Centre for Energy and Environmental Markets
UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY • AUSTRALIA

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Kate Reid

Australian Energy Market Commission

Level 6, 201 Elizabeth Street

Sydney, NSW 2000

Dear Kate,

Brief overview of some CEEM work relevant to the Electricity Networks Economic Regulatory Frameworks Review 2018 (EPR0062)

The Electricity Networks Economic Regulatory Frameworks (ENERF) review provides a timely and important opportunity to review the role and appropriate regulation of electricity networks, as the sector transitions to a more physically distributed model.

We welcome the opportunity to share some recent, still preliminary, findings from the Centre for Energy and Environmental Markets (CEEM), as well as the potential implications of these for the work of the AEMC Review. The analysis discussed here is based on a data set kindly shared by Solar Analytics, a company that provides performance analytics to consumers with solar PV. Whilst the work primarily considers the impacts of, and outcomes under current arrangements for solar PV, the findings may be relevant to Distributed Energy Resources (DERs) more broadly.

Broader CEEM work relevant to the review includes the creation of a distribution network tariff tool[1] and a number of studies on tariff design[2] , as well as other analysis on the impacts of distributed PV on network peak demand reduction at the zone substation level[3]. We would be delighted to provide further details should that be of interest to the AEMC.

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[1] Haghdadi N., Passey R., Bruce A., Young S., MacGill I., 'Tariff Design and Analysis Tool Users Guide' (2017), Available online here: http://www.ceem.unsw.edu.au/sites/default/files/documents/TDA_Instruction.pdf

[2] Passey, R., Watt, M., Bruce, A. , MacGill, I. 'Who pays, who benefits? The financial impacts of solar photovoltaic systems and air-conditioners on Australian households', (2018) Energy Research and Social Science, 39, p198-215

Passey, R., Haghdadi, N., Bruce, A., MacGill I. 'Designing more cost reflective electricity network tariffs with demand charges', (2017) Energy Policy, 109, p642-649.

[3] Haghdadi, N., Bruce, A., MacGill, I., Passey, R. 'Impact of Distributed Photovoltaic Systems on Zone Substation Peak', (2017) IEEE Transactions on Sustainable Energy, 9(2), p621-629.

The work we will describe here has focussed on two areas to date:

1. 'Day to day' voltage conditions in the Low Voltage (LV) network, and opportunities for equitable management of voltage
2. Rooftop PV response to 'extreme' conditions: possible system security implications of solar PV response to system disturbances

Both are relevant to DER integration and are somewhat interrelated, particularly with regards to the criticality of inverter connection standards (for instance, AS4777.2). However, it is important to note that these two areas of investigation are distinct and part of a broader set of challenges and opportunities, as detailed below.

Focus 1: Day to day voltage conditions in the LV network

Context

It is widely accepted that voltages are generally high with respect to state-based regulatory requirements in the NEM's LV networks. This is predominantly due to two historical factors: firstly, in many jurisdictions there has been / is planned a transition from a nominal voltage standard of 240V to 230V. As result, a proportion of older network equipment settings remain at the 240V nominal levels, with the voltage range of +10% / -6% adopted in some states a nod to this legacy. Secondly, distribution transformer taps have been set high in order to ensure voltage does not fall too low during times of peak demand. In particular, consumers are generally more aware of low voltage conditions, particularly in terms of appliance operation, than they are of high voltages.

There are a range of options available for managing voltage within LV networks, depending on the specific characteristics of the relevant part of the network. Some of these involve only relatively minor adjustments to business as usual voltage management (balancing across phases and adjusting transformer tap settings progressively over time), whereas others can require significant investment (reconductoring, installation of statcoms at high voltages or equivalent at lower voltages).

Distributed solar PV injects current into the network, thereby raising voltage, particularly at times of low load. However, there has generally been minimal operational data available, and therefore understanding has been limited with regards to actual conditions in the LV network, the extent to which PV increases voltage management challenges, and the impact of voltage on PV system operation.

Generally, Distribution Network Service Providers (DNSPs) require that inverter connected DERs comply with AS4777.2 *Grid connection of energy systems via inverters, Part 2: Inverter Requirements*, with some DNSPs specifying some additional requirements[4]. This standard contains several voltage response modes (passive anti-islanding protection, power quality response modes and limits for sustained operation), which should act to limit the extent to which solar PV (or other DERs) contribute to over voltage conditions. However, the current version of this standard was published in October 2015 and superseded the previous version in October 2016. Therefore, a large proportion of the existing solar PV fleet was installed prior to the current AS 4777.2 standard. In addition, there has been little analysis of actual response of PV inverters in the network to voltages.

Recent CEEM analysis: voltage conditions

The monitoring equipment used by Solar Analytics includes voltage measurements at the solar customer premise. Recent analysis undertaken at CEEM has confirmed that voltages in the LV network are generally high. There is some rise observed during solar generation hours. However, voltages are generally high irrespective of time of day, with the majority of voltages well above the nominal value in each jurisdiction. The key takeaway from this work is that it is likely distribution transformers could be stepped down without causing non-compliance on the part of DNSPs (i.e. excessively low voltages).

As an example, the hourly distribution of voltages observed by Solar Analytics equipment across South Australia during January 2017 is shown in Figure 1 (i.e. the box and whiskers at hour 12 indicate the spread of all voltages observed during the hour from midday to 1pm during January, noting that these voltages were measured at individual customer premise' across SA). Please refer to the attached paper for further analysis, including of conditions in other states.

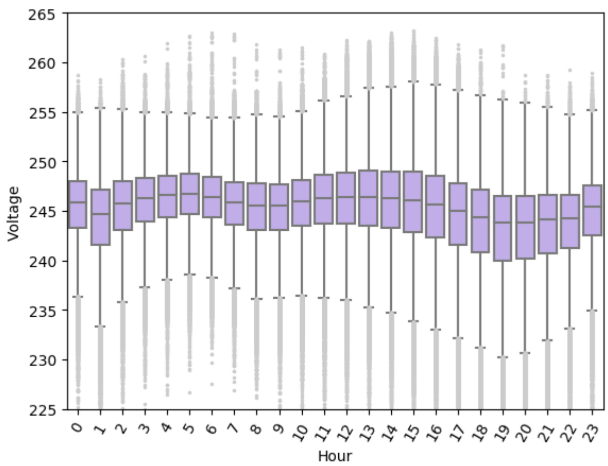

Figure 1 South Australia voltage distribution over the day, January

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[4] We note that Energy Networks Australia are currently undertaking a project to develop a national approach to inverter connection requirements. Previous work has included a review completed by Ben Noone (CEEM and APVI) in 2013.

CEEM's work: equitable curtailment

Earlier UNSW work led by Dr Simon Heslop modelled probabilistic voltage behaviour on LV networks for a wide range of potential household demand and PV deployment profiles. Voltages at all residential connection points in these LV networks were modelled at 30 minute intervals over a year of actual sampled household loads and PV output. The work highlighted the potential wide voltage range seen at different times and locations across the network. High voltages were associated with times of low load and high PV generation, low voltages with periods of high loads and low or no PV generation. High transformer tap settings saw more PV curtailment, low tap settings saw more periods of low voltages. The work highlights that voltage excursions on the LV network are an outcome of many factors rather than just PV. In particular, highly correlated peaky household appliances such as reverse cycle air-conditioners can be a major cause of low voltage excursions, potentially forcing tap settings up. Interestingly, PV is at present one of the only household 'appliances' that is actually required to be controlled in a way that reduces its voltage impacts.

This raises interesting questions of network access and equity - for example, it is reasonable to push transformer tap settings high to ensure voltage doesn't fall too low during those few periods of peak demand, even though such settings reduce the 'headroom' for PV to generate at times of low load? And why shouldn't appliances such as these air-conditioners be required to assist in managing low voltage excursions by curtailing their demand at these times, just as PV systems are asked to do?

There are also locational issues to consider. Work previously completed by Simon Heslop at CEEM[5] used probabilistic models to examine voltages in the LV network with high penetrations of PV. The work showed that without management, the impacts of out-of-range voltages such as PV curtailment fell predominantly on those consumers that the end of feeders. The concept of fair curtailment of solar PV and operation of controllable load to manage voltage equitably was explored.

This work is not yet formally published, however is extremely relevant to any discussion of voltage management mechanisms in a high penetration DER future. It sets out an approach to PV curtailment and operation of controlled load which ensures that the loss of generation is shared evenly between consumers within one region of the network. This mechanism is practical as it does not rely on extensive communication systems.

Please note that a publication on this work entitled *'A practical distributed voltage control method to ensure efficient and equitable intervention of distributed devices'* is forthcoming.

[5] Simon Heslop completed this work as part of his PhD at CEEM, Simon is now based at Intelligent Energy Systems

Potential implications

This work emphasises the value of operational data for evidence based decision-making. In particular, it highlights the importance of data when considering:

- **The extent of voltage rise due to solar PV and voltage management options:** the impact of solar PV on network voltages, should not be overstated and must be considered in an environment of pre-existing high network voltages, and the much larger voltage impacts of very peaky loads such as large air conditioners.
  - → Given the high voltages observed in this data set, reducing transformer tap settings may provide an appropriate low cost solution to over voltage concerns, rather than (or in combination with) increased curtailment of solar PV. The costs and benefits, as well as distribution of costs should be carefully evaluated for each option.
  - → Cross subsidisation between consumers with and without solar PV is clearly a key concern, and we strongly recommend careful consideration and further discussion of network access rights for solar PV, as well as DERs more broadly. The nature of the relationship between consumers and the electricity system should be considered, in particular whether the current asymmetry regarding the treatment of load versus the treatment of generation should persist and is aligned with the NEO. We note that improved understanding of actual operational conditions may aid this discussion.

- **The localised nature of voltage impacts and the role for data:** some sections of the network may require additional curtailment of PV or voltage management equipment. It is likely that these solutions could be more appropriately targeted with increased visibility of actual operating conditions.
  - → It may therefore be appropriate for networks to improve monitoring in the LV network.
  - → It is recommended that if DNSPs were to increase monitoring, that this data is made widely available, whilst taking into account any privacy and security concerns. This recommendation is made on the basis that non-network solutions are clearly an option for maintaining voltage and may present least cost solutions (ultimately benefiting consumers) if opportunities can be identified.

- **Whether the existing power quality standards are suitable:** emerging from this work are two broader questions, these are, what power quality is required by loads? And which participants are best placed to provide services such as management of voltage, reactive power and harmonic content?
  Whilst these are currently quite forward looking questions, technological change and uptake of distributed energy has proven faster than expected to date, and this review and any subsequent workstreams, are excellent opportunities for the Commission to consider whether the current power quality requirements are appropriate, whether data collection and transparency is appropriate, and whether arrangements should better facilitate third party provision of these network services, particularly given the opportunities that DERs present.

→ We therefore suggest the Commission considers a range of alternative approaches, for instance a regime in which power quality is less strictly specified, and consumers that require higher levels of power quality either manage this behind the meter, or pay a premium to their DNSP to provide this service. We note that this would also require consideration of the power quality requirements necessary for safe and secure operation of network equipment.

In addition to the implications outlined above, we feel it is important to note several key challenges (opportunities are also noted below):

- High voltages coupled with the current connection standards are likely to result in 'spilled' solar PV generation[6].
- High voltages existing in networks may limit DERs ability to participate in distribution level markets, and the ability of aggregators to reliably dispatch DERs.
- Legacy challenges may exist given the significant proportion of the solar PV fleet installed prior to the current AS4777.2(2015) which may 'lock out' new DERs due to higher voltage set points[7]. This could limit the aggregation opportunities or ability for DERs to participate in possible future Distribution Markets.

The following opportunities also exist:

- As stated above, stepping down distribution transformers may be a simple option for supporting higher penetration of DERs without, in many parts of the network, causing noncompliant voltages or significant curtailment of DERs. We note that there is some cost associated with such work.
- 'Fair curtailment' approaches coupled with use of controllable load, such as in the mechanism set out by Simon Heslop may enable higher penetrations of DER whilst maintaining fair network access.

For further details on this work and the context in which it sits, please refer to the attached paper, entitled '*Data driven exploration of voltage conditions in the Low Voltage network for sites with distributed solar PV*'.

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[6] This is an area of ongoing work in which we are aiming to quantify the current volume (and value) of 'spilled' solar PV generation.

[7] There is anecdotal evidence that this is already occurring in some regions, where excessive voltages exacerbated by legacy PV are preventing inverter connected batteries that do comply with AS4777.2 (2015) from charging, despite that this would help reduce voltages.

Focus 2: PV response to 'extreme' conditions

Context

The Australian Energy Market Operator (AEMO) has identified the lack of visibility and control over DERs as a significant challenge as the electricity system evolves to a more decentralised model. In particular, one emerging challenge is that the aggregate response of distributed (rooftop) solar PV can have material impact on system security following contingency events.

The response of inverters to frequency excursions is not a particularly new challenge (refer to 50.2Hz issues in Germany for instance) however the recent work undertaken by CEEM has indicated that response of inverters to voltage excursions following major events is also of concern.

As noted above, the current inverter connection standard focuses primarily on responding to voltage conditions on a day to day basis, in order to manage over voltage (amongst other critical functions). As result, there are no specific high or low voltage *ride through* requirements, and subsequently the voltage set points specified are extremely important for determining how the PV fleet is likely to behave following contingency events. In contrast, the inverter connection standard widely adopted across the USA (IEEE 1547 April 2018) was recently updated to include voltage ride through requirements during 'abnormal' conditions.

CEEM's work

CEEM's analysis has shown that a large volume of solar inverters disconnected following two separate non-credible contingency events in the NEM during the past 18 months. The first was located in South Australia on 3 March 2017 and closely resembled the conditions that resulted in the 2016 South Australia system black event. In this instance, the loss of PV exacerbated conditions.

Figure 2 below indicates the demand across South Australia over the event period. It initially dropped by ~400MW, then increased by ~150MW, which is believed to have been due to solar PV disconnection, and presented additional challenges for AEMO. Figure 3 shows the aggregate response of solar PV based on Solar Analytics data – it shows that PV generation did indeed reduce substantially for a short time at the time of the event. Figure 3 also shows the average local voltage and frequency conditions, with a voltage spike registered[8], likely the trigger for the PV response.

[8] There are some limitations to this analysis due to the method of data collection.

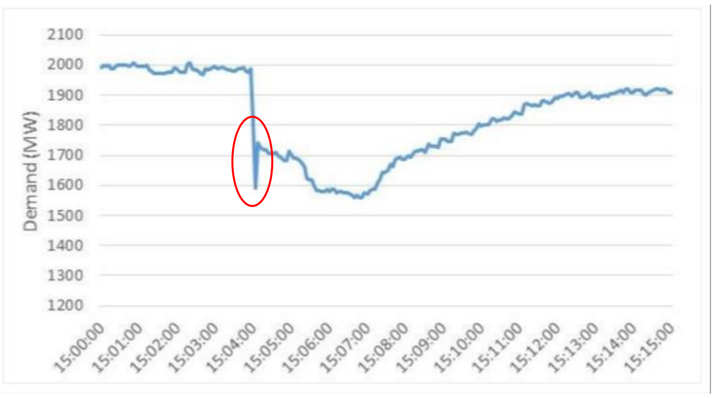

Figure 2 Demand in South Australia, AEMO 2017[9]

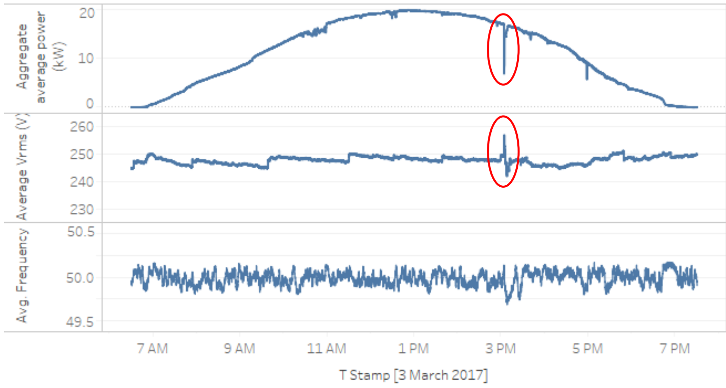

Figure 3 Aggregate solar PV response to event (top), average local voltage (middle), average local frequency (bottom)

The second event occurred in Victoria on 18 January 2018, when the loss of solar PV similarly exacerbated conditions. Notably, preliminary analysis has indicated that the response of PV inverters was centred in Melbourne, whereas in the South Australian case there was disconnection observed across the state.

Please note that a publication on this work entitled '*Possible system security impacts of distributed photovoltaics response to voltage excursions*' is forthcoming.

Potential implications

The relevance of this work to the ENERF review would appear to be as follows:

- **DNSPs play a key role in determining inverter connection standards:** as the solar PV (and future DER) fleet increases in size, the response during credible and on-credible contingency events is going to become more critical.
  - → The requirements imposed on inverters no longer merely affect the distribution network, and as such, it is recommended that ride through

[9] Incident report available here: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Report-SA-on-3-March-2017.pdf

requirements are considered. DNSPs are well placed to impose requirements.

- **Governance of DERs needs to be considered:** there is a broader question regarding the governance of DERs which we recommend the Commission consider (noting that it may sit outside the scope of this review). In particular:
  - → Are the existing inverter connection frameworks appropriate and do they strike an adequate balance between cost and control across the spectrum of system capacities[10]?
  - → What are consumer rights and responsibilities as electricity generators and how does this change across the spectrum of system capacities?
  - → In an increasingly distributed future, what role could DNSPs and third parties play in diagnosing, predicting and managing DER response to contingency events? How could this function interface with AEMO and support system security.

- **Improved visibility is likely to provide benefits:** operational data in the LV network may aid with ensuring system security into the future. DNSPs and/or third parties (such as aggregators, analytics or forecasting providers) may be well placed to assess PV behaviour and aggregate this information up to AEMO. We note that the recent AEMC rule change regarding the DER register related to this point. Further, the DER Register rule change referred to the Finkel Review recommendations regarding DERs and data; both static and real-time. We emphasise that such real-time data for DERs could prove invaluable.

If you have any questions on the views provided here or supporting analysis, please do not hesitate to get in touch.

Best regards,

Naomi Stringer
PhD Candidate
School of Photovoltaic and Renewable Energy Engineering, UNSW
n.stringer@unsw.edu.au

Dr Anna Bruce
Senior Lecturer
School of Photovoltaic and Renewable Energy Engineering, UNSW
a.bruce@unsw.edu.au

A/Prof. Iain MacGill
School of Electrical Engineering and Telecommunications &
Join Director, Centre for Energy and Environmental Markets, UNSW
i.macgill@unsw.edu.au

[10] i.e. from residential ~5kW systems through to commercial and industrial ~200kW systems, or even MW scale systems.