AEMO Virtual Power Plant Demonstrations

July 2020

Knowledge Sharing Report #2

Important notice

PURPOSE

The purpose of this document is to provide a second update to the Australian Renewable Energy Agency (ARENA) and the industry regarding the Virtual Power Plant (VPP) Demonstrations progress and lessons learnt.

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VERSION CONTROL

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ARENA summary

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AEMO contact	Jacqui Mills

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Executive summary

This report provides an update to the Australian Renewable Energy Agency (ARENA) and the industry regarding the Virtual Power Plant (VPP) Demonstrations progress and lessons learnt.

Key insights gained by the VPP Demonstrations since commencement (July 2019) include:

General insights

- The operational visibility and capabilities shown in the VPP Demonstrations project represent foundational building blocks to enable AEMO to operate the power system with high levels of distributed energy resources (DER).
- The VPP industry remains small, and in the early stages of capability development.
- AEMO is engaging with over 20 early stage VPPs that are seeking to rapidly develop their scale and capability to deliver energy services and competitive business models to consumers.

Performance insights

- VPPs continue to demonstrate their effective capability to respond to both contingency Frequency Control Ancillary Services (FCAS) events and energy market price signals.
- VPPs have demonstrated promising capability to accurately forecast their performance. Evidence indicates that 1-hour-ahead forecasts are clearly most accurate, and that there are only minor variances between the other intra-day and day ahead forecasts. Accurate forecasting would be an important capability for VPP participation in potential ahead markets in future.
- The forecasting and control methodology of VPPs will require careful planning to ensure the use of the resource can be well forecast, so as to provide assistance to the grid where required.
- When operating in both the energy and FCAS markets, VPPs should consider how responding to an energy price signal that conflicts with a contingency FCAS event could impact their ability to accurately deliver on their enabled FCAS.

Market insights

- Evidence indicates that VPPs could alleviate operational challenges such as low generation reserves and low minimum demands as they grow in scale and take advantage of both high prices during peak demand and low/negative prices during peak exports/low minimum demand events.

Data quality insights

- Evidence indicates that VPPs experience communications drop-outs that result in around 5-8% of required data from their fleet missing at any given time.
- When considering how VPPs are scheduled for energy in future, it is important to consider how communication issues could impact the accurate delivery of an energy market dispatch instruction.

Cyber insights

- Communications between households and VPP operators highlight the challenges faced with relying on household technology and connectivity through public telecommunication networks, which pose a cyber security risk that must be effectively managed.

1. Introduction

1.1 Background

The Virtual Power Plant (VPP) Demonstrations developed by the Australian Energy Market Operator (AEMO), in collaboration with the Australian Renewable Energy Agency (ARENA), the Australian Energy Market Commission (AEMC), the Australian Energy Regulator (AER), and members of the Distributed Energy Integration Program (DEIP), aim to understand how VPPs can integrate into the future energy landscape.

The Final Design Document[1] for the demonstrations outlines objectives, the approach taken, and various research questions. The objectives include:

- Identifying if VPPs can reliably control and orchestrate a portfolio of distributed energy resources (DER) to deliver network support services such as contingency Frequency Control Ancillary Services (FCAS).
- Understanding how VPP systems can provide operational visibility to AEMO.
- Informing new or suggesting amendments to regulatory arrangements affecting potential VPP participation.
- Providing insights into consumers' experience, and what type of cyber security capabilities are required.

The Program's first Knowledge Sharing report, published in March 2020, addressed early findings relating to the ability for VPPs to respond to power system events and provide FCAS to maintain power system security. It also provided preliminary insights into price signal responses, value stacking, and revenues for those participating.

Since the publication of the first Knowledge Sharing report, AEMO and the current registered VPP participants – Energy Locals (in consortium with Tesla) and AGL – have had the opportunity to develop further insights into how the VPPs are interacting with the power system. This report shares some of these key learnings and builds on the insights provided previously.

Data and insights provided in this report have been provided or verified by Tesla and AGL, and relate to:

- FCAS enablement and delivery behaviour.
- FCAS and energy provision.
- Performance verification.
- Operational forecast accuracy.
- Battery charge/discharge behaviour.

With further capability to analyse the operation of VPPs, this report will delve further into the islanding of South Australia in February 2020 and use additional data provided by AGL's VPP, which joined in February 2020, to begin answering the questions posed as part of the VPP Demonstrations Program's final design.

[1] Information and documents relating to the VPP Demonstrations Program are at https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/pilots-and-trials/virtual-power-plant-vpp-demonstrations.

2. VPP Demonstrations update

2.1 Participation update

As at 21 July, 2020, the Energy Locals/Tesla South Australia VPP and the AGL VPP remain the only participants in the VPP Demonstrations, although AEMO is engaging with numerous other VPPs regarding their potential participation as they reach the necessary scale and sophistication.

2.1.1 AGL enrolment

AGL successfully completed enrolment in February 2020, providing the demonstrations with additional insights into the ability for VPPs to integrate in to the FCAS market. AGL is utilising the same technology as Energy Locals for the purpose of its VPP operations, the Tesla Powerwall. AEMO has not yet been able to achieve a breadth of technology as per the original objectives, and will seek further participants to achieve this. It is also important to note that, due to the Application Programming Interface (API) integration timings, operational data and findings from AGL were not available at the point of conducting much of the analysis but will be included in subsequent reports as this data becomes available.

2.1.2 COVID-19 impact

Discussion with many prospective participants in the VPP Demonstrations has highlighted impacts from COVID-19 as a significant barrier to enrolment, due to:

- Delay of stock arrival (batteries imported from overseas).
- Delayed installation due to installers living across the border in another state and being impacted by travel restrictions.
- Reductions in workforce to support development of platforms required for sales, VPP orchestration, API development, and other components essential to the success of the VPP.
- Access to resources (funding) as programs are reprioritised.

Despite these challenges, however, approximately a third of these organisations have indicated their intention of joining VPP Demonstrations later in 2020, if the restrictions resulting from COVID-19 ease.

2.2 Project insights

The VPP Demonstrations to date have highlighted two common insights across current and prospective participants:

- Integration of APIs and maintaining data integrity has taken significant time.
- There are increased complexities when end users (customers) are involved in the service delivery pipeline.

2.2.1 Data ingestion

One of the key insights from the VPP Demonstrations is that the process for establishing data sharing arrangements between AEMO and participants is complex and resource heavy. The Demonstrations are establishing these arrangements for the first time, and VPP participants typically have small teams supporting their business units, leading to the API integration process taking a number of months to complete in full.

AEMO managed this process with participants by prioritising the order in which participants integrate with the APIs:

1. Enrolment.
2. Operational – aggregated actuals and forecasts.
3. Device level telemetry.
4. FCAS verification

Prioritisation of API development and integration has been a key learning for AEMO and participants throughout the initial stages of enrolment.

It has also been identified that the current capabilities of household modems, connectivity, and public infrastructure can limit the reliability of information being communicated, due to:

- Weak internet connections.
- Shut down of the 3G telecommunications network.
- Modems temporarily being disconnected for a range of reasons.
- Delays in data being sent through to aggregators after the required timeframe.

This will be further explored in Section 4.1.2.

2.2.2 Consumer dependencies

The nature of dealing with consumers has caused challenges to the onboarding process for many prospective participants:

- Consumers need to engage with and have a level of understanding of what a VPP is.
- Consumers must be willing to participant in the VPP and prescribe a level of control of their household batteries to VPP operators.
- Consumers, as part of the Demonstrations, must agree to a contract containing data sharing agreements with a third party as nominated by AEMO to facilitate the customer insights survey.
- A significant number of consumers must be signed up and have equipment installed/connected prior to being able to enrol in the program.

Due to the minimum FCAS delivery requirements[2] of the demonstration, prospective VPP participants are reliant on consumer uptake. AEMO will continue to work with Customer Services Benchmarking Australia (CSBA)[3] (through the consumer insights study) and prospective VPPs to understand how the consumer experience can be improved. As the VPP industry matures with a track record of performance, and consumer understanding about VPPs improves, participation rates in the demonstrations are expected to increase.

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[2] The VPP Demonstrations requires a minimum of 1 MW of FCAS available to participate.

[3] CSBA provides customer experience research and insights that enable business and organisations to provide better customer experiences.

3. Operational insights

3.1 South Australian separation event – February 2020

On 31 January 2020, a reviewable operating incident occurred in Victoria which involved the non-credible loss of both the Moorabool – Mortlake and the Moorabool – Haunted Gully – Tarrone 500 kV transmission lines, resulting in the electrical separation of the Victorian and South Australian regions in the National Electricity Market (NEM). The Moorabool – Haunted Gully line was restored using temporary towers on 17 February 2020 and the Moorabool – Mortlake line was restored on 3 March 2020[4].

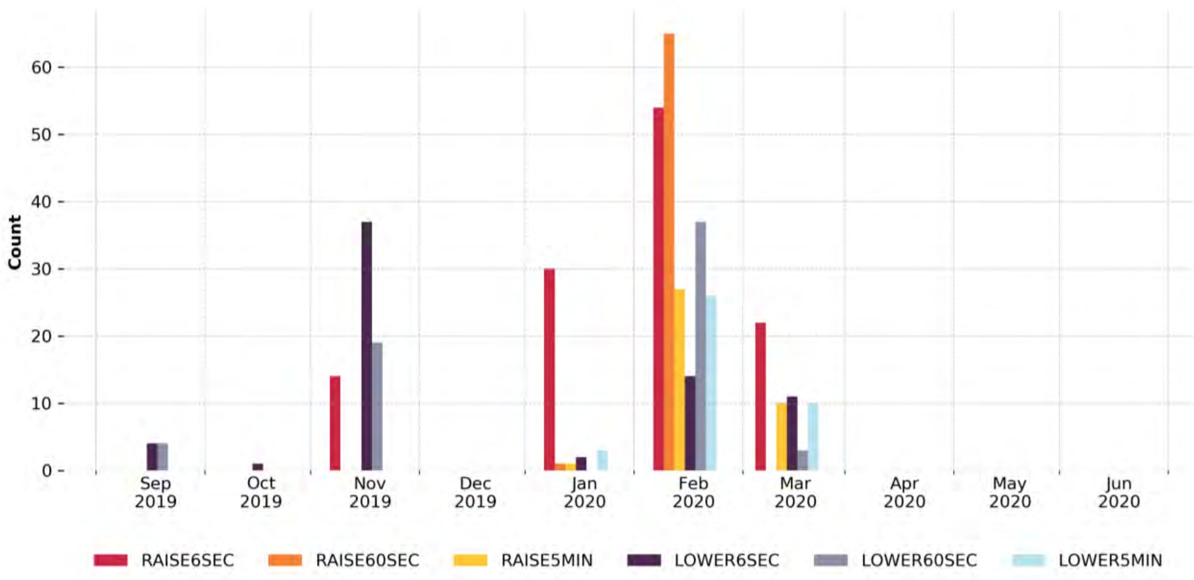
During the period of separation from 31 January to 16 February, FCAS prices in South Australia were elevated.

Figure 1 shows the number of dispatch intervals in which the contingency FCAS price in South Australia settled at over $10,000 per MW, each month between September 2019 to June 2020.

The number of occurrences in February 2020 is noteworthy, even though the islanding event occurred during only the first half of the month.

In November 2019, there were two high priced events. The first occurred on 9 November 2019, when there was risk of islanding which led to localised FCAS requirements. The 6 and 60 second lower services appeared to have seen a considerable number of extremely high prices (similar to in January 2020 for the raise 6 second service). The second event occurred on 16 November 2019, due to the trip of the Heywood interconnector resulting in a five-hour islanding of South Australia in which the 6 second lower and 6 second raise reached the market price cap of $14,700/MWh[5].

Figure 1 Count of dispatch intervals in which FCAS services in South Australia settled at greater than $10,000/MWh, September 2019 to June 2020



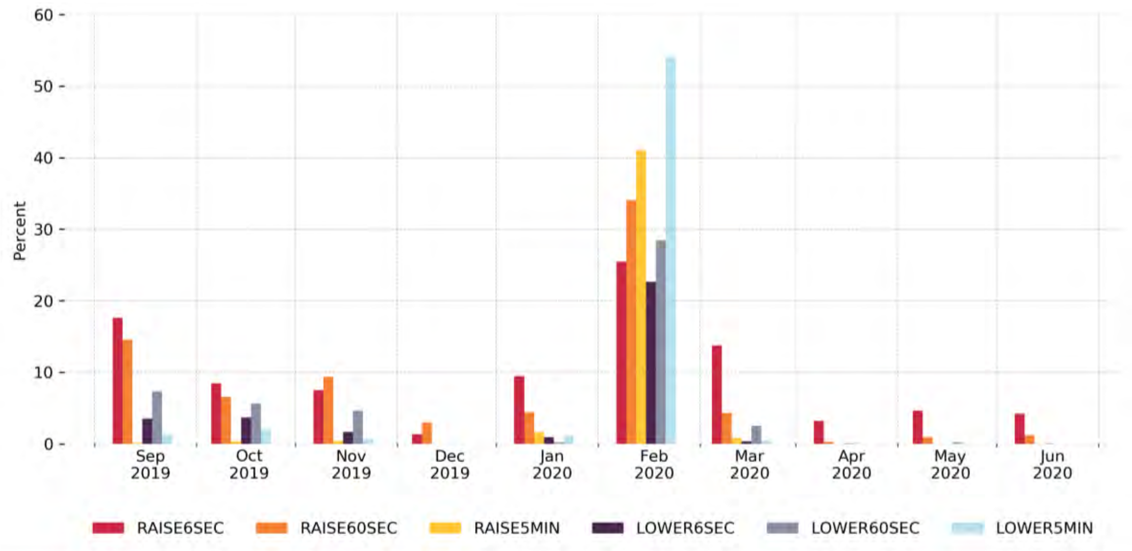
Extremely high FCAS prices are usually associated with incidents, but contingency FCAS prices are usually low ($25/MWh or less). February 2020 saw consistently elevated FCAS prices in South Australia, with all six

[4] AEMO's preliminary report into this event is at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports/power-system-operating-incident-reports.

[5] AEMC's price information available at https://www.aemc.gov.au/news-centre/media-releases/schedule-reliability-settings-2020-2021.

contingency services settling at over $25/MWh for more than 20% of the time, compared with <3% to 10% of the time under normal conditions for raise 6 seconds (see Figure 2).

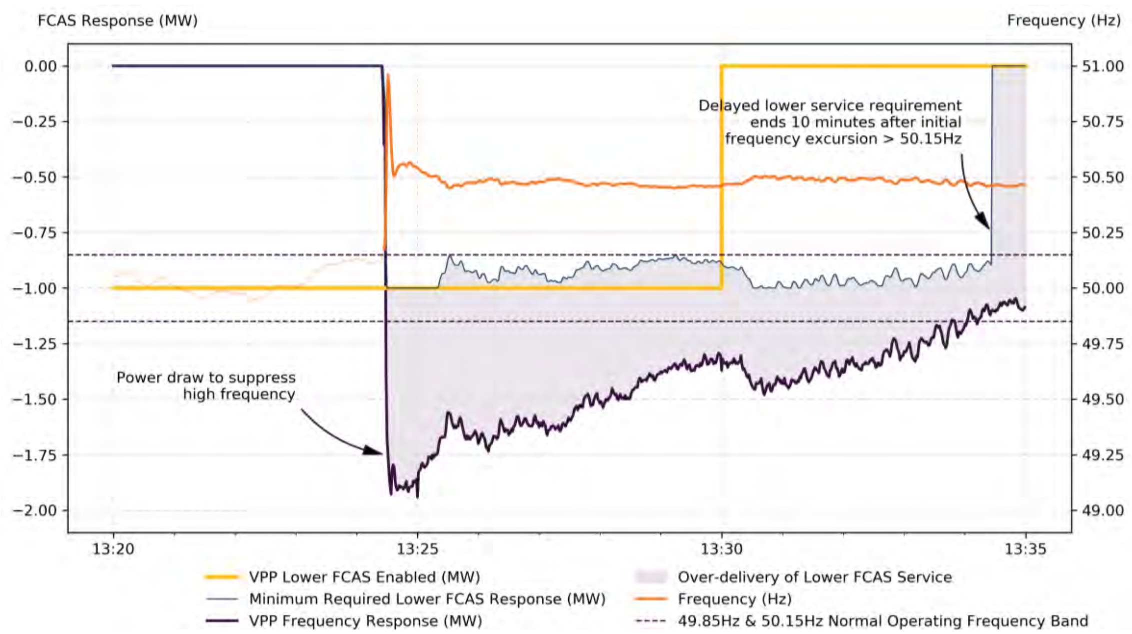
Figure 2 Percentage of dispatch intervals during which FCAS prices exceeded $25/MWh, September 2019 to June 2020



3.1.1 FCAS behaviour during islanding event

The response of the Energy Locals' VPP to the frequency disturbance associated with the disconnection of South Australia from the rest of the NEM is shown in Figure 3. To help suppress the high frequency, the VPP very quickly increased its power drawn to beyond the enabled minimum response. Of particular note is the speed of the response: from zero to approximately 1.9 MW output in under 10 seconds, with a peak rate of change in this period of over 1.1 MW/s.

Figure 3 Response of Energy Locals VPP to contingency event, 31 January 2020



The Energy Locals VPP started operating at 2 MW from mid-November 2019. AEMO has divided the period since then into four 'operating regimes' to compare typical daily contingency FCAS enablement in each operating regime, where 'typical' is characterised by the *median* enablement (see Figure 4).

The four operating regimes are:

a) Mid-November 2019 (start of operations) to end January 2020.

b) 1 February 2020 to 16 February 2020 – the period during which South Australia was separated from the rest of the NEM.

c) Mid-February 2020 to 26 June 2020.

d) 27 June 2020 onwards (increase to 4MW capacity; not shown in Figure 4 due to little data at this point in time).

In Figure 4, positive values represent raise FCAS services (responding to low frequency), and negative values represent lower FCAS services (responding to high frequency).

Raise FCAS services have typically been enabled at maximum capacity (2 MW from approximately mid-November to 26 June 2020). This suggests the batteries are usually available to respond to low frequency events; that is, the fleet is rarely discharged to such an extent that a response of 2 MW could not be achieved.

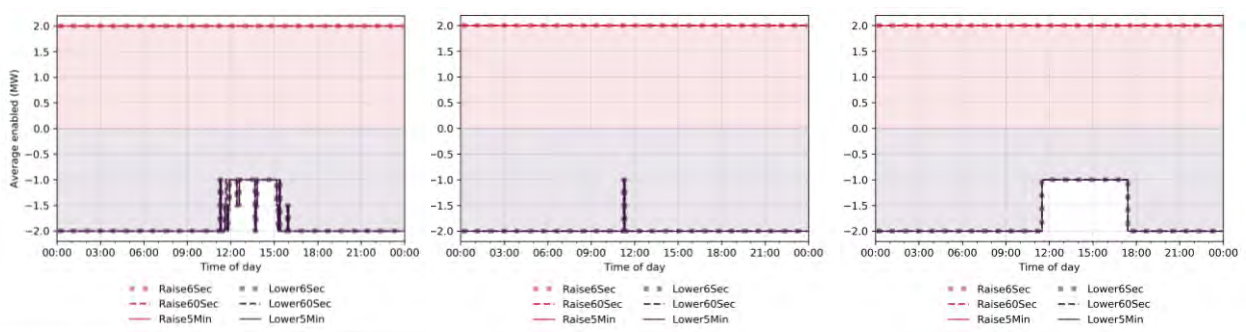
As Figure 4 shows, however, typical lower FCAS services varied between the three periods:

- During the islanded period (b), the VPP was enabled for lower FCAS services at capacity almost constantly, unlike during pre- and post-islanding periods.
- Outside the islanded period, lower FCAS services were typically not enabled either in part or at all during the afternoon.
- During the third period (c), lower services were not enabled until (typically) near 6.00 pm, compared with approximately 3.00 pm before islanding.

It is important that this behaviour is understood more generally – for example, whether the lack of lower FCAS in the afternoon is seasonal, and is common to other VPP operators (and indeed also for utility-scale battery storage) – hence AEMO recommends the VPP Demonstrations should cover at least a year of operation and ideally involve several VPP operators.

Figure 4 Typical (median) FCAS enablement, Energy Locals VPP, before, during, and after the February 2020 South Australia separation

(a)	(b)	(c)



3.2 FCAS and energy delivery during the VPP Demonstrations

To date, the VPP Demonstrations have provided AEMO and VPP participants with a significant amount of data and learnings. As the Demonstrations progress, AEMO will continue to analyse the data available and draw more detailed conclusions which will be shared among the VPP participants and industry. Information about the impact of seasonality, variety of technologies, and further events will become available and inform the future of VPPs outside of the Demonstrations as more participants join.

The following analysis provides insights into the operation of Energy Locals' and AGL's VPPs, both of which use the same underlying battery technology.

3.2.1 FCAS and energy provision under demonstration conditions

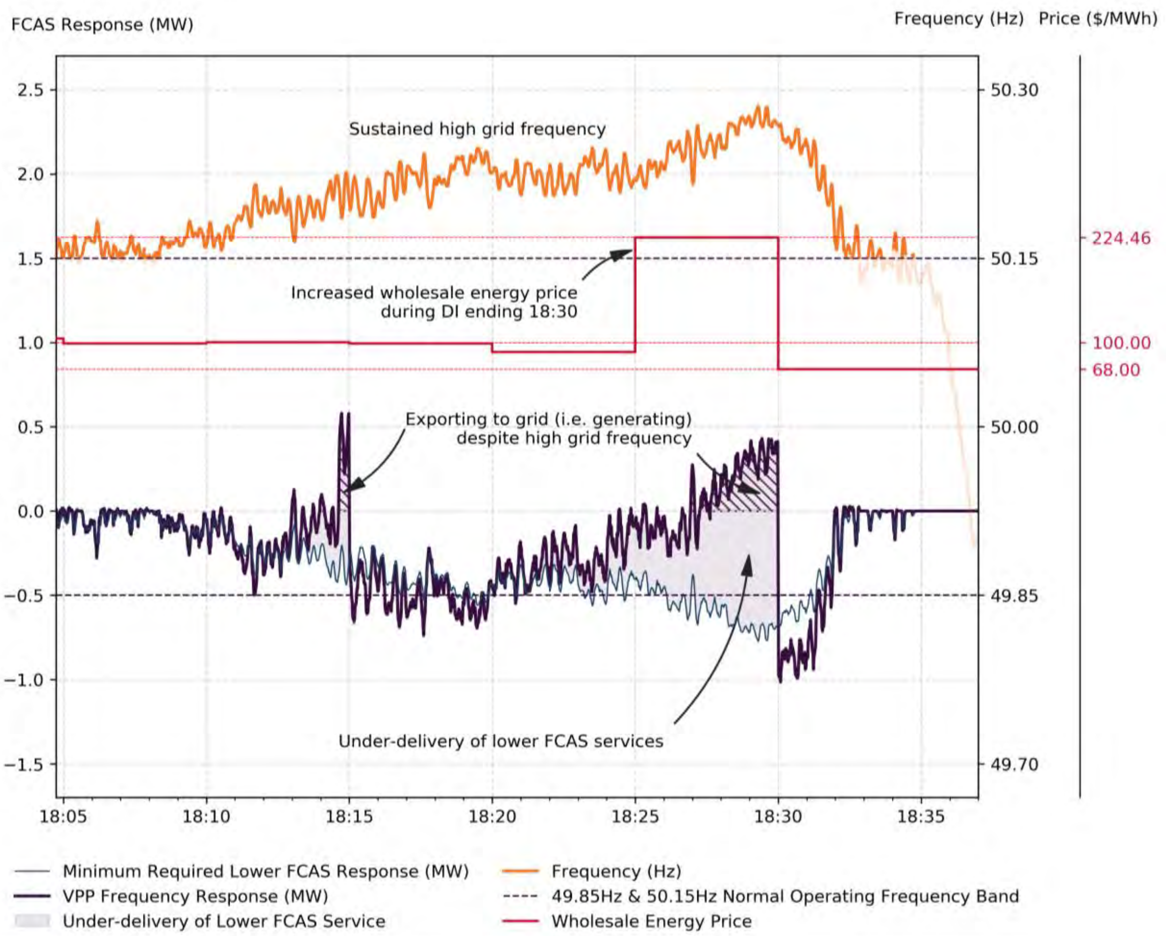
A key question in the VPP Demonstrations Final Design Document is the development of ongoing operational arrangements for DER to participate in the FCAS and energy markets and stack value streams.

AEMO has identified that if a VPP participant responds to energy price signals during a frequency excursion and the change in active power is opposite to the expected frequency droop response, the FCAS provider may not be able to provide sufficient evidence that the VPP remained compliant during the frequency excursion. The response to energy price signals cannot be distinguished in the measurements of power from the FCAS response, and the net outcome is that the data may indicate an under-delivery or unrealistic over-delivery of FCAS.

Value stacking the FCAS and energy markets

This creates a challenge for VPP Demonstrations participants that wish to also respond to energy price signals, demonstrated in Energy Local's under-delivery to a high frequency event in Figure 5, when the high energy price required an opposing response to the lower contingency FCAS event. At the time, the Energy Locals' VPP was operated to stack the revenue gained from both the contingency FCAS and energy markets.

Figure 5 Lower contingency FCAS response and energy price, Energy Locals VPP, 28 January 2020



As a result, Energy Locals has proposed a new method for verifying the FCAS performance, which has been accepted by AEMO for testing in the VPP Demonstrations. With this new method, when the frequency is within the normal operating frequency band (NOFB), the VPP may respond to energy price signals. However, the VPP will prioritise the delivery of contingency FCAS when the frequency is outside the NOFB and it will not respond to energy price signals. A baseline is calculated using the measurements of power from the battery systems over the last 5 seconds before a frequency excursion. The change in active power after the frequency leaves the NOFB is then used to calculate the FCAS response and to verify that the FCAS requirements have been met. This new method is expected to better facilitate the Energy Locals VPP operating in contingency FCAS and energy.

Participants need to carefully consider how to orchestrate the VPP, particularly if value stacking with the energy market, which may involve offering reduced or zero availability in one or more potentially incompatible services. If enabled for contingency FCAS, participants must ensure:

- They are able to deliver the service if a contingency event occurs, and
- Data is obtained to support the verification of this delivery.

If the data indicates a delivery shortfall, it will trigger a settlement clawback process.

3.2.2 FCAS performance verification

There are a number of reasons why the VPPs' FCAS performance is verified; this section lays out these scenarios and provides a worked example.

The actual aggregated FCAS response from the VPP is compared against the minimum required droop response (Figure 6) under the following circumstances:

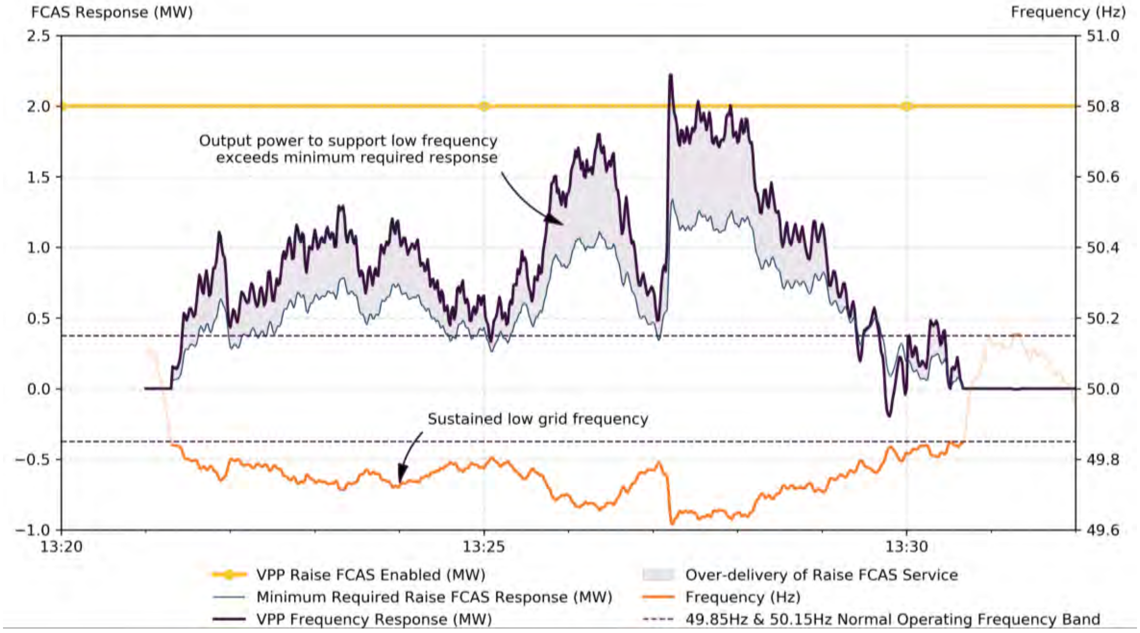
- Initially to register, the VPP participant must undertake a 'VPP wide test' to demonstrate its maximum ancillary service capacity. The participant submits the VPP's response to a historical frequency excursion.
- When seeking to increase the maximum ancillary service capacity of the VPP, a participant can submit the data for a frequency excursion that has already occurred.
- Following a contingency event, AEMO verifies that the response from enabled FCAS providers was in line with the market enablement of the aggregated ancillary service facility.

FCAS verification example

On 2 March 2020, grid frequency decreased below 49.85 Hz shortly after 13:20 AEST, and remained below 49.85 Hz for approximately 10 minutes. Figure 6 shows:

- The response of the Energy Locals VPP (measured response at 1 second temporal resolution) – thick purple line.
- The grid frequency (right axis) – orange line.
- The required minimum response (power, MW) based on a 0.7% proportional droop setting (left axis) – blue line.
- The level of FCAS power for which the VPP was enabled – yellow line (at 2 MW).
- Where the VPP response exceeded the minimum required response – shaded purple area.

Figure 6 Response to low grid frequency, Energy Locals VPP, 2 March 2020



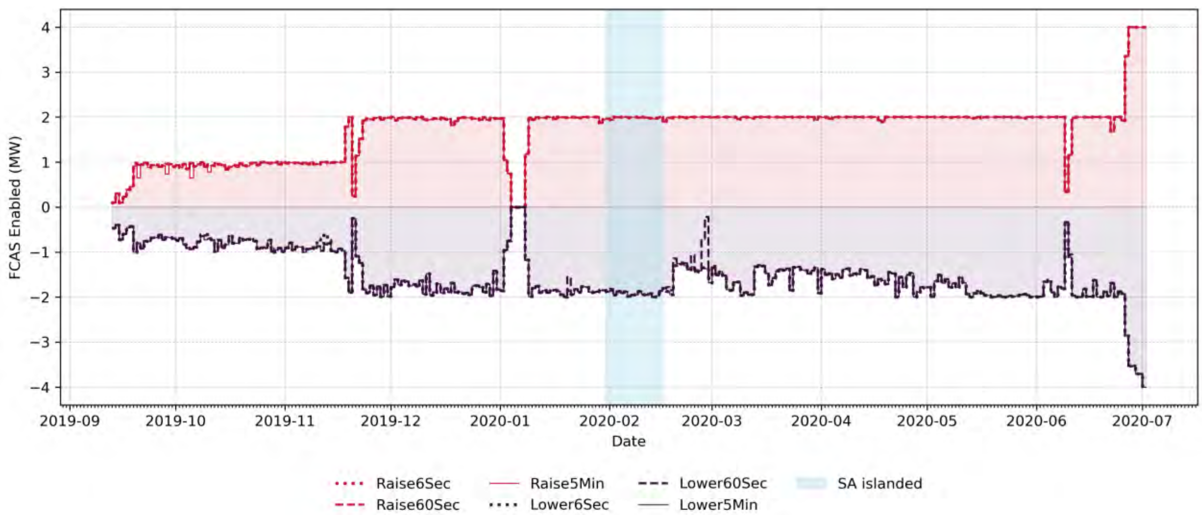
3.3 Contingency FCAS enablement behaviour

As operators gain an understanding of how to manage VPPs, their ability to deliver contingency FCAS is expected to evolve.

The average amount of FCAS (MW) enabled each day by Energy Locals' VPP is shown in Figure 7. This figure highlights:

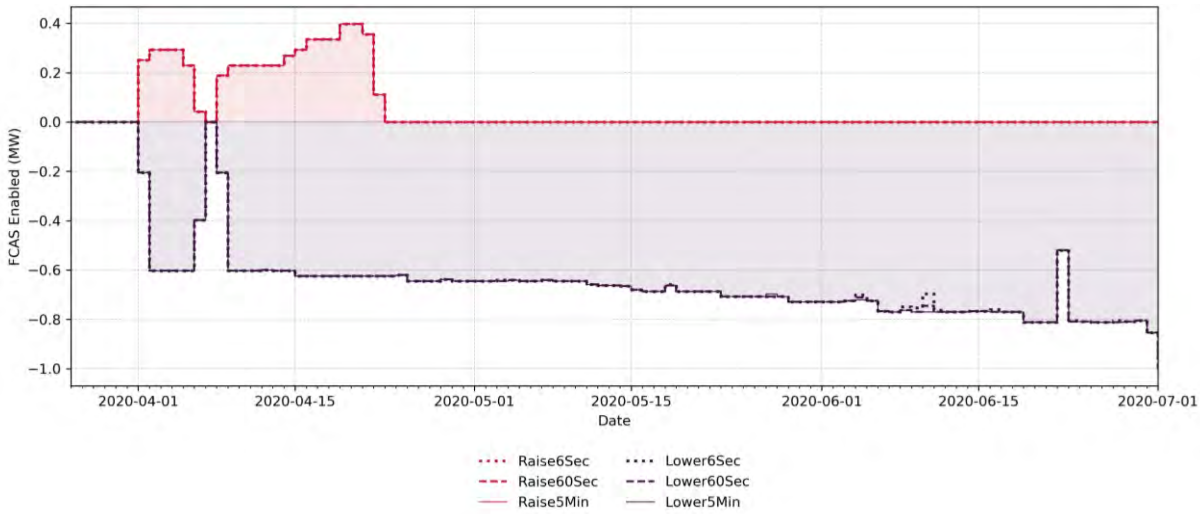
- The step change in mid-November 2019 when the capacity increased to 2 MW.
- An outage period of a few days in early January.
- A possible change in strategy of the provision of lower services from late February.
- An increase to 4MW capacity on 27 June 2020.

Figure 7 Average FCAS enablement each day, Energy Locals VPP, September 2019 to May 2020



AGL's VPP started operating in the contingency FCAS markets by bidding in 1 MW capacity on 1 April 2020; this is a portion of the 3 MW raise services and 2 MW lower services registered under its VPP. Figure 8 shows the average amount of FCAS (MW) provided each day by AGL's VPP. The cessation of provision of raise services from 23 April 2020 is evident, as well as a trend of increasing lower capacity.

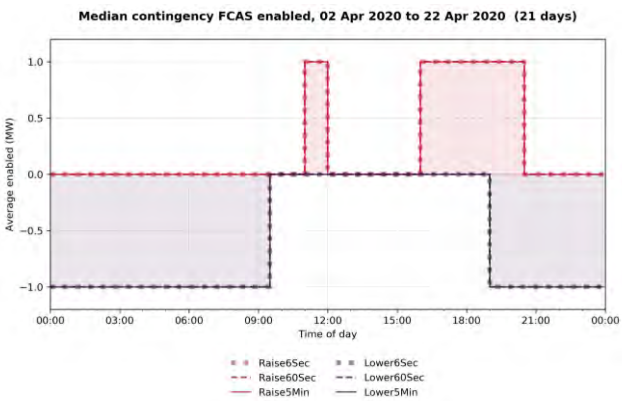
Figure 8 Average FCAS enablement each day, AGL VPP, September 2019 to May 2020

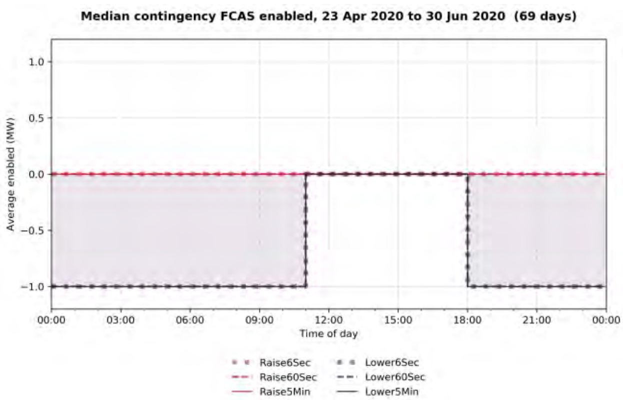


Looking separately at the pre- and post- 23 April periods, Figure 9 shows the typical daily contingency FCAS enablement. 'Typical' is characterised by the *median* enablement, and this figure clearly shows the cessation of raise FCAS from 23 April.

Figure 9 Daily profiles of FCAS enablement, AGL VPP

(a)	(b)





Having a broad range of VPPs delivering FCAS services using varying approaches will help AEMO understand how VPPs may respond and inform expected behaviour.

4. Research questions

The VPP Demonstrations were designed to respond to the research questions outlined in the Final Design Document, which covered operational visibility, market dynamics and planning, local power quality, customer insights, and cyber security. To the extent possible, this report provides early insights and indicates where further data and information is required.

4.1 Operational visibility

Operation visibility insights aim to:

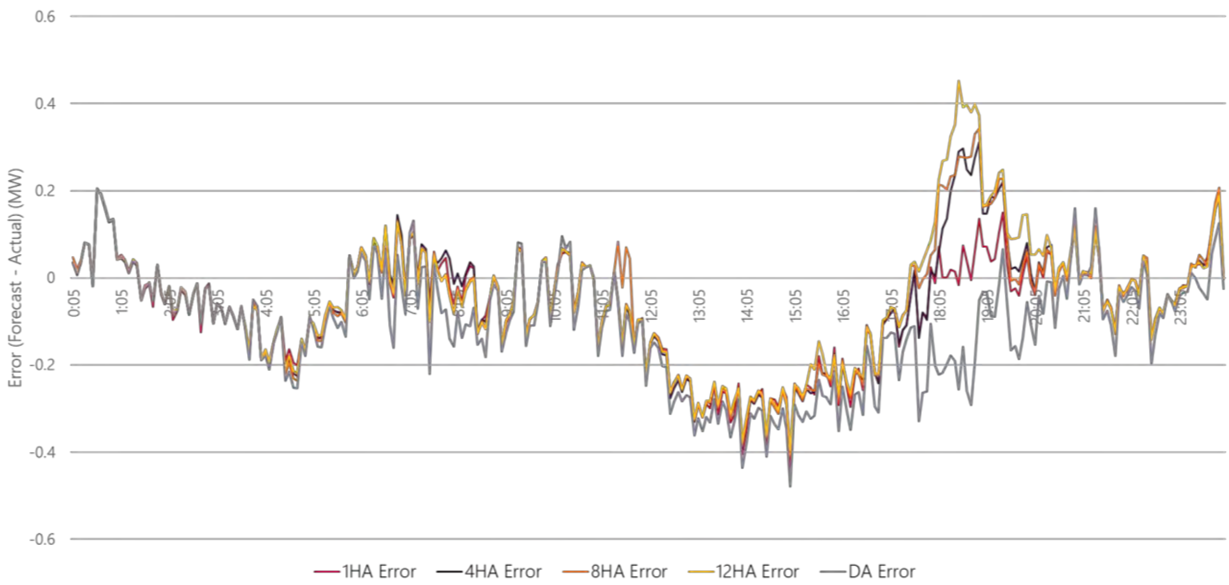
- Explore how accurately operators can forecast VPP capability over various timeframes.
- Explore how these forecasts may feed into existing AEMO forecasts.
- Explore what data AEMO requires to ensure the integration of VPPs at scale without negatively impacting the power system's reliability, security, or efficiency.
- Determine whether large-scale VPPs should become scheduled resources in the energy market, and if so, how and at what threshold should this be implemented.

AEMO has not yet had significantly large enough (aggregated MW) VPPs, or the range of VPPs, to understand whether large VPPs could reliably operate as scheduled resources in the energy market and, if so, how they should be scheduled. The following analysis therefore focuses on understanding the accuracy of VPPs' forecasting, with some assumptions being made as to the other queries posed and an intention to investigate these more fully as the demonstrations mature.

4.1.1 Preliminary analysis: VPP operational data

Data presented in this analysis is for a sample week only (1-7 May 2020). Preliminary analysis of operational forecast performance suggests that promising forecast performance of the VPP controlled generation or load has been observed (see Figure 10).

Figure 10 Forecast error for controlled generation and load of VPPs over a range of forecast time horizons over an averaged 24-hour time period, 1-7 May 2020



This analysis suggests that the forecasting of the daytime and into the typical evening peak demand time is the most difficult to forecast. Given the criticality of peak demands on the power system, the forecasting and control methodology of VPPs will require careful planning to ensure the resource can be utilised to its full potential without compromising power system reliability.

AEMO expects forecast performance to improve with greater diversity of resources through additional installations and increased experience.

Equally, forecasting the required generation across the evening has a tendency to be over-forecast in this sample. Figure 11 demonstrates the average forecasts against actual generation or load at different time horizons (controlled generation is positive, controlled load is negative):

- The forecast of the VPP load during the day and generation at night can be up to 40% different from the actual load when considering the hour ahead time horizon in this sample. AEMO expects that with greater experience and collaboration this can be improved.
- Despite the small sample set, this indicates that 1-hour-ahead forecasts are clearly most accurate, and that there are only minor variances between the intra-day forecasts. Further, it is of note that day-ahead forecasts can be more accurate than intra-day forecasts, presenting an opportunity where VPPs may in future be able to participate in a potential day-ahead market.

Further consideration of how this can be collaboratively improved by AEMO, solar forecast providers, and VPP operators may be required to avoid unnecessary duplication of forecast error in both the VPP operational data and AEMO's DPV generation forecast.

Figure 11 Average VPP forecast vs actual over a range of forecast time horizons, 1-7 May 2020

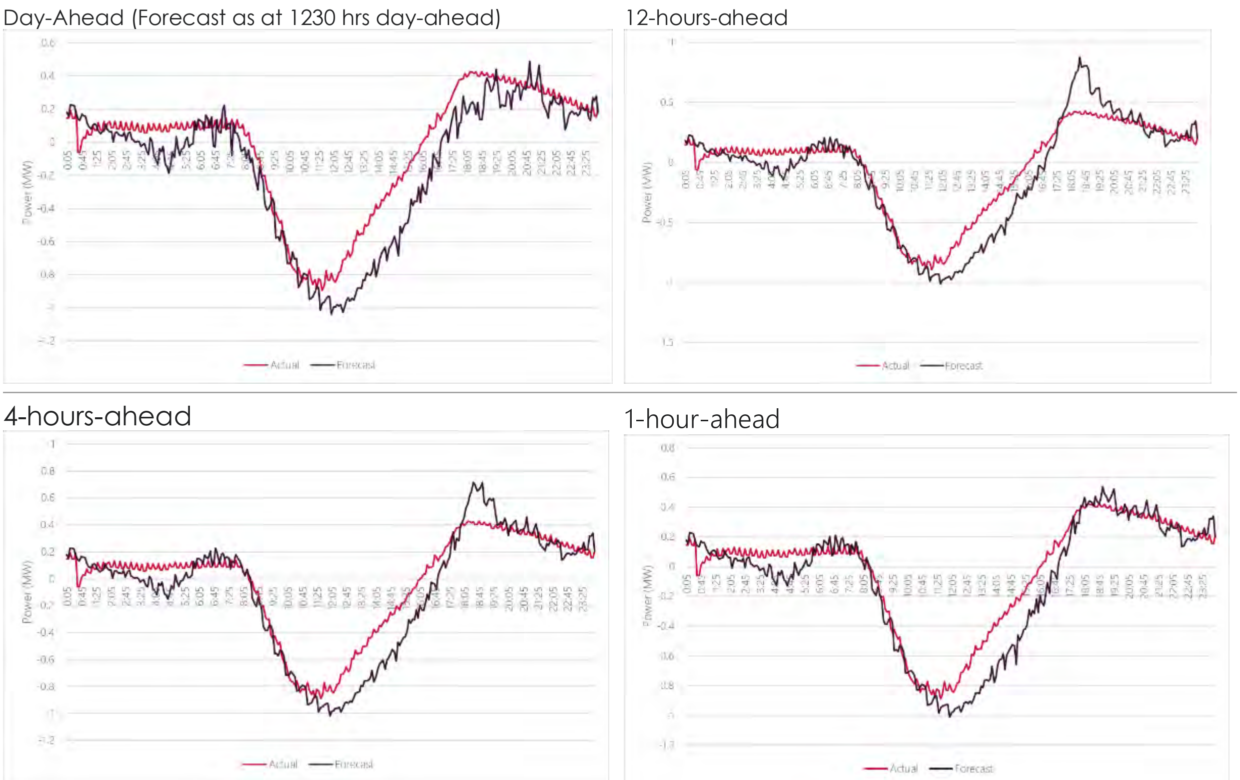


Figure 12 shows the controlled load of the VPP (charging of the batteries) against South Australian DPV generation.

Preliminary analysis suggests that:

- Batteries were able to become fully charged throughout the day in the study period, even with low DPV generation. This period was also impacted by COVID-19 restrictions, where more daytime household consumption is expected.
- Batteries become fully charged quicker on sunny days (see Figure 13), meaning the controlled load is rapidly reducing by the time DPV generation peaks and minimum grid demand occurs.
- If batteries are fully charged when solar maximum occurs, or if the appropriate control schemes are not in place, VPPs may not assist in the rapid decline of minimum grid load (which is an issue for power system security). This effect is expected to be exacerbated on mild days in summer when the solar resource is greater, but the overall load remains low (compared to hot days with high DPV generation).
- VPPs may accelerate the delay in peak demands later into the evening, which has already begun due to DPV. Battery generation across peak demand intervals, as is being seen, will help flatten demand peaks and may assist in generation reserve management.

Figure 12 VPP controlled load and South Australian DPV generation, 1-7 May 2020

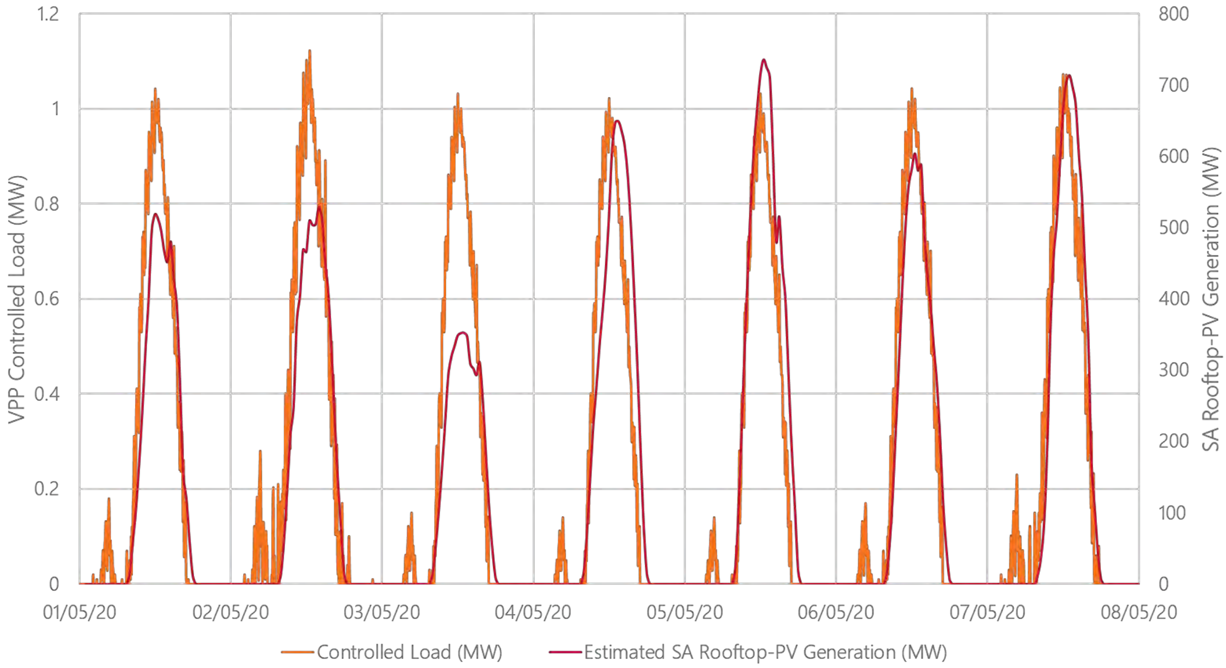


Figure 13 South Australian operational (grid) demand, VPP controlled generation and load, 4 May 2020

This preliminary data is insufficient to draw concrete conclusions from. AEMO however notes the following has been experienced:

- VPP proponents may continue to experience delays in producing forecasts, demonstrating the challenges faced in developing new technologies for participation in the operations and wholesale markets as well as the challenge of accurately forecasting diverse resources.
- Up to 5% of data from VPP proponents will be missing. Robustness of communications protocols/channels are essential for large-scale participation in the wholesale markets.
- Self-consumption is not necessarily the most difficult element of VPP forecasting. Large controlled events where the entire VPP is rapidly ramped up or down may pose power system security concerns if not scheduled.
- Forecasting is challenging, due to the dynamic nature of the resource.

Preliminary analysis suggests the data required during the VPP Demonstrations is fit for purpose for operational forecasting visibility of large-scale aggregated resources in the NEM. Further analysis under a range of power system conditions, such as price volatility, solar variability and seasonality are required to further assess the VPP's operational forecasts.

4.1.2 Preliminary analysis: telemetry data

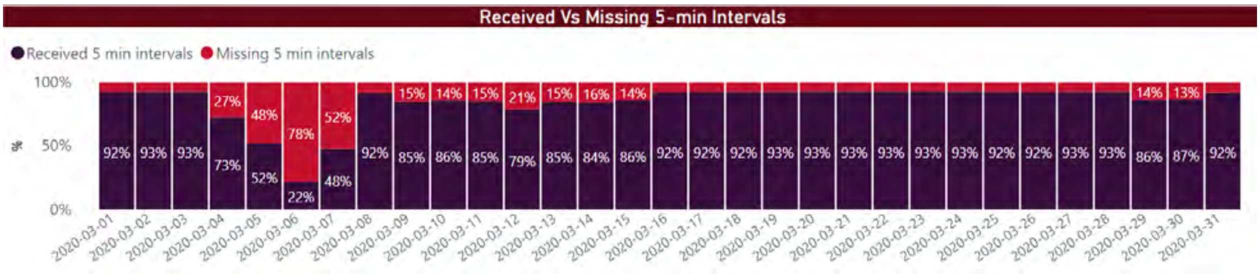
The telemetry data AEMO has received to date highlights that some households registered in the VPP are not communicating with the operator and by extension AEMO.

Figure 14 highlights that 5-8% of data was consistently not sent to AEMO (in red) during the month of March, with some interruptions lasting between half a day and four days. In some circumstances the gaps were rectified, for example by addressing issues with excessive packets of data overwhelming the API gateway or requesting resubmissions of data for certain time periods.

It is important to understand whether these communication dropouts impact the ability for VPPs to bid to their full capacity and the delivery of contingency FCAS. Given FCAS is locally detected and delivered, AEMO understands that communication dropouts will not impede households delivering FCAS. The lack of communication to the VPP operator may, however, reduce their visibility and therefore impact how much

FCAS they are willing to offer into the markets. By extension, if VPPs are scheduled for energy in future, these communication issues could limit the delivery of an energy market response because market prices/dispatch instructions need to be sent to the load management system and are not locally detected, like FCAS. This could have implications regarding how accurately VPPs can meet dispatch instructions.

Figure 14 Present and missing telemetry data records, March 2020

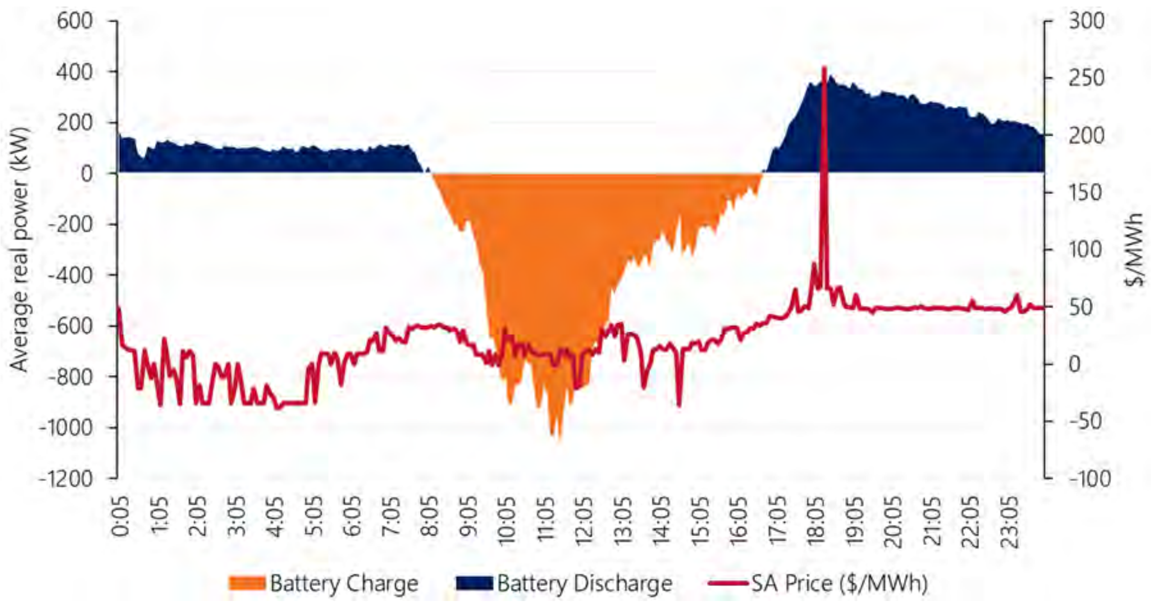


4.2 Market dynamics and planning

To understand whether VPPs respond to energy market price signals, AEMO examined data received in the VPP Demonstrations between 1 January and 19 May 2020. Based on initial analysis, the primary driver of VPP charging/discharging behaviour appeared to be optimising household self-consumption, rather than responding to energy market price signals. As Figure 15 shows, VPPs did not exhibit changes in generation during typical energy prices ($0-$300/MWh), and on most days VPPs followed similar generation patterns:

- One cycle of charging during daytime hours.
- Highest levels of generation during the peak evening period.
- Lower generation levels during the early morning hours.

Figure 15 Typical charging pattern, Energy Locals VPP, 20 April 2020



However, there have been displays of price responsiveness where there are extreme outcomes (very negative energy prices, or very high energy prices above $300/MWh), shown in Figure 16 and Figure 17.

Figure 16 Response to very high prices, Energy Locals VPP, 30 January 2020

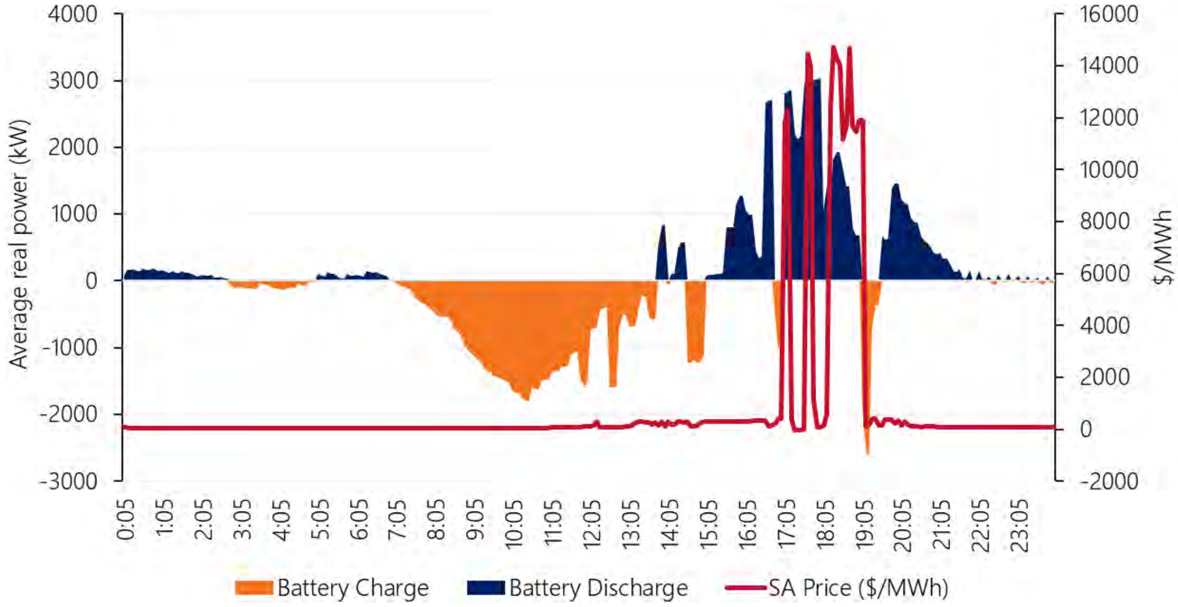
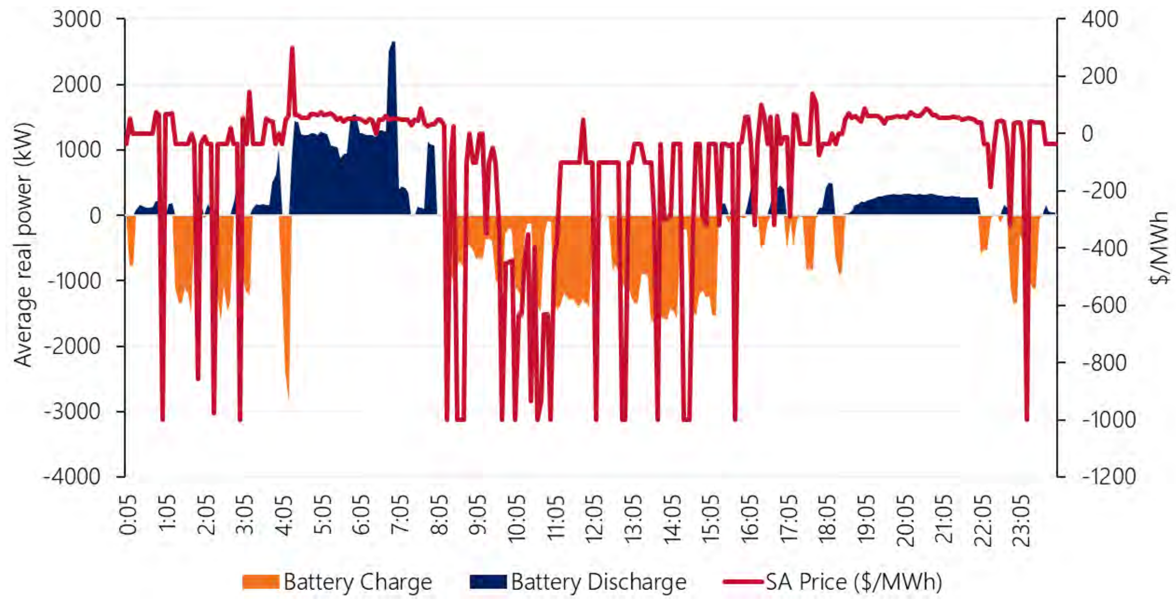


Figure 17 Response to very negative prices, Energy Locals VPP, 2 February 2020



AEMO's current learnings from the demonstrations indicate that, if extrapolated out, charging of a very large VPP to very low or negative energy prices could lessen the duration of the negative spot price period, as well as lessen the magnitude of the negative price event. For example, the price could clear at -$10/MWh rather than -$1,000/MWh.

AEMO observes this type of behaviour could contribute to reduced curtailment of variable renewable energy, as well as reducing the need for ramping large thermal units. AEMO assumes that discharging of a very large VPP during a very high-priced event could alleviate the price impact of the event. To investigate further, additional VPPs are required to participate in the demonstrations, or for current VPPs to grow in size.

AEMO's preliminary analysis suggests VPPs will respond to some, but not all, energy price signals, and are not as responsive as grid-scale storage to energy price signals in the typical range of $0/MWh to $300/MWh. However, examples of VPPs discharging at high levels during very high spot energy prices suggest that VPPs will be able to assist with the management of peak demand and prices on extreme days. These responses are likely to evolve over time and will depend on arrangements in place at the household level.

4.2.1 Update on participant revenue

Energy Locals and AGL have been able to earn revenues by participating in the six contingency FCAS markets. Since the South Australia islanding event, these earnings have reduced to normal levels, as Figure 18 shows.

Figure 18 Total FCAS revenue each day, Energy Locals (VSSEL1V1) and AGL (VSSAE1V1)

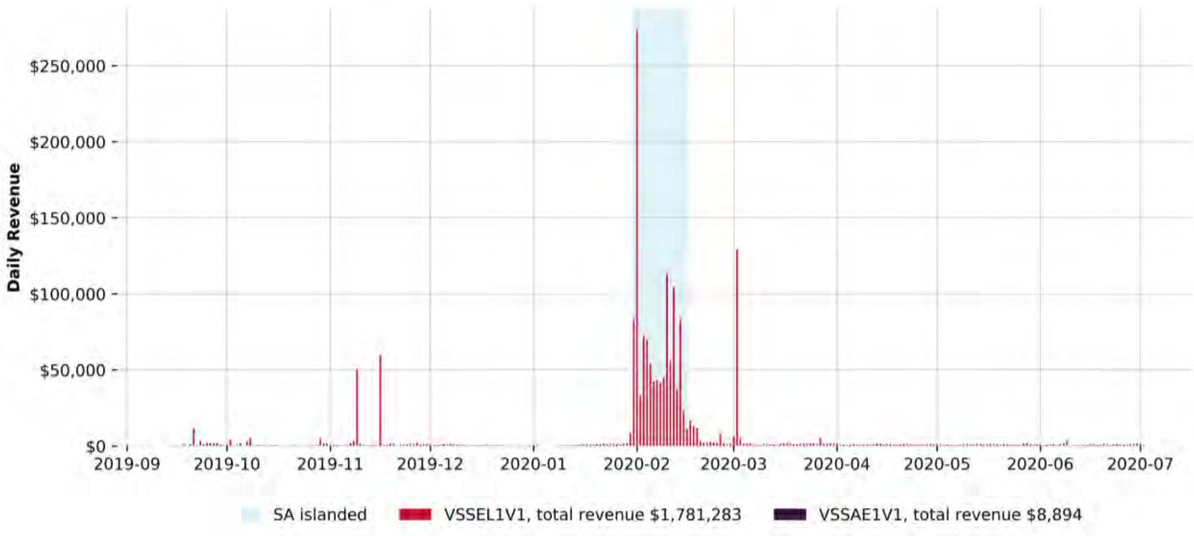
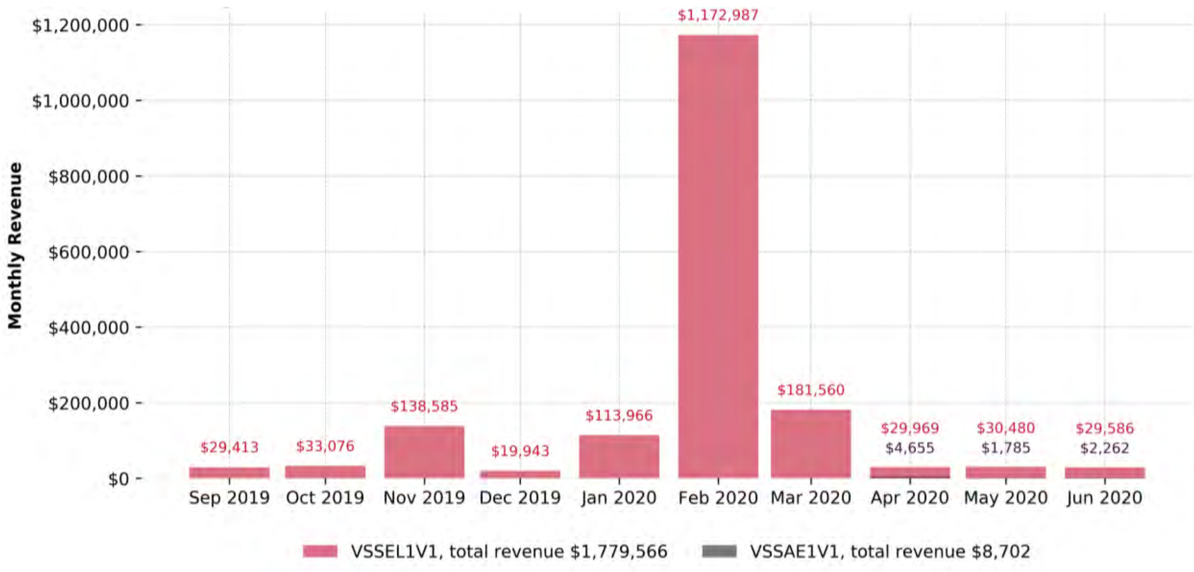


Figure 19 shows summated monthly earnings for each participant since Energy Locals joined in September 2019 and AGL in February 2020 (noting that AGL did not start bidding into the market until April 2020).

Figure 19 Total FCAS revenue each month, Energy Locals (VSSEL1V1) and AGL (VSSAE1V1)



4.3 Local power quality

AEMO has sought participants' responses to the following research question: *To what extent do local power quality or fleet communication issues impact VPPs' capability to meet their operational objectives?*

AGL provided the following input:

> *As FCAS is a locally set device mode, fleet communications do not have a significant impact on operational objectives, and any impacts can be mitigated through accurate forecasting.*
>
> *Power quality response modes such as Volt-Var and Volt-Watt result in progressive curtailment of real power of inverters as voltages experienced by the inverters get higher, particularly above 250 V. According to TS129[6] (SA Power Networks technical standard for small embedded generator connections), Volt-Watt can bring real power capacity down to 20% of the inverter's nominal capacity, and Volt-Var can bring the real power capacity down to 90% of the inverter's nominal capacity.*
>
> *If median grid voltages are around ~245 V, and there is approximately 1 V/kW added to each site during a dispatch, this forces the voltage experienced by inverters above 250 V. When energy storage systems are in a solar self-consumption mode, this may not amount to significant curtailment, as the battery inverters are charging, or only discharging relatively small amounts of real power and are typically seeking to maintain site power as close to zero as possible. Under smaller FCAS responses, where there is only a small amount of real power added, there will also be a relatively smaller voltage rise and a corresponding small real power curtailment. However, consider the case of grid voltages around 250 V to begin with (which is not uncommon amongst AGL fleet under normal daytime operation), and a large FCAS response requiring a full power discharge of inverters. In this circumstance, real power may be significantly curtailed. Under the current iteration of TS129, real power of a 5kW inverter will be curtailed to ~3.7 kW at 255 V. This would significantly impact the available real power for frequency control services.*
>
> *AGL recommends that a holistic approach is required when considering how to limit the impact of grid conditions on the ability of residential inverters to participate in important ancillary services markets in the NEM. This includes:*
>
> 1. *AEMO should consider the equitable impact of uniform power quality response modes which may impact some customers more often and more severely, including whether these modes ought to apply to inverter responses while enabled to provide ancillary services*
> 2. *Voltage management should also encompass a range of other measures undertaken by network businesses*

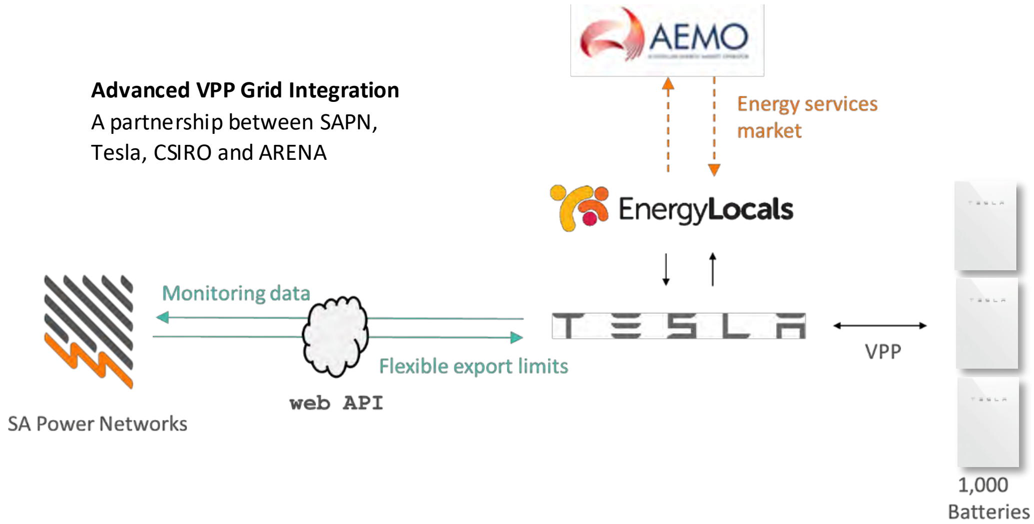
AEMO also sought input from South Australia Power Networks (SAPN), given the topical nature of its work with Tesla and relevance to the VPP Demonstrations. SAPN provided the following input:

> *SA Power Networks is implementing a number of initiatives to increase the capability of the distribution network to host DER exports, including from VPPs. When combined, these have the potential to double the amount of exports the distribution network can accommodate over the next five years. The initiatives include:*
>
> - *Introducing new residential Time-of-Use network tariffs which provides cheaper daytime network charges to encourage use of more solar-generated energy during the middle of the day.*
> - *With the support of the State Government, investing in enhanced voltage management to increase network hosting capacity.*
> - *Monitoring and analytics in the low voltage network to provide better real-time visibility of what is happening in local networks.*
> - *Developing industry approaches and standards to support introduction of flexible (time varying) export limits for DER that reflect the hosting capacity of the network at any given time.*
>
> *The flexible exports concept (see Figure 20) has been under trial with the Energy Locals and Tesla SA VPP in the ARENA-funded Advanced VPP Grid Integration project. This project aims to show how higher levels of energy exports to the grid from customer solar and battery systems can be enabled through dynamic, rather than fixed, export limits. This approach benefits VPPs by:*

[6] SAPN Technical Standard TS129 available at https://www.sapowernetworks.com.au/public/download.jsp?id=9561

- *Enabling higher levels of wholesale market participation through enabling the VPP to export more than the standard, fixed export limit (5 kW) at times when the network has the capacity to accommodate it, potentially doubling the export capability of the VPP (up to 10 kW per site);*
- *Providing a higher degree of certainty for dispatch through the provision of a 24-hour forecast of export limits that take the network conditions, including local voltage, into consideration.*
- *Enabling the sharing of available network capacity between VPP sites clustered on common network assets to enable a greater degree of VPP co-optimisation.*

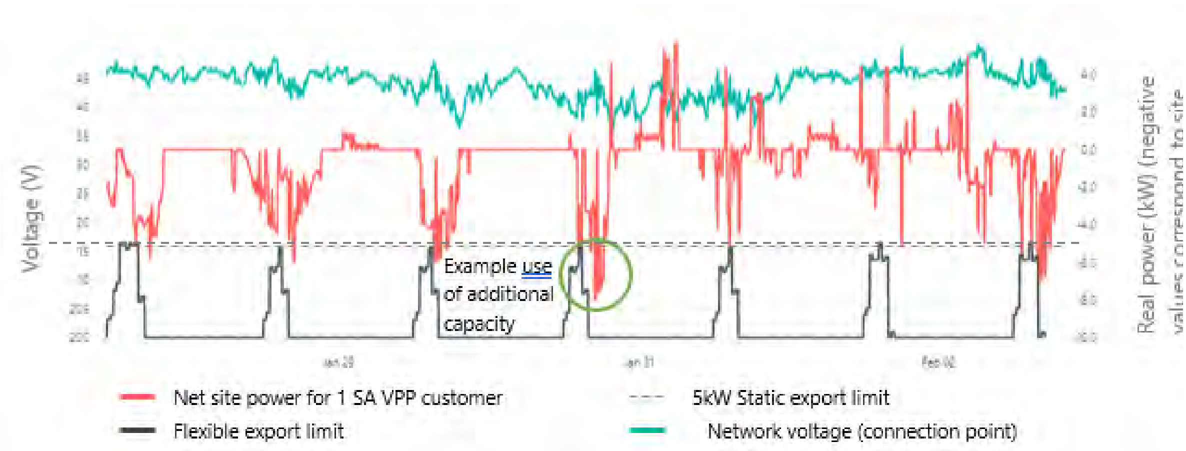
Figure 20 Flexible exports concept currently being trialled with Energy Locals and Tesla



The system has been in operation since July 2019, and the project has been able to successfully demonstrate the technical capability for SA VPP sites to export greater than the static export limit (5kW per phase) in response to a dynamic export limit. There are approximately 900 SA VPP sites currently interacting with the system, and we have been able to enable more than 1MW of additional dispatch capacity during certain network and market conditions.

Figure 21 below shows a single SA VPP site utilising additional network capacity afforded by the dynamic export limits during January/ February 2020.

Figure 21 Single SA VPP site utilising additional network capacity



While consideration of the interaction between contingency FCAS services, export limits and Volt-VAr and Volt-Watt power quality response modes was not a core consideration for the project, the high levels of contingency FCAS participation from the SA VPP during the trial period have highlighted the need for further investigation in this area. SA Power Networks believes the following areas warrant further work:

- *Definitions of the primacy of inverter responses that reflect the hierarchy of requirements of the power system. For example, short duration exceedances of local voltage may be tolerable when a contingency FCAS response is required to maintain system security.*
- *Extending the flexible exports capability for VPPs to provide a "normal" export limits for steady-state system operation and "emergency" export limits to allow short duration contingency FCAS responses of a greater magnitude.*

The full learnings from the project will be included in the final ARENA knowledge sharing report which will be published once the trial ends in September 2020.

AEMO will continue to seek insights from intending and current VPP participants, Distributed Network Service Providers (DNSPs), and retailers, and will seek to raise this feedback in regulatory reform processes and discussions.

4.4 Cyber security

Cyber security is an important component of ensuring energy system security and has been a focus for AEMO with DER and the VPPs. To ensure a reasonable level of cyber security is maintained in the VPP Demonstrations, AEMO developed the cyber security questionnaire, assessing prospective VPP participants on their maturity and identify any gaps.

The VPP Demonstrations have identified that VPPs' reliance on and connectivity with household technology may pose a future risk. AEMO is currently investigating this as part of a broader piece of work under the standards and connections workstream in the DER Program. The DER minimum technical standard rule change request[7] to the Australian Energy Market Commission will, pending the final determination, provide an avenue by which AEMO can set minimum cyber security standards for newly connected DER consistently across the NEM, ensuring all VPPs and other participants have in place the required cyber security capabilities.

Further to this, the limited participation to date in the VPP Demonstrations has not yet identified if new entrants or start-ups within the industry pose further security concerns. Enrolment and participation in the VPP Demonstrations by a broader range of participants and technology may raise issues that have not yet been experienced. This will be a point of further discussion in subsequent knowledge sharing reports and will also reflect the work AEMO is collaborating on across industry to encourage further uplift to maintain Australia's energy system security.

[7] Technical standards for distributed energy resources, at https://www.aemc.gov.au/rule-changes/technical-standards-distributed-energy-resources.

5. Next steps

The upcoming focus areas for the VPP Demonstrations are to continue informing the research questions that have been identified in the Final Design document:

- Consumer insights resulting from a broader distribution of surveys and collation of responses.
- Detailed and broader data analysis utilising information from increased participation.
- Develop recommendations regarding the appropriate ongoing operational and market arrangements for DER participation in markets via VPPs.

These focus areas are summarised below.

5.1 Consumer insights

A key aspect of the VPP Demonstrations is to understand how consumers respond to the VPP experience. Consumer experience specialist CSBA has developed a progressive approach to surveying consumers, starting with a baseline online survey, followed by a more in-depth longitudinal survey carried out at key intervals, a post-demonstrations survey, and the matching of these results against VPP enablement data collated throughout the demonstrations.

Outcomes from these studies will ascertain if consumers are willing to give up a level of control of their assets in return for value gained by being part of a VPP, how the experience can be improved, and how it can be made more attractive to consumers to maximise future participation.

These learnings are supported by the growing consumer base participating in VPPs resulting from increased VPP Demonstrations enrolments. This information is not only valuable to AEMO but will provide current and future participants an opportunity to improve their offering and customer take-up, in turn providing more value for energy consumers.

Early indications from an initial set of surveys distributed in April 2020 show a strong response rate of approximately 30%. Further surveys will be conducted with a view to publishing initial findings, feedback, and associated recommendations in the next report scheduled for Q1 2021.

5.2 Data insights to continue

AEMO will continue to receive, review, and draw out trends resulting from the information being provided. Should more participants join, and a broader range of information becomes available from a range of regions and over a longer period, more accurate assumptions, models, and extrapolations are possible, informing AEMO on how best to approach the technical and regulatory integration of DER.

These insights will be included as part of subsequent knowledge sharing reports as supported by the collaborative approach of all involved parties.

5.3 Ongoing arrangements

AEMO is considering options to extend the VPP Demonstrations. Any extension of the VPP Demonstrations will involve a process to assess whether the findings of the demonstrations support long-term arrangements to facilitate participation of VPPs in Contingency FCAS markets at scale. As well as considering the technical ability of DER to provide contingency FCAS, this assessment will involve considering consumer, industry, and market operator requirements to facilitate DER integration into FCAS markets. AEMO will engage with current and intending VPP participants over the coming months on topics including the cost of facilitating the FCAS services from DER for industry and for AEMO, the value of participation in the FCAS markets, and the key business model requirements for ongoing arrangements.

The VPP Demonstrations customer insights study will also highlight consumers' perspective on the value of VPPs. This information will feed, together with further industry consultation, into AEMO's consideration of participant fees and cost recovery to support the provision of new services. The initial findings from the customer insights study will be made available in the subsequent Knowledge Sharing report to be published in Q1 2021, with final decisions made on the ongoing VPP participation model scheduled for June 2021.