Meeting Date: 24 October 2019

Lessons for New Zealand from a 25 August 2018 event on the Australian power system

Security and Reliability Council

This paper sets out the lessons for New Zealand that Transpower identified from the 25 August 2018 power system event in Australia. One of those lessons relates to an Australia/New Zealand standard for inverter connected distributed generation and echoes concerns of Dr Allan Miller that he has written to the SRC about.

Note: This paper has been prepared for the purpose of the Security and Reliability Council (SRC). Content should not be interpreted as representing the views or policy of the Electricity Authority.

1. Purpose and background

1.1. On 25 August 2018, a major event occurred on Australia's National Electricity Market. The relevant system operator (Australian Electricity Market Operator, AEMO) investigated the event and published its findings in January 2019.

1.2. New Zealand's system operator (Transpower) subsequently reviewed the findings and liaised directly with AEMO to understand the implications of the event for New Zealand. Transpower materially completed that work in mid-2019 and published a report in October 2019. Transpower has prepared a summary report for the SRC – attached as Appendix A.

1.3. Independently of that, Dr Allan Miller[1] wrote to the SRC's Chair on 28 May 2019 expressing concerns about the adequacy of regulatory arrangements with respect to standards governing inverter-connected distributed generation. Extracts from Dr Miller's correspondence are attached as Appendix B.

1.4. As one of the lessons from the 25 August 2018 event in Australia relates to standards for inverter-connected distributed generation, the SRC's secretariat has bundled these matters together into this single paper.

1.5. Transpower representatives will be present at the 24 October 2019 meeting to answer any questions from the SRC.

2. Key lessons identified

2.1 Transpower's report to the SRC identified three significant lessons:

a) AEMO undertook to "review the performance of the [Emergency Alcoa Portland Tripping] Special Protection Scheme and other [special protection] schemes." Transpower, in its capacity as the grid owner and the system operator, undertook to review its processes for managing the ongoing performance of its special protection schemes.

b) With respect to the performance of power system stabilisers: establish assurance processes and investigate establishing real-time monitoring.

c) AEMO had a finding to "work on the technical requirements for…inverter standard (AS/NZS 4777.2) and its modelling of inverter response." Transpower identified a need to work with AEMO on inverter performance requirements under AS/NZS 4777.2 and encourage the Ministry of Business, Innovation and Employment to update regulations to improve compliance with AS/NZS 4777. This latter issue is the primary concern of Dr Miller's correspondence with the SRC Chair.

2.2 Dr Miller proposes that "I believe that updating the [Electrical Safety Regulations] to the most recent standards is of the utmost importance to removing the, at best, ambiguities…, and at worst, avoiding proliferation of grid emergencies and local supply quality issues. In the interim I recommend that all distributors refer to the voltage, frequency, and inverter power quality response settings required in AS/NZS 4777.2:2015."

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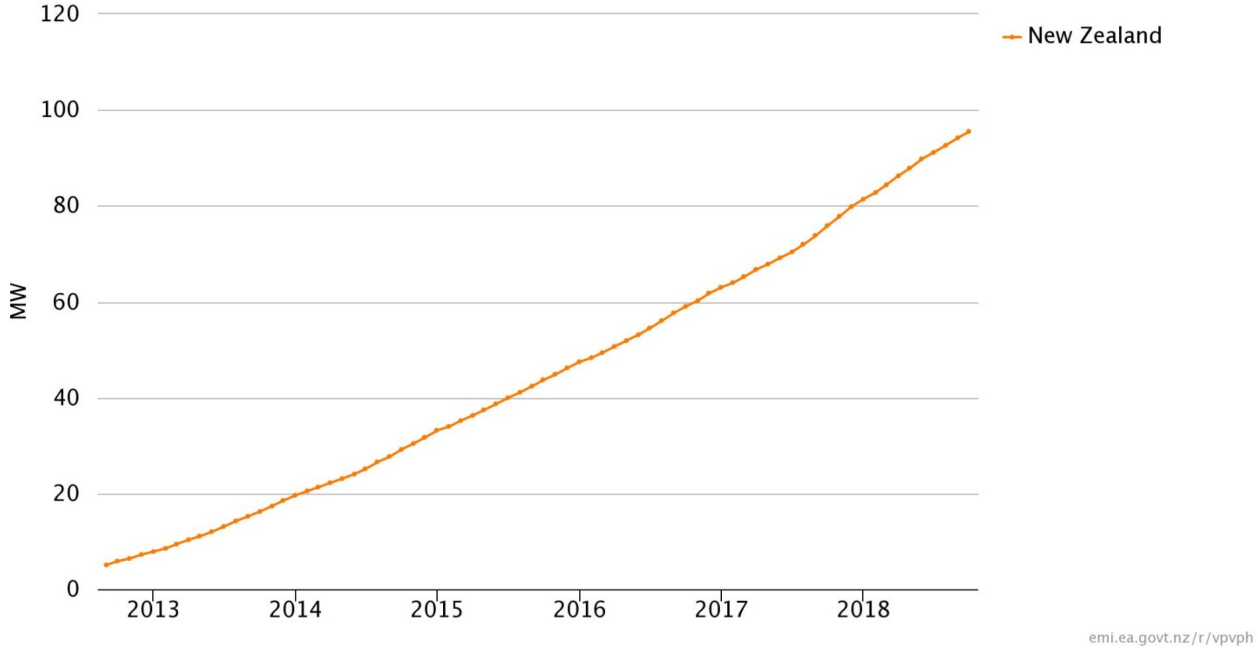
[1] Dr Miller is the director of Allan Miller Consulting Limited and an Adjunct Associate Professor of the Electric Power Engineering Centre (EPECentre) at University of Canterbury. Dr Miller has previously presented to the SRC (in October 2016) on reliability-related matters arising from the GREEN Grid Project (Link).

2.3 Dr Miller cites statistics about the penetration of distributed generation in New Zealand, as at 31 March 2019. As at 30 September 2019:

a) there are 25,417 connections with distributed generation (1.2% of all connections)

b) there is over 95.5 MW of small-scale distributed generation connected (Figure 1 below shows how this has grown over the last seven years).

Figure 1: Growth of small scale distributed generation 2012-19



3. Questions for the SRC to consider

3.1 The SRC may wish to consider the following questions.

Q1. What further information, if any, does the SRC wish to have provided to it by the secretariat?

Q2. What advice, if any, does the SRC wish to provide to the Authority?

Appendix A: Transpower (system operator) review and identification of lessons for New Zealand power system operations

INTERNATIONAL POWER SYSTEM EVENT REVIEW

Queensland and South Australia system separation on 25 August 2018

System operator review and identification of lessons for New Zealand power system operation

1. Purpose

The purpose of this paper is to inform the Security and Reliability Council of lessons for operation of the New Zealand power system following a review of a recent major power system event in Australia. Our review is part of ongoing activity in our role as system operator, where we actively engage with international peers to inform development of our own operating practices for managing high impact low probability events and impacts from new technologies.

This paper summarises the essential elements of the system operator's full review report which will be published on Transpower's website in early October.

2. Context and summary

On 25 August 2018, a major power system event separated the interconnected Australian National Electricity Market (NEM) into three independent operating islands. This event disconnected 997 MW of demand.

The NEM has a peak demand and total annual energy use approximately five times that of New Zealand. The interconnected system includes the transmission grids of all the eastern states (excludes Western Australia and the Northern Territory). Generation across the NEM is predominantly large coal-fired thermal stations, supplemented by significant rooftop solar, wind (in South Australia) and some hydro (Tasmania and New South Wales). The individual state grids are interconnected to each other by only one or two alternating current (AC) or direct current (DC) transmission links (refer to section 3 below).

The Australian Electricity Market Operator (AEMO) published *its review* of the event in January 2019. AEMO performs the functions of an independent system operator in dispatching generation and operating the market across the five state grids. The AEMO review explains the cause of and technical issues raised by the event.

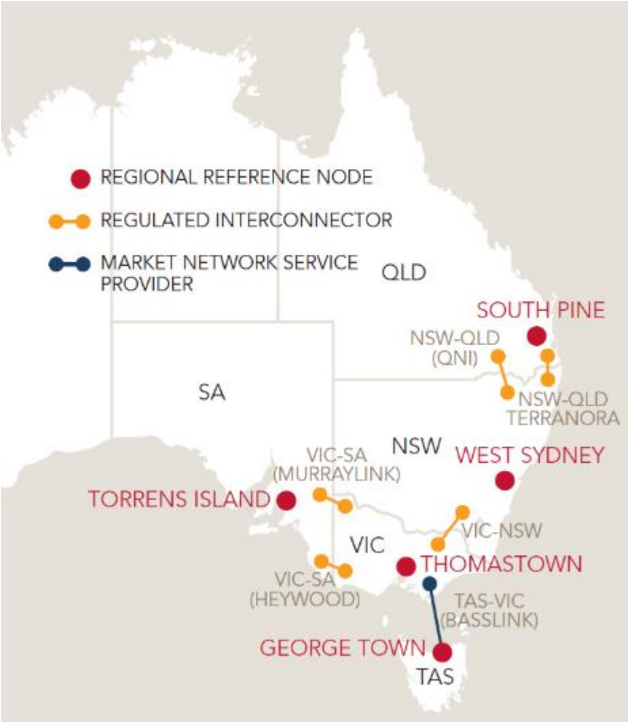
We were able gain further insights into the event and review process from an interview with a senior AEMO staff member involved in their review. In preparing their report on this major system event, AEMO were able to access high quality data for event analysis and used an independent panel to review and help finalise the report

Our review has considered both the event trigger and post-event response for the NEM separation event. Noting the similarities with the 2017 South Island AUFLS event, our view is that if a similar event were to occur here the impact on the New Zealand power system would not be as severe as occurred in Australia. This conclusion reflects the way New Zealand manages frequency, schedules reserves, our own awareness of system performance as system operator, along with the Electricity Industry Participation Code (Code) mandated requirements for generator governor response and the limited penetration of residential rooftop solar PV.

We assessed the relevant factors from the event for New Zealand against our risk framework to determine if critical controls are providing adequate risk mitigation. We have identified one control for grid owner provided special protection schemes (SPS) that should be updated, and an additional control to be added in relation to the provision of data from asset owners. Other relevant controls related to asset performance were assessed as adequate.

The balance of this paper describes the event and our observations; it also sets out the lessons and actions for New Zealand. The appendix to this report lists the eight AEMO recommendations and their applicability to New Zealand.

3. Australian National Electricity Market



Regional interconnectors:

a) Queensland-New South Wales AC interconnector (QNI)
   - *initially tripped due to lightning*

b) Victoria-South Australia AC interconnector (Heywood)
   - *tripped due to subsequent Emergency Alcoa Portland Tripping (EAPT) special protection scheme operating*

c) Queensland-New South Wales DC interconnector (Terranora)
   - *remained connected but provided no frequency support*

d) Victoria to New South Wales AC interconnector (VIC-NSW)
   - *remained connected*

e) Victoria-Tasmania DC interconnector (Basslink)
   - *remained connected and provided frequency support (similar to the New Zealand HVDC link)*

f) Victoria-South Australia DC interconnector (Murraylink)
   - *remained connected but provided no frequency support*

Post-event the NEM separated into the following three independent power systems after the loss of the QNI then the Heywood interconnector:

- South Australia
- Queensland
- New South Wales, Victoria and Tasmania

4. Event and commentary

Event triggers

On 25 August 2018, the QNI double circuit AC interconnector—between Queensland (QLD) and New South Wales (NSW)—was tripped by a single lighting strike to a tower causing a double back flashover of the insulators. This separated QLD from the rest of the NEM and was the initial trigger for the event. At the time, AEMO was not treating the loss of the double circuit QNI interconnector as a credible event[1].

The QNI tripping was followed six seconds later by the tripping of the AC Heywood interconnector between South Australia (SA) and Victoria (VIC). This separated SA from the remainder of the NEM, essentially NSW, VIC and Tasmania (TAS). This occurred when the EAPT scheme operated. This special protection scheme was triggered by power system oscillations and the power swing created when reserves, including those from the recently installed Hornsdale (Tesla) Power Reserve in SA, responded to the disconnection of QLD from the NEM.

[1] Like Transpower, AEMO manage for the loss of a single transmission circuit and can reclassify a non-credible event to credible under certain conditions such as the presence of lightning. Post-event, the loss of the double circuit QNI AC interconnector has been reclassified as a credible event.

The circumstances that produced the conditions to trigger the EAPT scheme (including system oscillations and rapid response from Hornsdale) had not been considered as part of the EAPT design. This failure resulted in this unexpected scheme operation.

The two interconnector tripping events separated the Australian NEM into three frequency islands[2] (being QLD, NSW/VIC/TAS and SA). Other interconnectors including the HVDC Basslink from VIC to TAS remained connected and performed as expected.

Post-event response

At the time of the event, generation was predominately synchronous - 95.5 per cent (coal, gas and hydro generation) - with only 4.5 per cent of total generation from wind and solar. System response was therefore not materially impacted by large scale penetration of asynchronous generation.

3 As the loss of the QNI interconnector had not been treated as a credible event, the NEM frequency reserve market did not consider the location of frequency reserve when dispatching reserves to manage and recover frequency across the NEM. This meant that after the system split into three islanded power systems; some islands had sufficient frequency reserves to aid recovery and others did not.

Problems managing frequency were further exacerbated by AEMO's energy dispatch system which assumed the NEM was still intact, thereby dispatching generation in a manner that created regional supply and demand imbalances that were difficult to manage until the power system was remodelled.

Post-event recovery was hindered by a lack of response from large thermal generators. Generating units were being operated at their maximum capacity, some above rated maximum continuous rating. This left little headroom to respond and support the system frequency in response to the event.

AEMO found that generating unit and overall system response had markedly changed since a similar event in 2008. System response did not match AEMO's generator response modelling, which was out of date. This change in response was identified to be in part due to new generator digital control technologies which restricted generator response to that for which generation companies were financially compensated in the frequency reserve market. From our discussions with AEMO we understand this behaviour change is a result of outcomes from Australian regulator rule breach determinations, where generators were penalised for moving off dispatch in response to changes in system conditions. In New Zealand, generators must automatically respond to major frequency deviations such as those from a major power system event.

In New Zealand, generators must automatically respond to major frequency deviations such as those from a major power system event. There is some limited evidence of reduced generator response due to governor technology updates here, but not to the scale seen in Australia due to our codified performance obligations (which are reviewed during routine testing and commissioning, and after major events).

The review identified several other issues:

- Some wind generation in the NEM did not support system recovery due to incorrect protection settings. These setting updates were made remotely by equipment manufacturers without the knowledge of the asset owner or AEMO.
- Many solar PV inverters did not respond correctly[3].

We have undertaken considerable work on wind generation settings in New Zealand with windfarm owners. The issue of solar PV inverters not conforming to the required standard is not impacting operations at present in New Zealand (solar PV is less than 1 per cent of total supply). However, if not addressed, this will over time result in significant added costs to future power system operation as solar PV generation increases.

This issue of enforcing inverter equipment to meet the appropriate standard needs to have a higher priority. As system operator we are working with the Authority to draw this issue to the attention of the Ministry of Business, Innovation and Employment (MBIE), who is responsible for overseeing these standards.

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[2] Note there were small HVDC interconnections still in place between SA-NSW/VIC/TAS and QLD-NSW/VIC/TAS, but unlike the New Zealand HVDC link these do not respond to or support frequency management.

[3] From sampled data, 15 per cent of pre-2016 inverters disconnected and for post-2016 inverters, 15 per cent of those in QLD and 30 per cent in SA inverters failed to reduce output as required by AS/NZS 4777.2 to support over-frequency management.

Other issues identified

1. Power System Stabilisers (PSS)

As system operator we have been relying on PSS to manage regional frequency oscillations from system events. PSS have been installed at selected generation stations (by generation companies). We have enabled these devices at selected power stations to increase power transfer out of three generation-rich regions (Otago, Taranaki, Waikato). Currently, there are no real-time indications of the status of enabled PSS and no requirements as to how enabled PSS are managed. Initiatives to confirm each these PSS is correctly managed and adding real time monitoring are being implemented.

2. System dynamic performance modelling and monitoring

As our power system environment continues to change we need to ensure that post-event dynamic system performance is effectively managed and we have the capability and expertise to identify new issues.

3. System performance data

AEMO's event analysis benefitted from availability of high resolution system performance data from various sources. Current rule requirements in New Zealand specify a **one** second resolution for compliance checking of reserve providers; this requirement is inadequate when initial system response to an event occurs typically within 0.1–0.2 of a second. As in New Zealand, provision of high resolution data in Australia is not a specific rule requirement. However, working in conjunction with Australian transmission network providers, AEMO has developed and implemented a NEM-wide high-speed monitoring system. This is an issue to be advanced with both the grid owner, other asset owners and ancillary service providers.

5. Lessons from our review

The significant matters identified in our review for New Zealand and our recommended actions as system operator are:

1. **SPS maintenance**: Work with the grid owner to review the existing grid and system operator processes for maintaining the ongoing performance of our 35 SPS and any future SPS, including impact of changing power system conditions and during non-credible events.
2. **Managing system dynamic performance**:
   - 2.1. Implement internal process changes and work with PSS asset owners to provide assurance of ongoing performance.
   - 2.2. Engage with asset owners and the Authority to identify any Code changes required for real-time indication of PSS status.
   - 2.3. Continue to build internal capability in power system dynamics and monitoring supported by access to external experts and contacts within the international system operator community.
3. **Solar PV inverter standards**:
   - 3.1. Continue to work with AEMO on the AS/NZS 4777.2 inverter standard on the performance requirements for solar PV.
   - 3.2. Engage with the Authority to identify the likely system costs of non-compliance with the standard and encourage MBIE to enforce inverter installations to comply with the current standard and future revisions.

The four further issues identified as system operator:

4. **Automatic topography**: Further investigate automating the mapping of grid configuration changes, to remove the need for manual intervention to enable accurate system redispatch after a separation event.
5. **Generator performance modelling**: Continue to update our generator modelling with the current performance information from generators, including reminding asset owners of their Code reporting obligations.
6. **Data provision and resolution**: Engage with asset owners, other post-event data providers and the Authority to determine improvements to the provision and resolution of post-event asset performance data for major event reporting.

7. **Major event reporting**: Consider the use of an independent panel of experts and a register of possible experts for future major event reviews.

Overall, the review of this recent major power system event in Australia, while not fully applicable in the New Zealand context, has provided a number of lessons and actions to aid system operation in New Zealand. The most valuable aspect of the review was the ability to engage directly with the AEMO senior staff member involved in the review. This provided further insights into the event and the AEMO report.

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APPENDIX – AEMO recommendations and actions for New Zealand

This is a summary of each of the eight AEMO recommendations, with comments on the applicability to the operation of the New Zealand power system.

AEMO Recommendation 1 – AEMO to establish both interim and permanent arrangements for additional primary frequency control.

NZ Response – Our mandated performance and frequency keeping arrangements address this issue. We will monitor frequency performance and ensure frequency response capability of generators is not eroded when new control technologies are deployed as part of the required commissioning and testing. Refer to action 5 in section 5.

AEMO Recommendation 2 – Automate the ability to provide secondary frequency control in a separated system after a separation event.

NZ Response – We have the ability to dispatch single frequency keepers to separated regions immediately after a separation event. In the 2017 South Island AUFLS event we were unable to quickly update the market model to enable correct dispatch for the separated regions. This is being addressed in an action from the 2017 South Island AUFLS event review to improve our ability to make real time changes to system topology in the market system. Refer to action 4 in section 5.

AEMO Recommendation 3 – AEMO to review the need for regional secondary frequency control.

NZ Response – This recommendation is not applicable to New Zealand. Instantaneous reserves requirements (secondary frequency control) can be modelled separately for the North and South Island if the HVDC link is not in operation.

AEMO Recommendation 4 – AEMO to improve its frequency response capability models

NZ Response – The nature of the New Zealand power system provides good feedback on post-event frequency capability of generators and any performance changes. The onus is on asset owners to advise the system operator of capability changes; however, we will continue to proactively remind generators of this obligation. Refer to action 5 in section 5.

AEMO Recommendation 5 – AEMO to work on the technical requirements for PV Invertor standard (AS/NZS 4777.2) and its modelling of invertor response.

NZ Response – We are working with AEMO on changes to the PV invertor standard. We are working with the Authority to engage MBIE to mandate compliance with the current standard. This is mindful of the future additional system costs from non-compliant PV invertors with increasing solar PV. Refer to action 3 in section 5.

AEMO Recommendation 6 – AEMO to review the performance of the EAPT Special Protection Scheme and other SPS schemes.

NZ Response – We are updating internal processes and working with the grid owner to ensure the performance of SPS schemes are reviewed to accommodate changes in power system response and configuration. Refer to action 1 in section 5.

AEMO Recommendation 7 – Emergency frequency control schemes.

NZ Response – This recommendation is not applicable to New Zealand.

AEMO Recommendation 8 – Generator over frequency disconnection settings.

NZ Response – This recommendation is noted; we have an over frequency ancillary service to manage the risk of generators tripping simultaneously in response to an over frequency event.

Appendix B: Outdated New Zealand Standards: Risks to Quality and Reliability of Supply, by Dr Allan Miller

Outdated New Zealand Standards: Risks to Quality and Reliability of Supply

Allan J.V. Miller

27 May 2019

Standards Background

The New Zealand Electrical (Safety) Regulations 2010 (ESRs) cite certain standards that must be met. This includes PV installation and inverter standards. For the vast majority of low voltage 400 Volt installations[1], the ESRs require compliance to AS 4777.1:2005, and by indirect reference (via the AS/NZS 3000:2007 standard) to AS 4777.2:2005 and AS 4777.3:2005. Yet the most recent and relevant standards, which have not been updated directly or indirectly in the ESRs, are:

- AS/NZS 4777.2:2015 Grid integration of energy systems via inverters, Part 2 Inverter Requirements (published 9 October 2015)
- AS/NZS 4777.1:2016 Grid integration of energy systems via inverters, Part 1 Installation Requirements (published 30 September 2016)
- AS/NZS 3000:2018 known as the Australian/New Zealand Wiring Rules (published 26 June 2018)

The new standards, particularly AS/NZS 4777.2, are important to New Zealand because they require voltage, frequency and other protection parameters specific to New Zealand – later sections elaborate on this. However, because the ESRs still cite the Australian only 2005 standard, it is not possible to require inverters in PV installations under the power thresholds mentioned in the footnote[1] to meet the newer, and New Zealand relevant standards.

Standards Australia consulted on these newer 4777 standards over several years (2013 to 2015), finally publishing the new standard for inverters in October 2015. Generally, the industry recognised the standards as well overdue for replacement, given that the existing standards at the time were published in 2005. It was recognised that inverter technology had changed considerably in the circa eight years between 2005 and Standards Australia's consultation for the new standard. The timing coincides with the boom in PV, led in particular by Germany, other European countries and Australia. The growth of PV accelerated around 2008 when the Chinese began manufacturing PV panels. 'Smart' or advanced controls were incorporated into inverter technology, enabling control of local voltage in networks (grid support), and better protection including ride-through of grid events such as under-voltage and frequency deviations.

[1] Specifically, those being below 34.5 kW balanced three-phase, or 18.4 kW single-phase power thresholds. This threshold encompasses all small-scale domestic rooftop systems which make up about 90% of the PV capacity, and many large-scale systems. Hence these are the majority of installations by number and total capacity.

Importance of the New Standard to System Grid Reliability, Local Supply Quality and Standardisation to Achieve These

Frequency Standards, Stability and Grid Reliability

During the Standards Australia consultation, the GREEN Grid project led the development of two submissions by the EEA to the draft AS/NZS 4777.2 standard's committee. In its submission, it asked that Standards Australia recognise in the new standard a lower disconnection frequency limit unique to New Zealand. This is lower than Australia's, largely due to the hydro dominated generation in New Zealand.

Standards Australia recognised the request and included the lower frequency, specifically for New Zealand, in the new standard released in October 2015.

The old standard that covered inverter protection requirements, AS 4777.3, gave a wide range of frequency settings, but did not give the exact frequency setting required for New Zealand. The new standard that covers inverter requirements including protection, gives the exact minimum system frequency above which inverters must remain connected to the grid. This is consistent with the requirements set out in Part 8 of the Electricity Industry Participation Code.

If New Zealand cannot install inverters to the new standard, there is ambiguity over the frequency setting to use, and a risk that inverters in New Zealand will trip-off at a higher frequency than required to maintain generation during a grid emergency. For example, in an under-frequency grid emergency involving the loss of generation, when AUFLS blocks are tripping to help stabilise system frequency, PV generation may be lost. Consequently, there may be a further loss of generation which could exacerbate the grid frequency decline. As more PV is installed in New Zealand, changing the dynamics of the power system, this becomes an even more serious issue; a large loss of generation may occur during an 'under frequency' event, depending on the time (and solar conditions) at which the event occurs.

The new standard also lowers the under-voltage limit at which inverters will disconnect. This will also allow inverters to better 'ride-through' such loss of generation disturbances described above. Similarly, over-frequency limits for inverters have been improved in the new standard.

Voltage Standards and Local Supply Quality

In the EEA's submissions, the GREEN Grid project also asked that the new standard include grid support voltage levels relevant to New Zealand. These particularly relate to 'power quality response modes', which are new and advanced inverter features described only in the new standard. They are designed to limit degradation in supply quality within distribution networks – specifically voltage level.

If New Zealand cannot install inverters to the new standard, management of voltage within distribution networks becomes more of a challenge with higher levels of PV. Conversely, installing inverters to the new standard will allow greater levels of PV while maintaining local supply voltage within the limits given in the ESRs. GREEN Grid research has shown this to be the case.

The situation at present is that the voltage levels specified in the currently cited standard relating to protection (AS 4777.3:2005) are within a wide range and are not actually consistent with the ESRs. This leads to ambiguity when specifying and setting the voltage levels in PV systems by distributors and installers. Moreover, the old standard does not include the advanced inverter features as discussed above.

Standardisation

The EEA has developed, through the GREEN Grid project and with industry, a best practice guide for the installation of PV systems which was finalised in 2017. This provides electricity distributors with clear guidance on what to require of PV inverter systems. However, the 2017 guide is built around the parameters and advanced inverter controls described in AS/NZS4777.2:2015. Until this standard is cited by the ESRs, the guide cannot be made final and standardisation of inverter settings for PV across New Zealand is unlikely to occur. Over time this could lead to different approaches by distributors because they are unable to use or refer to the guide. Quite apart from the risk of different approaches being taken, I am concerned that this will lead to confusion over the correct settings for inverters, and the reliability and quality issues already described. The issue is becoming more pressing as the installed capacity of PV increases.

PV Uptake

The table below gives statistics on the uptake of PV in New Zealand (drawn from data available from the Electricity Authority's EMI website), starting from the month the new inverter requirements standard was published.

PV System	Number of ICPs			Capacity Installed (MW)		
	31 October 2015	31 March 2019	Average Annual Increase	31 October 2015	31 March 2019	Average Annual Increase
Small-scale (≤10kW)	8,422	22,670	4,170	30	82	15
Large-scale (>10kW)	104	387	83	4	12	2
Total	8,526	23,057	4,253	34	94	18

As shown in this table, there is already a reasonably large amount of PV generation installed in New Zealand; 94 MW equates to a reasonably sized generator. As more is installed, the potential reliability and supply quality issues outlined earlier become more significant. About 90% of PV installations by capacity are small-scale domestic rooftop, and because their power ratings are below those outlined earlier, they must comply with the old standards cited by the ESRs. The number of large-scale commercial installations is growing as PV costs continue to reduce, and as outlined earlier, a number of these must also comply with the old standards cited by the ESRs. It is therefore probable that this issue relates to well over 90% of the capacity of PV installed to date, and will continue to relate to PV installed in the future until the most recent standards are cited by the ESRs.

Timing of Incorporation of the new Standard into Legislation

I have approached WorkSafe to ask when the new standard will be cited, and been told that they are currently scoping this and will have a better idea of the work required later this year. While I can understand that WorkSafe have a lot of work to do to update the ERSs, this is a very frustrating situation, especially given that the new inverter standard was first published more than 3 years ago, and the new 'wiring rules' standard was published almost a year ago. Furthermore, with the pace of change of technology, we can expect new or revised standards to become available regularly. Examples of emerging technologies that may be introduced into new or existing standards include electric vehicle charging, demand response, vehicle-to-grid standards, and the need for updated power quality standards such as harmonic standards. For this reason, and that these technologies may impact supply quality and reliability, it would be desirable to see prompt adoption of standards into legislation; or ability of the industry to use the new standards by automatic referral in the ESRs to the most current published version of any standard it cites.

Suggested Interim Measure

I believe that updating the ESRs to the most recent standards is of the utmost importance to removing the, at best, ambiguities described above, and at worst, avoiding proliferation of grid emergencies and local supply quality issues. In the interim I recommend that all distributors refer to the voltage, frequency, and inverter power quality response settings required in AS/NZS 4777.2:2015.

Relevant Experience and Background

I have assisted a number of clients with matters related to PV and dealt with the standards. This includes:

(1) Writing electricity distributor Connection and Operation Standards and Distributed Generation Information Packs for electricity distributors. In doing so it has been necessary to deal with the challenge created for distributors of not being able to refer to the new standard;

(2) Assessing the impact of small-scale PV on quality of supply, and how this might be improved using inverters compliant with the new standard; and

(3) Assessing the connection of large-scale and very large-scale PV to distribution networks, the quality of supply challenges from this, and how it can be improved using inverters compliant with the new standard,

My background is also directly relevant:

- I established and was and Principal Investigator of the GREEN Grid research programme from 2012 to 2017, funded by MBIE, Transpower, and the EEA. This research programme investigated integration of more variable renewable sources, such as PV and wind into the New Zealand grid.

- I led and contributed to two cross-industry submissions to Standards Australia when they consulted on AS/NZS 4777.2 (the inverter requirements), as well as a submission on the AS/NZS 4777.1 (installation) standard.

- I led the development of the now draft EEA Guide for the Connection of Small-Scale Inverter-Based Distributed Generation referred to earlier, which is awaiting the new standard to be cited before it can be finalised.

- I drafted requests for changes to the Electricity Industry Participation Code to enable the operation of the above Guide and, in combination with the above Guide, to allocate and maximise the potential for PV in local (low voltage) distribution networks. This involves introducing the concept of 'hosting capacity' of a distribution network to host PV.