

Overseas examples of edge technologies affecting security or reliability

A summary of security and reliability issues that may arise from the uptake of electric vehicles, solar photovoltaics and batteries

3 June 2016

Note: This paper has been prepared for the purpose of discussion. Content should not be interpreted as representing the views or policy of the Electricity Authority.

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Executive summary

The function of the Security and Reliability Council (SRC) is to provide advice to the Electricity Authority (Authority) on the performance of the electricity system and the system operator, and reliability of supply issues.

This paper arises in response to an action from the 22 October 2015 SRC meeting during discussion of new and emerging technologies ('edge' technologies):

"The secretariat is to provide information to the SRC on two or three specific problems that have arisen overseas in the context of security and reliability issues caused by the use of 'edge' technologies."

Accordingly, this paper outlines some of the potential impacts of new consumer technologies such as solar photovoltaics (PV), batteries and electric vehicles (EVs) on power system security and reliability. This paper also considers what impacts may arise in New Zealand in the context of the current industry arrangements.

In general, if no mitigation occurs, it is expected that New Zealand could face similar issues to those seen overseas arising from these new technologies. Given that these impacts can be material, it is prudent that there be scrutiny of these before there is significant technology uptake. The potential issues are as follows:

Potential Issue	Potential Impact	New Zealand-specific studies planned or completed
Very high PV penetration at times of low demand reduces system inertia	Under a scenario of very high residential PV uptake ¹ , the current industry settings could result in reduced security during periods of high PV output and low demand. This is because PV would be the dominant generation source at about 70% of total. If there was an under-frequency event, the lower system inertia increases the risk of the system not being able to return to equilibrium.	The system operator has work underway and planned to investigate these issues, which is to be completed in 2016/2017. ²

¹ For example, uptake as outlined in the Smart Grid Forum paper, "Scenarios of consumer investment in new technology Update for SRC October 2015"

² The system operator's presentation to the SRC is available from: <http://www.ea.govt.nz/development/advisory-technical-groups/src/meeting-papers/2015/22-october/>

Solar PV inverters disconnecting from the network during an under-frequency event	If distributed generation disconnects earlier than expected during an under-frequency event, it will exacerbate the event and lead to larger frequency perturbations.	The AS/NZS 4777.2 2015 standard goes some way towards addressing set-points for disconnection from inverter-based distributed generation. The Electric Power Engineering Centre (EPEC) at the University of Canterbury has undertaken some analysis and testing of inverter settings and grid support features through the Green Grid project ³
Voltage rise	Exceeding voltage limits	The EPEC/Green Grid project has looked at the impact of PV on distribution networks ⁴
Voltage drop	Exceeding voltage limits	The EPEC/Green Grid project has looked at the impact of EVs on distribution networks ^{5 6}
Voltage flicker	Customer annoyance	The EPEC/Green Grid project has looked at some aspects of flicker.

While all of the issues identified are resolvable, and the technologies may in some cases result in net benefits, changes to current systems or processes may be required.

The need and timing of changes will depend on the rate of technology uptake. While to date the rate of uptake of the technologies has been modest in New Zealand, Australia has shown that uptake can be very rapid (3,000 MW PV installed in 3.5 years) if the right conditions are in place. Given the lead times for identifying issues and developing and implementing solutions, it is important to get a better understanding of these potential issues well in advance of them becoming material.

³ More information is available from: http://www.epecentre.ac.nz/docs/green%20grid%20conf%20posters/UC-GG-15-PR-SP-02_RD%20Expo%20Poster%20PV%20Solar%20Inverter%20Testing_0.3_WJH01.compressed.pdf

⁴ More information is available from: http://www.epecentre.ac.nz/research/need_slides/GTD-2014-1076.pdf

⁵ More information is available from: http://www.epecentre.ac.nz/research/need_slides/EEA_Paper_2015_EV_Modelling-V5.pdf

⁶ More information is available from: http://www.epecentre.ac.nz/docs/green%20grid%20conf%20presentations/9.UC-GG-16-CP-NRW-01_Green_Grid_10Feb2016_EV_PQ_EPECentre.pdf

1 Introduction

1.1 Purpose of the paper

1.1.1 The SRC has been appointed, in accordance with the Electricity Industry Act 2010, to provide independent advice to the Authority on:

- a) the performance of the electricity system and the system operator; and
- b) reliability of supply issues.

1.1.2 This paper arises in response to an action from the 22 October 2015 SRC meeting during discussion of 'edge' technologies:

“The secretariat is to provide information to the SRC on two or three specific problems that have arisen overseas in the context of security and reliability issues caused by the use of ‘edge’ technologies.”

1.1.3 Accordingly, this paper discusses the potential impacts of new consumer technologies such as PV, batteries, and EVs on the security and reliability of the New Zealand electricity system. This looks at overseas examples where issues have arisen, and also considers the potential impacts in the context of the current New Zealand industry settings.

1.1.4 The examples used in the paper mainly arise from PV as this technology has a higher rate of uptake internationally, and also appears to have greater potential for adverse impacts. Batteries and EVs do have potential to cause issues, but they also offer considerable benefits to the electricity system in terms of security and reliability. However, the extent and nature of the impacts of storage technologies depends on the control algorithms used, and there is limited information on these at this stage as there is currently minimal deployment of these technologies.⁷

1.1.5 The issues considered in this paper are:

- a) issues arising from low demand periods and high ramp rates
- b) exacerbating under-frequency events
- c) voltage rise
- d) voltage drop
- e) voltage flicker.

1.1.6 All of the issues identified are resolvable, and the technologies may in some cases result in net benefits, but may require changes to current systems or processes (including allocation of costs).

1.1.7 A further potential issue is that of harmonics. This topic has not been explored in detail as it is understood that in Australia even in areas of high PV penetration, this has not been an issue^{8 9 10}.

⁷ The issues with batteries are more likely to be ensuring that the potential upside benefits are fully realised, rather than mitigating adverse outcomes. The Smart Grid Forum has looked at this issue, but it may warrant ongoing monitoring.

⁸ <http://sites.ieee.org/pes-enews/2015/03/12/photovoltaics-in-australia/>

⁹ http://www.elec.uow.edu.au/apqrc/content/technotes/UOW009_Tech%20Note%2010_AW_screen.pdf

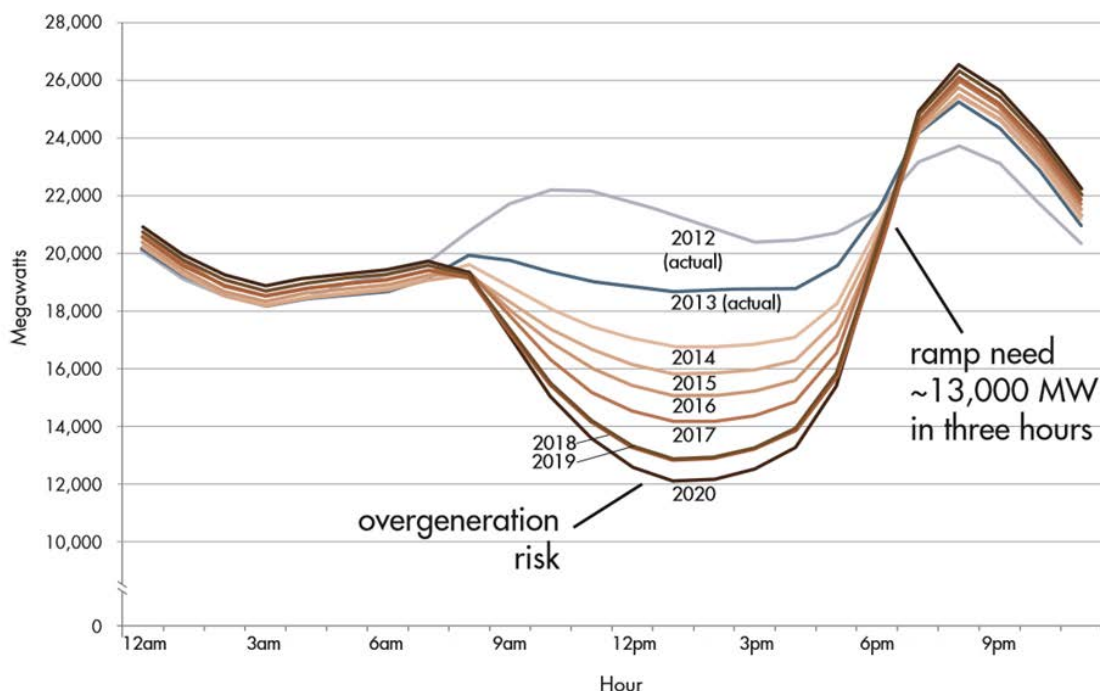
¹⁰ There is ongoing research into high frequency harmonics associated with switching frequencies of inverters (i.e. as opposed to the inverter wave form itself), however these harmonics do not appear to be causing problems.

This is largely a result of ongoing technology improvements in inverters and the implementation of the AS/NZS 4777.2 2015 standard that was approved in 2015.

2 Ramp rates and low demand issues

- 2.1.1 Rapid growth of PV penetration can substantially change the shape of intra-day net (or residual) demand. Net demand, in this context, essentially means the demand as measured at the grid level.
- 2.1.2 While the output of any distributed generator affects net demand, the signature shape of PV generation has an inverse effect on the shape of net demand. This is important because it is net demand that the dispatched grid generation serves. This issue has been most extensively described in California with the well-known 'duck curves', so-called because the daily demand profile with and without PV resembles a duck (see Figure 1 below).
- 2.1.3 The two primary issues arising from the duck-curve are:
- managing the ramp-rate prior to the evening peak demand period
 - managing the risk of over-generation (i.e. requiring generation curtailment).
- 2.1.4 This also has price and market consequences as each day the market transitions from relative surplus to potential scarcity of generation over the period of a few hours. In the case of California, the increased need for gas-fired peaking generation has had 'upstream' consequences for gas supply.¹¹

Figure 1 - California's 'duck curve' (daily net-demand profile with increasing PV generation)



Source: *What the duck curve tells us about managing a green grid* (2016), by California ISO

Notes: 1. Report is available from [here](http://www.ferc.gov/market-oversight/reports-analyses/mkt-views/2015/10-15-15-A-3.pdf)

¹¹ <http://www.ferc.gov/market-oversight/reports-analyses/mkt-views/2015/10-15-15-A-3.pdf>

2.2 Ramp rates in New Zealand

- 2.2.1 In theory, the ramp rate issue should be less of a potential problem in New Zealand compared to other jurisdictions, because of the New Zealand power system's intra-day hydro flexibility and five-minute dispatch. However, it may be more challenging to maintain power quality in the face of growing inherent uncertainties, especially at times when:
- a) PV generation is rapidly ramping down
 - b) evening demand is ramping up
 - c) wind generation is varying as well.
- 2.2.2 High penetration of PV nation-wide would have much lower variability than for an individual PV array (due to geographic diversity, and thus different weather conditions). Nonetheless, PV generation would still be quite variable at the national level due to the concentration of New Zealand's population (and hence likely residential PV) in the Auckland region. Weather in the Auckland region, and particularly changes in cloud cover, would be expected to be the main driver of nationwide PV generation uncertainty.¹²
- 2.2.3 Accordingly, accurate forecasting of PV output and net demand takes on a growing importance.
- 2.2.4 The system operator currently has work underway and planned in 2016/17 to investigate the power system ramping capacity. This is to identify the maximum PV penetration the system can accommodate without adverse impacts. Ancillary service arrangements may need to be reviewed to ensure the electricity system copes with increased ramping requirements without any adverse impacts. The Authority's [Review of Instantaneous Reserve Markets](#) project is examining the suitability of existing reserve products.
- 2.2.5 The upstream gas market implications experienced in California (discussed in paragraph 2.1.4) is unlikely to be an issue in New Zealand because we have flexible hydro which is generally the least cost option for daily ramping. However, an increased reliance on flexible hydro could reduce energy security if it raises the minimum required flows out of controlled hydro storage. In the timeframes in which this issue might manifest itself, it may be reasonable to expect significant demand-side response (perhaps supported by batteries).
- 2.2.6 New Zealand could be somewhat prone to unit commitment issues arising from harder-to-predict ramp rates. Unit commitment describes an issue where a generator (typically thermal generation owners) needs to make a decision about whether to start up its plant some hours in advance but lacks sufficient certainty at that time to know whether enough of its output will be dispatched to justify starting up.

2.3 Low demand (and low inertia) in New Zealand

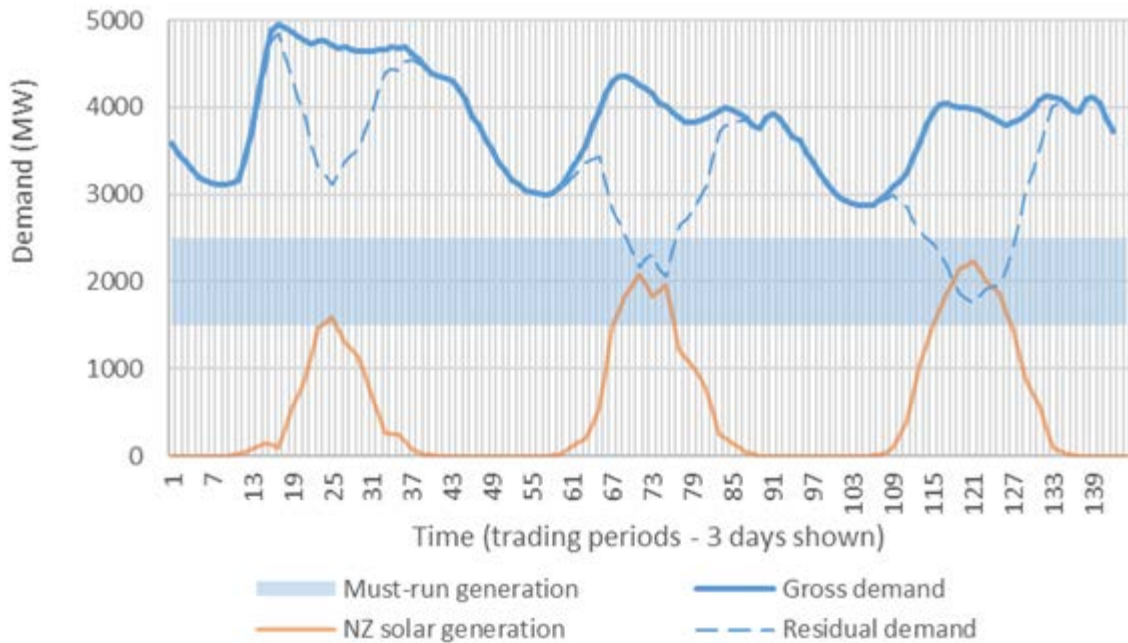
- 2.3.1 The issue of generation curtailment and its consequence of reducing system inertia, may be significant in New Zealand. This is because it is feasible (under some policy settings) that New Zealand could have in the order of 2,500 MW (or more) of PV installed capacity in future.¹³

¹² The inherent time-of-day variability of PV generation due to the angle of the sun is ignored here as this is entirely predictable. It is the weather-induced uncertainty (eg cloud cover) that is of concern.

¹³ This is not a forecast, but simply a hypothetical scenario. It is based 50% penetration of PV (3.75 kW systems) on residential housing, (no commercial systems), and 85% of this PV generating near peak output. This level of uptake could theoretically be achieved in less than a decade (cf. Australia's 3,000 MW PV installed in 3.5 years). This level of uptake is about three times higher

- 2.3.2 Therefore, during sunny summer weekends when daytime gross demand can be as low as 4,000 MW, and other must-run generation can be greater than 1,500 MW (i.e. co-generation, wind, geothermal, and hydro minimum flows), PV could be generating more than 2,000 MW (see Figure 2 below).

Figure 2 – Indicative summer demand scenario with high PV uptake



Source: Electricity Authority

- Notes:
1. This scenario is based on historical demand data for February, a modelled PV scenario of about 60% uptake amongst residential sector and 20% diversity of PV output
 2. This scenario is intended to simulate a situation of low (but not minimum) demand and a high PV output (most areas sunny, but a small amount of diversity due to clouds)
 3. This scenario assumes no demand-side response such as PV output being routed to batteries for later discharge
 4. This scenario assumes no constraints on PV output (such as might be expected within distribution networks)

- 2.3.3 Curtailment of some generation may be required at these times of low demand and high PV output because must-run generation could exceed net demand. PV generation is currently unable to be actively curtailed¹⁴ by the system operator (e.g. constrained off) through the Must-Run Dispatch Auction, so grid generation would need to be reduced. Hydro and wind generation are more likely to be curtailed since geothermal may be restricted by consent conditions on venting and would therefore incur a higher curtailment cost.

than used in MBIE's Electricity Demand and Generation Scenario analysis, but is consistent with the Smart Grid Forum work when looking at high PV uptake.

¹⁴ This is technically feasible with some inverters, but few, if any, are configured to use this feature as it is not currently required (and consumers would lose revenue if it was used). Further, policy around who gets curtailed, and who controls curtailment may be issues that take time to resolve given competing stakeholder interests.

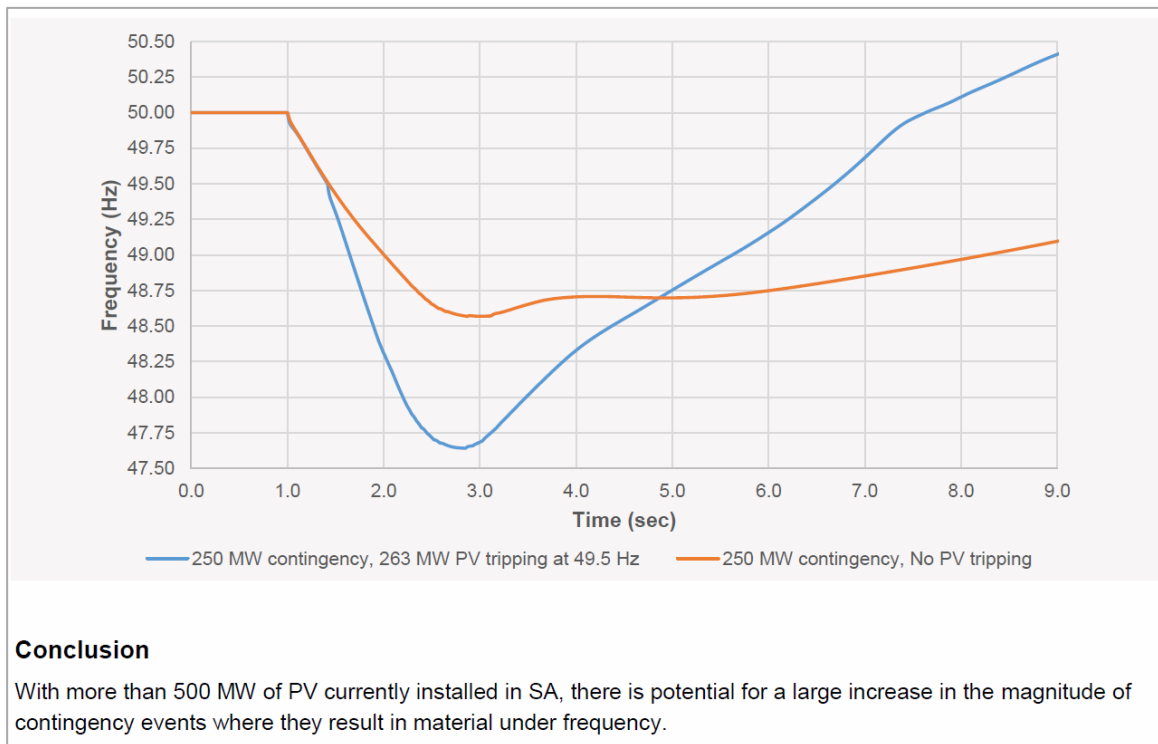
- 2.3.4 Curtailing flexible hydro and wind generation is unlikely to cause any reliability problems in its own right. However, curtailing flexible hydro generation and keeping the inflexible geothermal generation in operation will make the grid more susceptible to voltage and frequency excursions given the high proportion of low inertia generation. In theory, nearly 70% of generation could be coming from PV at times. It is not clear whether the electricity system would be stable in response to normal demand variability (and PV generation uncertainty), or be able to recover from the loss of a large supply asset (e.g. the HVDC) at such times.
- 2.3.5 Conducting grid stability studies and a review of ancillary service requirements would be prudent for these low demand and high ‘must-run’ renewable generation scenarios.¹⁵ While lower system inertia is likely to lead to a need for more instantaneous reserves, curtailment of must-run generation may also be required to ensure these reserves are available. The system operator currently has work planned in 2016/17 to study the impact of a low-inertia system with the present ancillary service approach.¹⁶ The Authority has previously considered whether an inertia market might be required but concluded further investigation was not warranted at this time. The Authority’s [Normal Frequency-Generator Asset Owner Performance Obligations](#) project may enable new technologies (such as batteries) to compete to provide an inertia-like response to the power system frequency.

3 Exacerbating Under-Frequency Events

- 3.1.1 There are currently many requirements on existing large-scale generators to provide grid support (such as provided through governor response) during sudden periods of extreme power system stress. The regulatory arrangements seek to cover for a sudden loss of a major source of supply in order that the system can recover from the interruption without incurring a blackout.
- 3.1.2 Large-scale generators have regulatory requirements to maintain output even if frequency drops to as low as 47 Hz for the North Island and 45Hz for the South Island.
- 3.1.3 However, many distributed generators are believed to have frequency set-points at which they will disconnect from the grid that are higher than that of large-scale generation.
- 3.1.4 An example of this is that as grid frequency falls during an under-frequency event, residential grid-tied PV generation may disconnect earlier than is desirable from a system view point. Since only the PV generation is lost and the household demand is still connected, the grid sees an effective increase in demand, which exacerbates the under-frequency event.
- 3.1.5 Modelling of the South Australia grid (see Figure 3 below) indicates that the residential PV inverter settings can have a material impact on grid response during under frequency events. It added about 1Hz to the frequency excursion when 263 MW of PV out of a total of 500 MW was assumed to have disconnected.

¹⁵ <https://emp.lbl.gov/sites/all/files/lbnl-6525e.pdf>

¹⁶ <http://www.ea.govt.nz/development/advisory-technical-groups/src/meeting-papers/2015/22-october/>

Figure 3 - South Australia contingency modelling with and without PV tripping

Source: *Renewable Energy Integration in South Australia* (October 2014) by AEMO and ElectraNet

Notes: 1. Report is available from [here](#)

- 3.1.6 This issue is now an important consideration for some Australian States¹⁷ and also the United States¹⁸ and the United Kingdom¹⁹, and is resulting in a focus on distributed generation connection criteria (e.g. inverter under-frequency settings). This should also be a consideration for battery installations (without PV) as the battery sits behind the inverter, so if the inverter disconnects the battery cannot inject electricity.

3.2 Exacerbating under-frequency events in New Zealand

- 3.2.1 While the Figure 3 above is dramatic, the issue is likely to be less of a concern in New Zealand. The new standard AS/NZS 4777.2 2015 for grid-tied inverters implemented in late 2015 goes some way towards addressing inverter set-points for disconnection. Assuming that inverters connected in future are standards-compliant, this means that New Zealand will have a relatively modest legacy issue of existing PV systems, compared to the issue in Australia. However, there is the potential for non-compliance of some future PV installations due to:

- a) installations where the inverter may be capable of meeting the standards but has been incorrectly programmed with non-compliant settings

¹⁷ 'Renewable Energy Integration In South Australia', October 2014

¹⁸ http://ceeep.rutgers.edu/wp-content/uploads/2013/11/RutgersPresentation_NERC_JM.pdf

¹⁹ The Smart Grid Forum references a 2008 example of an under-frequency event from John Scott's presentations (see the 19 June 2015 SRC paper 'Smart Grid Forum matters relating to security and reliability') in which a significant amount of distributed generation tripped off during the event.

- b) the actual performance of inverters during a real frequency event not achieving the expected performance.²⁰

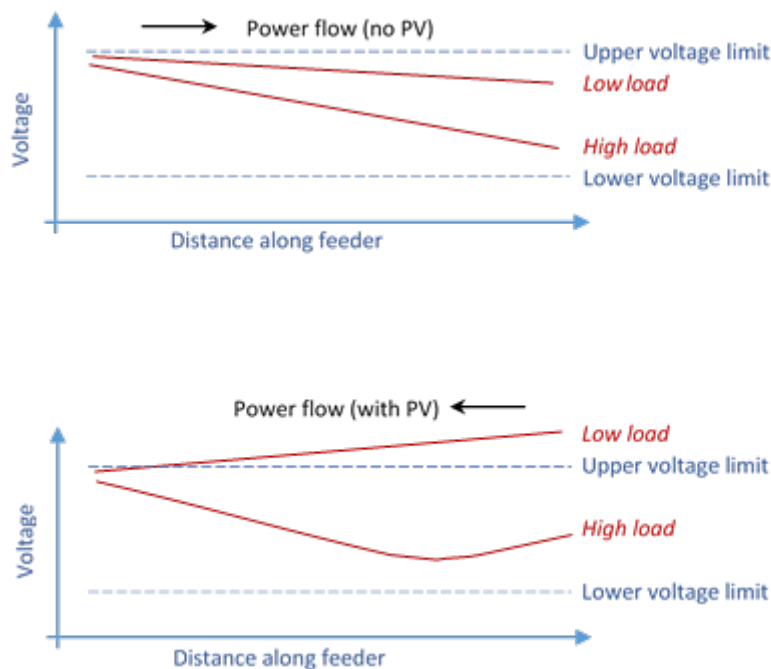
3.2.2 This issue has been investigated to some extent by EPEC in terms of actual inverter performance during under-frequency events. The system operator currently has work underway and planned in 2016/17 to investigate the effect of PV inverter ride-through capability and its effect on system frequency regulation. Presently, if the system operator becomes aware of inverters under-performing in aggregate, the system operator can model this into reserve requirements although there is no mechanism to recover the additional reserve cost from the under-performing assets. The Authority's [Fault Ride Through](#) project has examined this issue in terms of larger-scale generation, although consideration has been given to future phases dealing with smaller-scale generation.

4 Voltage Rise

- 4.1.1 The most prevalent power quality issue related to grid-connected PV is steady-state voltage rise, particularly at the end of distribution feeders. This has been experienced in Australia, the US and many other countries with a high concentration of grid-tied residential PV.
- 4.1.2 Electricity distribution systems are often designed to deliver power predominantly in one direction, from zone substations through feeders to load (a traditional 'radial' network design).
- 4.1.3 In a radially designed network, and absent any significant distributed generation, voltage is highest (but typically within the upper voltage limit) at the transformer, and decreases along the feeder, being lowest at the end of the feeder.
- 4.1.4 When distributed generation is added to a radial network, voltage rise can occur along a feeder due to a distributed generator's output exceeding the household demand, resulting in net flow of electricity back into the network. Figure 4 below illustrates how this can result in voltage moving outside the allowable limits, potentially causing damage to electricity appliances.

²⁰ http://www.epecentre.ac.nz/docs/green%20grid%20conf%20posters/UC-GG-15-PR-SP-02_RD%20Expo%20Poster%20PV%20Solar%20Inverter%20Testing_0.3_WJH01.compressed.pdf

Figure 4 - Schematic representation of voltage rise



Source: Electricity Authority

Notes: 1. Figure is illustrative only
2. Similar charts can be found in various reports, such as [this EPEC report](#)

- 4.1.5 There are some relatively simple measures that can reduce the impacts of voltage rise, and these are now being introduced in Australia where the issue of voltage rise is well known. Mitigation measures include:
- a) requiring inverters on larger household PV systems to have reactive power control ²¹
 - b) using domestic electric hot water cylinders to increase daytime demand coincident with PV generation.
- 4.1.6 Inverters with improved reactive power control can be more expensive to purchase and typically reduce the volume of exported electricity and so reduce the owner's revenue. However, in rare cases it may increase exported electricity due to a reduction in the instances of the inverter tripping-off due to over-voltage settings. Overall, these more stringent inverter power factor requirements have allowed a greater PV capacity to be connected to the networks in Australia.
- 4.1.7 Some Australian distribution networks are adopting a much simpler connection process for larger PV systems (for example, greater than 5 kWp) if they are completely precluded from exporting electricity to the network.
- 4.1.8 There is always the option of network investment to increase capacity to alleviate voltage rise issues, though this obviously comes at a cost.

²¹ From October 2015 Energex introduced a ruling that makes it mandatory for every solar power inverter **greater than 3kW** in size to have reactive power control set to 0.9 lagging.

- 4.1.9 Lowering the initial voltage at the transformer is not always an effective option for distributors as they may still need to manage for regular voltage drop during periods of negligible distributed generation output.

4.2 Voltage rise in New Zealand

- 4.2.1 Voltage rise is most likely to occur on distribution networks when demand is low and PV output is high. In New Zealand this may arise on summer weekdays in suburbs where many workers are not home during the day. Modelling of the New Zealand situation suggests that voltage rise can occur at relatively low levels of residential PV uptake (about 10%).²² This is because of the following factors:

- a) New Zealand has a winter peaking demand (Australia has predominantly summer peak demand), meaning our periods of low demand and high PV output are more strongly correlated
- b) typical PV installed capacity of 2kW to 5kW is much higher than the typical New Zealand daytime residential household demand, so the instantaneous generation from one house with PV can offset the instantaneous demand of many houses
- c) PV has little, and often no, diversity across a feeder area so all PV will be generating at the same time on clear-sky days
- d) radial network design, with limited active voltage controls, is common
- e) PV output can be allocated unequally across the phases, thus concentrating the voltage rise impacts.

- 4.2.2 Overall, it is considered that voltage rise could cause some issues for New Zealand networks. This has been shown in the EPEC's work to date.²³ The extent of this issue will depend on the level of PV uptake. The new standard for inverters (AS/NZS 4777.2 2015) will help manage the issue if networks are requiring appropriate power factor settings to be implemented at the time of PV system installation. Under Part 6 of the Electricity Industry Participation Code 2010, New Zealand distributors can set connection and operation standards that prospective owners of distributed generation need to meet in order to connect to the network.

- 4.2.3 In addition, uptake of battery technology may help mitigate some voltage rise issues. However, it is not clear if batteries will be most cost effective at the end-user point, or at the utility level. In the case of the latter there may still be voltage rise issues, depending on the battery location and capacity in relation to the distributed generation.

5 Voltage Drop

- 5.1.1 A compounding issue for distribution network voltage management arises from the combination of EVs and PV on a single feeder line. While PV can lead to voltage rise as described above, the EVs will add load, but generally not coincident with PV generation.²⁴ This means that the additional EV demand won't mitigate the PV voltage rise, and may exacerbate voltage drop at times of peak demand.

²² http://www.epecentre.ac.nz/research/need_slides/GTD-2014-1076.pdf

²³ http://www.epecentre.ac.nz/research/need_slides/GTD-2014-1076.pdf

²⁴ Work to date (e.g. Smart Grid Forum, and Concept Consulting New Technologies Study) indicate that the majority of EVs will (initially at least) be primarily charged at home overnight.

- 5.1.2 Any increase in peak demand is likely to cause additional voltage-drop in feeder lines (see Figure 4 above),²⁵ potentially requiring a different transformer set point (the ‘voltage tap’) once EV uptake increases. Accordingly, voltage control is increasingly needing to be managed dynamically using technology like online tap change capability, or inverters offering grid support capability.
- 5.1.3 The most obvious near-term solution to the EV-induced voltage drop is to encourage EV charging to occur off-peak. Suitable price signals, including those relating to the energy market, can encourage such action. Consumers can respond to such price signals using the charging timers built-in to most EVs. Distributors will be keen to see the development of tariffs and technology that achieves off-peak diversity across all EVs on the network, in order to avoid creating a delayed, but larger peak in demand.
- 5.1.4 Where EV charging can’t readily be moved off-peak to a sufficient extent, network enhancement can provide a useful mitigation, albeit at additional cost.
- 5.2 Voltage drop in New Zealand**
- 5.2.1 While most EVs have timers that allow charging off-peak, few distributors and retailers currently offer ‘EV rates’ that are sufficiently attractive to encourage off-peak charging. Therefore, there is currently a risk of people returning home from work and plugging their EV in to charge immediately, as this is most convenient for them. Given that the commute home is immediately prior to the evening peak electricity demand for the majority of networks, uncontrolled EV charging will add to the residential evening electricity demand peak.
- 5.2.2 Relying on consumers using in-built timers to trigger ‘off-peak’ EV charging may be effective when EV penetration is low, but it is less likely to be effective when EV penetration is high. Some managed form of EV charging may be necessary as EV penetration increases to ensure appropriate coordination (or at least some diversity) amongst the EV charging load (cf. ripple control water heating).²⁶ If everyone sets their EV charging to start at 9pm (for example) this could cause additional problems arising from the step change in demand.
- 5.2.3 While technology can readily provide a range of solutions, these will require efficient price signals to ensure effective overall coordination. The Authority’s has several projects underway that are expected to improve price signals:
- a) distribution pricing review
 - b) transmission pricing review
 - c) real-time pricing.
- 5.2.4 The issue of voltage management is an ongoing topic of discussion for the Smart Grid Forum and will be a key issue for the Smart Technologies Working Group.²⁷

²⁵ http://www.epecentre.ac.nz/docs/green%20grid%20conf%20presentations/9.UC-GG-16-CP-NRW-01_Green_Grid_10Feb2016_EV_PQ_EPECentre.pdf

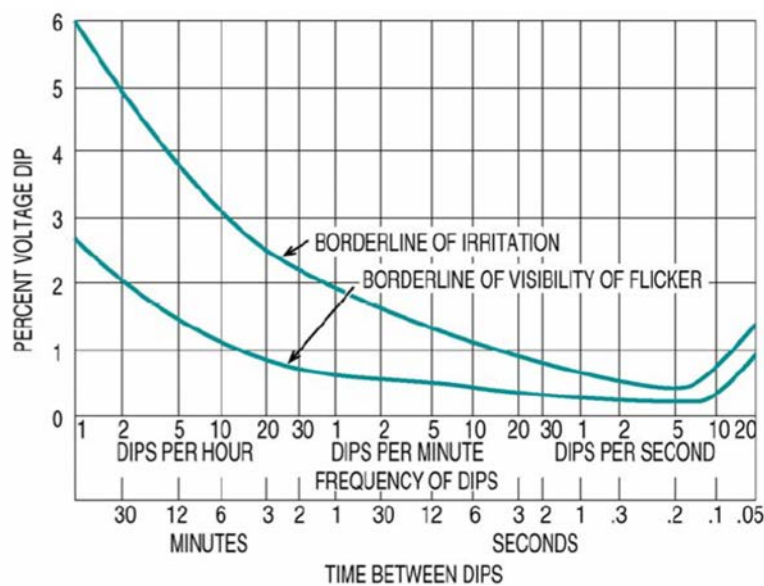
²⁶ While some comparison can be drawn between EVs and electric storage water heating, we need to note that hot water cylinders are fixed to a single lines network whereas EVs move between networks. Therefore, while water heating control can be undertaken differently between networks it may be beneficial to have a locally controlled, but nationally consistent, approach to EV charging to ensure coordination (see link in next footnote).

²⁷ <http://www.mbie.govt.nz/info-services/sectors-industries/energy/electricity-market/nz-smart-grid-forum/meeting-6/distributor-perspective.pdf>

6 Voltage Flicker

- 6.1.1 Voltage fluctuations (i.e. flicker) on electricity distribution networks can be caused by load variation, or distributed generation such as PV. The principal adverse effect of flicker is lighting flicker visible to the human eye which can be irritating. It does not cause material damage to electrical appliances.
- 6.1.2 Flicker is most noticeable (and causes more irritation) over shorter timeframes such as sub-second to several seconds (see Figure 5 below). This chart is of interest because flicker is shown to be most noticeable, and cause most irritation, over the time period of a few seconds that PV can cause flicker.

Figure 5 - IEEE 519_1992 Maximum allowable voltage fluctuations



Source: *IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems* (2005), by IEEE Power Engineering Society

Notes: 1. Report is available from [here](#)

- 6.1.3 PV variability can be large enough and frequent enough to give rise to perceptible changes in electrical lighting output. This is because local PV output can change considerably in a few seconds due to the passage of clouds over a suburb.²⁸ This can be seen in Figure 6 below, showing the difference between a clear-sky day and a day with passing clouds.

²⁸ Unlike system frequency effects which can be thought of as being felt instantaneously across the entire system, voltage effects can be very localised due to the balance of supply and demand on a particular part of a network.

Figure 6 - Irradiance from clear skies versus intermittent cloudy skies

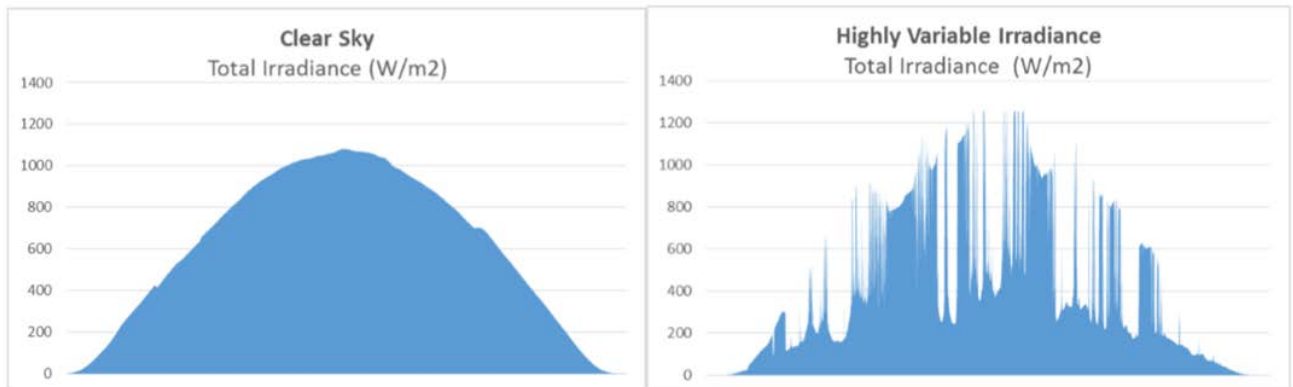


Figure 10 Clear Sky Irradiance and Highly Variable Irradiance due to Intermittent Cloud Cover

Source: *Investigating the Impact of Solar Variability on Grid Stability* (2015) by CAT Projects Australia

Notes: 1. Report is available from [here](#)

6.1.4 There are three main aspects to the issue of voltage flicker caused by PV:

- a) the prevalence of low-level broken cloud on windy days²⁹
- b) geographic diversity (or concentration) of PV
- c) network characteristics (such as impedance, and relative magnitudes of generation and load).

6.1.5 International studies suggest that residential PV is sufficiently spatially diffuse such that it only causes mild voltage flicker, as shown in the following two examples (from the United States and Australia respectively):

“The effect on voltage depends on the amount of PV and the location. Although PV induced voltage changes are typically well inside ANSI voltage limits, it is possible that under certain conditions, the frequency and magnitude of the voltage changes could drive a flicker impact.”³⁰

“PV intermittency and unpredictability have presented new challenges to the electricity generation, transmission and distribution sectors. From a power quality perspective, these PV systems cause additional flicker, unbalance and steady-state voltage fluctuations within distribution networks.”³¹

6.1.6 It is possible that any voltage flicker caused by PV goes largely unnoticed because of:

- a) the residential uptake of compact fluorescent lamps which are more tolerant of minor voltage changes
- b) the negative correlation of residential lighting use with PV output.

²⁹ While high-level cloud reduces direct sunlight, it gives rise to more diffuse light and tends to be more uniform, and therefore has less of a time-varying shading effect and does not generally give rise to flicker.

³⁰ Sandia National Laboratories, 2013: <http://energy.sandia.gov/download/21973/>

³¹ *Voltage rise impacts and generation modelling of residential roof-top photo-voltaic systems*, 2014

- 6.1.7 Commercial- and utility-scale PV installations can cause material voltage flicker issues, albeit infrequently. These systems have little or no benefit from spatial diversity (i.e. the PV is concentrated in one location), so a cloud can affect the entire installation relatively quickly. For example, it is feasible to get a change of 75% of installed PV capacity in a matter of seconds.

6.2 Voltage flicker in New Zealand

- 6.2.1 New Zealand's climate is likely to be an exacerbating factor for PV-induced voltage flicker. Our coastal climate, and relatively high wind speeds, mean that much of the country can be exposed to conditions of low broken cloud driven by moderate to strong winds.
- 6.2.2 However, a mitigating factor for New Zealand is that PV-induced voltage flicker is much more significant where PV is highly concentrated. To date, New Zealand has predominantly residential PV systems (about 90% of installed capacity), with a limited number of commercial installations (e.g. Sylvia Park Mall at 350 kW), and no utility-scale PV at this time.
- 6.2.3 On balance, voltage flicker is not considered to be a material issue arising from uptake of PV in New Zealand.

7 Questions for the SRC to consider

- 7.1.1 The SRC is asked to consider and provide advice on the following questions:

- | | |
|------------|--|
| Q1. | Does the SRC agree with the description of the potential security and reliability impacts for New Zealand? |
| Q2. | Does the SRC agree that the current suite of studies underway is sufficient to identify any issues that may arise from new technologies? If not, what studies or issues ought to receive additional attention? |
| Q3. | What further information, if any, does the SRC wish to have provided to it by the secretariat? |
| Q4. | What advice, if any, does the SRC wish to provide to the Authority? |