Data-driven assessment of DPV inverter behaviour under enhanced voltage management

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As distributed PV (DPV) penetrations across Australia have grown, they have brought with them new complexities for maintaining power system security. Aspects of the Australian Standard for low-voltage inverters (AS4777.2), which specifies behaviours expected of PV inverters have recently been revised, including for disturbance ride-through and power quality responses. Increasingly, network service providers have been implementing further capabilities to help manage DER in the network. This includes flexible exports, dynamic operating envelopes and emergency backstop mechanisms. In November 2022, a contingency event occurred in which South Australia (SA) islanded from the rest of the National Electricity Market (NEM) and some of these mechanisms were utilised to support the power system. Of particular note was the application of Enhanced Voltage Management (EVM) to curtail distributed PV during extreme power system conditions. Data collected after the event was used to evaluate the effectiveness of these mechanisms and identify the impacts on the PV systems.

Event overview

At 4:39pm AEST on 12 November 2022, storms caused a transmission tower in SA to fail and resulted in the state islanding from the rest of the NEM. For the following seven days, the electricity grid in SA operated as an island. Forecast high generation from DPV raised concerns of minimum operational demand being exceeded and DPV curtailment of up to 400MW was employed to maintain power system security.
The distribution network service provider in SA, SA Power Networks (SAPN), used four mechanisms to curtail solar PV: SCADA controlled generation, Smarter Homes regulations, Flexible Exports, and Enhanced Voltage Management (EVM). SCADA control applies to larger DPV systems (typically > 200kW) and allows these systems to be directly turned off when necessary. The Smarter Homes regulations were introduced in September 2020 and require all newly installed DPV systems in SA to appoint a relevant agent with the capability to disconnect or export-limit the system when requested by SAPN. The flexible exports scheme allows SAPN to remotely set export limits to enable higher hosting capacity on the network. EVM is considered a last-resort method in which distribution network voltages can be increased to reduce DPV generation through power quality response modes and protective functions. This has the benefit of being able to target all PV systems independent of compliance with Smarter Homes, and during telecommunications outages. However, it does not discriminate between DER inverters on a feeder and so will impact both PV and battery inverters. This may cause issues if the DER system is being used for other purposes that may be assisting to maintain system security, for example as part of a virtual power plant. Furthermore, the response of each inverter is difficult to predict since it will depend on the local conditions and the settings applied on the device.

Method

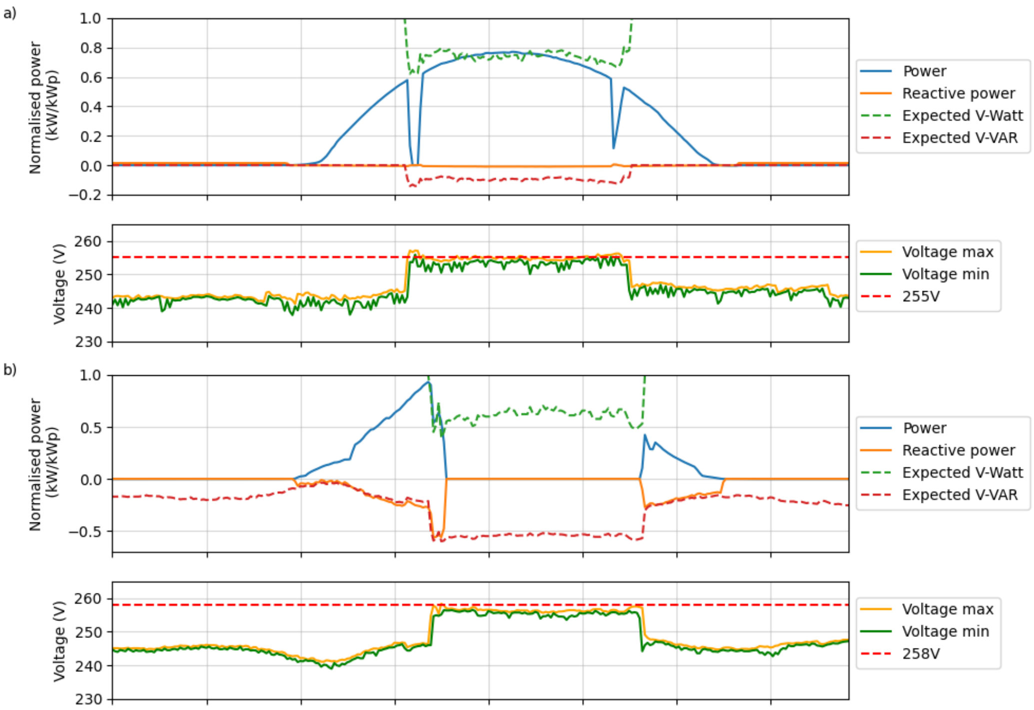
This study aimed to assess how DPV operated during EVM. The analysis focussed on a single day during the event, the 17th of November, because it was a clear sky day and so variations in PV output were less likely to occur due to weather conditions. Data was collected from around 2800 sites at a 5-minute resolution from solar monitoring company Solar Analytics. PV behaviour at each site was classified into one of the following categories: sustained disconnect, unsustained disconnect, power quality (PQ) response, off all day, low voltage, or undefined. The criteria for each is given in Table 1. Note that these categories are not mutually exclusive and sites were categorised into the first relevant category (in the order provided in the table).

Table 1 Summary of the criteria applied to categorise PV responses to EVM.

Category		Criteria
Sustained disconnect		Power dropped to less than 5% of rated capacity for at least 4 hours consecutively.
Unsustained disconnect		Power dropped to less than 5% of rated capacity for at least 1 timestep and less than 4 hours, or non-consecutively.
PQ response	V-VAr	Reactive power decreased to more than 10% of rated power.
	V-Watt	Power stayed below 95% of the V-Watt curve.
Off all day		Power remained at less than 5% of rated power between 8:30am and 5:30pm.
Low voltage		Site voltage was not measured to exceed the 255V threshold.
Undefined		The site did not fall into any of the other categories.

Results

A number of different behaviours were observed within the dataset. This variation was due to differing voltage conditions across the network, and different responses of PV inverters depending on their settings, when they were installed, what standard was applied, and what setpoints were used. Sample profiles are included in Figure 1. a) disconnected twice, at the start and the end of the day as the voltage was raised and lowered and was classified as unsustained disconnect. It did not perform either type of PQ response. b) disconnected at around 10am and remained off until it reconnected at ~5pm, hence was classified as sustained disconnect. It also performed PQ responses in line with AS4777.2:2020. c) displayed cycling behaviour and a compliant V-Watt response, and was classified as unsustained disconnect.



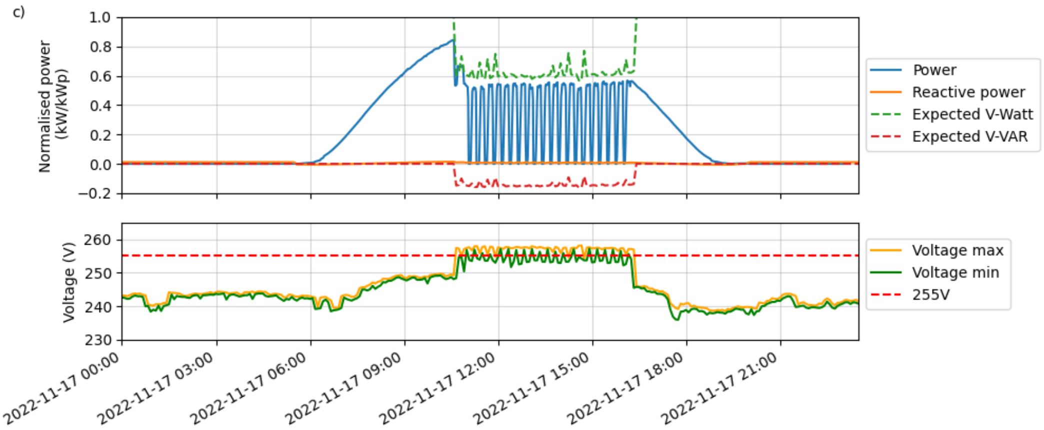


Figure 1 Example profiles showing some of the responses of individual systems. a) unsustained disconnect. b) sustained disconnect with PQ responses. c) unsustained disconnect with cycling and V-Watt.

Figure 2 shows the breakdown of responses observed within the dataset. Just under half of the sites disconnected for some period of time during the day. Most of these were observed to do an unsustained disconnect (red). This includes sites where EVM was activated and/or voltage was measured to be elevated for less than 4 hours. This also includes sites that cycled (continual disconnect and reconnect). Around 20% of sites were classified as sustained disconnect (dark blue), which will include any sites that were targeted by Smarter Homes or flexible exports activation. The most common response across the analysed sites was a power quality response with no disconnection (green). A small percentage of sites were not operating that day or didn't measure elevated voltages (purple and light blue respectively), and 10% of sites were not observed to respond in any of these ways (orange).

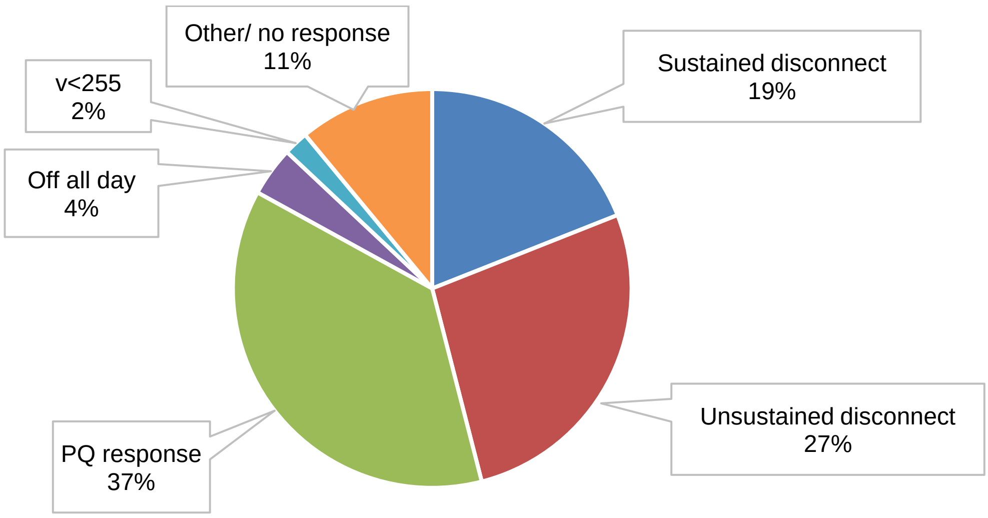


Figure 2 Categorised responses of PV systems to EVM.

An odd behaviour that was observed in the data was cycling. Around 15% of sites were observed to repeatedly switch on and off for some period of the day. This is an unintended side-effect of the elevated voltages. It is suspected to be caused by the 10-minute sustained overvoltage function specified in AS4777.2:2015 and 2020. When aggregated across multiple sites this behaviour is smoothed out and still results in decreased generation. However, more research is required to understand the effects of this on equipment and implications for system restart where oscillations may cause instability.

Conclusion

EVM has been shown to be an effective method for reducing the output of DPV under emergency minimum demand conditions. It was estimated to deliver at least two-thirds of the DPV curtailment during the November 2022 event (AEMO, 2023), which represented an extreme power system scenario. Importantly, the impacts of elevated voltages on appliances are unclear and EVM is only anticipated to be used as a last resort (similarly to Under Frequency Load Shedding). In addition, it has some limitations such as causing cycling in DPV output. EVM is also expected to become less effective in the future as more DPV systems are installed under AS4777.2:2020 and have power quality responses enabled to help lower local voltages before they reach the tripping setpoint. This event is a useful case study and has provided rich datasets which can be used to further analyse DPV responses to elevated voltages. Future work will utilise this data to undertake an assessment of PQ responses and in-field compliance with the specified V-Watt and V-VAr profiles. This event will also be used to investigate the implications for virtual power plant operations especially Frequency Control Ancillary Services (FCAS) delivery.

References

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