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Investigation of distributed energy resources curtailment in South Australia

Baran Yildiz[1,2], Naomi Stringer[1,2], Sophie Adams[1,4], Shanil Samarakoon[1,4], Anna Bruce[1,2], Iain MacGill[1,3], Alistair B. Sproul[1,2]

[1]*Collaboration on Energy and Environmental Markets UNSW, Sydney, Australia*
[2]*School of Photovoltaic and Renewable Energy Engineering UNSW, Sydney Australia*
[3]*School of Electrical Engineering and Telecommunication UNSW, Sydney, Australia*
[4] *School of Humanities and Languages UNSW, Sydney, Australia*

Voltage management in low voltage (LV) networks is one of the most imminent challenges posed by the integration of increasing levels of distributed energy resources (DER). Traditionally, in a network with uni-directional energy flow, distribution network service providers (DNSPs) set the LV voltages at the higher end of their allowed range to maintain reasonable voltages during peak demand periods, especially driven by air-conditioning demand. However, as energy flows bi-directionally through the LV network with increasing levels of DER installations, DER exports can push the local voltages over the recommended ranges. To help DNSPs in managing network voltage effectively, it is increasingly required that inverter based DER implement one or more of the following power quality response modes (PQRM):

1. Tripping (anti-islanding and limits for sustained operation) on excessive voltages
2. Volt-VAr (V-VAr)
3. Volt-Watt (V-Watt)

The PQRMs effectively curtail power output which may limit opportunities and revenue that DER owners obtain from their investments. On the other hand, these modes can help with the management of voltage and therefore, support the integration of higher levels of DER.

Our research group in Collaboration on Energy and Environmental Markets (CEEM) at UNSW collaborated with industry partners AGL, SA Power Networks (SAPN) and Solar Analytics in a 6-month RACE for 2030 fast-track project: Curtailment and Network Voltage Analysis Scoping Study (CANVAS) [1]. CANVAS's main motivation was to develop preliminary socio-technical insights to inform industry stakeholders and policy makers about the current state of DER curtailment due to PQRM requirements. CANVAS consisted of two research streams, social science and technical data analysis, with both delivering evidence-based results that have important implications for Australia's fast growing and ever-changing energy landscape, where previous evidence-based results and studies have been limited.

In this paper, we present an overview of the results from the technical data analysis which investigated two datasets including 996 BESS sites from AGL's Virtual Power Plant (VPP) trial in metropolitan Adelaide and 500 D-PV sites from Solar Analytics' customer database in metropolitan Adelaide. CANVAS was the receipient of Microsoft AI for Earth grant and main data analysis for the big data (~7 TB) was carried in Microsoft Azure Data Explorer platform. The analysis focused on the first two PQRM modes: tripping (anti-islanding and limits for sustained operation) and Volt-VAr curtailment and did not analyse Volt-Watt mode which is expected to cause more significant curtailment than the first two modes; therefore, the results presented in this paper are likely to underestimate the extent of curtailment.

Tripping (anti-islanding and limits for sustained operation) curtailment

The D-PV tripping curtailment analysis applied the methods developed in [2] to identify the start and end points for periods in which D-PV generation reduced to near zero. A linear approximation method is applied to non clear-sky days, whilst the polyfit-iteration method is applied to clear-sky days to estimated curtailment, as described in [2]. The BESS tripping curtailment analysis applied the methods developed in [1] which focused on instances where BESS real power output dropped to zero even though BESS had sufficient state of charge (SOC) to discharge when site was net importing or sufficient depth of discharge (DOD) to charge when site was net exporting. It was more challenging to define the tripping curtailment for BESS compared to D-PV systems. This is because BESS has storage capability and for the instances where BESS could not discharge due to tripping, the unused stored energy will be available for later use. Similarly, for the instances where BESS could not charge due to tripping, the excess-D-PV generation can be exported later (assuming there is no export-limitation which is out of the scope of this study). Nevertheless, the analysis focused on the instances where BESS's operational capabilities were limited by the identified tripping.

Figure 1 shows the distribution of D-PV tripping curtailment for the studied 500 D-PV sites. The average D-PV curtailment was low with 0.35% of generation being lost. On the other hand, a small proportion of sites are found to be significantly impacted, consistent with previous work [2]. The most impacted D-PV site in the dataset experienced around 20% curtailment over the 10-month period, however the majority experienced negligible curtailment as shown in Figure 1. Further, the proportion of days on which some curtailment occurred was relatively high, with 20% of sites experiencing curtailment on at least 21% of days over the 10-month period. This suggests, that whilst curtailment due to tripping impacts a small proportion of overall generation, it does appear to occur frequently.

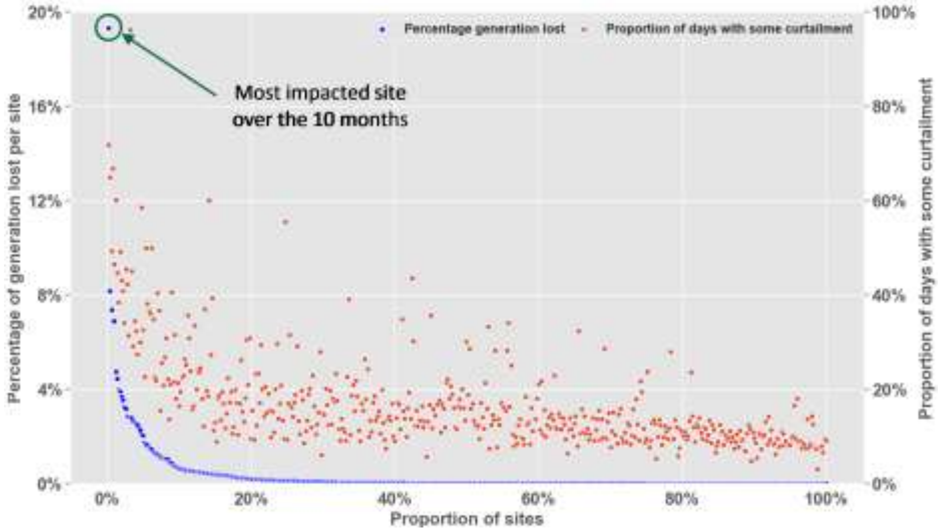

Figure 1 Distribution of D-PV tripping curtailment: percentage of total generation being curtailed and proportion of days with curtailment occurring for 500 D-PV sites

Figure 2 presents 100 AGL VPP sites with highest tripping curtailment shown as a percentage of the total D-PV generation. The site with the highest curtailment lost around 1.75% of total generation and great majority (99%) of the VPP fleet lost less than 1% of total D-PV generation due to tripping curtailment. Figure 2 also breaks the curtailment down to instances of charging and discharging. It is seen that tripping curtailment is mostly attributed to instances where BESS would otherwise be discharging to avoid imported energy.

It is important to emphasize that depending on the VPP's operational strategy, the VPP operator may decide to stop discharging batteries at any point in time and reserve the BESS's SOC. For example, a short term forecast of a high spot price event may trigger BESS to stop discharging immediately. Or similarly, a VPP operator may decide to stop charging batteries and start exporting all available excess D-PV generation due to an operational decision. Therefore, it is not straightforward to differentiate these VPP decision-based events from real tripping events, since during both types of events BESS real power drops to zero and remains inactive for a period of time.

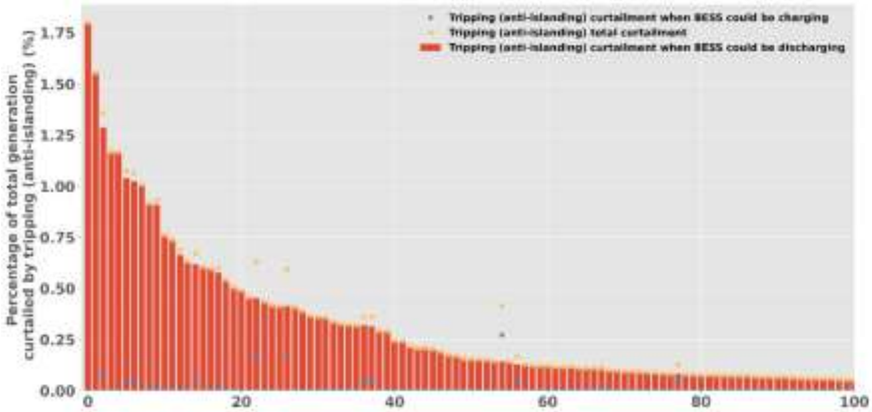

Figure 2 Percentage of total generation curtailed by tripping (anti-islanding) for 100 BESS sites with highest tripping curtailment

Volt-VAr (V-VAr) Curtailment

Volt-VAr (V-VAr) curtailment analysis is carried in three steps. Firstly, BESS and D-PV system VAr characteristics are investigated using real operational data. In the next step V-VAr curtailment is investigated using real operational data and in the final step, future V-VAr curtailment scenarios are modelled under different V-VAr curves referenced from different regulations and standards. In this paper, we present results from the second step, and readers are encouraged to refer to [1] for more details on other steps of V-VAr curtailment analysis.

During the D-PV generation window, injection, or absorption of VAr may limit the maximum power as per the limited VA rating of the D-PV inverter as demonstrated in Figure 3. Similarly, injection or absorbtion of VAr may limit the real power output of BESS due to its limited VA rating as demonstrated in Figure 4. Different to D-PV where V-VAr curtailment can occur only during the solar hours, especially during peak irradiance, BESS V-VAr curtailment can take place throughout the day. Furthermore, like the tripping curtailment, it is more challenging to define a definite 'loss' due to V-VAr curtailment for BESS as the energy that can't be discharged or charged during curtailment events can be used later. Nevertheless, the analysis focused on all instances where BESS's operational capabilities were limited by the VAr injection or absorbtion.

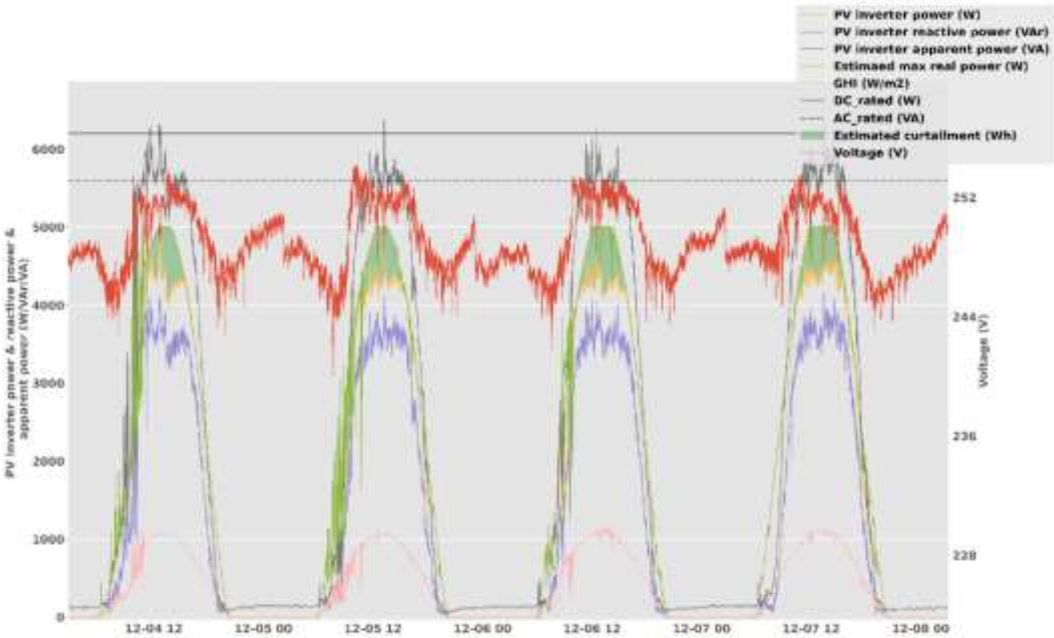

Figure 3 Example operation from a sample D-PV inverter where energy curtailed by V-VAr is highlighted by the green shaded area

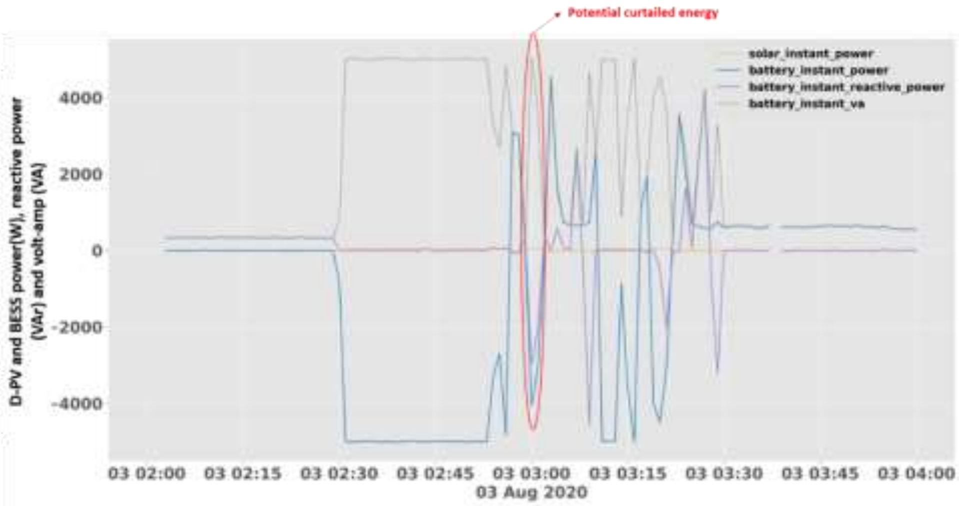

Figure 4 Example daily operation from a sample BESS where V-VAr curtailment can be observed

The results showed that V-VAr curtailment was more significant for D-PV compared to BESS like the tripping curtailment. For D-PV sites, the site with highest V-VAr curtailment lost 4.6 % of total generation and for the 10 sites highest curtailment, the lost generation was greater than 1% of total generation. The BESS site with highest V-VAr curtailment only lost 0.06 % of total generation and average V-VAr curtailment per site was negligible. Table I summarizes the curtailment results for the two studied datasets. It is seen that total curtailed energy due to the studied two PQRMs is less than 1% of total generation. For D-PV systems, tripping and V-VAr caused almost equal curtailment whereas for BESS, tripping curtailment made up 90% of the total curtailed energy. Further analysis in [1] also showed that although the overall curtailment was small, it could incur up to $35k/year of financial losses for the VPP aggregators depending on the spot market prices.

Table I Summary of the anti-islanding (tripping) and V-VAr curtailment results

	D-PV sites (Solar Analytics – 500 sites)	**BESS sites (AGL – 996 sites)**
Total curtailed energy (kWh/year)	6,301	4,434
Average curtailed energy per site (kWh/year/site)	13	5
Total curtailed energy as a percentage of total generation (%)	<1%	<1%
Percentage of total curtailment due to tripping (anti-islanding)	48 %	90%
Percentage of total curtailment due to V-VAr	52 %	10%

Even though the overall curtailment was small, some sites lost up to 20% of total generation which raises fairness concerns regarding the DER curtailment. Further analysis will be carried to investigate the sites which experienced highest curtailment to gain insights into potential causes. Moreover, future research will analyse the impact of V-Watt curtailment which will give a more complete picture for the extend of the DER curtailment.

References

[1] Yildiz B, Adams S, Samarakoon S, Stringer N, Bruce A, MacGill I. Curtailment and Network Voltage Analysis Study (CANVAS) Project Report. Sydney: 2021.

[2] Stringer N, Haghdadi N, Bruce A, MacGill I. Fair consumer outcomes in the balance: Data driven analysis of distributed PV curtailment. Renew Energy 2021;173:972–86. https://doi.org/10.1016/j.renene.2021.04.020.