Integrating hosting capacity into Part 6 of the Code on low voltage networks

Issues paper to develop a proposal for future Code amendment

Submissions close: 5pm, 13 November 2018

4 September 2018

Market Services

Executive summary

Many household consumers are becoming interested in installing small generation units in or on their homes, such as solar panels and battery systems. These assets are called small-scale distributed generation (SSDG) because they're small and they can be distributed across the electricity system.

Although New Zealand currently has very low levels of SSDG, other countries such as Australia have very high levels of SSDG and have experienced technical network problems associated with connecting more SSDG. The problems are usually associated with high voltage, overloads of some network equipment, and the management of grid-level frequency.

Traditionally, low voltage network design has assumed that electricity flows predominantly in one direction only ie, from the transmission grid through the local network to consumers' premises. It has not been necessary to remotely monitor, or actively control, the local voltage or loading levels on low voltage networks. As a result, high levels of SSDG can put pressure on distributors' low voltage networks if generation from the SSDG system exceeds household requirements and the excess flows into the local network.

Although SSDGs can cause network problems they can also provide services useful for managing local and national power quality. However, markets for such services have not yet developed, and may not develop for quite some time. In general, current distribution pricing does not provide efficient price signals that could incentivise investors to connect SSDG (and other) systems with the capability to improve power quality and mitigate network congestion. And even with more efficient distribution pricing, there could be significant transaction costs due to the number of potential market players.

For these reasons it makes sense in the interim to investigate a standards-based approach to managing power quality and congestion problems in this issues paper. The Authority is cognisant of the general pitfalls with mandated approaches. However, we consider that risks can be mitigated so long as any standards-based approach is structured in a way that doesn't inhibit or foreclose market-based approaches developing in the future.

New Zealand distributors have studied the technical network problems and have developed a proposal they consider would address power quality and congestion issues before they become big problems. Coordinated through the Electricity Engineers' Association (EEA), distributors have requested that the Authority amend Part 6 of the Code to add requirements for applicants looking to connect SSDG (ie, distributed generation not exceeding 10 kW in capacity), which uses an electrical interface device known as an 'inverter'.

Rather than simply consulting on the EEA's proposal, the Authority's preferred approach is to have a broader examination of this topic. This paper presents three options to address the problems:

- Option A: do nothing or, at least, wait until the issues become clearer and the options more clearly defined.
- Option B: amend Part 6 of the Code to:
    - adopt the latest inverter standards and make use of some of their new optional features
    - provide clarity and consistency around distributors' standards for connection and operation, and policies for managing congestion.

- Option C: significantly change how we regulate the process for applications to connect SSDG, by comprehensively rewriting Part 6 of the Code.

Our preliminary view is that option B may provide the greatest net benefits as it likely to have low, or no regrets. This is because SSDG systems that include the capability to improve power quality and mitigate local network congestion may already be available at no, or very low, incremental cost compared with systems that don’t have these capabilities.

The paper also briefly introduces further potential issues that might arise from emerging technologies associated with household batteries and in-home electric vehicle charging.

We would value receiving comments from a wide range of interested parties, before we decide our next steps.

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1 What you need to know to make a submission

What this issues paper is about

1.1 Part 6 of the Electricity Industry Participation Code 2010 (Code) regulates how distributed generation connects to a local network.

1.2 The Authority has been asked by the Electricity Engineers' Association (EEA) to amend Part 6 of the Code—specifically, Part 1A of schedule 6.1, which deals with how small-scale distributed generation (SSDG) connects to a local network.

1.3 Before making a decision on the EEA's request, we would like to hear the views of a wider range of interested parties on the implications of connecting more SSDG to low voltage networks.

How to make a submission

1.4 The Authority's preference is to receive submissions in electronic format (Microsoft Word) in the format shown in Appendix A. Submissions in electronic form should be emailed to submissions@ea.govt.nz with "Issues Paper—Integrating hosting capacity into Part 6 of the Code on low voltage networks" in the subject line.

1.5 If you cannot send your submission electronically, post one hard copy to either of the addresses below, or fax it to 04 460 8879.

<u>Postal address</u>	<u>Physical address</u>
Submissions Electricity Authority PO Box 10041 Wellington 6143	Submissions Electricity Authority Level 7, ASB Bank Tower 2 Hunter Street Wellington

1.6 Please note the Authority wants to publish all submissions it receives. If you consider that we should not publish any part of your submission, please

(a) Indicate which part should not be published

(b) Explain why you consider we should not publish that part

(c) Provide a version of your submission that we can publish (if we agree not to publish your full submission).

1.7 If you indicate there is part of your submission that should not be published, we will discuss with you before deciding whether to not publish that part of your submission.

1.8 However, please note that all submissions we receive, including any parts that we do not publish, can be requested under the Official Information Act 1982. This means we would be required to release material that we did not publish unless good reason existed under the Official Information Act to withhold it. We would normally consult with you before releasing any material that you said should not be published.

When to make a submission

1.9 Please deliver your submissions by **5pm** on Tuesday **13 November 2018**.

1.10 The Authority will acknowledge receipt of all submissions electronically. Please contact the Submissions' Administrator if you do not receive electronic acknowledgement of your submission within two business days.

2 Introduction and background

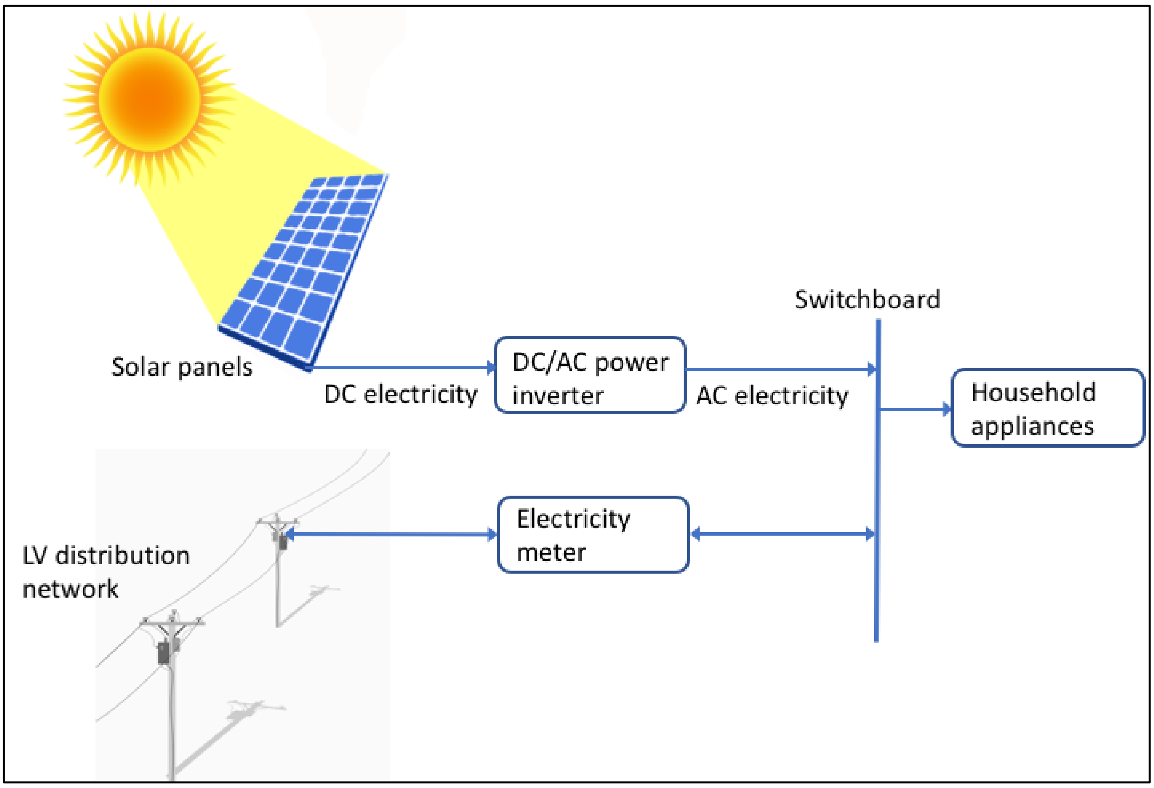
Part 6 provides for connection of distributed generation

2.1 Distributed generation is generation connected directly or indirectly to a distributor's local network.[1] Part 6 of the Code regulates how distributed generation connects to a local network.[2]

2.2 Distributed generation includes small-scale systems such as solar photovoltaic modules (solar PV), small wind turbines, and micro-hydro schemes. Small-scale systems have capacities up to 10 kilowatts (kW). These small-scale systems typically provide electricity sources for businesses, homes or farms. Larger distributed generation schemes may have capacities up to several tens of megawatts (MW).

2.3 Figure 1 shows the main components of a residential small-scale solar PV installation. The generation from the solar panels connects through a DC/AC power inverter (inverter) to the consumer's switchboard and directly supplies household appliances. Any instantaneous power imbalance (either over or under) between the generation output and the household appliance demands flows through the electricity meter to or from the local network.

Figure 1 - Main components of a small-scale solar PV installation



1 The relevant definitions are contained in Part 1 of the Code, available at https://www.ea.govt.nz/code-and-compliance/the-code/

2 Part 6 is available at https://www.ea.govt.nz/code-and-compliance/the-code/

2.4 Increasingly, distributed generation systems incorporate storage batteries, which act as flexible in-home energy storage and provide a controllable energy source.[3] A battery integrated with a solar PV installation provides, within its capacity limit, a local energy 'buffer' that can time-shift when the solar-sourced energy is released from the small-scale distributed generation (SSDG) system.

2.5 This paper does not discuss stand-alone, off-grid systems that may supply an isolated load; these systems do not connect to a local network and are designed to meet very specific consumer needs for electricity supply.

2.6 Part 6 applies if a distributed generator wishes to connect distributed generation to a local network, whether on the regulated terms included in Schedule 6.2, or on other terms negotiated between the distributed generator and the distributor.

2.7 Part 6 also applies to owners of DG already connected to a local network, or to a consumer installation that is connected to a local network, if the distributed generator wishes to:

(a) continue an existing connection of distributed generation where there is, or was, a connection contract

(b) continue an existing connection of distributed generation that is connected without a connection contract if the regulated terms do not apply; or

(c) change the nameplate capacity or fuel type of connected distributed generation, for example, to increase the capacity of an existing distributed generation scheme.[4]

Distributors are responsible for low voltage network power quality and safety

2.8 Part 6 reflects that distributors are best placed to understand and manage local technical electricity supply issues and set technical standards governing what distributed generation can be connected to their networks. These standards are called *connection and operation standards* and the Code requires that each distributor publishes them.[5] Connection and operation standards must include the distributor's congestion management policy, which must set out the distributor's policies related to curtailing or interrupting distributed generation output if network congestion occurs.[6]

2.9 Congestion occurs when a part of the network has reached its design capacity. Designers determine network capacity with the safety of people and equipment as primary objectives. Capacity is measured in terms of voltage and current:

(a) voltage must operate within a defined band, eg, 230 V ± 6%

(b) current has a defined maximum limit, eg, 100 amps.

2.10 In general, connection and operation standards must reflect good industry practice but it is not always clear what this is, particularly in respect of new circumstances and emerging network-connected technologies. Since the 23 February 2015 Code

3 Figure 1 does not include a storage battery, but one could be connected to the DC side of the power inverter, or connected to the switchboard through its own inverter.

4 See clause 6.4(1)

5 Clause 6.3(2)(b)

6 Clause 6.3(2)(d)

amendment, the Authority's compliance team has dealt with cases requiring it to interpret what a distributor may include in its connection and operation standards.

2.11 Appendix B provides further background relevant to Part 6 and covers:

(a) that Part 6 was originally the former Distributed Generation Regulations

(b) the Authority's review of Part 6 in 2011-14

(c) the streamlined connection application process for inverter-connected SSDG compliant with standards that was introduced in 2014 as Part 1A

(d) recent updates to the AS/NZS 4777 standards suite, which applies to inverter-connected distributed generation.

There are other workstreams dealing with new technologies

2.12 Technologies such as solar PV panels, batteries and electric vehicles allow consumers to produce and store their own electricity. Smart controls for equipment and appliances, such as 'smart' hot water cylinders, allow consumers to more easily control when and how they use electricity. As well as buying electricity, consumers may increasingly be able to participate in the market as sellers of electricity and related services.

2.13 New and existing suppliers are competing to win customers by offering innovative products and services that reflect consumer preferences. Some of these innovative products include the technologies discussed in this paper.

2.14 However, low voltage networks have capacity limits, which may inhibit what can be safely connected while maintaining local power quality. This may limit consumers' access to future services available through the network.

2.15 The Authority has other relevant workstreams addressing these broader questions related to access to services via the network. This paper acknowledges these broader issues but focuses on connection technical issues relevant to Part 6 of the Code.

3 This paper discusses three main problems

The technical problems we discuss in this paper relate to historic practices

3.1 Since the inception of network-supplied electricity, electricity distributors have designed local networks to transport electricity from remote, large-scale generation plants to individual consumers. Electricity networks typically have a high voltage transmission grid that supplies successively lower-voltage local networks. Power flow is generally from grid-connected generation plants, across the transmission grid (eg, at 220 kV) to sub-transmission (eg, at 33 kV) to radial distribution (eg, at 11 kV) and finally to low voltage networks (ie, 400/230 V).

3.2 Distribution engineers have designed local networks, particularly at the 11 kV distribution feeder and 400/230 V low voltage feeder levels, to transport energy in one direction, from 'upstream' generators to 'downstream' consumers. High levels of distributed generation using local renewable energy resources (eg, solar PV using residential roof-mounted panels) fed directly into local networks challenge these design assumptions.

3.3 Additionally, distributors do not usually monitor low voltage network power quality in real time—distributors monitor and control their sub-transmission and distribution voltage networks only. Traditionally, the benefits of monitoring low voltage networks have not justified the costs. The accepted approach to addressing local low voltage network issues is to investigate consumer complaints related to power quality issues and supply interruptions as and when they occur.

3.4 Distributors are responsible for maintaining power quality at consumer points of connection to their low voltage networks. In New Zealand, the statutory voltage and frequency limits are stated in the Electricity (Safety) Regulations 2010, as follows:

(a) in s.28, low voltage must be maintained equal to 230 volts (V) ± 6%

(b) in s.29, frequency must be maintained equal to 50 hertz (Hz) ± 1.5%, except for momentary fluctuations.

3.5 In simple terms, SSDG connected to low voltage networks can cause power quality problems related to electrical voltage (measured in volts), current (amperes or amps) and frequency (Hertz or cycles per second). These technical problems are explained in the following paragraphs.

High levels of SSDG can lead to sustained high voltages

3.6 High levels of SSDG connected to a low voltage network, or spread across a number of low voltage networks supplied through step-down transformers by a single distribution voltage feeder, can cause problems associated with sustained high voltages.[7]

3.7 Other voltage-related problems can occur, such as voltage flicker and short duration voltage spikes, but these are not specifically associated with high levels of SSDG.

3.8 Power quality thresholds relating to waveform harmonic distortion are also relevant.[8] The standard NZECP 36:1993 defines the total harmonic distortion permitted at any point on a local network.[9]

3.9 While harmonic issues can arise from the electronic components incorporated into inverters that do not comply with standards, the main voltage-related problem relevant to increasing amounts of SSDG connected to low voltage networks is sustained high voltage (and, in some circumstances, sustained low voltage[10]).

3.10 Low voltage network problems occur now, and international experience shows that, without mitigations, more SSDG will exacerbate the problems. For example, consider the following daily load profile scenario for a residence that has a network-connected solar PV system installed on the roof:

(a) Outside of daylight hours, there is high consumer load (eg, winter evening mealtime) and no SSDG output. This leads to periods of high export from the

7 In general, generation tends to push local voltage higher; consumption tends to pull local voltage lower.

8 Harmonics are AC waveform components comprised of frequency multiples of 50 Hz superimposed on the primary 50 Hz voltage waveform. For example, the 3rd harmonic of 50 Hz is 150 Hz. Harmonic issues, which are generally complex and can be difficult to diagnose, are related to voltage and current waveform distortions that can cause appliance malfunctions.

9 NZECP 36:1993 is available as a PDF download at http://worksafe.govt.nz/dmsdocument/1562-new-zealand-electrical-code-of-practice-for-harmonic-levels-nzecp-36-1993

10 Important note: Sustained low voltages may become an issue if/when battery charging is introduced into the equation. For example, there is anecdotal evidence of increasing levels of SSDG solar PV systems that incorporate a battery in their system design. Further, in-home rapid (ie high load capacity) charging of electric vehicle batteries will likely track increasing EV sales. The load capacity, timing and location of EV battery charging is a more complex issue that this paper simply notes, so as to retain the current focus on the issues associated with inverter-connected SSDG systems.

network into a consumer's premises, which 'appears' to the network as a normal consumer load.

This may give rise to excessively low network voltages if the distributor has reduced the distribution voltage to cater for over-voltage conditions that may be caused by high levels of SSDG connected to the low voltage network. Adding further peak load such as in-home electric vehicle chargers that charge at this time will likely exacerbate this problem.

(b) Across the daylight hours between the traditional morning and evening peak consumption periods, there is low consumer load and high SSDG output. Depending on the installed SSDG capacity and the instantaneous SSDG output and consumer load, this can lead to high levels of power import from the consumer premises voltages into the low voltage network.

In turn, this may give rise to excessively high local voltage and, where there is a high level of SSDG connected to the same low voltage network and sunny conditions, can cause local network overloads from reverse power flows back through the distribution transformer and into the high voltage distribution feeder.

3.11 Distribution engineers do not normally provide low voltage networks with the capability to locally regulate their voltage. In local networks, active voltage regulation is usually provided at the higher voltage levels in the network.[11]

3.12 The new problem (high SSDG levels) is that the traditional distribution feeder target voltage range may no longer be adequate to maintain supply on connected low voltage networks within the statutory voltage limit of 230 V ± 6% at all times.[12]

Incorrect inverter protection settings can affect the ability to ride through faults

3.13 Standard AS/NZS 4777.2:2015 defines operating bands for voltage and frequency. If the AC voltage or frequency falls outside of the set bands for a set period of time, the inverter's protection circuitry will electrically disconnect the inverter from the consumer's installation.

3.14 The standard prescribes maximum and minimum operating voltage settings with the objective of maintaining the local low voltage network voltage within the statutory limits. In general, an actively generating network-connected SSDG system:

(a) helps to improve a local low voltage condition; accordingly, the minimum voltage protection limit is set at a relatively low level

(b) may exacerbate a local high voltage condition; accordingly, the maximum voltage protection limit is set at a level to prevent a sustained, potentially dangerous overvoltage.

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11 They do this using automatic on-load tap changers fitted to the zone substation transformers that reduce (sub) transmission voltages (eg, 110, 66 or 33 kV) to distribution voltages (eg, 22, 11 or 6.6 kV). Tap changers regulate the downstream distribution voltage by changing the transformation ratio between the two voltages in several small steps. This has the effect of automatically and continuously boosting or dropping the distribution voltage as loading conditions require, so as to keep the distribution voltage operating within a target range.

12 Note that Australia operates a slightly different voltage range than New Zealand which can be up to 240 ± 10%, although this can vary between States. 240 V + 10% is 264 V, which is significantly higher than New Zealand's 243.8 V upper voltage threshold.

3.15 While voltage is more a local network management issue, system frequency in an AC network is a grid-level management issue. For frequency, the inverter standard prescribes maximum and minimum operating frequency settings with the objective of supporting the grid frequency to remain within the statutory limits. In general, an actively generating network-connected SSDG system:

(a) helps to improve a low frequency condition; accordingly, the minimum frequency protection limit is set to disconnect the inverter at a relatively low frequency (at which level grid-coordinated automatic frequency management actions, such as interruptible load and automatic under-frequency load shedding will have been triggered to avoid a total system collapse)

(b) may exacerbate a high grid frequency condition; accordingly, the maximum frequency protection limit is set at a level to remove the generation output for sustained high frequency.

3.16 Transpower, as the system operator, is concerned that distributed generation inverters are tested and conform to the latest standards so as to maximise their ability to 'ride-through' system low voltage and low frequency disturbances. This requires nationally-consistent voltage and frequency protection settings.

3.17 Of course, with installed capacities typically under 4 kW (ie, 0.004 MW), individual SSDG systems have a relatively small impact on network voltage and grid frequency. However, at an anticipated future level of SSDG within low voltage networks—and collectively across the whole grid—individual SSDG system capacities will aggregate to act as a very large 'virtual generator'. If this happens, individual inverter capabilities and protection settings will significantly affect the power quality and supply reliability enjoyed by all consumers.

Concentrations of solar PV may lead to network congestion

3.18 Operating as a traditional local network supplying 'downstream' consumers, low voltage networks are designed with enough capacity to supply anticipated consumer peak demands based on assessed aggregate feeder loads. Very high levels of daytime generation from SSDG systems coinciding with very low local consumption can reverse the power flow direction in low voltage networks.

3.19 At extreme levels of aggregated installed SSDG capacity, import into low voltage networks of generation in excess of local consumer demand—eg, during sunny weekdays—can overload low voltage network equipment.

3.20 At a current aggregate installed capacity of just 70 MW of solar PV across some 17,800 ICPs nationwide,[13] up from 53 MW a year earlier, New Zealand's SSDG solar PV industry is still at a relatively immature stage. Accordingly, we have not yet experienced some of the technical network problems already encountered in Australia and some other countries. But New Zealand is well placed to learn from international experience and take prudent, timely steps to prevent or manage problems.

3.21 Compounding this issue, we have anecdotal evidence that increasing numbers of small-scale solar PV systems now incorporate a storage battery in their design. Properly controlled to charge and discharge at network-optimal times, the local storage provided by an in-home battery integrated into a solar PV installation would serve to offset peak

13 From the Energy News article *Solar inverters must meet standards, 29 March 2018* citing Electricity Authority EMI data. This equates to an average installed capacity of 3.9 kW per solar PV system.

network import, alleviating ‘reverse-flow’ network congestion. This indicates that significant uncertainty remains over whether, or the extent to which, problems will occur.

Q1. Have we adequately outlined the issues with increasing levels of SSDG, particularly inverter-connected solar PV systems?

Q2. What other factors are relevant to these technical network considerations?

4 There are a range of options to address future problems

Markets will take time to develop

4.1 An SSDG system is a small but active local generator that can, when aggregated with many other such generators through a low voltage local network, have a relatively large effect. Designed with suitable capabilities, a SSDG system can also provide services useful for improving local and national power quality and for mitigating local network congestion.

4.2 However, markets for such services have not yet developed, and may not develop for quite some time. In general, current distribution pricing does not provide efficient price signals that could incentivise investors to connect SSDG (and other) systems that have the capability to improve power quality and mitigate network congestion. And even with more efficient distribution pricing, there could be significant transaction costs due to the number of potential market players.

4.3 For these reasons this issues paper investigates a standards-based approach to managing power quality and congestion problems. A standards-based approach appears to be fit for purpose because SSDG systems that include the capability to improve power quality and mitigate local network congestion may already be available at no, or very low, incremental cost compared with systems that don’t have these capabilities.

4.4 The Authority is cognisant of the general pitfalls with mandated approaches. We consider that risks can be mitigated so long as any standards-based approach is structured in a way that doesn’t inhibit or foreclose market-based approaches developing in the future.

Transpower and distributors have studied potential technical issues

4.5 Transpower—in its role as the system operator—seeks to anticipate and manage grid stability issues, particularly grid frequency and regional grid voltage. For their part, local distributors are more concerned with local power quality, including voltage management, and network capacity issues.

4.6 Transpower has recently published the results of a study about the grid-level challenges that very large aggregated capacities of solar PV may have in New Zealand.[14] The study found that the core transmission grid could comfortably accommodate 2 GW (ie, 2,000

14 *Solar Power in New Zealand*, available in PDF format at https://www.transpower.co.nz/sites/default/files/plain-page/attachments/Solar%20PV%20in%20New%20Zealand.pdf

MW) of solar PV generation. To put this amount in context, the current grid exit point peak demand on the New Zealand grid is around 6,400 MW and the current level of installed solar PV capacity is 70 MW.

4.7 However, Transpower raised concerns about the need to ensure that inverters should be fully compliant with standards, to ensure that solar PV systems successfully 'ride-through' power system voltage and frequency disturbances that occur from time to time. Disturbances triggered by the sudden loss of large amounts of generation capacity, or the tripping of both poles of the HVDC link at high levels of inter-island power transfer, will cause near-instantaneous drops in frequency and voltage.

4.8 For their part, distributors have studied the technical issues associated with power quality and potential network overloading (congestion) anticipated from increasing levels of SSDG. While Transpower's grid interfaces with its customers' generation plants and local networks are at grid injection and exit points, distributors are uniquely situated at points of connection with more than 2 million consumers and distributed generators. The vast majority of customer points of connection are serviced by distributors' low voltage networks.

4.9 We will describe a particular distributor-led initiative to improve low voltage network performance in areas of high SSDG in section 5.

We consider it prudent to consider a range of options

4.10 While there appears to be no current systemic technical problem or, arguably, even a problem looming in the relatively near future, reflection on international experience in some countries demonstrates that problems can arise quite quickly.

4.11 Government policies that aim to rapidly reduce carbon emissions, including increasing the proportion of electricity generated from renewable energy resources and powering increasing electric vehicle fleets, can affect traditional assumptions about how electricity networks operate and about what services those networks provide to their connected customers. Policy settings, including rapid reversals in policy direction, can significantly impacts global markets.[15]

4.12 In respect of the observed (relatively low) and anticipated (possibly high or, at least, higher) levels of SSDG systems, options could include:

(a) Option A: do nothing or, at least, wait until the issues become clearer and the options more clearly defined.

(b) Option B: amend Part 6 of the Code to:

(i) adopt the latest inverter standards and make use of some of their new optional features

(ii) provide clarity and consistency around distributors' standards for connection and operation, and policies for managing congestion.

(c) Option C: significantly change how we regulate the process for applications to connect SSDG, by comprehensively rewriting Part 6 of the Code.

4.13 Before looking further into these options, it may be useful to briefly outline why you would prefer one of these options over the others:

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15 See, for example, news of the recent sudden policy reversal regarding solar PV subsidies in China, at https://nz.finance.yahoo.com/news/china-just-dealt-massive-blow-131900214.html

(a) You may prefer option A if you believe that the issues outlined in this paper are overstated or that they might only arise so far into the future that there would be time to assess the situation and respond. In short, you believe the anticipated costs of any short-term remediation provisions would exceed the benefits.

(b) You may prefer option B if you believe that the existing regulatory provisions are not as efficient as they could be at this time and that there is a net benefit in moving to clarify and coordinate nationally-consistent:

  (i) minimum equipment standards specific to inverters procured for use in SSDG systems

  (ii) protection and operation settings

  (iii) policies that better manage network congestion, where it is anticipated that such congestion is likely to occur.

  You might also prefer option B if you consider that the causers of any problems relating to high levels of in-home generation being imported into low voltage networks should be required to minimise and ideally eliminate those problems.

(c) You may prefer option C if you believe there is a different, superior approach to the current process for applying to connect under Part 6.

Q3. Do you agree these options broadly represent the range of actions we could consider at this time? Are there other broad conceptual options we should consider that are not covered by these three approaches?

Our high-level preliminary view is that option B may provide the greatest net benefits

Option A is the easiest to pursue now but may miss early opportunities to improve efficiency

4.14 Doing nothing now beyond analysing and discussing observed trends and checking in with stakeholders to canvass alternative views is a valid approach.

4.15 Small-scale, network-connected solar PV in New Zealand is certainly at a low level, as New Zealand has not adopted policies that would incentivise widespread investment in such technology. While many ‘early-adopting’ householders have seen value in investing in a solar PV system for their home, the vast majority have not. The current trend appears to be of a steadily increasing rate of investment in SSDG solar PV systems off a very low base.

4.16 In respect of industry initiatives, we have noted the significant studies undertaken by Transpower and distributors and we consider it prudent at this time to consider the conclusions of their work and their advice. This is a good time to discuss and seek feedback on the current regulatory provisions governing connection of SSDG to low voltage networks.

Option C is theoretically feasible but requires specific proposals

4.17 At this stage, we are open to ideas that might address the problems identified and that best meet the Authority’s statutory objective.

4.18 That said, we currently consider the better approach is to look in more detail at developed options based on local experience, including incorporating lessons available from relevant international experience.

Option B would target low/no regrets initiatives

4.19 This option includes considering the request received from the Electricity Engineers' Association (EEA) on behalf of distributors—and including input from Transpower—to consider a proposal that appears to provide supply reliability benefits.

4.20 The EEA proposal may address, or at least defer or mitigate, anticipated technical problems with low voltage networks, and is based on a well-developed body of research.

4.21 The EEA proposal seeks to make the best use of existing network infrastructure and, to the extent possible, to future-proof network use. The next section describes the proposal, which, if adopted, would require amendments to aspects of Part 6 of the Code, in particular to the Part 1A process for applying to connect.

4.22 It is important to note that in presenting this proposal in some detail, we have yet to form firm conclusions. We are particularly interested in ideas about alternative approaches from businesses and industry associations that provide services to SSDG investors, and from current and potential investors in those technologies.

Q4. Do you think the Authority should pursue the types of measures that Option B would require? If not, please outline your alternative preferred approach, including if possible the costs and benefits. If you consider there is a valid Option C-style alternative, please provide details, including your view on how your alternative would meet the Authority's statutory objective.

5 The EEA has asked the Authority to consider specific amendments to Part 6

5.1 As previously outlined, at a technical level, despite increasing pressures, low voltage networks must continue to operate:

(a) reliably, avoiding unnecessary interruptions

(b) safely, keeping within equipment ratings

(c) while delivering electricity to consumers within statutory power quality thresholds.

5.2 This is important as local networks will increasingly act as the 'physical host' to a range of competitive technology-driven 'hosting services', for example, demand response and other ancillary services.

5.3 Smaller consumers that invest in distributed energy sources will demand access to markets for the services their technology-based systems can provide. Examples of these are solar PV systems that incorporate built-in battery storage and electric vehicle chargers that allow EV batteries to act as either a power source or as a normal load. Prosumers that may lack the knowledge or the desire to operate 'hands-on' in the relevant markets might participate via services provided by third parties.

The EEA guides represent good industry practice

5.4 The EEA's role includes developing and publishing good practice guides for industry members. The guides cover a wide range of subjects related to network engineering.

They define and disseminate good industry practice, which provides significant value to network owners and operators—and in turn to consumers by enhancing the operational efficiency of distributors.

5.5 Because they provide relevant current guidance only, the EEA guides should not stifle innovation; if appropriate, the EEA can update the guides as and when better policies, practices and technologies evolve.

5.6 As previously discussed, the application process in part 1A of schedule 6.1, introduced into the Code in 2015, placed a number of new obligations on distributors. Coordinated by the EEA,[16] distributors have completed a significant project to develop a draft guide for use by distributors when assessing SSDG connection applications.[17]

5.7 The EEA's Code amendment request would require the Authority to amend the Part 1A process. The Code amendment is necessary because the new inverter standards include a range of advanced power quality modes as optional features only. Making some of the optional features mandatory would dovetail with the EEA's draft guide.

5.8 The EEA suggests this will enable an efficient, comprehensive assessment framework that could govern connection of relatively high penetration levels of SSDG to low voltage networks in a technically-coordinated manner.

5.9 The objectives of the draft EEA guide are to:

(a) ensure the safety and security of personnel, plant and equipment

(b) avoid disruption to electricity consumers and distributed generation owners

(c) provide a practical, efficient and consistent method for assessing SSDG connection applications for all distributors

(d) provide an equitable allocation of low voltage network SSDG *hosting capacity* to anticipated SSDG applicants[18]

(e) accommodate the use of simple, low-cost inverter technology for SSDG connections where possible

(f) ensure that inverter-connected SSDG installations contribute equitably to voltage management through appropriate inverter functionality

(g) assist distributors to make available information about the requirements for network export congestion and SSDG connection, for dissemination to prospective SSDG applicants

(h) avoid the occurrence of unforeseen technical or financial obstacles for connected SSDG owners

(i) minimise the occurrence of 'end of feeder' SSDG connections being required to reduce inverter output to prevent over-voltage at the point of supply

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16 See https://www.eea.co.nz/tools/products/details.aspx?SECT=publications&ITEM=2917 ~~https://www.eea.co.nz~~. The EEA project included technical expertise from the University of Canterbury, the Electric Power Engineering Centre and the GREEN Grid Network Analysis Group, which is widely represented by senior industry power system engineers.

17 EEA *Guide for the Connection of Small-Scale Inverter-Based Distributed Generation*, Draft Version 0.22, May 2016.

18 *Hosting capacity* is the term that describes the capacity of a network to accept import (injection) from connected distributed generation, while maintaining local voltage within the statutory limits and not overloading network equipment.

(j) more fully realise a low voltage network's aggregate export potential.

The EEA guide would require distributors to use more advanced inverter power quality modes

5.10 Inverters that comply with AS/NZS 4777.2 may *optionally* implement a range of advanced power quality support modes. If inverter manufacturers build these advanced modes into their hardware, the inverters can, within limits, support local network power quality by actively regulating the local voltage (referred to in the standard as 'volt-var mode') and, if necessary, throttle back SSDG output if the local voltage goes too high (referred to in the standard as 'volt-watt mode').[19]

5.11 Essentially, the EEA proposal would amend the Part 1A process to *require* the advanced volt-watt and volt-var modes to be included for all new SSDG installations on low voltage networks where the local distributor considers the network has, or will foreseeably have, limited hosting capacity.

5.12 It is possible that incorporating such a requirement may not give rise to new costs for SSDG investors. The Authority understands that New Zealand exists within a global marketplace for small-scale solar PV power inverters and has anecdotal evidence that advanced power quality mode hardware may already be incorporated into current inverter models on sale in New Zealand as a default option. If this is the case, it may simply be a question of applying appropriate settings in the inverter.

5.13 If inverter power quality modes can be included at zero or minimal incremental cost, and provided with well-understood and nationally-consistent settings in ways that resist tampering, the option of simply standardising on a single inverter capability specification for New Zealand may have the greatest net benefit.

5.14 Power quality support modes on all inverters could offset the adverse power quality impacts of the large new EV charging loads that some anticipate. This is especially the case if the requirement was extended to EV smart/fast chargers (ie, inverter/rectifiers, capable of operating as both a power demand (battery charging) and a power source (network support).

5.15 We would like to find out more about this area, in particular submitters' views of the option of amending the Part 1A connection process for SSDG to require use of an inverter that:

(a) conforms with AS/NZS 4777.2 in all mandatory respects

(b) also includes the volt-var and volt-watt power quality modes *as mandatory features*.

5.16 The Part 1 connection approval process would remain available to applicants that sought to connect using an inverter that did not incorporate the advanced power quality modes but was otherwise compliant with the mandatory aspects for AS/NZS 4777.2.

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[19] The draft EEA guide describes much more technical detail about the two power quality modes outlined here.

Q5. Do you have any comments on the draft EEA guide's stated objectives?

Q6. What advanced power quality capabilities do inverters sold into the New Zealand market possess?

Q7. Is it reasonable to assume that the advanced power quality modes outlined are currently available in the marketplace at no additional cost? If not, what are the likely incremental costs involved to obtain these modes?

Q8. Would a default requirement to provide volt-var and volt-watt modes for all future inverter installations that use the Part 1A connection process have any unintended adverse consequences (for example, leaving a stock of unsold inverters that are otherwise compliant with the superseded AS4777:2005 standard suite)? Are these adverse consequences surmountable?

The EEA guide would require distributors to assess the hosting capacity of each low voltage network

5.17 Whether installed overhead or underground, distributors typically deploy established 'rule-of-thumb' standard designs that incorporate no active, remote (ie, SCADA) monitoring of local power quality or loading levels. Monitoring and troubleshooting of power quality on low voltage networks generally relies on consumer service requests and complaints about local power quality.

5.18 Low voltage networks broadly provide open-access distribution services to electricity retailers. In this way they act as the primary platform for retail competition in energy supply.

5.19 The Code currently requires distributors to publish information about the locations on their networks that are already congested, or that they anticipate will become congested within the next 12 months. This information is intended to signal to prospective distributed generation investors, early in their investment decision-making process, areas of the network where a distributor's policy for constraint management might need to limit the amount of surplus SSDG generation imported into the local low voltage network, to avoid local over-voltage and/or overloading low voltage transformers or circuits.

5.20 The recommended good industry practice described in the draft EEA guide would standardise an approach for assessing areas of network congestion. It would require that applications to connect SSDG in low voltage networks that are congested, or that the distributor assesses will become congested, to:

(a) include inverters with the power quality support modes enabled

(b) limit the amount of power imported into the network.

5.21 The draft EEA guide gives further details about how this would work.[20]

Q9. What comments do you have about the hosting capacity assessment process described in detail in the draft EEA guide?

[20] We expect the EEA will make its draft guide available on its website by the time we publish this issues paper.

The EEA has asked for amendments to Part 6 of the Code

5.22 As outlined earlier, Part 6 of the Code currently requires distributors to publish standards for connection and operation that include their policy for managing congestion. Distributors must also process applications to connect SSDG installations that comply with standards under the streamlined Part 1A process.

5.23 Distributors have researched countries that have experienced significant SSDG in recent years. Their research has revealed difficult technical issues related to poor power quality (eg, very high local voltages when the sun shines) and, sometimes, overloaded network equipment. However, these problems can be difficult to proactively pinpoint and address because low voltage networks are not generally actively monitored for power quality and degree of loading.[21]

5.24 The Code amendment requested by the EEA would affect only the Part 1A connection process. It would not require amendments to the Part 1 or Part 2 application processes, which allow a distributor to assess the network impact of each new or upgraded distributed generation installation. For these applications, the distributor can impose tailored requirements and conditions if necessary.

5.25 The Code amendment requested by the EEA would require applications under Part 1A to meet two new criteria:

(a) the proposed inverter must have the appropriate inverter power quality modes that enable it to regulate local voltage

(b) the proposed maximum export power must be under a threshold limit published by the distributor.[22]

5.26 Criteria (b) would apply only if the distributor published such a threshold.

Q10. Do you support the Code amendment request discussed in the draft EEA guide? If not, please explain why and, if possible, suggest an alternative approach.

6 We would like your views on two other issues

Should Part 6 divide large and small distributed generation at 10 kW total or at 5 kW per phase?

6.1 Part 6 divides the process for applying to connect distributed generation into Parts 1 and 1A (small-scale) and Part 2 (large-scale). The small-large threshold is at 10 kW total installed capacity, regardless of whether the distributed generation system is connected to 1, 2 or 3 phases.

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21 Actively assessing overload and overvoltage along an low voltage feeder can be very difficult as different points of connection will variously act as points of import or export ie small sections of low voltage feeders may become overloaded, depending on what neighbouring network users are exporting or importing. Also, in technical terms, low voltage networks are relatively resistive, meaning that quite high voltage drops can occur along relatively short lengths of a highly loaded low voltage feeder. This is further complicated by there being three electrical phases in a feeder, with most SSDG connected to a single phase—so imbalanced phase loadings is also an issue.

22 'Maximum export power' is discussed in detail in the EEA draft guide but, in simple terms, is a distributor-determined limit on the maximum amount of power that may be injected into the distributor's low voltage network at any time. Note that the EEA guide uses the term 'export' in the opposite sense to which this paper uses 'export' and 'import'.

6.2 However, AS/NZS 4777.2:2015 applies to inverter installations of up to 5 kW capacity *per phase*. A 3-phase standards-compliant inverter could therefore have a maximum capacity of 15 kW.

6.3 Stakeholders have not raised this as a problem, but we would be interested in submissions on this point. Although any change would require a Code amendment, we could align the small-large threshold in Part 6 with the inverter standard suite if that better met the Authority's statutory objective.

Q11. Do you think there is a problem or conflict with the '10 kW total' versus '5 kW per phase' thresholds respectively adopted in the Code and AS/NZS 4777.2:2015? If so, would you support the Authority aligning the Code threshold with the inverter standard?

In-home electric vehicle chargers may put further pressure on local networks

6.4 Vector's has published a paper *Green Paper on EV Network Integration* which discusses potential network issues with in-home electric vehicle chargers. [23]

6.5 The Vector paper states the issue as follows:

"An average house has a load impact of 2.5 kW, which means that every EV trickle charger (2.4 kW) effectively adds another home to the network. Given the long charging times associated with trickle charging, Vector expects customers to opt at least for the 7 kW slow charger whenever financially possible. Adding a 7 kW charger equates to the equivalent of 2.8 homes being connected to the local network. A fast (22 kW) and rapid (50 kW) charger equals to 8.8 and 20 new houses being added to the local network (Figure 8). With longer EV ranges, the customer value for higher capacity chargers and shorter charging duration increases. Faster chargers may therefore be necessary to avoid "charge anxiety," that may limit the potential for EV mass market adoption."

6.6 The voltage and network capacity implications of in-home electric vehicle charging are similar to those presented in this issues paper associated with connection of SSDG to low voltage networks.

6.7 With installations increasingly clustered around residential consumers connected to low voltage networks, the capacity of some local network segments may come under particular pressure. Some observers project rapid uptake of privately-owned electric vehicles. Others hold alternative views, for example, projecting that individuals may not own private electric vehicles but increasingly use fleet electric vehicles as a better option.[24]

6.8 Problems of network capacity and power quality may be particularly costly and take time to remedy. Distributors currently have no visibility of (large) new demand being added to houses, but they do have visibility of SSDG being connected through the Part 6 process for applying to connect.

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23 The paper is available at https://vectorwebstoreprd.blob.core.windows.net/blob/vector/media/the-spin-off/ev-network-integration.pdf

24 See, for example, the views held by Stanford economist and futurist Tony Seba—at https://cleantechnica.com/2017/05/12/tony-seba-2030-95-people-wont-private-car-automaker-death-spiral-coming/

6.9 In this paper we do not try to predict the future, but rather to raise and discuss some alternatives. Market mechanisms, such as better signalling of network congestion through distribution pricing, must also be considered.

6.10 For example, one technical solution might be to require all in-home electric vehicle chargers with an installed capacity over, say, 3 kW to be subject to a process of connecting similar to Part 6. Technical steps could include, for example:

(a) external control of the charge rate

(b) automatic throttling of the charge rate if the local voltage goes too low

(c) smart charging capability, so that the charger will determine the required energy to charge the battery and spread that charge over time, to address problems with network capacity.

6.11 Increasingly, distributors will need to think differently about their distribution and low voltage networks. Alternative views exist and near-term options that provide policy makers, regulators and network planners with information about changing load profiles are likely to add light to the topic.

Q12. Do you think there are emerging problems with capacity or power quality from in-home electric vehicle chargers, or is it too early to tell? We are keen to hear industry views and experiences and from parties that supply electric vehicle charging equipment.

Appendix A Question format for submissions

A.1 Please use the following table to provide your feedback on the questions included in this paper.

Question	Response
Q1. Have we adequately outlined the issues with increasing levels of SSDG, particularly inverter-connected solar PV systems?	
Q2. What other factors are relevant to these technical network considerations?	
Q3. Do you agree these options broadly represent the range of actions we could consider at this time? Are there other broad conceptual options we should consider that are not covered by these three approaches?	
Q4. Do you think the Authority should pursue the types of measures that Option B would require? If not, please outline your alternative preferred approach, including if possible the costs and benefits. If you consider there is a valid Option C-style alternative, please provide details, including your view on how your alternative would meet the Authority’s statutory objective.	
Q5. Do you have any comments on the draft EEA guide’s stated objectives?	
Q6. What advanced power quality capabilities do inverters sold into the New Zealand market possess?	
Q7. Is it reasonable to assume that the advanced power quality modes outlined are currently available in the marketplace at no additional cost? If not, what are the likely incremental costs involved to obtain these modes?	
Q8. Would a default requirement to provide volt-var and volt-watt modes for all future inverter installations that use the Part 1A connection process have any unintended adverse consequences (for example,	

leaving a stock of unsold inverters that are otherwise compliant with the superseded AS4777:2005 standard suite)? Are these adverse consequences surmountable?	
Q9. What comments do you have about the hosting capacity assessment process described in detail in the draft EEA guide?	
Q10. Do you support the Code amendment request discussed in the draft EEA guide? If not, please explain why and, if possible, suggest an alternative approach.	
Q11. Do you think there is a problem or conflict with the '10 kW total' versus '5 kW per phase' thresholds respectively adopted in the Code and AS/NZS 4777.2:2015? If so, would you support aligning the Code threshold with the inverter standard?	
Q12. Do you think there are emerging problems with capacity or power quality from in-home electric vehicle chargers, or is it too early to tell? We are keen to hear industry views and experiences and from parties that supply electric vehicle charging equipment.	

Appendix B Background about Part 6 of the Code

B.1 This appendix provides background relevant to Part 6 of the Code.

Part 6 is based on the former Distributed Generation Regulations

B.2 Part 6 replaces the now revoked Electricity Governance (Connection of Distributed Generation) Regulations 2007 (DG Regulations).[25]

B.3 The purpose of the DG Regulations was to enable connection of distributed generation where consistent with the distributor's standards for connection and operation.

B.4 The DG Regulations provided a consistent process for submitting and assessing an application to connect. They included default regulated terms of connection, a dispute resolution process and pricing principles. The DG Regulations provided separate processes for:

(a) SSDG ie, for systems of 10 kW capacity or less

(b) distributed generation systems with a capacity more than 10 kW.

B.5 The two processes were included in a schedule to the DG Regulations titled:

(a) Part 1 – for SSDG

(b) Part 2 – for distributed generation systems larger than SSDG.

B.6 When the Code came into force in 2011 the DG Regulations were incorporated as Part 6.

The Authority reviewed Part 6 in 2011-14

B.7 By 2011, it had been four years since the DG Regulations had originally been developed. There were still few SSDG connections, particularly solar PV systems, but the rate was steadily increasing as the costs of PV systems fell and consumer interest in renewable generation increased.

B.8 In 2011 the Authority initiated an operational review of Part 6 of the Code. Details of the review are available on the Authority's website.[26]

B.9 The scope of the review included all aspects of Part 6 other than Schedule 6.4, which provides the pricing principles. The Authority subsequently reviewed the pricing principles in a separate workstream.[27]

B.10 The outcome of the review was an improved Part 6 that reflects that the majority of new applications to connect distributed generation are of relatively small-scale systems that connect using standards-compliant inverters.

B.11 Inverters convert direct current (DC) electricity from the SSDG source (eg, the solar PV panels) into low voltage alternating current (AC) electricity, suitable for consumers to

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25 See http://www.legislation.govt.nz and search the title under revoked Legislative instruments.

26 See https://www.ea.govt.nz/development/work-programme/operational-efficiencies/operational-review-of-part-6/

27 See https://www.ea.govt.nz/development/work-programme/pricing-cost-allocation/review-part-6-dg-pricing-principles/

use. If the SSDG output exceeds the amount consumers use at any instant, the local network imports the excess generation.[28]

B.12 Inverters also perform important system protection functions, essential to ensure the safety of people and equipment from exposure to electrical hazards. Inverters are therefore a critical interface device in any distributed generation system that generates DC electricity that is converted to AC electricity.

Part 1A provides a streamlined connection application process for standards-compliant SSDG

B.13 The operational review of Part 6 introduced a new connection application process in a new Part 1A of schedule 6.1. Part 1A sought to improve the efficiency of approving applications to connect SSDG where the SSDG system incorporated an inverter that complied with published standards. The Part 6 amendment came into force on 23 February 2015.

B.14 Part 1A of schedule 6.1 acts as an alternative application process to the Part 1 process. If their proposed SSDG system meets certain requirements, an applicant can elect to apply for connection under Part 1A. The Part 1 process remains as an option for a more complex SSDG system, for example for connecting a SSDG system that does not use an inverter.

B.15 An application to connect an SSDG installation under Part 1A requires that the distributed generation installation:

(a) is designed and installed in accordance with AS 4777.1:2005[29]

(b) incorporates an inverter that complies with AS/NZS 4777.2:2015

(c) has protection settings applied that meet the distributor's connection and operation standards

(d) submits basic information about the installation to the distributor

(e) is not to be connected within an section of network that the distributor has identified as being congested.[30]

B.16 If these requirements are met, the distributor <u>must</u> approve connection of the SSDG installation.

B.17 Under Part 1A, distributors must:

(a) develop comprehensive standards for connection and operation, including policies to manage congestion

(b) publish, and keep up to date:

(i) easy-to-understand guidance about the connection application process

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28 This paper uses the terms "import" and "export" from the perspective of the local network, reflecting standard practice in respect of describing consumer metering systems. For example, we refer to electricity flowing from a consumer installation into the local network as "import".

29 Note that this is the older 2005 standard and has not yet been updated to the newer 2016 joint standard by Energy Safety, which administers the electricity safety regulations.

30 *Congested* means that the local network is incapable of accepting any increased injection from local distributed generation without exceeding equipment ratings or causing the local voltage to exceed the statutory limit.

(ii) fit-for-purpose application forms

(iii) connection and operation standards documents

(iv) information related to current and anticipated network congestion

(v) a list of previously approved inverter makes and models

(c) act promptly when assessing received connection applications.

Inverter standards have evolved

B.18 As outlined above, having an inverter that complies with the standards should ensure that the proposed SSDG system will operate safely and provide power of suitable quality.

B.19 Before 2015, the relevant standard for network-connected inverters was the former AS 4777:2005 standard suite. This standard suite has since been revised by a joint panel of Australian and New Zealand technical experts. The revised standard is now a joint Australian and New Zealand standard suite, comprised of:

(a) AS/NZS 4777.1:2016 Grid connection of energy systems via inverters—Part 1 Installation requirements

(b) AS/NZS 4777.2:2015 Grid connection of energy systems via inverters—Part 2 Inverter requirements.31

B.20 The new standard suite draws significantly on experience gained in countries that have experienced high levels of consumer SSDG connections. These countries include Australia and other countries whose governments have adopted policies to incentivise new generation from renewable sources, including small-scale systems.

B.21 In many cases, high levels of SSDG have given rise to capacity and power quality issues on the low voltage networks the SSDG systems connect to.

[31] These standards are available to purchase at: https://shop.standards.govt.nz/search/ed?q=as%2Fnzs+4777

Glossary of abbreviations and terms

Authority	Electricity Authority
EEA	Electricity Engineers' Association
ICP	installation control point
SCADA	system control and data acquisition
SSDG	small scale distributed generation, ie, not exceeding 10 kW capacity
Hz	hertz, the unit of frequency measurement equal to cycles per second
V, kV	volt, kilovolt (ie 1,000 volts)—units of electrical voltage
kW, MW, GW	kilowatt (ie 1,000 watts), megawatt (ie 1,000 kW), gigawatt (ie 1,000 MW)—units of electrical power