sector. https://www.cleanenergyregulator.gov.au/RET/Pages/About%20the%20Renewable%20Energy%20Target/Rooftop-Solar-Sector-Review.aspx

the SRES scheme) and more broadly encompass governance frameworks, that are relevant to power system security.

AEMO has collated insights to inform the roles and responsibilities, compliance activities and coverage of these enduring governance frameworks in Section 5.

4.3 Opportunities to deliver immediate rectification actions

Table 17 provides further detail on the opportunities that AEMO suggests may be pursued in the short-term to address gaps under the current frameworks, however consultation may need to consider where they would apply in an enduring context. This list is a starting point only of activities that stakeholders are already progressing or could be explored and is not intended to be exhaustive. AEMO considers that collaborative action between parties, led by an appropriate body with clear accountability, should lead to effective and efficient outcomes in the short-term, and ensure activities are worthwhile in the long-term.

Table 17 Immediate rectification actions to improve compliance

Key Parties	Proposed actions	Status
Original Equipment Manufacturers (OEMs)	OEMs to explore opportunities to uplift their commissioning processes and remote capabilities across the board, while managing cybersecurity risks. Specifically, OEMs can voluntarily: • **Provide datasets** – Provide datasets to DNSPs and AEMO to allow assessment of compliance rates. • **Implement remote updates** – Remotely update settings to the 2020 Standard. • **Hide legacy settings from product menus –** Hide the older 2015 and 2005 standards from the options presented to installers at the time of commissioning. • **Improve product design –** Innovative product design and improved commissioning processes can dramatically improve compliance in the field.	AEMO is working with 10 major OEMs on these activities at present. A number of large market share OEMs have yet to commit to these activities. It is noted that it is in OEM interests to improve compliance rates, to underpin continued flourishing of the DER industry. In WA, AEMO and Synergy (through their vendor) worked with four major OEMs on the provision of datasets to allow the assessment of compliance rates with 2020 Standard region B settings in the WEM.
Distribution Network Service Providers (DNSPs)	DNSPs to consider uplifting capabilities, to progress activities such as the following:	
	• **Mandatory close out process following installation** -– Update connection and registration processes to require mandatory commissioning datasheets from installers and/or a digital close-out, including a requirement to confirm selection of AS/NZS4777.2:2020. This could potentially be made a requirement before the customer's meter change-over (via the retailer) or linked to installer accreditation or tied to obligations such as state-based schemes (or the SRES scheme).	• CitiPower, Powercor and United Energy have implemented mandatory commissioning datasheets. Other DNSPs could pursue similar initiatives. • SAPN's SmartInstall requires installers to provide a mandatory close-out process as obligations for their Smarter Homes scheme
	• **Update Model Standing Offer (MSO)**[87] – to ensure customer consent to make remote changes to inverter settings.	• Victorian DNSPs have updated MSO. Other DNSPs could pursue similar initiatives.

[87] This may not be applicable across all regions, for example in the SWIS the MSO is agreed between the energy retailer and the customer.

Key Parties	Proposed actions	Status
	• **Assess non-compliance –** Implement processes to detect non-compliant installations through in-field analysis. This option needs to consider the longer-term frameworks, to ensure that this is a no-regrets option.	• CitiPower, Powercor and United Energy and SAPN have activities underway and some other DNSPs have started trials/initial investigation. Other DNSPs could pursue similar initiatives. • In WA, the NSP considered using the WA Electrical Inspectors (WAEI) to inspect non-compliant systems but later confirmed this was not feasible due to sheer number of non-compliant installers and limited WAEI's manpower resources.
	• **Remote rectification –** Where the NSPs assess non-compliance, work with OEMs to request remote updates to settings at sites where non-compliance is identified, while managing cybersecurity risks, unit corruption failure, or other consequences (such as incorrect firmware creating other unintended consequences). Consider options to undertake this periodically.	• CitiPower, PowerCor and United Energy are working with five large OEMs. Other DNSPs could pursue similar initiatives. • In WA, the NSP has engaged with one OEM to implement remote updates where non-compliance was identified.
	• **Coordinate and align DNSP actions** – The suite of actions undertaken by DNSPs should be coordinated where necessary to improve alignment, efficiency and effectiveness.	• Not yet underway.
All stakeholders	• **Information sharing –** Consider the dissemination of information across stakeholders including state governments. Creates opportunities to align compliance data, development of an action plan, progress status reporting, and discussion of identified barriers.	• In WA, AEMO issued a letter to Energy Policy WA (EPWA) to inform security issues associated with non-compliance, inform the current actions in place and to provide recommendations of immediate actions. This has resulted in the development of a state-level working group to address AS/NZS4777.2 non-compliance.
	• **Reading and writing of inverter settings** – Explore pathways to facilitate standardised reading and writing of inverter settings. Options such as enhancing CSIP-Aus to define control messages to read and update individual inverter settings or common file formats could be explored.	• Not yet underway. • Some capabilities established in IEEE 2030.5, however not in CSIP-Aus.
	• **DER Register data -** Consider opportunities to improve the quality of data uploaded to the DER Register and for this data collection to be consolidated across multiple collection mechanism (i.e. the SRES program), data may involve use of CSIP-Aus or common file formats and automated data uploads noted above. • Consider potential to use the DER Register data for assessing compliance.	• Not yet underway.
	• **Standardised test reporting –** Develop a standardised test format that all test labs are required to follow and align to. This includes specification of results reporting to ensure that there is consistency in assessment and approval.	• AS/NZS4777.2:2020 includes specifications of the tests to be performed, but does not provide a standardised reporting format, test details and structure to facilitate ease of confirmation that results meet requirements.
	• **Inverter product listing –** Consider opportunities to nominate a list of preferred inverters, this can include additional requirements beyond the standard, and act as an incentive on OEMs to improve their devices (including commissioning menus) and penalise where non-compliant to technical standards.	• CitiPower, PowerCor and United Energy have introduced a preferred list of inverters as part of their commissioning datasheet process.

Key Parties	Proposed actions	Status
Clean Energy Regulatory (CER) and/or Energy Safety Regulators	• **Mandatory or higher level of installer training** – Require that installers/electricians undertake training on new standards as a part of accreditation or licencing requirements. • **Demerit point system** – Consider demerit point system for installers/electricians to consider technical standards compliance, such as incorporating results from existing CER inspections program or safety regulator audits.	• AEMO, the CEC and the Victorian Government have collaborated to roll out a voluntary training course developed by AEMO to the CEC installer base. After 6-months of availability, there is a completion rate of approximately 45%. • SAPN's SmartApply requires that installers undertake training at the point of their first application.

Further details where relevant are provided below.

4.3.1 Inverter product listing

As part of device accreditation, inverters are required to be listed on the CEC's product listing to be available in the market. AEMO understands that this product listing has an influence in consumer selection, so product listing processes could be further utilised to:

- Fast-track connection approvals processes for OEM products that are white-listed as having superior design that supports high compliance rates in the field. Connection approval processes are defined and managed by DNSPs but could be supported by national alignment via a centralised coordinating body.
- Provide minimum specifications for OEM product design to support compliance, as a requirement for being listed as an approved product for connection to Australian distribution networks. This could either be managed alongside the existing approved product listing (managed at present by the CEC), or by DNSPs as an additional connection approval requirement, supported by national alignment via a centralised coordinating body.
- Call out and/or apply sanctions to OEMs whose products are found to not be behaving in accordance with relevant standards in the field (based on post disturbance assessments, for example). This might include temporary de-listing as an approved product for connection to Australian distribution networks.

5 Insights to inform enduring governance frameworks

The AEMC review into consumer energy resources technical standards is considering the regulatory and market context for improving compliance. Some insights, that AEMO has drawn from the analysis on compliance summarised in this report that could be considered as part of the review into the development of long-term governance frameworks, including roles and responsibilities for managing DER compliance, are outlined in the sections below.

5.1 Areas requiring further clarity

Despite multiple governance frameworks that reference AS/NZS4777.2 (as listed in Section 1.2), AEMO's discussions with stakeholders (including the CEC, CER, DNSPs, the ENA, the AEMC and the AER) indicated there is a general lack of clarity and lack of consensus around the extent to which these existing functions monitor, address, and enforce technical standards compliance of new installations.

Some of the questions that need to be clarified include:

- Which parties have responsibility for:
  - Managing processes for DER compliance in the field at the point of commissioning.
  - Monitoring and assessing DER compliance in the field (both immediately following commissioning, and ongoing over time).
  - Enforcing and rectifying DER compliance in the field.
  - Collecting accurate data for the DER Register.
  - Clarifying the interpretation of standards where there is lack of consensus.
- Do the relevant parties have access to adequate tools and datasets to fulfill these responsibilities?
- What penalties or incentives should be applied, and to which parties, in order to drive high rates of compliance?
  - Who would monitor and apply these penalties or incentives?
  - What data is available, enduring, and of sufficient quality for application of penalties or incentives?
- Where would there be efficiencies from centralising various functions? (for example, centralising various functions being delivered by DNSPs).
- Where are these responsibilities defined? (in the NER, WEM Rules, or elsewhere?).
- How will cybersecurity and firmware updates be managed? (given that many OEMs are able to remotely change settings and interact with their devices in the field).
- How will compliance and performance behaviours of new types of DER be managed? (such as EV charging and medium voltage DER connections).
- Are the same compliance governance frameworks suitable for all types of DER behaviours? (e.g. how should compliance with interoperability requirements be managed?)

Aspects that may inform decisions on the above questions are outlined in the following sections.

5.2 Roles and responsibilities

5.2.1 OEMs

As noted in section 2.5.2, the evidence available indicates that OEMs have considerable influence over the rates of compliance for their products at the point of installation. There are a wide range of innovations that OEMs can implement to dramatically improve compliance of their products at the point of installation, and to support remote rectification of technical settings following installation.

This suggests it would be highly beneficial to develop governance frameworks that have a clear pathway to place obligations on inverter OEMs to:

- Design out the risk of non-compliance in the way they deliver their products; and
- Implement capabilities to remotely update technical settings, en masse.

Cybersecurity needs to be considered in light of the ability of many OEMs to update technical settings remotely.

5.2.2 DNSPs

Some DNSPs are already demonstrating innovation in the area of DER Technical Standards compliance, such as the Victorian DNSPs implementing mandatory commissioning datasheets (see section 2.4.1), and the application of Volt-VAr non-compliance detection by CitiPower, Powercor, United Energy and SA Power Networks (see sections 2.4.1 and 2.4.2).

Further innovation is likely possible. However, in AEMO's discussions with many DNSPs, there was a significant lack of clarity and lack of consensus around the responsibilities of DNSPs and the tools that are realistically available to them.

Data collection

One area of inadequacy is the incomplete and error-prone nature of the data collection method used in the DER Register (collected by DNSPs). For example, in Q1 2022 for a number of OEMs serial numbers were found to be only available and correct for 75 – 85% of installations. Serial numbers were required by many OEMs to facilitate remote updates to technical settings, and these remote updates could not be enacted for any installations where the serial numbers were not correctly recorded in the DER Register. Initiatives such as mandatory commissioning datasheets could be implemented by all DNSPs as part of the registration and connection process, provide improved datasets into the DER Register, and eventually become an automated process between the DER device and DNSP facilities directly. Such automation would likely involve the development and establishment of minimum standardised data formats for manufacturers to provide their inverter data in a consistent manner for review and approval upon connection. This is expanded on in section 5.3.2.

Levers available to DNSPs

A number of DNSPs noted that they felt the only lever available to them to address non-compliance was complete disconnection of a customer with a DPV system identified as non-compliant. This was felt to be excessive, and would penalise the incorrect party (ie the customer, who has limited ability to rectify non-compliance, other than by requesting a repeat visit from their installer, who may charge the customer an additional fee).

However, there may be further opportunities for DNSPs to innovate in this area, such as:

- Refining DNSP compliance approvals processes to only allow connections from a subset of approved products from OEMs that have been confirmed to deliver additional requirements that support compliance improvements; or
- Working with bodies responsible for installer accreditation to apply penalties and eventually de-accredit installers that are repeat offenders in non-compliance; or
- Implementing programs to identify non-compliant sites, and requesting rectification by OEMs, customers and installers.

There is an opportunity for these to be explored, and where there are blockers or gaps identified, these need to be rectified.

Consistency in approach across DNSPs

Opportunities to coordinate these processes for alignment and streamlined delivery across the many DNSPs in the NEM should also be explored.

For example, prior to the 2020 Standard, each DNSP determined their own individual settings for delivery of Volt-VAr power quality modes, which led to OEMs creating long lists of possible settings for each DNSP in their product menus. Consolidation of these into just three “Australia A”, “Australia B” and “Australia C” settings in the new 2020 Standard should help improve compliance by reducing the choices presented to installers. Future governance frameworks should learn from this example by consolidating requirements across Australian networks as much as possible and avoiding different approaches being applied network-by-network wherever possible.

5.2.3 Installers

Through the analysis, it was consistently identified that non-compliance to technical settings most commonly arose from the point of installation. This was identified through manufacturer reporting for the latest 2020 Standard, but also appeared to be a challenge for the 2015 Standard (as seen in the CER audits), and specific Volt-VAr settings (as per the DNSP rates). This highlights the need to further consider the role of the installer as well as the feasibility of requiring the installer to be responsible for achieving compliance with technical standards.

There are opportunities to improve compliance with DER Technical Standards by linking installer accreditation for existing incentive schemes (such as SRES) with the installers level of compliance and applying penalties for non-compliance and de-accrediting installers that are repeat offenders.

Training for installers aims to provide access to tools and resources so that installers understand their obligations in installing and commissioning new systems. Evidence to date suggests this should only be considered a complementary measure and should not be relied on as the sole pathway to improving compliance.

AEMO, the CEC and the Victorian Government have rolled out voluntary training, however a 6-month availability period only 45% of installers have undertaken the course. Opportunities such as mandatory courses for technical standards, and requirements aligned to their accreditation and demerit point systems could help to address this completion rate.

While there are activities to directly address installer knowledge and compliance, the available evidence suggests that complex OEM menus and commissioning processes which do not support installer selection of the correct grid codes are likely to result in low rates of compliance, despite extensive installer training. In contrast, OEMs with strong product design that supports compliance already demonstrate very high rates of compliance, even in the absence of any improvements in installer education and training.

5.3 Compliance monitoring and assessment

Compliance monitoring and assessment is a critical aspect of DER governance. Applicable governance frameworks should define roles and responsibilities to monitor and assess compliance, and ensure that adequate datasets and tools are available to support this process.

Compliance monitoring and assessment needs to be conducted in two distinct phases:

- **At the time of installation** – Compliance checks at the time of installation (or soon after) allow prompt rectification while the device is more likely to be connected to the internet and accessible for remote updates (as connectivity rates deteriorate over time), and in the period where it may still be possible for the original installer to rectify non compliances.
- **Ongoing monitoring** – Compliance should be monitored and assessed on an ongoing basis to ensure inverter behaviour remains compliant and operates satisfactorily in the field for the life of the installation. Examples have been identified where OEM firmware updates resulted in unintended changes to product behaviour such that they were no longer compliant. Ongoing processes are required to monitor product behaviour so that these types of errors can be identified and rectified.

Roles and responsibilities around capturing and accessing data, should be developed within these compliance frameworks, as well as how and to what extent these data sources can be used for rectification and enforcement purposes. For example, there are potential levers available to apply penalties to installers with repeated non-compliant installations through the CEC, however DNSP smart meter compliance methods based on detecting non-compliant Volt-VAr behaviour (as discussed in Section 2.4) are probably not sufficiently accurate to be enforceable.

Additionally, roles and responsibilities of other actors, such as OEMs, should be considered, given their considerable influence over visibility and ability to remotely update technical settings in their fleet. Improved frameworks may be required to ensure OEMs have adequate obligations to require periodic capture of the relevant datasets, and to provide these to the parties that need those datasets.

5.3.1 Enforcement and rectification

Roles, responsibilities and pathways for enforcement and rectification of compliance should be considered as part of the overall framework for improving compliance. The following shortcomings have been identified with the existing frameworks:

- Under the NER, the DNSP is responsible for DER Technical Settings compliance. However as noted above, some DNSPs have advised their only lever for rectification is to disconnect consumers at their connection point, which is unreasonably “heavy-handed”. This action penalises the consumer rather than the party directly responsible for the non-compliance (i.e. the installer), and thus far AEMO is unaware of any situations when this sanction has been applied.
- The CEC’s installer accreditation program operates a “demerit points” scheme where installers who have been found to have incorrectly installed a DER system “lose” points, which can eventually lead to suspension of their accreditation. At present, this scheme primarily covers electrical safety and SRES eligibility requirements, and AEMO understands that it is not appropriately resourced to extend it to DER Technical Settings compliance.

- Jurisdictional electrical safety requirements that provide state-based licensing schemes for electricians include inspection programs which only focus on electrical safety and do not address technical standards.
- The CER's audit of technical settings now attempts to assess whether technical settings have been applied correctly, but where technical settings are identified to be incorrect, does not result in rectification or penalties or provide other modes of enforcement.

These processes all address some elements of compliance, but none comprehensively address compliance with technical settings. They are all enacted under different legislation and frameworks. The feasibility of expanding these schemes to cover incorrect inverter technical settings should be considered.

Roles and responsibilities of OEMs in enforcement and rectification

Some OEMs can remotely correct settings and firmware to address non-compliance or improve behaviour. Currently, only a subset of OEMs have this capability, and only with the subset of devices that they can remotely communicate with (which reduces over time after installation). In requesting that OEMs undertake voluntary rectification, some have raised concerns with their responsibility to make changes on behalf of the customer. To address this concern, Victorian DNSPs have updated their MSO to allow the DNSP to request changes to inverter settings be made by the manufacturer if a non-compliance is identified. This is method is not universally available outside Victoria.

The roles and responsibilities to develop and maintain the capability to communicate with and to rectify non-compliant DER installations should be considered as part of enduring governance frameworks, as well as ensuring that frameworks are in-place to provide appropriate powers to enact changes and pursue rectification.

Remote rectification, firmware and cybersecurity

In establishing options for remote rectification, consideration should be given to minimising potential unintended consequences, such as ensuring that setting changes and firmware updates do not inadvertently result in non-compliance with technical standards or introduce new power system security risks.

For example, some OEMs have stated they delivered the requirements of the new AS/NZS4777.2:2020 standard simply through firmware updates (with no changes to hardware). This means that a subsequent firmware update pushed out to the existing fleet could fundamentally change the behaviour of inverters, such that they no longer meet the requirements of that standard, as demonstrated during their accreditation testing.

At present, there is no process for OEMs to demonstrate re-testing of their products before or after firmware updates are rolled out.

Governance frameworks for remote interactions with devices should be established, which include the roles and responsibilities of relevant parties to ensure that firmware updates are logged, reviewed and occur in a controlled manner that does not introduce new risks.

Considering the ability of many OEMs to remotely update settings, push firmware updates, and control their devices in the field, governance frameworks should address the implications for cybersecurity, how this might be managed, and compliance maintained.

5.3.2 Penalties and incentives

In order to drive meaningful and sustained improvements in DER compliance in the field, it may be useful to define clear penalties and incentives frameworks.

As noted above, at present, there are some avenues to penalise installers that do not deliver high compliance rates, although AEMO understands that to date these have not been applied with regards to technical settings. Furthermore, as discussed above, OEMs and DNSPs may have more influence over DER compliance rates, and therefore may be more appropriate parties to apply penalties and incentives for improving compliance to.

A range of different kinds of penalties and incentives could be defined, for different parties involved in compliance frameworks. Where these penalties/incentives should be defined (in the NER or elsewhere) and which party would monitor and enforce each of them should also be considered.

As a starting point for stimulating industry discussion which could be considered as part of the AEMC review, some possible questions to consider include:

- What penalties and/or incentives could be applied to OEMs in an enduring framework to maintain compliance of an installed fleet? How to ensure OEMs are considered nationally but requirements are met for power system security in the NEM and WEM?
- What penalties and/or incentives could be applied to installers in an enduring framework to ensure technical compliance at the point of installation? How do we ensure these requirements, and requirements for power system security are met nationally? Are there options to disconnect (or remotely limit) an inverter separate to the whole customer load?
- Should minimum compliance targets apply to DNSPs? What is the incentive and penalty framework for meeting those targets? Who would monitor and enforce?
- Depending on the datasets utilised to assess compliance, what penalties or incentives can be applied to achieve sufficient data quality (such as that supplied to the DER Register)? Who would enforce this?
- Under their connection agreement with their DNSP, the customer is responsible for technical compliance. What role should the customer have in ensuring their system is compliant?

It is anticipated that these questions would be explored with a wide range of stakeholders. They are provided as starting points for discussion only.

5.3.3 Data and tools for assessing compliance

The governance review will need to form a view around the datasets and methods available for assessing compliance.

These considerations will inform an assessment of which parties are best placed to monitor and enforce compliance, the datasets that will be required for adequate delivery of these functions, and confirmation that these parties have adequate access to those datasets. This review also needs to consider which datasets can be used for enforcement purposes.

AEMO's assessment to date has identified a range of datasets and tools that can be used for assessing compliance of technical settings. The methods fall into two broad types:

- Directly viewing technical settings on devices (either through remote surveying, or site audits); or
- Observing in-field behaviour at a site, and determining if it is consistent with the required standard.

Both methods are important. A direct view of the technical settings applied in the device can offer an indication that the device is set correctly. This needs to be complemented with monitoring of the actual response of DER in the field to validate its behaviour; monitoring for compromise, malfunction or maloperation in practice across the lifecycle of the device. AEMO is aware of examples where a fleet of DER devices had the correct settings applied at the inverter but, due to the use of an external device, behaved in a manner that could give rise to a system security issue under some circumstances[88]. This kind of ongoing monitoring may, for example, indicate a need to update the relevant standards to more precisely define the required behaviours.

Data sources applied in assessments to date

The data sources that AEMO has identified and explored to date are summarised in Table 18. AEMO recommends engagement be undertaken across the industry to identify the full range of datasets that may be available, and the properties and limitations of each.

Table 18 Data sources used for compliance assessments to date

	Compliance assessment	Data owner	Details	Limitations
Manufacturer polling data	Technical settings	OEMs	Remote visibility of grid-code selection on individual inverters. Provides indication of behaviour of inverter based on Standard version.	• Information is self-reported. • Currently relies on OEM voluntary cooperation, capability and site internet connectivity – only subset of fleet so there may be bias. • Settings specifications may depend on firmware and grid-code options.
CER on-site audit of settings	Technical settings	CER	Manual on-site check of statistically significant sample of inverters (listed under SRES). Provides evidence of compliance to both grid-code and specific parameters set at the inverter.	• High-level of non-visible sites indicated by auditors due to poor access to the inverter app or screen. • Data is collected at a one-year lag from install. • Manual reporting can result in some inconsistencies in validity.
DER Register	Technical settings	AEMO and DNSPs	Installer manually reported data on DER device technical settings at the time of installation. Data is required to be collected by DNSPs as per the NER.	• Data is manual and installer reported and often inaccurate (early comparison with manufacturer data suggest major inconsistencies), blank, or unreliable (e.g. serial numbers are invalid).
Smart meter power quality assessment	In-field analysis	Metering Coordinators (and/or third-party monitoring providers)	AMI (or third-party monitoring) data used to determine power quality compliance based on voltage readings comparing actual behaviour with expected behaviour (if set correctly). Where an energy source (i.e. PV or BESS) is monitored separate to load, this allows a more accurate assessment of performance.	• Requires DNSP access to smart-meter data. • Limited to only power quality assessments, cannot determine grid-code compliance and other behaviours. • Requires networks to have high-voltage conditions, this may reduce as DNSP introduce additional actions. • Not sufficiently accurate for enforcement (preliminary indicator only).

[88] One manufacturer approached AEMO following a voltage oscillation event in SA on 23 June 2022 that occurred over a four-hour period, identifying that 95% of their battery fleet disconnected at some point during the duration of the event. Collaborating with the manufacturer, it is understood that the disconnection across the fleet, is due to the distortion of the voltage waveform affecting the measurement of frequency by an external device that is incorporated as part of the manufacturer's typical system install configuration. It was confirmed that the inverters connected had the correct settings and measured the event correctly.

	Compliance assessment	Data owner	Details	Limitations
Post-event analysis via third party data (e.g. Solar Analytics)	In-field analysis	Third party monitoring businesses (on customer sites that opt in) and some OEMs.	5-second data during and following an event, used to determine individual device behaviour, and compare with behaviour specified in standards.	• Relies on a suitable event occurring for relevant analysis. • Only investigates specific behaviours that are visible in the event. • Only provides data for a small sample of inverters. • Some biases in the sample set limit the relevance of data for some OEMs.

Data sources should preferably meet the following criteria:

- Representative of the fleet, or coverage of close to the entire fleet (some data sources that rely on sampling have significant bias).
- Digital and automated (minimise data entry errors).
- Potential to extend to additional DER sources.
- Data is consistently available and accessible.
- Data is independent and verifiable.
- Data can be legally used for rectification and enforcement purposes.

Standardising data collection

As part of the integration of increasing DER, it is necessary to standardise the data and information models used to share the settings and monitoring information between parties. Issues of non-compliance may be reduced, by improving data quality and enhancing remote and automatic capabilities.

Current options that could be explored include either:

- reading or writing inverter settings via a minimum communication protocol (such as CSIP-Aus)[89] or
- defining a common file format for all DER settings[90].

Some level of standardisation could allow consistent sharing of data between the device, and relevant agents, OEMs, network service providers, and AEMO.

Currently there are over 70 unique data field settings for a single DER device as part of AS/NZS4777.2, with many of these settings customisable at a site level. Each OEM uses their own terminology and labels for each of these settings, with some even differing between models. Standardisation of data would help to ensure that reading and writing of settings can be easily achieved across different fleets.

Standardisation of inverter settings for DER could assist the following areas:

- **Improved commissioning process** – Installers could set parameters with minimal manual handling. This could be used by DNSPs as an approval gateway (DNSPs approve requirements

[89] CSIP-Aus has already been established for the active management of DER through the provision of dynamic import and export limits. For further details see here: https://arena.gov.au/knowledge-bank/common-smart-inverter-profile-australia/

[90] EPRI has developed and established a Common File Format for DER Data exchange and storage via a basic csv file format for the IEEE 1547.1-2020 Standard. This work could be leveraged to develop similar requirements for AS/NZS4777.2. For further details see here: https://www.epri.com/events/1CBF5F01-D6E6-4D0A-BDBB-8F7F3253A7D7

before allowing a DER to connect) and provide an automated process for populating the DER Register (reducing data errors related to manual data entry).

- **Visibility of DER in the field** – Enable continued visibility of the applied settings in the field and after they have been configured.
- **Rectification of settings** – Support simpler data rectification processes to correct for compliance issues identified as part of the ongoing monitoring of the device, or where new learnings identify a need to change settings.
- **Consistency of testing** – Settings and results from the AS/NZS4777.2 accreditation testing process can be standardised, more easily compared and archived.
- **Proper archive and storage of settings –** Usable system-wide records for operational and planning purposes.
- **Integration with other APIs** – Facilitate the data reading from third party APIs, enabling the development of solutions to support non-compliance detection (e.g. QR Code reading through smart App).

Standardisation should be designed with the potential to extend further to other settings such as error flags, and other DER such as larger MV systems, EVs and demand response loads.

Cyber informed engineering

In developing the data and tools for monitoring and assessing ongoing compliance of DER devices, it may be necessary to incorporate architecture that considers the potential risk of data being compromised, through cyber-informed engineering.

Recently, the US Department of Energy[91] released a report on cyber-informed engineering, which provides learnings for the CSIP-Aus and AS/NZS 4777.2 implementation and compliance management. Cyber-informed engineering recommends principles that assume compromise in energy sector controls and data exchanges and implementation of a zero-trust architecture.

When applied to compliance monitoring it suggests that independent data – that is, data not coming from the DER operator or the device itself (to assume compromise) – and an independent party evaluating this data (zero-trust architecture) is integrated into the DER compliance monitoring framework.

5.4 Development and interpretation of standards

During the implementation and testing process of inverters to the 2020 Standard, it was identified by some manufacturers that there is no single party responsible for a uniform interpretation of the Standard, nor an adjudicating body to provide advice on ambiguous clauses within the Standard[92], potentially causing inconsistent performance between DER devices.

Currently, the 2020 Standard sees DER devices manufactured, tested and certified based on the interpretation of individual subject matter experts/businesses. With the current practice of Standards

[91] US Department of Energy, Cyber-informed Engineering Strategy, Available at: https://www.energy.gov/sites/default/files/2022-06/FINAL%20DOE%20National%20CIE%20Strategy%20-%20June%202022_0.pdf

[92] See Tesla submission to AEMC's EMO045 – Review into consumer energy resources technical standards. https://www.aemc.gov.au/sites/default/files/2022-11/12._tesla_-_stakeholder_submisison_-_emo0045_-_20221104.pdf

development, it is difficult to capture all possible OEM use-cases, such as application to different configurations of inverters and external devices or unique functional designs.

Since the AS/NZS4777.2 technical standard is a national requirement, having a single body (for example, a national technical regulator) to promote and ensure that matters of interpretation with respect to the NER, WEM Rules and other regional requirements can be reviewed and addressed on an ongoing basis, would avoid the ambiguity and uncertainty of multiple interpretations and scenarios (such as unique OEM configurations). Such a body could ensure that technical requirements are not wilfully misinterpreted, and that the intent of the 2020 Standard is upheld. This body could also provide interim requirements where Standards do not yet exist or scenarios have not yet been specified.

5.5 Coverage of DER Technical Standards

5.5.1 Electric Vehicles

AS/NZS4777.2 applies to electric vehicles (EVs) that may operate as vehicle to grid (V2G), as they are considered a bidirectional battery energy source that has the capability to export to the grid. It also applies to DC electric vehicle supply equipment (EVSE), which is typically a stationary, wall-mounted inverter.

AEMO is unaware of any mechanisms that seek to enforce the AS/NZS4777.2 Standard as part of the manufacture and accreditation of V2G inverters for sale in the Australian market. One V2G wall charger has opted to satisfy the requirements for AS/NZS4777.2 compliance, but unfortunately the CEC's Inverter product listing does not have a sufficient review criteria nor an appropriate listing category that is applicable for EVs separate to batteries[93].

Additionally, there are no clear pathways on the means by which disturbance capabilities would apply to AC (or onboard) V2G chargers, particularly as current mechanisms such as network connection agreements apply to a static location and compliance testing to the standard is not suitable for EV requirements. This highlights that addressing compliance to DER Technical Standards will need to consider more broadly the application and enforcement of standards to ensure the full suite of DER technologies are covered.

Furthermore, while AS/NZS4777.2 covers bi-directional EV inverters, there is a critical gap for unidirectional EV inverters[94]. There are currently no established Australian or international standards in relation to disturbance performance and grid support capability for unidirectional chargers, which currently make up the majority of the charging fleet and will likely continue for many years to come. There is little precedent for these requirements on loads more generally. This suggests that there is a growing risk in the potential behaviour of EVs that may not align with the needs of the distribution network and bulk power system.

5.5.2 Medium Voltage installations

AS/NZS4777.2 is intended to provide performance behaviour and testing for inverter systems up to approximately 200 kW, or specifically low voltage connections. However, there is a growing proportion

[93] Battery Storage and Grid Integration Program. Lessons Learnt Certification and Performance of Charger against AS/NZS4777.2 Standard: Insights from the Realising Electric Vehicle to grid services (REVS) trial. See Figure 6. https://arena.gov.au/assets/2022/05/realising-electric-vehicle-to-grid-services-lessons-learnt-2.pdf

[94] AEMO, May 2021. Distributed Energy Integration Program Electric Vehicle Grid Integration – Vehicle-Grid Integration Standards Taskforce – Key Findings. Available at: https://aemo.com.au/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/deip-ev-taskforce

of DER connections in the medium voltage network, up to 5 MW. Compliance to AS/NZS4777.2 may be required for larger connections, often bundled together. However, these requirements vary between distribution networks and there may be thresholds where this can apply.

Currently, there is no Australian Standard for medium voltage (MV) inverters. Depending on DNSP network connection requirements, MV inverter behaviour may be assessed during commissioning testing. The desired behaviour required of these larger MV systems may not consider bulk power system needs.

Consistent frameworks are required to ensure bulk power system requirements are established and applied for MV connections. This should include a minimum level of disturbance withstand requirements, and require monitoring and control of these larger size systems.

As MV Standards are established, future ongoing compliance arrangements will also need to be developed for these installations.

5.5.3 Compliance for other factors such as remote curtailment and Interoperability (CSIP-Aus)

This report focuses on compliance against the technical requirements of AS/NZS4777.2, and specifically the disturbance ride-through requirements. However, suitable frameworks for assessing and enforcing compliance with other aspects will also need to be considered. For example, compliance against the various state-based curtailment frameworks and recently defined minimum interoperability standards, such as the Common Smart Inverter Profile-Australia (CSIP-Aus) will also need to be developed. These functionalities, once mandated, will be required on an ongoing capability that is critical to managing distribution network and bulk power system operations, which means that non-compliance would have significant implications.

Compliance to curtailment frameworks would need to consider registration and commissioning processes to ensure devices are setup correctly, as well as ongoing performance during system events (to ensure that devices remain connected and are physically responding as expected).

Confirming compliance with CSIP-Aus would primarily involve ensuring a DER remains connected and physically responds to a request for its generating output to be dialled up or down. In assessing on-going compliance, cyber-informed engineering principles noted in section 5.3.3 must be applied. The governance review may want to consider which party can most efficiently deliver this service or perform this role, and ensure these principles can be met from a system architectural design. Leveraging the certification arrangements already in place in the US as part of the IEEE2030.5 device certification (noting that CSIP-AUS is a modification of IEEE2030.5) could be considered as part of the enduring frameworks for improving compliance.

6 Ongoing work

AEMO has an ongoing program of work to investigate and improve compliance with technical standards. This includes:

- **Project MATCH** – ARENA-funded collaboration with UNSW and Solar Analytics to develop tools and expand datasets to improve and automate processes to monitor compliance.
- **Amendment to AS/NZS4777.2:2020** – AEMO is working via Standards Australia to seek an amendment to the 2020 Standard to require removal of legacy grid codes, to improve compliance.
- **Engagement with OEMs** – Continuing to work with inverter manufacturers to improve and provide visibility of compliance in the field.
- **Engagement with DNSPs** – Continuing to work with DNSPs to improve processes to identify and rectify non-compliances.
- **Contributions to AEMC governance review** – Providing technical insight and support to the AEMC to assist the governance review around technical settings compliance.
- **Engagement with WA AS/NZS4777 Compliance Working Group** – Ongoing engagement with Energy Policy WA, Synergy and Western Power to address compliance in the SWIS.
- **Engagement with other stakeholders** – Ongoing engagement with other stakeholders such as the CEC, CER, AER, ENA and others as relevant.

Any stakeholders that are interested in collaborating with AEMO on these initiatives or any others related to compliance with technical standards should contact DERProgram@aemo.com.au.

AEMO acknowledges the important contributions of a range of stakeholders, with whom this analysis has been delivered. In particular, AEMO acknowledges the significant collaborative contributions of 10 OEMs, Solar Analytics, UNSW, CitiPower/Powercor/UE, SA Power Networks, Energy Policy WA, Synergy, Western Power, the CER, the CEC and funding from ARENA.

Operational measures for managing power system security

AEMO is in the process of implementing various operational measures that account for the observed poor disturbance ride-through of DPV inverters in the field. To deliver obligations to maintain power system security, AEMO will need to assume the observed rates of compliance for new installations persist (with disturbance ride-through performance in alignment with observations for the older 2015 Standard) until there is robust evidence of compliance and ride-through behaviour improvements to the 2020 Standard.

7 Next steps

This report represents the findings to date of the compliance issues related with DER Technical Standards. It aims to clarify the nature of the challenges, as a foundation for negotiating and implementing suitable solutions. Stakeholders each bring different perspectives and capabilities which can contribute greater understanding and influence the nature of the solutions pursued.

AEMO will proactively work as part of the AEMC's review of customer energy resources technical standards to progress and collaborate with industry on the various activities proposed within this document.

A1. Volt-VAr methodology

A1.1 AS/NZS4777.2:2020 Volt-VAr assessment method

This appendix details the method used to assess the compliance of Solar Analytics data to the AS/NZS4777.2:2020 Volt-VAr requirements, as per the excerpt in Figure 19 below. This method was applied for both the Solar Analytics NEM and SA smart meter datasets.

Figure 19 AS/NZS4777.2:2020 Excerpt: Volt-VAr response set-point values

Table 3.7 Volt–var response set-point values

Region	Default value	V_{V1}	V_{V2}	V_{V3}	V_{V4}
Australia A	Voltage	207 V	220 V	240 V	258 V
	Inverter reactive power level (Q) % of S_{rated}	44 % supplying	0 %	0 %	60 % absorbing
Australia B	Voltage	205 V	220 V	235 V	255 V
	Inverter reactive power level (Q) % of S_{rated}	30 % supplying	0 %	0 %	40 % absorbing
Australia C	Voltage	215 V	230 V	240 V	255 V
	Inverter reactive power level (Q) % of S_{rated}	44 % supplying	0 %	0 %	60 % absorbing
New Zealand	Voltage	207 V	220 V	235 V	244 V
	Inverter reactive power level (Q) % of S_{rated}	60 % supplying	0 %	0 %	60 % absorbing
Allowed Range	Voltage	180 to 230 V	180 to 230 V	230 to 265 V	230 to 265 V
	Inverter reactive power level (Q) % of S_{rated}	30 to 60 % supplying	0 %	0 %	30 to 60 % absorbing

NOTE 1: Inverters may operate at a reactive power level with a range up to 100 % supplying or absorbing.

NOTE 2: Australia C Parameter set is intended for application in isolated or remote power systems.

A1.1.1 Solar Analytics dataset

For the Solar Analytics data assessment, 60 second site data for systems installed since the introduction of the new standard, for the highest irradiance day of the month of March 2022 was provided. The data included voltage and reactive power, for a single clear sky day for each region as shown in Table 19. Due to data collection issues during the month of March, data was only available for the afternoon of each of these days, this was deemed satisfactory since more than half of identified maximum voltages of the dataset occurred after 16:00.

Table 19 Solar Analytics dataset information

State/Territory	Date of Data	Number of sites (raw)	Number of sites (after assessment)[95]	Volt-VAr parameter set
ACT	2022-03-22	28	13	Australia A

[95] Refers to proportion of sites that experienced sufficiently high voltages within the observation window that an assessment of volt-var response could be assessed.

State/Territory	Date of Data	Number of sites (raw)	Number of sites (after assessment)[95]	Volt-VAr parameter set
NSW	2022-03-22	313	109	Australia A
QLD	2022-03-23	333	100	Australia A
SA	2022-03-26	25	8	Australia A
TAS	2022-03-26	7	3	Australia C
VIC	2022-03-26	69	14	Australia A

A1.1.2 SAPN dataset

SAPN collected data from a number of smart meter data providers for a week during April 2022 (from 7 April to 14 April). The data included voltage, reactive power and export data, for a sample of 572 NMI's.

A1.1.3 Methodology

The methodology to assess whether the site output was in line with the expected AS/NZS4777.2:2020 response is detailed in the steps below:

1. Determine maximum voltage and generation experienced at the site. For multiple inverter and three phase sites, a single site voltage and generation value is determined by aggregating to determine the net output at the site boundary. For generation data, this is summed across all inverter outputs. For voltage data, this is deemed as the maximum voltage across all phases.
2. Remove sites that would not experience a Volt-VAr response. These were identified where either of the below conditions are satisfied:
   a. Maximum Voltage < V_{V3} + 2.3V (where 2.3V defines the measurement error of 1% V_{nom})
   b. Generation < 20% S_{Rated} (4777.2:2020 Clause 2.6)
3. From the remaining sites, at the time of maximum voltage, the expected Q output (Q_e) is calculated and compared against the measured value (Q_m), then categorised into one of the three categories below.

$$\frac{Q_m}{S_{rated}} > \frac{Q_e}{S_{rated}} + 10\%: \quad \text{Above Expected}$$

$$\frac{Q_e}{S_{rated}} + 10\% \geq \frac{Q_m}{S_{rated}} \geq \frac{Q_e}{S_{rated}} - 10\% : \text{Expected Response}$$

$$\frac{Q_e}{S_{rated}} - 10\% > \frac{Q_m}{S_{rated}}: \quad \text{Below Expected}$$

A +/-10% var threshold from the expected AS4777.2:2020 Volt-VAr curve was applied.