Short Duration Undervoltage Disturbance Ride-Through

June 2020

Inverter Conformance Test Procedure for South Australia

A memo and consultation paper

Important notice

PURPOSE

This document outlines a proposed inverter conformance test procedure to support improved inverter capabilities to address power system security risks in South Australia. The Australian Energy Market Operator Limited (AEMO) is publishing this consultation paper for the purpose of gaining feedback from industry with specific emphasis on solar installers and solar retailers (or representative groups), original equipment manufacturers and impacted consumer groups. Also included is a recommendation for implementation which is for information purposes only and is subject to uptake by the involved parties.

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VERSION CONTROL

Version	Release date	Changes
#1	5/6/2020	

Executive summary

- AEMO has identified through analysis of recent power system events, that a proportion of distributed PV (DPV) disconnect in response to short duration transmission undervoltage disturbances. In South Australia (SA), possible contingency sizes associated with tripping of DPV following a credible fault is estimated to exceed 500 MW (on average approximately 100,000 residential rooftop PV systems) by the end of the year, and this will grow as more DPV is installed. If this eventuates, AEMO will have very few courses of action available for secure operation of South Australia if separated from the rest of the National Electricity Market (NEM). Load shedding and resulting customer disruption may be inevitable in response to credible faults, and cascading failure may be possible.
- To reduce the potential for disruption and improve power system security, most immediately in South Australia, AEMO has developed and will publish a Short Duration Undervoltage Disturbance Ride-Through (VDRT) Test Procedure to ensure inverters, and DPV by extension, respond appropriately during short duration voltage disturbance events to mitigate any further and potential risks to power system security.
- Development and publication of a VDRT Test Procedure is part of AEMO's broader strategy to address this DPV inverter behaviour, which also includes AEMO's submission of a Rule Change Request to the Australian Energy Market Commission (AEMC) to establish nationally consistent minimum distributed energy resource (DER) technical standards within the NEM by October 2020 and a project to update the Australian Standard defining the performance and capability of inverters for grid connection for energy sources on the low voltage network, AS/NZS 4777.2. AEMO anticipates this VDRT Test Procedure will ultimately be part of the 'initial standard' to be made under the proposed DER minimum technical standards rule and the updated AS/NZS 4777.2. However, AEMO considers there is a pressing need to accelerate implementation of the VDRT Test Procedure in South Australia.
- Laboratory bench testing of inverters (conducted by UNSW[1]) tested 17 commonly installed inverters developed against AS/NZS 4777.2:2015, 10 were already able to perform satisfactorily for short duration undervoltage disturbances, proving the capability is achievable, and that many inverters will not require changes to meet the new requirements.
- AEMO is proposing that all new inverter installations in SA be limited to those that demonstrate the appropriate short duration undervoltage withstand capability, and to this end, is developing and seeks to publish this Test Procedure. The process to accelerate implementation of this requirement is being defined in collaboration with SA Power Networks and the South Australian government.
- These measures will not be implemented retrospectively, however, if they do not come into place by November 2020 alternative options may need to be considered to preserve system security.

[1] UNSW Sydney, Addressing Barriers to Efficient Renewable Integration – Inverter Bench Testing Results (Test 27). Available at: http://pvinverters.ee.unsw.edu.au/

1. Background

1.1 Objective

The purpose of this paper is to consult on AEMO's development and publication of a short duration undervoltage disturbance ride-through (VDRT) Test Procedure, which may be incorporated into DNSP Technical Standards for inclusion in connection agreements as required.

AEMO has observed that a large portion of distributed PV (DPV) disconnect following short duration voltage disturbances. This behaviour of DPV inverters during voltage disturbance creates a risk in regions of high DPV penetration. AEMO's Renewable Integration Study identified that there is a pressing need to address the increasing contingency sizes associated with potential mass disconnection of DPV in South Australia due to their already high DPV penetrations and potential to electrically island (i.e. become 'electrically separated' from the rest of the grid, as occurred in February 2020).[2] The VDRT test procedure proposed demonstrates the ability for an inverter to ride-through these faults and therefore limit the growing risk in the region.

Development and publication of a VDRT Test Procedure is part of a broader strategy to address DPV inverter behaviour, which also includes the submission of a rule change request to the AEMC to establish consistent minimum distributed energy resource (DER) technical standards within the NEM by October 2020 and a project to update the Australian Standard defining the performance and capability of inverters for grid connection for energy sources on the low voltage network, AS/NZS 4777.2.

AEMO anticipates implementation of the short duration VDRT Test Procedure will be part of the 'initial standard' to be made under the proposed National Electricity Rules (NER) DER minimum technical standards rule and the updated AS/NZS 4777.2, but advises there is a need to accelerate implementation in South Australia. To this end, AEMO seeks to publish the Inverter VDRT Test Procedure such that it can be implemented as required in South Australia ahead of the Rule Change determination and initial standard development process.

The proposed test procedure tests for default inverter performance that already satisfies AS/NZS 4777.2:2015 requirements but includes an additional test. A process to implement this standard is currently under discussion with relevant stakeholders including the South Australian Government, SA Power Networks (SAPN) and the Clean Energy Council (CEC) and will be published upon finalisation of the test procedure.

AEMO is seeking feedback on the proposed short duration VDRT test procedure as part of this consultation.

All feedback must be provided in full by 5:00pm (AEST) Friday 26 June 2020 via email to DERProgram@aemo.com.au. During the consultation, AEMO will hold a stakeholder forum to discuss issues relating to the test procedure and provide clarity as required. This will also provide a forum for further Q&A and discussion such that we can move forward and achieve the objectives outlined in this paper.

To ensure all stakeholders are kept informed and aware of changes, an engagement and communication plan is currently being finalised which will include:

- Stakeholder forums
- Email and newsletter communications
- Website updates with relevant information
- News and social media updates relevant to the industry

For further information, or to request an update, please contact AEMO on DERProgram@aemo.com.au.

[2] AEMO, Renewable Integration Study Stage 1 (Action 3.1), at https://aemo.com.au/-/media/files/major-publications/ris/2020/renewable-integration-study-stage-1.pdf?la=en.

1.2 DER Minimum Standards Rule Change Request

On 20 March 2020, the Council of Australian Government Energy Council (COAG EC) agreed to a recommendation by the Energy Security Board (ESB) that the ESB and AEMO progress a Rule Change Request to put in place nationally consistent minimum distributed energy resource (DER) technical standards in the NEM by October 2020[3], and to replicate this process in Western Australia (ESB Recommendation). The intent of the minimum standards is to facilitate consumer access to DER markets and services and to provide for grid and power system security and reliability.

In May 2020, AEMO in collaboration with the ESB, submitted to the Australian Energy Market Commission (AEMC) a rule change request to establish a framework in the National Electricity Rules (NER) for the creation of nationally consistent minimum DER technical standards. The rule proposes:

- AEMO must make, publish and may amend, the DER Minimum Technical Standards in accordance with the Rules consultation procedures.
- Distribution Network Service Providers (DNSPs) must ensure that connected DER, either by its own means or by way of a DER device, meets the DER Minimum Technical Standards (including without limitation, through the inclusion of appropriate provisions in connection agreements).

The ESB Recommendation agreed to by COAG EC included the development and submission of the rule change request to the AEMC to put in place DER technical standards by October 2020, together with an 'initial minimum DER technical standard' focussed on *AS/NZS 4777.2 Grid connection of energy systems via inverters (Inverter requirements)*, to be developed in consultation with stakeholders[4], by October 2020. To facilitate the October 2020 timeframe, AEMO committed to consult with stakeholders in parallel with AEMC rule change consultations, on an initial standard to be published as a transitional measure alongside an AEMC final Rule determination.

AEMO intends for the initial standard to include the interim short duration VDRT requirements proposed in this consultation paper and will publish a separate issues paper to seek stakeholder views on the scope and content of the initial standard for the other NEM jurisdictions.

Feedback received on this consultation paper will be applied to the VDRT Test Procedure and will also be considered as part of consultations for the NEM standard. The outcomes from this consultation on a VDRT Test Procedure, if adopted by SA Power Networks (SAPN), will be applied as an interim measure to achieve power system security in South Australia.

1.3 AS/NZS 4777.2

A proposal to update the Australian Standard, AS/NZS 4777.2 was put forward by AEMO in June 2019 and was accepted by Standards Australia. AS/NZS 4777.2 defines the performance and capability of inverters for grid connection for energy sources on the low voltage network. The revised Standard is currently being drafted by the EL-042-03 committee, where AEMO is a leading member, working on the following relevant aspects:

- Defining improved undervoltage disturbance ride-through requirements, which provide acceptable power system stability, while also meeting distribution network requirements for safety and suitable anti-islanding protection.
- Improving the accuracy and stability of measurement systems used in these inverters to improve reliable performance characteristics for a range of grid disturbances.
- Designing suitable testing procedures and improving test reports to clearly demonstrate that an inverter confirms to the standard.

[3] COAG Energy Council Communique 20 March 2020, at http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/EC%20-%20communique%20-%2020200320.pdf.

[4] AEMC Technical Standards for distributed energy resources, at https://www.aemc.gov.au/rule-changes/technical-standards-distributed-energy-resources.

- Aligning requirements with international best practice and applying (where appropriate) similar performance capabilities as large-scale generation.

The Standards Australia review for AS/NZS 4777.2 is a collaborative, consensus-based process involving a wide range of stakeholders including AEMO, distribution and transmission network service providers in all Australian regions, the Clean Energy Council, inverter manufacturers, testers, installers, solar customers and others. This ensures that coordination across the full breadth of impacted stakeholders is undertaken.

Standards Australia anticipates publication of the standard will occur by December 2021, noting that delays may arise as it is a consensus process via ballot. Once published, there would then be a delay period before the new standard is mandatory to allow manufacturers to adjust their inverter design and undertake retesting. Following publication of AS/NZS 4777.2:2015 (the last time the standard was changed), this delay period was 12 months. Following the same process, the new version of the standard may not apply until December 2022.

An earlier timeframe is being proposed which would allow publication of the new standard by March 2021 and applying to all new inverters by March 2022

The work being undertaken through the DER Minimum Technical Standard Rule Change Request and the associated initial standard will address some of these issues, however, the broader AS/NZS 4777.2 uplift must be balanced with the need to ensure all affected parties are properly involved and have adequate opportunity to review and provide input to the process.

2. DPV disconnections to voltage disturbances

As detailed in the RIS, AEMO has identified that a large portion of DPV disconnects following voltage disturbances[5]. This disconnection appears to be influenced by the severity of the disturbance, and the distance of the DPV from the source of the disturbance. This has been further verified through analysis of data conducted by the University of New South Wales (UNSW) in a study which also bench tested inverter responses to high-speed (or short duration) voltage disturbances[6].

2.1 Evidence of PV disconnection

AEMO has identified through analysis of recent power system events, that a proportion of DPV disconnect in response to short duration transmission undervoltage disturbances. In SA, possible contingency sizes associated with tripping of DPV following a credible fault is estimated to exceed 500 MW (on average approximately 100,000 residential rooftop PV systems) by the end of the year, and this will grow as more DPV is installed. If this eventuates, AEMO will have very few courses of action available for secure operation of South Australia if separated from the rest of the NEM. Load shedding and resulting customer disruption may be inevitable in response to credible faults, and cascading failure may be possible.

[5] Renewable Integration Study Stage 1 Appendix A: High Penetrations of Distributed Solar PV, at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

[6] UNSW Sydney, Addressing Barriers to Efficient Renewable Integration – Inverter Bench Testing Results (Test 27), at http://pvinverters.ee.unsw.edu.au/.

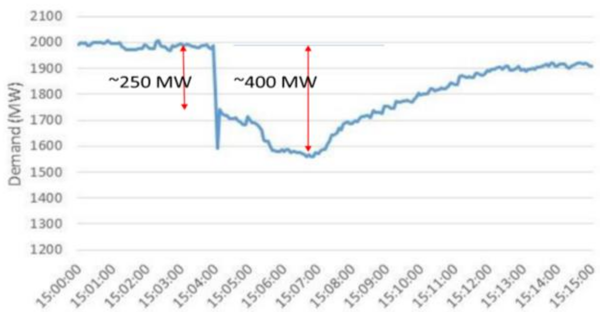
2.1.1 South Australia 3 March 2017 Case Study

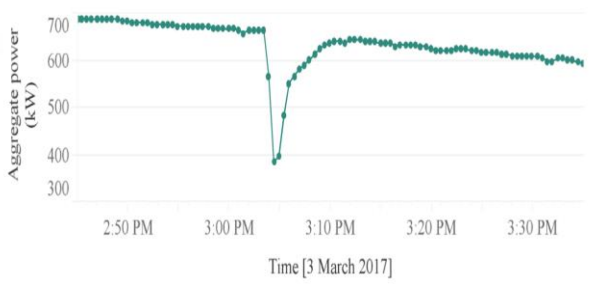
At 3:03 pm on 3 March 2017, approximately 610 MW of transmission-connected generation in South Australia disconnected, following a series of faults at the Torrens Island 275 kV switchyard. This resulted in flows on the Heywood interconnector to increase to ~918 MW to account for the shortfall[7]. In response, approximately 400 MW of load reduction was experienced. Although detailed counterfactual simulations have not been performed, it is believed this demand reduction was a significant factor in mitigating the interconnector flow increase and in preventing wider impact of the disturbance on the South Australian power system.

Just prior to the event, approximately 350 MW of DPV was operating. In response to the disturbance, analysis shows disconnection of DPV led to approximately 150 MW (~40%) reduction in generation from these devices, counter-acting the load relief. The PV systems that reduced generation during the event neutralised part of the load relief, and consequently the resultant interconnector flow was higher than would have ordinarily occurred.

The figure on the left below shows the total demand in South Australia during the event, with an initial demand reduction of 250 MW (400 MW of load relief, offset by 150 MW of distributed PV generation ceasing operation). DPV systems reconnected progressively over the following several minutes such that the total demand reduction of 400 MW becomes visible.

Figure 1 Case Study 3 March 2017 (a) Operational demand for SA (b) Aggregate DPV generation





The behaviour of DPV during the event is further supported by analysis of data provided by Solar Analytics. The figure on the right above shows the aggregate behaviour of 200 DPV sites monitored by Solar Analytics in South Australia during the event. It was observed that aggregate DPV reduced by 42% following the event, then slowly returned to the pre-disturbance level as DPV systems restored output over an approximate six-minute period, confirming that DPV contributed a significant response to this event.

This type of response highlights the need for inverter standards to be uplifted to mitigate further risks. As the amount of connected DPV increases the potential response in a similar event with a greater amount of generation loss could result in the separation of SA from the rest of the grid, or potential cascading failures. The ability for DPV to ride-through these disturbances will also reduce the overall impact to households with less load shedding required and therefore less power outages to homes.

2.1.2 Solar Analytics Data

AEMO analysed additional DPV disconnection behaviour from historical short duration transmission system originated voltage disturbances that occurred in periods with meaningful levels of DPV operating during 2016 to 2020. For each disturbance, data from a sample of hundreds of individual DPV inverters was provided by Solar Analytics[8], under a joint ARENA funded project[9]. Many inverters were observed to reduce power to zero

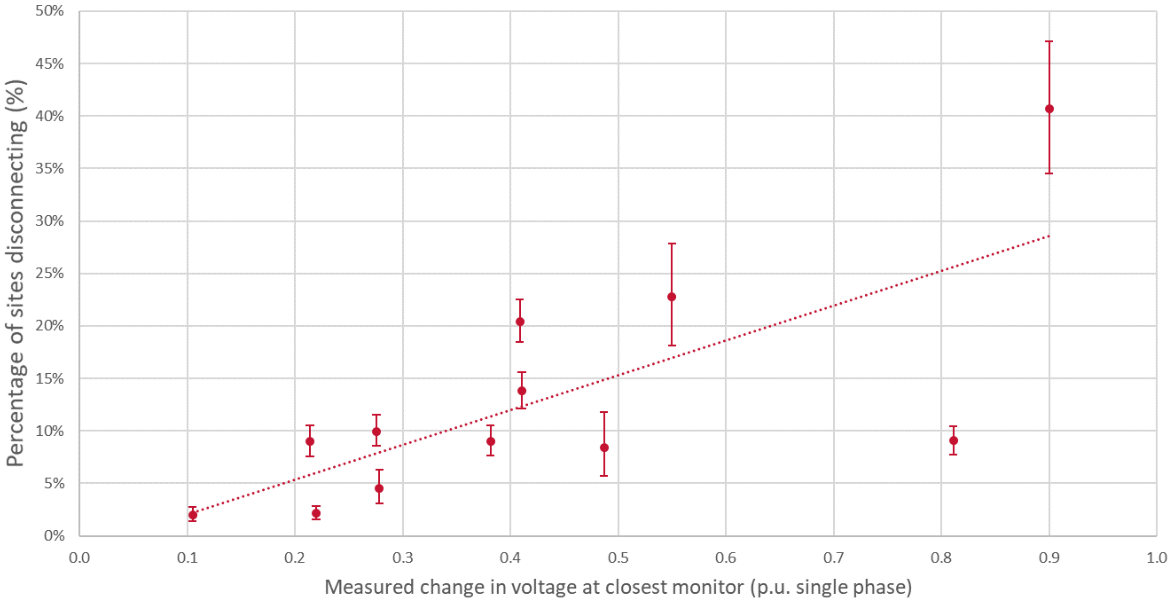
[7] This level is significant as it is greater than the level of power flow that resulted in a loss of synchronism and a subsequent cascading failure to a black system on 28 September 2016.

[8] Solar Analytics data was anonymised to ensure system owner and address could not be identified.

[9] ARENA, Enhanced Reliability through Short Time Resolution Data, at https://arena.gov.au/projects/enhanced-reliability-through-short-time-resolution-data-around-voltage-disturbances/.

(indicative of disconnection) immediately following a voltage disturbance. The proportion of DPV inverters demonstrating this behaviour in each historical event was calculated. Inverters were categorised by installation prior to October 2015 (under the AS/NZS 4777.3:2005 standard), or after October 2016 (under the AS/NZS 4777.2:2015 standard). Both categories showed similar disconnection behaviour.

Figure 2 Percentage of distributed PV sites in a region observed to disconnect following historical voltage disturbances



Distributed PV disconnection behaviour was confirmed to be related to the severity of the voltage disturbance, as illustrated in Figure 2. In the most severe voltage disturbance analysed, disconnection of more than 40% of DPV in the region was observed. Individual cases may deviate from the linear trend line if the fault location was electrically remote from DPV centres, or if the high speed monitor used to estimate the severity of the fault was remote from DPV centres (therefore providing a less accurate estimate of the voltage experienced by DPV during the disturbance).

2.1.3 Bench testing of inverters

DPV disconnection behaviour was further validated by bench testing of individual inverters under laboratory conditions, conducted by UNSW Sydney[10]. Their analysis exposed an inverter to a 100 ms duration voltage sag from 230 V to 50 V and returned to above 230 V to simulate a short duration voltage disturbance. In this test, 17 of the 23 inverters tested were installed under the 2015 AS/NZS 4777.2 standard; these inverters will form the focus of this consultation as all inverters currently being installed must meet these requirements as a minimum. The results of the testing showed:

- 10 out of the 17 inverters certified/accredited against the 2015 Standard[11], rode-through the voltage sag disturbance without disconnecting.
- 7 out of the 17 inverters certified/accredited against the 2015 Standard, that did not demonstrate satisfactory behaviour; their responses varied as below:
  - Reduced power output to 0%, 20% or 50% of rated power, and returned after 6-7mins,
  - Resulted in control instability, or

[10] UNSW Sydney, Addressing Barriers to Efficient Renewable Integration – Inverter Bench Testing Results, at http://pvinverters.ee.unsw.edu.au/.

[11] For this report, have considered only 2015 inverters as these are currently being installed.

– Disconnected completely.

Based on the inverters tested, and extrapolating this out to the broader market, it was determined that approximately two-thirds of the current inverters in the SA market would meet this short duration voltage disturbance ride-through requirement.

2.2 Undervoltage Disturbance Ride-through Specifications in AS/NZS 4777.2

AS/NZS 4777.2:2015 includes a passive anti-islanding requirement which requires the inverter to disconnect for an undervoltage disturbance lasting at least one second, thereby proving capability to ride-through undervoltage disturbances of shorter duration. The existing specifications require that an inverter has a trip delay time of 1 second once the voltage falls and remains below 180 V (as per Table 13 of AS/NZS 4777.2:2015), with the intent to provide anti-islanding for distribution networks beyond 1 second, and ride-through for under 1 second. An additional note in Section 7.4 of the Standard specifies that when the voltage falls below the undervoltage limit it is permissible to continue, reduce, or stop the inverter output during the trip delay time and if voltage returns above the limit during the trip delay it may resume normal operation, that is, an undervoltage event should not result in the inverter activating the automatic disconnection device. Such behaviour is consistent with AEMO's expectations that supply from DPV should not be interrupted following short duration transmission level events.

However, the testing procedure in AS/NZS 4777.2:2015 Appendix G.2 of the Standard only tests to confirm that an inverter trips after one second for incremental voltage reductions (in steps of less than 1 V from 182.5 V to 177.5 V, with a dwell time of 5 seconds for each voltage step); which does not sufficiently test for the behaviour of an inverter during the short duration undervoltage disturbance described above. This identifies a gap in the current test procedure for the desired behaviours and has allowed inverters to be marked as compliant without meeting this response requirement, exacerbating the current challenges being faced in the SA power system.

2.3 Load and DPV disconnection in South Australia

AEMO has since developed a model that utilises historical response data to analyse the impact of DER and load disconnection that results from these voltage disturbances, and the impact on power system security.

An analysis of South Australia indicates that a severe but credible short duration voltage disturbance in the Adelaide metropolitan area could cause 14-28% of underlying regional load to disconnect, and 49-53% of DPV generation to disconnect. This highlights that in periods with high levels of solar generation now experienced in South Australia a net loss of generation will occur, increasing contingency sizes. For example, if a severe fault had occurred in the Adelaide metropolitan area in the highest solar insolation period in 2019, the resulting net loss of distributed PV and load would have been 280 MW. This is a significant amount, especially if combined with the loss of a large generating unit.

Applying AEMO's Draft 2020 ISP 'High DER' projections for DPV uptake, and assuming underlying load and DPV generation patterns as observed in 2019, leads to the net contingency sizes (DPV disconnection net of load disconnection) in Table 1 below.

In these periods the quantity of DPV disconnecting exceeds the quantity of load disconnecting, meaning that the combined (DPV minus load) contingency is a net loss of generation in these periods. In the worst case, these values could be additional to the loss of a synchronous generating unit if they occurred as a result of a fault at the large generator's transformer.

The extreme worst case estimate is shown (with maximum PV loss, minimum load loss, and in the most severe period of the year), as well as a more moderate estimate of the 85th percentile case (assuming a middle projection of possible load and DER loss, and the 85th percentile of half-hourly periods in the year by severity of the possible net contingency size). The 85th percentile case could be expected to be exceeded on 55 days of the year. The 85th percentile case also assumes that all > 200 kW distribution-connected PV has been curtailed (assuming AEMO requests this of the local DNSP, when operational demand reduces below 700 MW). In contrast, the extreme worst case assumes that DPV has not been curtailed, which may be the case in system normal conditions, or where operational conditions do not require curtailment for system security.

Table 1 **Table 1 Net contingency sizes (MW) based on the 85th percentile and extreme worst-case scenarios**

	85th percentile case	Extreme worst case
2019 (Actual)	70	280
2020	190	430
2021	260	520
2022	300	560
2023	330	600
2024	370	650
2025	390	680

This becomes particularly problematic in the scenario where South Australia is operating as an island[12]. When South Australia operates as an island, if a severe voltage event in the Adelaide metropolitan area coincided[13] with high solar PV generation that triggered PV disconnection, the ability for AEMO to arrest the event would be impacted. As detailed in the RIS, studies indicate that:

- When net loss of PV and load exceed around 150 MW, frequency is likely to fall below 49 Hz. This means that activation of automatic under frequency load shedding (UFLS) is inevitable, representing disconnection of customers. Yet, the capability of UFLS to arrest a frequency decline below 49 Hz at these times is unclear; analysis has indicated that there could be very little net load available to shed in periods with high levels of DPV operating.
- When the net loss of DPV and load contingency size exceeds around 300 MW, frequency may fall outside the 47-52 Hz range. Cascaded tripping and major supply disruption might be inevitable under these circumstances.

As noted above, contingency sizes may have already exceeded 150 MW in some periods and may exceed 300 MW by late 2020 if DPV installations continue to proceed according to AEMO's High DER forecast. This indicates that in the imminent future, AEMO may no longer have the ability to operate South Australia in a secure state if islanding occurs at times of high distributed PV generation.

AEMO has very limited real-time options to reduce risk in these periods. These studies suggest that options used to improve system security in other circumstances, such as application of network constraints, increasing supply of FCAS, or the dispatch of additional synchronous generators, do not offer much improvement for this type of severe contingency under islanded conditions. Improving voltage disturbance ride-through capabilities of all new distributed PV, as rapidly as possible. This reduces the size of the contingency associated with disconnection of DPV.

[12] During this time frequency is required to be maintained above 49 Hz for single contingencies, and require that reasonable endeavours are made to keep frequency above 47 Hz for multiple contingencies.

[13] These are extreme operating conditions that are anticipated to occur rarely. Since Market start in 1998, South Australia has separated from the rest of the NEM ten times, six of those times were the past three years. Circumstances such as bushfires can increase the likelihood of these events.

3. Publication of VDRT Test Procedure

AEMO has identified that even if a March 2021 timeline for the updated AS/NZS 4777.2 Standard to be published (and therefore applicable on all new inverters by March 2022) is achieved (and this timeframe is not certain), there are serious risks to the South Australian power system. For every month of inaction, 15 MW of new inverters are installed in the region. Between now and March 2022, it is estimated that 318 MW of new PV[14] will be installed, without intervention up to 40% of these inverters could disconnect in a disturbance placing system security at risk.

This supports AEMO's recommendation for an accelerated pathway to implement interim arrangements prior to the release of the revised AS/NZS 4777.2 Standard and separate from the NEM-wide initial standard in development as part of the DER minimum standard rule change.

To manage this risk, AEMO has developed the VDRT Test Procedure, which may be incorporated into DNSP Technical Standards for inclusion in connection agreements. The process to implement the VDRT Test Procedure in South Australia is currently under discussion with relevant stakeholders including the South Australian Government, SA Power Networks (SAPN), and the Clean Energy Council (CEC), with a view to publishing this process upon finalisation of the test procedure.

The publication of the VDRT Test Procedure and envisaged implementation supports AEMO's recommendation for an accelerated pathway to implement interim arrangements in South Australia to respond to the identified pressing need, prior to the release of the revised AS/NZS 4777.2 Standardand ahead ofthe NEM-wide initial standard in development as part of the DER minimum standard rule change. As the voltage disturbance ride-through capabilities are already implied in the existing specifications of AS/NZS 4777.2:2015, and the UNSW bench testing indicates approximately two-thirds of inverters can already meet this requirement, AEMO assesses that the potential inverters impacted by the additional Test will be limited. This approach presents an opportunity to rapidly alleviate the growing power system security issue by limiting installation to the subset of conforming inverters.

AEMO considers the process to be published on finalisation of the VDRT Test Procedure will support the timely uplift of industry. A delay in establishing these inverter requirements could result in customers being disconnected during power system events or the inability for AEMO to restore the power system in the event SA becomes islanded, both of which are undesirable outcomes.

AEMO considers implementing this activity swiftly in South Australia is likely to:

- Assist with securely integrating the future DPV fleet with the needs of the power system.
- Avoid the further build-up of legacy inverters that will continue to pose risks to grid operation and reliability, by applying the revised Standard to newly installed, upgraded or replaced distributed PV than would otherwise be captured under business as usual processes.
- Bring certainty regarding the contribution of DER to the power system during and following severe disturbances, enabling power system managers to avoid conservative (and inefficient) operational

[14] Based on SAPN's projections for systems up to 200 kW.

measures in anticipation of loss of DER for a range of severe disturbances. This in turn, supports delivery of more affordable energy to consumers.

- Lead to a reduced size of the contingency required to mitigate disconnection of distributed PV.
- Improve resilience of the power system (a key component of reliability) while also meeting distribution network requirements for safety and suitable anti-islanding protection.

If the VDRT Test Procedure is incorporated into Technical Standards and included in connection agreements in South Australia, AEMO understands South Australian consumers are likely to continue to have access to a wide range of market options, albeit reduced from the present market, as many inverters already satisfy the desired behaviour without requiring changes to the inverter design. Furthermore, it provides an opportunity for manufacturers to understand if inverters will meet the requirements of the initial standard intended to be applied more broadly across the grid and take necessary measures to address this.

3.1 Testing

The proposed test procedure is available in Appendix A1 and is intended to determine whether an inverter can meet the prescribed short duration voltage disturbance ride-through provisions as expressed in AS/NZS 4777.2:2015.

The proposed test procedure utilises the inverter's default settings, to demonstrate that an inverter remains connected and in sustained, continuous operation for a short duration, transmission undervoltage step reduction (50 V or 20% retained voltage for a duration of 80-220 ms). The values selected are based on the protection clearance times applicable to high voltage distribution and transmission networks.

This proposed test report seeks to confirm two aspects of the inverter's behaviour:

- Inverter remains connected during an event where the voltage reduces to below 180 V and consequently returns above 180V within one second or less.
- Inverter disconnects after 1 second following an event where the voltage reduces and remains below 180 V.

The proposed test procedure has been designed to align closely to existing test procedures within AS/NZS 4777.2 as well as the UNSW Sydney bench testing and is intended to be used as the basis for AEMO's interim DER initial Standard. Following consultation, the proposed test procedure will be finalised and published on AEMO's website.

Upon publication of the upcoming revised AS/NZS 4777.2, all inverters will require full certification to the new standard as a full suite of additional functionality is also being incorporated.

To determine compliance against the short duration VDRT test procedure, manufacturers will need to undertake testing of their inverters by a testing laboratory that has already been certified against AS/NZS 4777.2 through the Joint Accreditation System of Australia and New Zealand (JAS-ANZ) accredited certifying bodies or from state electrical regulators.

Where an inverter does not satisfy this short duration undervoltage disturbance ride-through test, and the manufacturer elects to redesign their inverter, the full suite of AS/NZS 4777.2:2015 testing plus this test will need to be undertaken to demonstrate full compliance.

3.2 Conformance and registration

The test is intended to be supplementary to any compliance already received for AS/NZS4777.2:2015, so additional conformance and registration will be required to be undertaken. Once a test procedure is made available, AEMO envisages satisfactory inverters will be given approval by CEC and listed in an additional field on the CEC's existing Inverter Product Listing register.

This departs from the usual Standards process whereby conformance accreditation is reviewed and evaluated by an independent third-party conformity assessment body (CAB), typically accredited through JAS-ANZ.

AEMO considers the proposed VDRT Test Procedure has low complexity, relative to some other aspects of the AS/NZS 4777.2:2015 testing procedure, allowing the process to be simplified and reduce the potential cost to industry. Since the CEC are independent and already administer the register of inverters, AEMO considers the CEC would be the best placed to evaluate conformance based on test reports and maintain the list of conforming inverters however, AEMO acknowledges this does raise a potential risk if formal assessment is not undertaken by an accredited organisation. This risk has been minimised by:

- Specifying in the test report that it clearly state whether the inverter passes or fails the test,
- Requiring that the testing laboratory is already accredited to AS/NZS 4777.2, and
- Aligning the test procedure with the existing AS/NZS 4777.2:2015 style and structure.

3.3 Next steps

This consultation will be open until 26 June 2020. AEMO asks that all respondents:

- Review the test procedure available in Appendix A1.
- Provide feedback on the Test procedure and any considerations for applying this test procedure to DERProgram@aemo.com.au
- Review details of the final published test procedure and process for implementation once notified of the publication – details will be advised on AEMO's Short Duration VDRT Test Procedure Consultation Pager
- Contact AEMO via DERProgram@aemo.com.au with any questions so responses can be provided.

Once all submissions and feedback have been collated, AEMO will publish a response and final test procedure. A process to implement this VDRT Test Procedure in South Australia will also be provided with details on where and how to find further information. AEMO appreciates stakeholders' support and input on the VDRT Test Procedure.

Appendix A1: Short duration undervoltage response test

A1.1 General

The intention of this test is to confirm the behaviour of an inverter during a short-duration voltage sag, the inverter should sufficiently demonstrate the ability to remain in continuous operation through a 220 ms voltage sag to 50V. This test should be used in conjunction with existing test reports and compliance to AS/NZS 4777.2:2015, and has been developed as a supplementary test.

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

This test is used to verify –

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

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

A1.2 Test conditions

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

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

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

In the case of a three-phase supply, the angle between the fundamental voltages of each pair of phases shall be maintained at 120 ± 1.5°. The average r.m.s. voltages between each pair of phases shall be maintained within ±1 %.

The grid test voltage shall be 230 V a.c. phase to neutral, 50 ± 0.1 Hz.

A1.3 Inverter setup

Each inverter that is to be tested shall have its internal settings and configurations set to the default set-points required by AS/NZS 4777.2:2015, as they would be for operation in an installation. The power quality response mode settings should be set according to the Energy Networks Australia Recommended default power quality response modes and settings for Inverter Manufacturers.

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

Before commencement of the test, all model information and specific information concerning the version of software, firmware and hardware used by the inverter shall be recorded. This information shall be provided in the test report.

Sufficient records shall be kept and photographs taken so that the model tested can be verified.

A1.4 Grid source

Either a real grid or a simulated test grid shall be used in the testing.

Whether a real grid or simulated test grid is used, the impedance of the test point shall be rated appropriate to the rating of the inverter or combination of inverters under test. The impedance of the test point should not cause a voltage rise greater than 0.5 % of the grid test voltage at the rated current output of the device under test.

NOTE: This is to ensure that the application of the inverter in a customer installation will not adversely affect the quality of supply to the customer.

The type of source and the impedance of the source shall be declared in the test report for each test performed.

During the tests, the steady-state voltage of the real or simulated test grid shall not vary by more than ±1 % of the grid test voltage. The grid test voltage shall be set as required by each test.

For tests requiring step changes in voltage, the simulated test grid shall be at least capable of being stepped at 0.5 times the smallest step required for testing, to determine the set-points with required accuracy.

The real grid or a simulated test grid needs to be free from harmonic distortion which could interfere with testing. The voltage harmonic distortions of the real or simulated test grid shall be less than the limits specified in the table below.

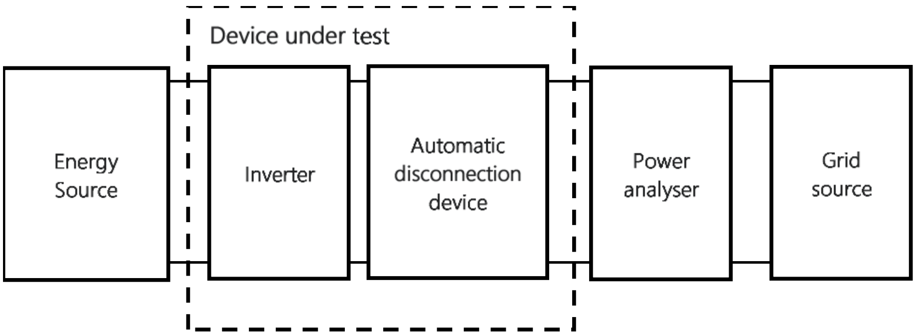
Harmonic order number	Limit based on percentage of fundamental
3	0.9 %
5	0.4 %
7	0.3 %
9	0.2 %
Even harmonics 2–10	0.2 %
11–50	0.1 %
Total harmonic distortion (to the 50th harmonic)	5 %

A1.5 Test procedure

A1.5.1 General

The following test procedure steps should be completed sequentially.

Figure 1 Test circuit for voltage limits



For each of these tests the inverter and automatic disconnection device shall be connected into a test circuit equivalent to that shown in Figure 1.

NOTE: The above test circuit applies to a single-phase system. To test a three-phase system, an equivalent three-phase circuit is required.

A1.5.2 Undervoltage (V<) disconnection test in response to event duration exceeding trip delay time

The disconnection time for the protective function undervoltage (180 V) for a voltage step shall be confirmed. The procedure shall be as follows:

(a) Set the grid source equal to the grid test voltage. The energy source shall be varied until the a.c. output of the device under test equals 50 ± 5 % of its rated current output.

NOTE: For three-phase inverters or inverter combinations, the required inverter output is based on the per phase inverter current rating.

(b) The grid source voltage shall be stepped to 177.5 V (2.5 V below 180 V) with the step change completed within 2 ms and occurring at the zero crossing of the grid source voltage. The time interval between the start of the voltage step and the device under test disconnecting from the grid source shall be recorded.

(c) Adjust the grid source to return the voltage to the grid test voltage. The reconnection time (the time taken for the device under test to reconnect to the grid source) shall be recorded.

A1.5.3 Undervoltage (V<) withstand test in response to event duration of less than trip delay time

The trip delay requirement for the protective function undervoltage 1 (V <) of 180 V for a voltage step shall be confirmed. The procedure shall be as follows:

(d) Set the grid source equal to the grid test voltage. Vary the energy source until the a.c. output of the device under test equals 50 ± 5 % of its rated current output.

NOTE: For three-phase inverters or inverter combinations, the required inverter output is based on the per phase inverter current rating.

(e) Record the stabilised active power output.

(f) Step the grid source voltage to 50 V with the step change completed within 2 ms and occurring at the zero crossing of the grid source voltage, remain at 50 V for 220 ms. Increase the grid source voltage to the grid test voltage with the step change completed within 2 ms and occurring at the zero crossing of the grid source voltage. Record the time interval between the start of each voltage step passing through 180 V each time.

(g) Monitor the active power output and record the time taken to reach the level ± 4 % recorded at step (e).

A1.6 Criteria for acceptance

(1) The disconnection time recorded at Step (c) shall be greater than the trip delay time of AS4777.2:2015 of 1 s and less than the disconnection time of AS4777.2:2015 of 2 s.

(2) The time interval recorded at Step (f) for the duration below the undervoltage limit (V<) shall be less than 1 s.

(3) The device under test shall remain connected for the duration of test step (f).

A1.7 Test report specifications

For each test performed, the results specified in the criteria for acceptance shall be recorded in the test report. The report shall include a time-series plot that shows the instantaneous and RMS voltage waveform and the power output of the device under test over the duration of each test (A1.5.2 and A1.5.3). The presented waveforms shall demonstrate that the inverter appropriately disconnected after 1 second, and that the inverter remained connected and recovered to a stable output for a disturbance of less than 1 second.

The test report should clearly indicate whether the inverter passed or failed each acceptance criteria.