Flinders University smart charging trial

SA Government Smart Charging Trial

Final Report v5

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Executive Summary

The Flinders University Smart Charging Trial was developed by EVE Assets Pty Ltd (formerly trading as ENGIE Australia) and Flinders University with the aim to trial the commercial application of Electrical Vehicle (EV) smart charging systems at Flinders University Bedford Campus for fleet and public users. This included the deployment of 10 x Vehicle to Grid (V2G) bidirectional chargers, 15 x smart AC chargers and 2 x DC rapid chargers.

Trial development commenced in January 2022 with the operational trial period from March 2023 to November 2024.

The trial was a recipient of the *Sustainable Development Goals Global Initiative of the Year* in 2023 at the Triple E Awards.

The V2G hardware was manufactured by Wallbox with infrastructure design & installation by JET Charge. South Australian technology provider Air Con Serve (ACS) were engaged to develop the V2G and AC/DC smart charging control software. This included integration of the control software with the University's Energy Management System (EMS).

Flinders University Bedford Campus is powered from 100% renewable energy, including 2.2MWp on site solar PV system and wind power from the Willogoleche Wind Farm. Under this arrangement, the smart charging system, including V2G chargers offered potential commercial benefits for the University and improved environment outcomes for fleet and public users. This includes smart charging being used as a renewables sponge (using excess renewables at lower energy cost) and reducing site demand by reducing the charging rate or discharging the EV batteries during high energy prices.

The trial required the V2G chargers to be managed within the constraints of the University's electrical network and to provide fleet users with sufficient battery charge each day to meet their operational needs. In addition, the V2G hardware had a limited user display and feedback. The use of dynamic displays was therefore required to provide the user with real time charging data and instructions to enhance the user experience and utilisation.

The V2G system serviced between 8 to 16 vehicles each month (each service representing an EV plugged in and cycled over multiple days) with up to 4 cars charging / discharging at a time. This saw an average of 70-90kWh used each day for charging and 25-45kWh discharged and returned to the network.

The energy savings realised from the Trial was modest (typically $823-$1,350 per month) due to lower-than-expected V2G utilisation and number of fleet vehicles participating in the trial. This was due to the use of V2G hardware with CHAdeMO connectors and the lower average uptime of the V2G hardware (noting CHAdeMO has been mostly phased out by EV manufacturers since the trial commenced in 2022).

The energy savings could increase with improved hardware uptime and an increase to the number of V2G enabled fleet vehicles. The release of V2G charging using CCS2 standard would see improved uptake of the technology in the future. An increase to the EV fleet battery capacity would also unlock new revenue streams through participation in FCAS markets, including energy arbitrage.

The Trial has demonstrated a proven control protocol for V2G and smart charging system for commercial fleet operators and public. This includes integration of smart charging systems with on-site renewables. grid demand & spot energy pricing. This trial serves as operating model to support future implementation of VPP controlled V2G / smart charging systems at scale for commercial fleet operators including University's, fleet depots and urban precincts.

1. Introduction

The Flinders University Smart Charging Trial was developed by EVE Assets Pty Ltd ('EVE Assets') (formerly trading as "ENGIE Australia") and Flinders University with the aim to trial the commercial application of Electrical Vehicle (EV) smart charging systems at Flinders University Bedford Campus for fleet and public users.

EVE Assets received funding from the South Australian Government's EV Smart Charging Program to undertake the Trial.

The following smart charging systems and commercial models were trialled (Table 1):

Table 1 - Smart charging trial systems

Charger type	Make / model nos	Charger description inc. commercial model trialled
10 x Vehicle to Grid (V2G) bidirectional charging stations for fleet users, controlled via Virtual Power Plant (VPP) (integrated with the University's Energy Management System (EMS))	Wallbox / Quasar (7.4kW, single phase), CHAdeMO connector 8 x 2022 Nissan Leaf (8 x 62kWh = 496kWh capacity) 2 x 2023 Mitsubishi Outlander PHEV (2 x 20kWh = 40kWh) Total = 536kWh capacity	V2G station can charge the EV battery using grid power like a conventional EV charger and discharge power from the EV battery into the University network / grid depending on EV State of Charge (SoC), site electrical demand and spot energy prices using the VPP software. V2G stations were free for fleet users to reduce usage barriers. Revenue streams from energy credits (i.e. renewables sponge / demand reduction) were assessed based on cost reduction mechanisms in the University's energy supply agreement. Energy arbitrage, via participation in Frequency Control Ancillary Services (FCAS) markets was explored as a future commercial opportunity. This was not tested during the trial as total EV fleet battery capacity connected to V2G system was < 5MWh, required for FCAS market participation.

15 x smart AC charging units for fleet & public users, controlled via Energy Management System (EMS)	Jet Charge / Chargemate (7.4kW), Type 2 connector	Smart AC & DC charging can increase, decrease charge rate or stop charging depending on site electrical demand and amount of onsite solar generation using EMS software. AC charging was free for users to reduce usage barriers. Revenue streams from energy credits (renewable sponge / demand reduction) were assessed based on cost reduction mechanisms in the University's energy supply agreement. DC charging was paid per use trailing fixed & Time of Use (ToU) pricing tariffs to observe effects on charging times & volumes relative to periods of high/low renewables generation. DC chargers also provided emergency / rapid top-up charge for fleet users in case V2G units were faulty out of service.
2 x DC rapid charging units for fleet & public users, controlled via Energy Management System (EMS)	2 x Tritium / RTM75 (75kW), 2 x CCS2 + 2 x CHAdeMO connectors (replaced with 1 x Kempower C station and satellite charger (200kW, 4 x CCS2 connectors)	

Flinders University Bedford Campus is powered from 100% renewable energy, including 2.2MWp on site solar PV system and wind power from the Willogoleche Wind Farm via Green Power Purchase Agreement (PPA). Under this arrangement, the following mechanisms were explored for VPP controlled smart charging systems to provide commercial benefits and improved environmental outcomes for fleet and public users:

- ***Renewables sponge:*** Prioritise EV charging to make use of excess on-site solar PV or renewables within the grid at lower energy costs (compared to conventional grid supply)
- ***Demand reduction:*** Reduce demand either by reducing EV charging or discharging EV batteries during high energy prices. This allows energy credits to be generated for University during high price periods (typically above $300/MWh).
- ***Firming capacity:*** Utilise EV batteries to add firming capacity to the network by discharging EV batteries during low renewable generation periods. This is to demonstrate the ability for EV batteries (via V2G charging) to reduce the long term PPA firming costs for retailers and energy supply costs for the University. This mechanism applies when the PPA price includes a firming cost.

In addition, the University operates a complex electricity network which is controlled by a centralised Energy Management System (EMS).

The VPP was required to operate in an integrated manner with the EMS to prevent potential disruption to the electrical network.

Trial development commenced in January 2022 with the operational trial period from March 2023 to November 2024.

2. Change to VPP software provider following Trial commencement

Sunverge Energy was initially engaged to provide V2G control software following trial commencement. This included integration of the control software with the University Energy Management System (EMS).

Sunverge software was commissioned in March 2023 on 2 x V2G chargers for testing and validation with operational control of all 10 x V2G chargers occurring in July 2023. Sunverge Energy went into receivership in June 2024 and unfortunately was not able to continue operating for the remaining trial period. Subsequently, it was decided V2G control would be managed under the existing University EMS. The University EMS was developed and managed by South Australian technology provider Air Con Serve (ACS).

ACS were engaged to develop the control system to resume V2G operation. This report includes the data, results and findings from the University EMS using the existing V2G control protocols. Any reference to “VPP” or “V2G” software in this report relates to the VPP control protocols developed by ACS and operating under the University EMS.

3. Trial Objectives

The trial aimed to demonstrate a commercial and operating model for VPP enabled smart charging systems for commercial fleet users. This included the following objectives:

- Reduce overall energy supply costs to fleet owners by maximising site energy self-consumption (renewables sponge) and demand reduction opportunities
- Demonstrate operating model which enables smart charging systems to safely operate within the constraints of a complex grid / electrical networks (i.e. Universities, Precincts etc.)
- Implement charging incentive structures (i.e. ToU, credits etc.) to positively influence charging behaviour and environmental outcomes.

4. Key Performance Indicators

Update on Key Performance indicators as per Project Execution Plan (Table 2). Detail on actual performance across key indicators is summarised below:

- No loss time injuries or recordable incidents reported
- The project had a 35% variance to the total approved budget at completion (on a cash basis), due to:
    - Complex integration of VPP software within a University existing energy management system
    - Unforeseen costs related to integration of smart digital screens with V2G unit operation to enhance driver experiences

    - Construction material and labour cost escalations which occurred during the construction industry over 2022-2023
- Timely and regular communication with Flinders University, SA DEM stakeholders and suppliers, including:
    - Weekly project coordination meeting
    - Monthly progress update and reports to SA DEM
- Project issues or changes were raised with SA DEM as they are identified and change proposals developed in a coordinated manner.
- Project defects resolved in a timely manner
- No outstanding commercial disputes with suppliers

Table 2 - Key Performance Indicators

			Target	Actual
#1	**Metric**	**Measure**		
1	HSE	TRIFR	Zero	Zero
2	Schedule	Meeting Contract milestone dates including any approved amendments	100%	100%
3	Cost	CPI (against the approved budget)	95-105%	135%
4	Project controls – change management	Prior identification and endorsement of project change	100%	100%
5	Quality	NCRs closed out within agreed timeframe	100%	100%
6	Project reporting	Timely submission of complete and acccurate project reports	100%	100%
7	Commerical performance	Volume of disputed claims (variations / EoTs) Proactively avoids increases in total project cost and unwarranted claims	<5%	<5%
8	Project team performance	Timely and proactive communication, common team approach, no suprises as assessed by Flinders University and SA Government	Meeting Expectations	

5. Trial Deployment Costs

The total trial deployment cost was A$1.23m, including A$1.0m for the V2G and smart AC charging systems and A$0.23m for the smart DC charging system (Table 3).

The V2G system used first generation V2G product technology (Wallbox Quasar) which at the time was the only V2G product approved for commercial use in Australia. The V2G hardware unit cost was approximately 4.5 times the cost of a similar smart AC charger. It is expected V2G hardware unit costs will reduce as the technology improves and market adoption of V2G technology grows in the future.

The software development costs were high in relative terms due to the complex integration of the V2G system with the University EMS. It would be reasonable to expect that V2G systems would require some level of integration with an energy management system, particularly when applied to commercial EV fleets or public EVs at scale (i.e. depots, universities, urban precincts). The software developed for the trial is scalable and would allow additional V2G units to be integrated. Therefore, there would be minimal further development cost required to expand the V2G system should additional EVs enrol into the system in the future.

In addition, the dynamic displays were a high-cost component for the trial. The use of individual dynamic displays was required due to the limited user feedback and poor screen illumination offered by the V2G units. The use of enhanced display, with dynamic user feedback and improved illumination on the V2G units would significantly reduce this cost component for future V2G deployments.

The engineering, design and installation costs were within industry norms for the project size and value. The University is a large energy consumer which offered infrastructure, including electrical mains, spare switchboard connection, IT network infrastructure, carpark provisions etc. which was suitable for the trial deployment and significantly reduced the installation costs. The additional electrical loads added to the University for the smart charging system was small in relative terms. In addition, the smart charging systems had the ability to limit charging output during high demand periods which combined with the existing electrical infrastructure negated the need for electrical upgrades.

Table 3 – Trial Deployment Cost Summary

Trial Deployment Cost Summary	A$ (000)	% Total Costs
V2G hardware supply	103	10%
Smart AC hardware supply	33	3%
Dynamic displays	69	7%
V2G / VPP development inc. Integration with University EMS	123	13%
Engineering & design	35	3%
Installation	640	64%
Total Cost – V2G & smart AC charging system	1,003	100%
DC hardware supply	101	46%
Engineering & design	15	7%
Installation	104	47%
Total Cost – smart DC charging system	220	100%
Total deployment cost – V2G, AC & DC systems	1,223	

6. Operating Philosophy

The primary function of the University fleet is to provide a mode of transport for staff and students. As a secondary benefit to the electrification of the fleet there is also potential to provide additional environmental and cost saving benefits from demand management. However, from a fleet user perspective the fleet must be available with the vehicles sufficiently charged to allow the vehicles to be used.

Figure 1 provides a typical overview of how the charging stations are used. During the working week EV charging stations would operate in the same manner as any other charging station, as the vehicle is connected the charging station would begin charging. After 4 pm on a weekday or any time on the weekend the EV charging stations would become part of a VPP. Prior to the commencement of a working day (8 am) the system would ensure that the EV's were fully charged and available for use during the day.

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0:00							
1:00							
2:00	Likely Charge Zone - Faster charging when conditions are favourable.						
3:00							
4:00							
5:00	Ensure high SOC - for transport and 'Morning Peak' V2G						
6:00							
7:00							
8:00	Allow top 50% of SOC for V2G and Solar sponge use.						
9:00							
10:00						Allow top 85% of SOC for V2G and solar sponge use	
11:00							
12:00							
13:00	Likely Charge Zone - Faster charging when conditions are favourable.						
14:00							
15:00							
16:00	Ensure high SOC - for 'Evening Peak' V2G						
17:00							
18:00							
19:00	Allow top 60% of SOC for V2G and solar sponge use						
20:00							
21:00							
22:00	Likely Charge Zone						Likely Charge
23:00	Faster charging when conditions are favourable.						Zone

Figure 1 – Typical operating week with defined charging zones

Once part of the VPP any charging stations would look to avoid high-cost energy periods by delaying the onset of charging.

Those charging stations that are V2G capable and connected to vehicles that are VPP enabled will discharge the vehicle battery if the wholesale price is high. This will most likely be between 4pm and 9pm. The discharge period will be heavily influenced by grid conditions and may occur later in the evening or not at all depending on the whole sale electricity price. Charging of the vehicles will likely occur in the early hours of the morning when the available renewable energy generation (wind) can often exceed demand or during the solar peak during the day when solar PV generation on site may exceed demand. The resultant change in the energy usage profile of Flinders university will directly impact and reduce the firming cost associated with the universities Power Purchase Agreement (PPA). This should result in a lower per kWh charge for the University.

7. System Description & Results

The Flinders University Smart Charging System consists of the following key elements (Figure 3).

- University Energy Management System (EMS)
- Virtual Power Plant (VPP)
- BMS/EMS VPP controller
- V2G bidirectional chargers (Wallbox Quasar)
- DC fast chargers
- AC smart chargers

6.1 VPP Hierarchy of Control

There were several technical and operational constraints identified during the trial development phase, as it related to network constraints, energy management, fleet operations etc. It was expected the smart charging trial would be able to operate within these constraints without unduly affecting the trial outcomes (Table 4). Therefore, it was necessary to develop a hierarchy of control which allowed these constraints to be prioritised in an appropriate manner and the VPP control system to be developed from (Table 4). The application of these controls is described in the subsequent sections.

Table 4 - VPP Hierarchy of Control

Constraint (in order of priority)	Parameters	Control method
Distribution Network (SAPN)	Connection permission, generation limits (import, export)	EMS-Controller (via SAPN SCADA)
University electrical network (demand, export)	V2G – charge (demand) / discharge (export) limits	EMS-Controller
Fleet vehicle State of Charge (SoC)	Min driving SoC (for fleet usage) Min / max operating SoC (by vehicle manufacturer)	VPP SoC management
Energy price	Real time, day ahead ($/MWh)	EMS Controller (with data from AEMO API)

6.2 V2G System

There are 10 x 7.4kW V2G chargers installed at University Carpark 9 (Figure 2). The V2G chargers use CHAdeMO connection to support Flinders University EV fleet, including 8 x Nissan Leaf EVs and 2 x Mitsubishi Outlander PHEV. The Nissan Leaf and Mitsubishi Outlander PHEV are currently the only pure electric vehicles to support CHAdeMO V2G charging in Australia.

The 10 x V2G chargers are electrically supplied from switchboard EV-DB-CP9 (fed from the Earth Sciences Main Switchboard) and connected to the University IT network via a fibre optic connection inside the Earth Sciences Building (Table 5).

Table 5 - V2G System Detail - Carpark 9

V2G System	Total Capacity (kW)	Power Supply	University HV 'Feeder	Communications connection point
10 x V2Gs (Carpark 9)	74	EV-DB-CP9 (via ES-MDB)	Darlington 11kV feeder (BS0369) (NMI SAAAAA138)	Existing FOBOT located inside ES network cabinet CC2S

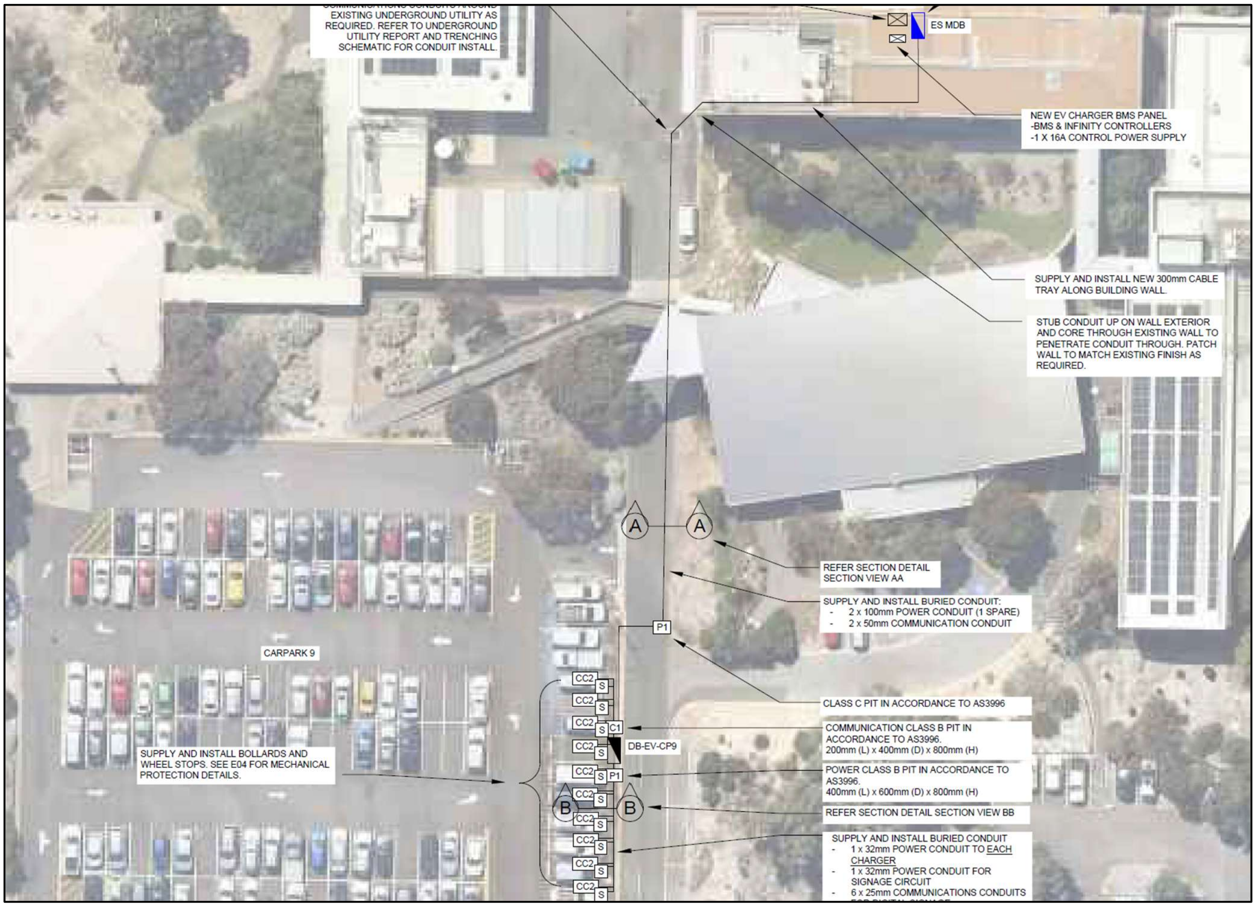

Figure 2 - Carpark 9 - V2G charging stations (x10)

EV-DB-CP9 is centrally located between the 10 x V2G units and includes an emergency stop which will shutoff power to all V2G units (and vehicles) in the event of an emergency. Power meters were installed at the main power supply to the V2G system (via EV-DB-CP9). The power meters were four-quadrant type to allow live metering of bidirectional power flows between the V2G chargers and University BMS. The meter data is passed through from the University EMS to SAPN according to SAPN network requirements.

The V2G system is configured with the University EMS as the master controller (Figure 3). This allows the EMS to control the V2G units independently of the VPP control in special circumstances, including:

- University experiences unusually high site electrical demand or during a load shedding event
- SAPN network action is imposed which is passed through the University EMS to the V2G units (for example grid renewable curtailment). SAPN connection requirements relating to V2G system is explained further in Section 5.0.

Each V2G unit includes a local controller which receives / transmits commands from the VPP remotely. The V2G controllers communicate with the EMS in real time via a Modbus TCP communication gateway. This control architecture was developed with a view to maintain integrity of the University electrical network (in case of V2G disruptions during the trial) and to ensure the University electrical network is operating in compliance with SAPN network requirements.

It is reasonable to expect that VPP enabled smart charging deployed for fleet at scale, such as universities, fleet depots or urban precincts would be require VPPs to operate under existing energy management systems and associated DNSP network conditions.

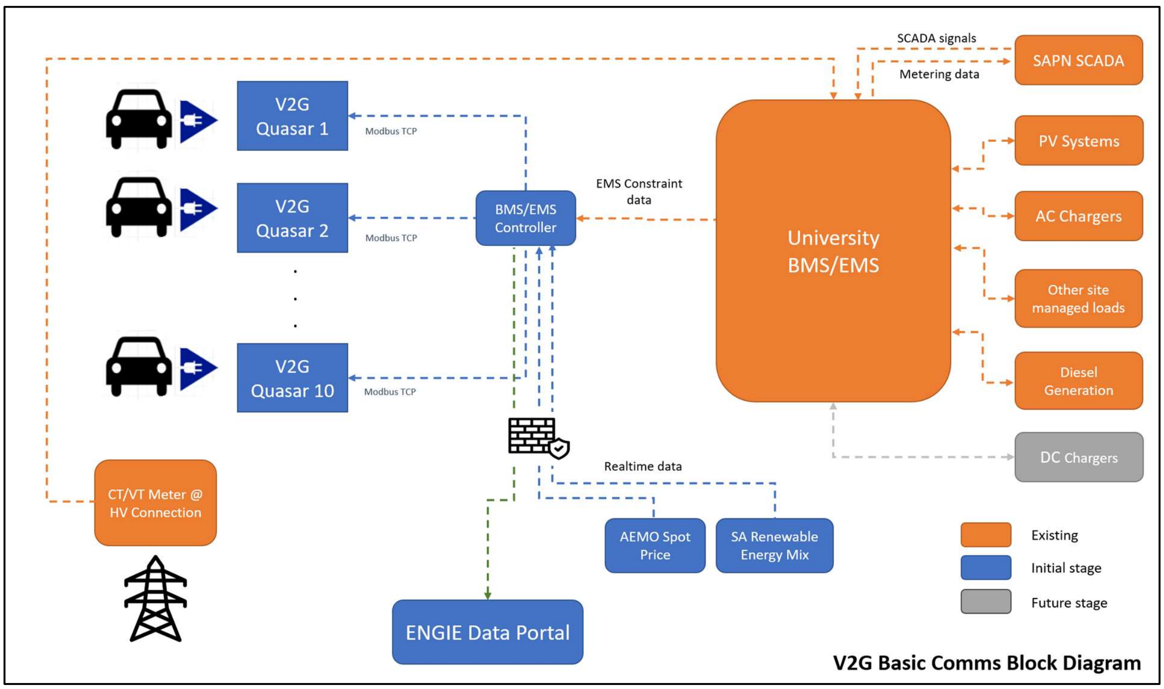

Figure 3 - V2G System Block Diagram

6.3 V2G Dynamic Displays

Fleet users reported the Quasar V2G units were small and not well luminated during the initial trial period. Fleet users found it difficult to view the displays, including charging status and power flow data when outdoors due to the increased solar glare. To address this issue smart dynamic displays were installed next to each V2G unit (Figure 4). The displays were connected to the V2G units via communication pathway which allowed pass through of charging status data to users in real time.

Figure 4 - Quasar V2G unit display & dynamic displays

Smart digital displays were installed next to each V2G unit. The content of the displays is dynamically updated to show state of the charger and relevant instructions to users. The displays may also include parking time limit and use condition (i.e. public, fleet only) depending on University carpark demand. The displays are remotely monitored and controlled by the University via software.

When no vehicle is plugged into the charger the display typically shows ‘Fleet vehicles ONLY.’ If the V2G control logic has been set to ‘Long Range’ charge profile, this is shown as grey badge at the top right corner of the screen display (Figure 5).

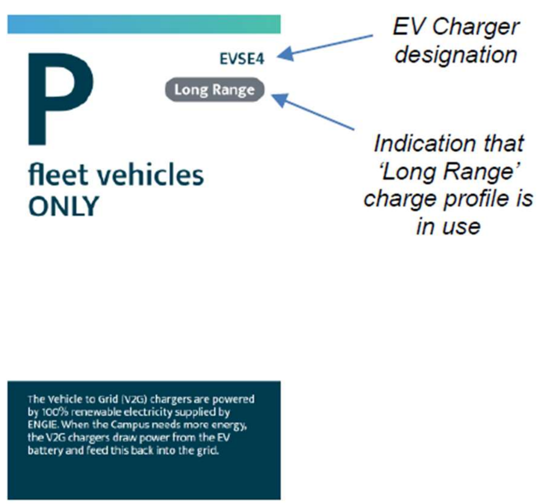

Figure 5 - V2G Dynamic Display

When an EV is connected to the charger, it will show a plug icon with the status text that flashes below. Status display includes *Charging, Discharging & Paused* depending on the state of the V2G control logic. There is an orange text box which provides instruction to the user and changes depending on the status of the charger.

If the charger is charging or discharging, the text will advise to *“Tap RFID card on V2G charger to stop charging.”* If the charger is paused, it will display *“You’re free to unplug.””*

If a fault is detected on the charger, the plug icon will turn red in colour and display message *“This charger is currently unavailable*” regardless of whether a vehicle is connected to the charger (Figure 6).

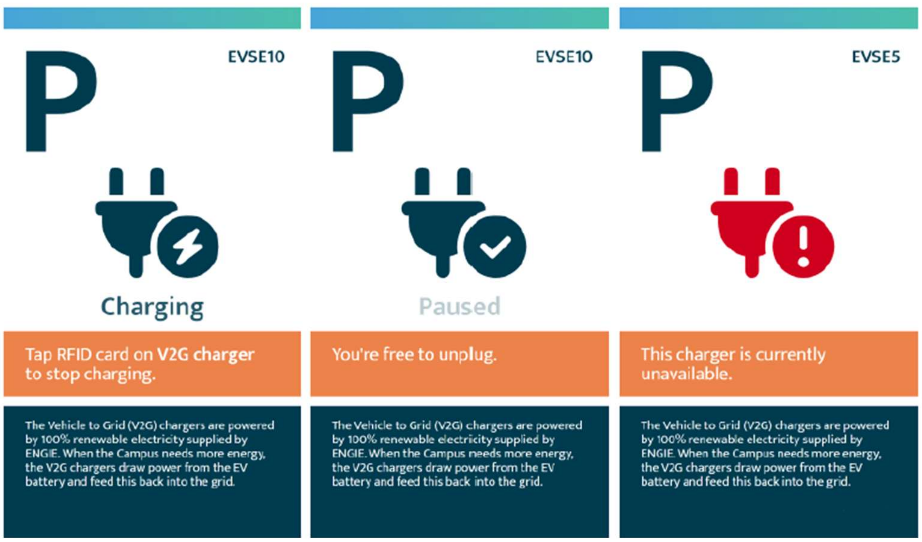

Figure 6 - Charging Display Screens (Charging, Paused, Fault)

Dynamic parking conditions may be used to allow parking bays to be made available for both fleet and public use during periods of high carpark demand. Adherence of fleet and public users to the parking conditions was monitored by the University.

The dynamic displays were positively received by the fleet users. This included clear & readable feedback to the user on charging status and simple instruction to guide user on how to use the V2G chargers.

6.4 VPP Software Control Protocol

6.4.1 SoC Management

VPP software controlled V2G charging and discharge periods based on mechanisms discussed previously i.e. self-consumption (renewables sponge), demand reduction and firming capacity. The overall aim of the VPP is to deliver the lowest overall energy supply cost for charging and by consequence maximise the use of renewable energy capacity.

In addition, the VPP must manage the state of charge (SoC) appropriate to meet operational requirements of EV fleet. Flinders University EV fleet are used for both intra & inter campus transport within greater Adelaide. It was thus important for the SoC to be managed during the week to ensure fleet users had enough range (km) to undertake their daily activities without unduly affecting outcomes for the trial.

The VPP logic monitors the state of charge (SoC) of any connected EV and will initiate charging or discharging to maintain a suitable SOC.

Each charger can be set to either charge cars for 'Local Use' or 'Long Range.' Long range car are held at a high state of charge each morning, where as 'Local Use' cars are allowed to discharge in the morning to support network during high demand periods (while also taking advantage of high price intervals).

A suitable SoC is set via hourly SoC target settings, and a schedule to set when these target settings apply. An upper and lower SoC limit is set, with the region between these two limits representing the energy available for V2G charging (import) or discharging (export) and any time (Figure 7).

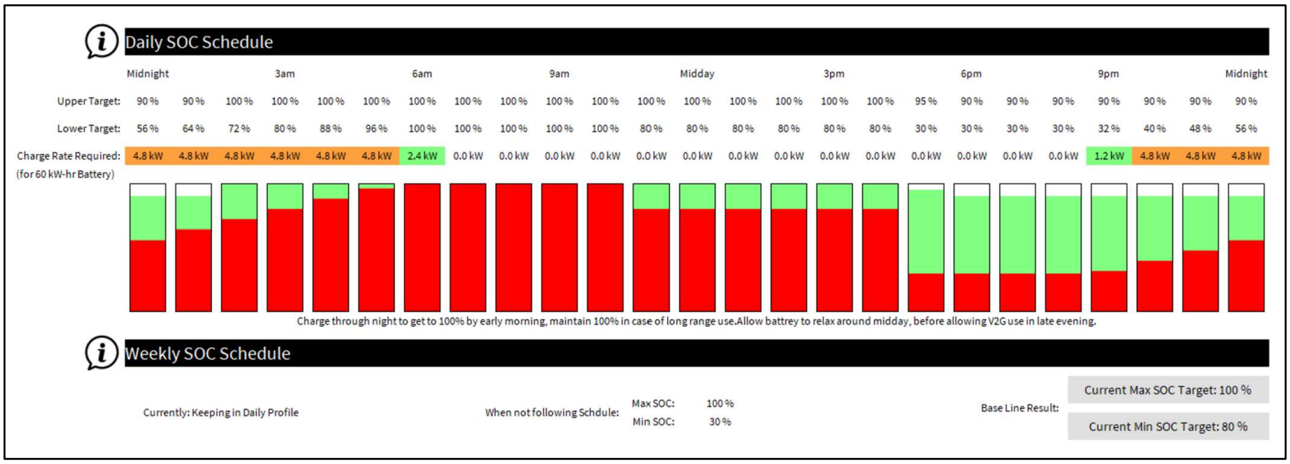

Figure 7 - SoC limit schedule

When an EV is plug into the V2G charger, a slow charge rate is initiated for 30 seconds to allow SoC to be determined by the VPP. If the SoC falls outside the target limits, an increase charge/discharge rate is initiated to bring the EV to a suitable SoC.

The charging window will be adjusted towards the upper or lower limit based on the mechanisms previously discussed. This in effect pushes lower cost renewable energy (either via on site solar PV or grid) into the EVs and pulls energy from EVs back into the network / grid where there is higher demand (and at higher cost).

The method on if and how each of these mechanisms is applied is adjustable via VPP interface parameters (Figure 8):

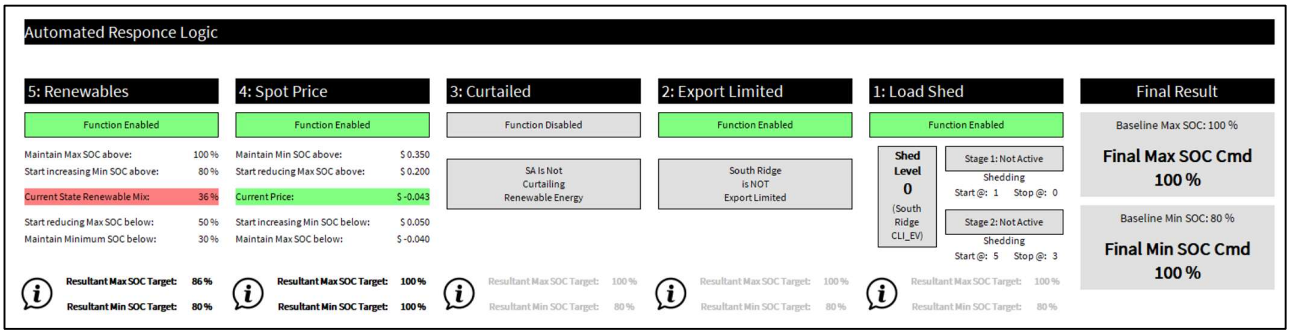

Figure 8 - SoC logic parameters

If parameter is active, the resultant SoC target will be shown in black (i.e. Renewables and Spot Price above). If the parameter is disabled, or not actively controlling the SoC target, the text will be shown in grey (i.e. Load Shed, SAPN export limit, SAPN renewable curtailment).

If the EV SoC is within the target SoC range, it will be set to the minimum charge rate. If this continues for a period, the charging sessions is paused. The users are free to unplug the EV without using an RFID tag. If the EV is actively charging or discharging, tagging off via RFID card will pause the charge, allowing the EV to be unplugged.

6.4.2 Spot Price

The energy spot price influences the SoC window in which charging and discharging may occur (noting the requirement for fleet EVs to be maintained within a suitable SoC). If the spot price is between 20-120 $/MWh the full window of SoC is available for use by the V2G system. In this scenario, EVs charge if they are below the minimum SoC (i.e. no discharge).

If the spot price is above 120 $/MWh the VPP reduces the maximum SoC target, which allows those EVs which are at lower range of SoC to continue to charge and at a slower rate. Once the spot price reaches 300 $/MWh, the EVs are allowed to discharge and maintained to the minimum SoC.

Conversely, if the spot price is below 20 $/MWh the VPP increases the minimum SoC target, to encourage EVs to get “ahead of the curve” and undergo most of the charging at the lower price. If the price is below -40 $/MWh (where price is effectively free after supply charges are applied) all EVs are charged at full rate (Figure 9).

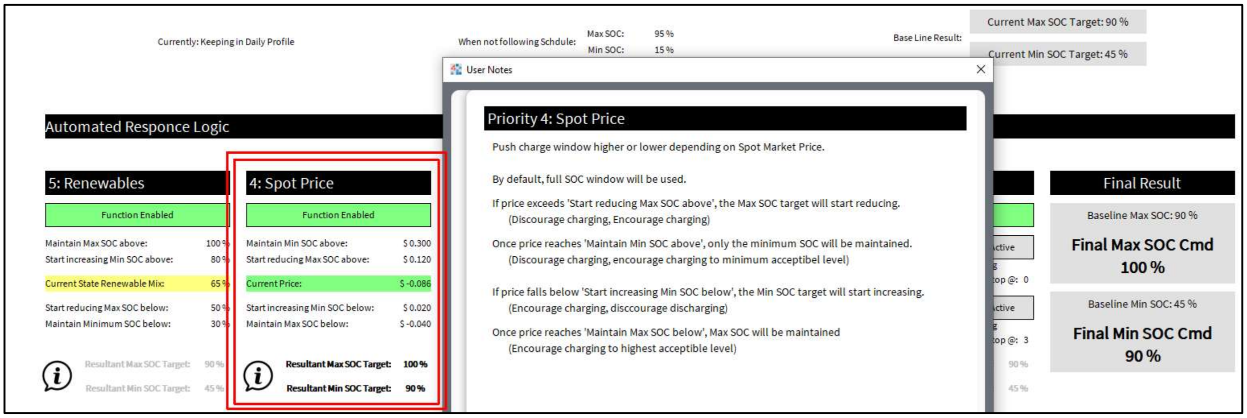

Figure 9 - Spot Price Control Settings

6.4.3 VPP Charging Planned Profile

Figure 10 illustrates an example of V2G 24 hour charging cycle, to highlight influence of SoC and spot price on charging/discharging behaviour.

Black line – Spot price
Light green line – Default max SoC target
Light red line – Default min SoC target
Dark green line – Actual max SoC target after spot price is factored
Dark red line – Actual min SoC target after spot price is factored

The spot price (**black line**) shows relatively low price during middle of day and high price during late morning (9-11am) and evening (4-10pm).

The default min (**light red line)** & max SoC (**light green line)** target (before spot price is factored) has large window (15-95% SoC) being the weekend (where fleet usage is lower) up until 9pm, where the min SoC target beings to increase to ensure EVs are charged ready for Monday morning.

The actual min (**dark red line**) & max SoC (**dark green line)** target adjusts depending on spot price. As shown, there is a sudden drop in max SoC from 4pm as the spot price spikes, so EVS that were in the 25-80% SoC range were set to discharge. As spot prices eased from 7pm, the EVs had reduced or stopped discharging.

From 10.30pm to midnight the spot price has no effect on the SoC window, but EVs would have been charging to keep up with the rising minimum SoC target required to have the EVs at suitable SoC for starting of working day Monday (and ready for discharging during morning peak).

From 12.30pm onwards, the pricing was low, so the minimum SoC target increased to encourage charging rate and soak during high renewable / lower price windows.

From 5am onwards, the default min SoC drops as the spot price increase to encourage charging rate to reduce / stop and discharge to occur.

As spot price approach the its maximum, the maximum SoC was reduced from its default 90% to around 60%, which allow EVs plugged in at the time to be actively discharging.

Figure 10 - V2G Charging 24hr Cycle Example

6.4.4 VPP Charging Actual Profile (EVSE10)

Figure 11 illustrates charging profile of EVSE10 over 24 hour charging cycle.

Black line – EV SoC
Green line – Actual max SoC (after spot price is factored)
Dark red line – Actual min SoC (after spot price is factored)
Dark background – Export limited
Ligher background – Price driven
Light background – High renewables (firming driven)

The chart illustrates there were multiple periods where the system was export limited (due to SAPN network conditions). Although spot price during this period would typically discourage charging, the actual command was to charge at full rate between around 11am to 4pm from 55% to 95%. From 4pm onwards, the network was no longer export constrained and spot price were high so the EV was discharging at full rate from 4pm to 7pm from 95% to 50%.

The SoC is maintained until around 10.30pm after prices normalise. The renewable mix in network is high from around 10.30pm after which charging begins again. Charging continues throughout the night meeting its target 90% SoC by around 5am and maintaining SoC until 7.30am after which there is a short discharging event as spot prices spike.

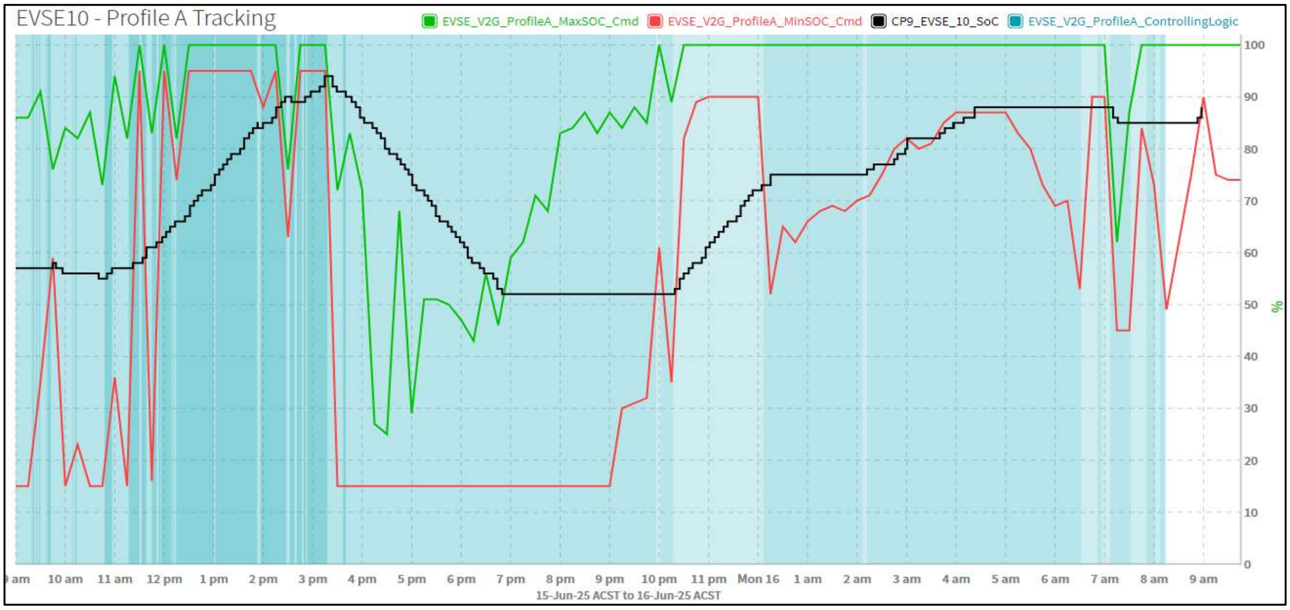

Figure 11 - Charging profile tracking - Example (EVSE10)

In this example, the actual charging profile (EVSE10) reflected the intended behaviour of the VPP controlled V2G system (Figure 12).

- Charging mostly occurs up to 4pm – maximising excess on site solar PV generation (at no cost that would have otherwise been curtailed)
- Discharging mostly occurs between 4pm to 7pm – to reduce demand during high price windows (200 $/MWh)
- Intermittent charging between 10pm-12am during high renewable period (at lower spot of 50-100 $/kWh)
- Intermittent charging between 2am – 5am during high renewable period (at near zero cost)
- Intermittent discharging around 7.30am when price spiked at 300 $/MWh followed by charging as spot prices dropped

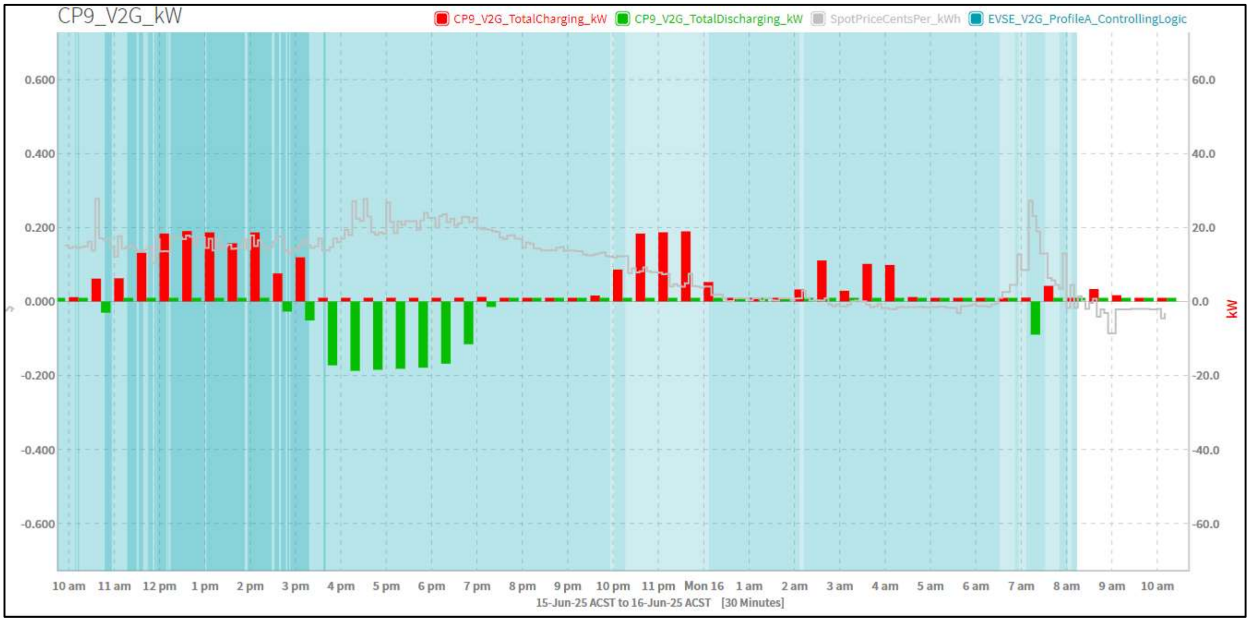

Figure 12 - Charging & discharging intervals

6.5 Commercial Benefits

The V2G system and stored BEV capacity in total (10 x 7.4 = 74kW, 536kWh) Is small in relation to the total University demand and thus any commercial benefits of the Trial system is small.

However, it should be highlighted the Trial demonstrates a proof case for the VPP controlled V2G technology and if implemented at scale could contribute significantly to the demand profile of the University (or other large commercial sites) and realise commercial benefits for fleet operators. The V2G control software is scalable and allows additional V2G units to be enrolled as EV fleet grows. This would reduce the unit cost associated with development, integration and management of V2G system for fleet operators.

Unfortunately, the full capacity of the V2G system could not be realised at times during the trial due to the reliability of the Quasar V2G units. The V2G units were found to intermittently fault due mainly to:

- Data cache issues encountered with the units i.e. V2G local memory cache would not clear, causing memory storage to be overload over time from the VPP communication and result in data connection loss
- Intermittent mechanical faults encountered when operating the units at higher ambient temperatures (i.e. >30-35^{o}C)

This resulted in 6 (out of the 10) V2G units working at a time. It is understood the Quasar V2G units were a new technology, and it is anticipated reliability will improve in time as market / product development for V2G technology improves in the future

On average, for the 6 V2G units that were operating, these serviced between 8 and 16 vehicles each month. This included vehicles that would be plugged in for multiple days and may undergo multiple battery cycles (either partially or full) before being unplugged.

The chart below highlights the VPP control supports the University demand profile, with V2G charge rate increase during lower site demand periods and charge rate reducing and discharging occurring during high site demand intervals Figure 13 & Figure 14).

- **Blue** and **Magenta** are main grid feeds
- **Green line** is V2G – above zero line is charging rate used by V2G system and below the line is V2G discharging back into the University

V2G stations were free for fleet users to remove the usage barriers with revenue generated from energy credits (renewables sponge / demand reduction). There is opportunity to introduce charging tariff for public users in future trials. This would include lower charging tariffs to encourage usage during higher renewables and lower energy pricing intervals and higher charging tariffs during low renewables and higher energy pricing intervals. Due to the lower charging volumes from V2G charging it is anticipated that any difference in tariff pricing difference during the day would be small. In the future, should V2G charging rates and volume increase the tariff pricing differences (and incentive for users) may also increase.

Generally, the V2G charge / discharge peaked at 27kW (or 4 cars charging / discharging at a time). This has seen an average of 70-90kWh used each day for charging and 25-45kWh discharged and returned to the network. Higher utilisations would be expected with improved reliability of the V2G units (Figure 15).

The energy savings realised from the Trial was modest (typically $823-$1,350 per month) due to lower-than-expected V2G utilisation and number of fleet vehicles participating in the trial (Table 6). This was due to the use of V2G hardware with CHAdeMO connectors and the lower average uptime of the V2G hardware (noting CHAdeMO has been mostly phased out by EV manufacturers since the trial commenced).

The energy savings could increase with improved hardware uptime and an increase to the number of V2G enabled fleet vehicles.

The release of V2G charging using CCS2 standard would see improved uptake of the technology in the future. An increase to the EV fleet battery capacity would also unlock new revenue streams through participation in FCAS markets, including energy arbitrage.

Table 6 - Trial Data

Parameters		
No. vehicle serviced	8-16	p/month
Charge / discharge rate, peak	27kW	
Charging volumes - Actual		
60% V2G availability (actual)	2,700kWh	p/month
95% V2G availability (estimate)	4,275kWh	p/month
Discharge volumes - Actual		
60% V2G availability (actual)	1,300kWh	p/month
95% V2G availability (estimate)	2,138kWh	p/month
Energy savings from demand reduction events (inc. loss factors)	$823-$1,350	p/month

Figure 13 - University Total Site Demand

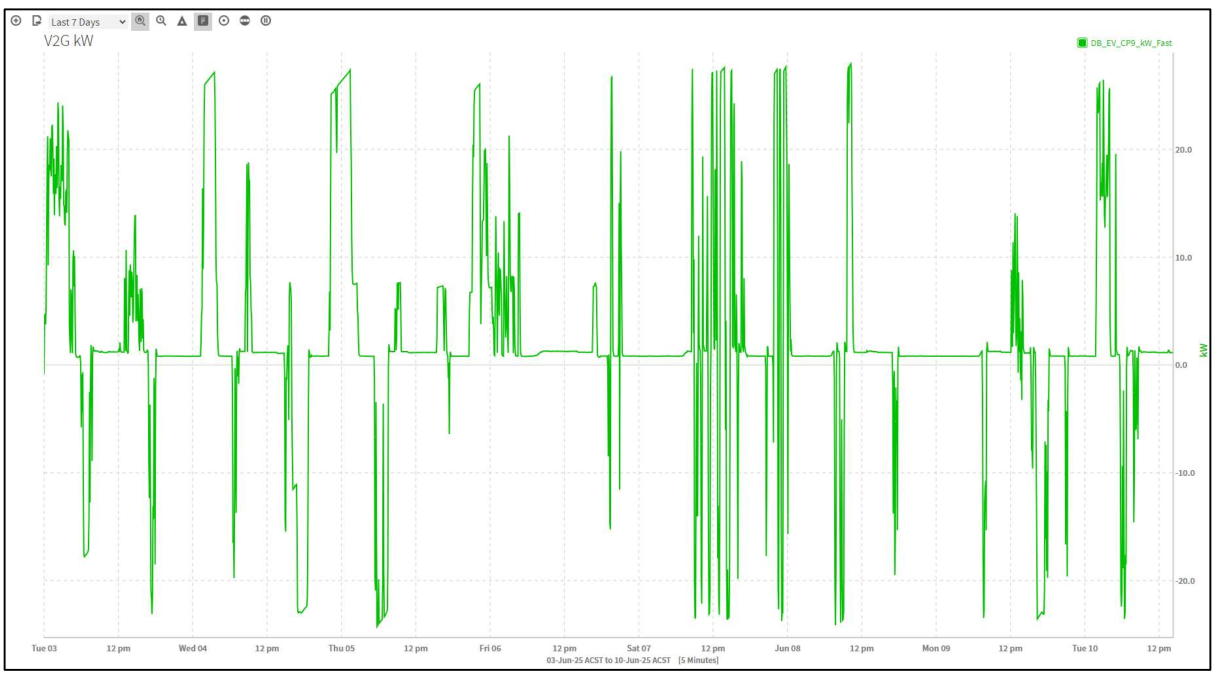

Figure 14 - V2G Charge / Discharge Rate

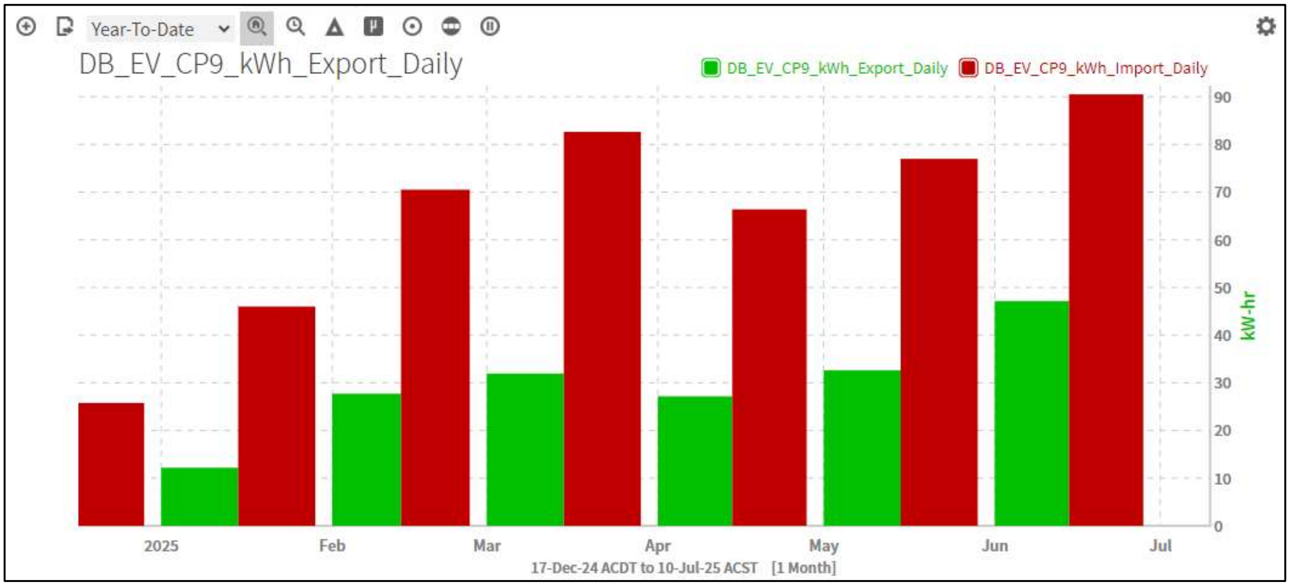

Figure 15 - Avg. daily Import / export volumes (kWh) per month

6.6 Key Challenges with VPP control implementation

The V2G technology and associated hardware was relatively unknown and therefore required to undergo significant bench testing, integration and validation to suit application. It was found during operational testing there were reliability issues with V2G hardware (as discussed previously) that can occur with first generation technology.

6.7 Simultaneous Charge & Discharge Conditions

There were instances observed during the initial trial period when V2G units would simultaneously charge and discharge which would affect the overall charge or discharge rate at total. For example, if a vehicle returned and plugged in below the minimum SoC while other V2G units were discharging at the same time (due to high energy price). This resulted in energy being transferred between vehicles and limiting the V2G system overall charging and discharging capacity.

This require the VPP control logic to be changed to prevent cars from charging and discharging at the same time unless a vehicle plugged in at a very low SoC.

6.8 Battery Cycling & 12v battery issue

The V2G charging & discharging action also identified some unique operational characteristics for different vehicle manufacturers (i.e. Nissan Leaf, Mitsubishi Outlander PHEV). It was observed in some cases the 12v auxiliary battery would discharge and run flat during V2G operation.

Following significant testing it was found this was the result of the vehicle battery cycling between a narrow band of SoC when approaching a high SoC. The battery cycling hysteresis would continue to occur until the auxiliary battery ran flat.

To address the issue, the SoC maximum limit was reduced. At the reduced maximum SoC, it lowered the occurrence of charging hysteresis and kept the 12V battery at a stable charge. Although this solution addressed the main operational issue (i.e. flat 12v battery) it reduced the available battery capacity for V2G operation. Further investigation into longer-term solution, including V2G communication interface and 12V battery demand from vehicles is required.

6.9 V2G cable unlocking

V2G units did not provide a method of unlocking the charging cable from the vehicle locally. Wallbox software allows charging cable to be locked when the unit is operating in local control mode. However, for the VPP system to operate the unit must be operating in remote control mode. Therefore, an alternative method to allow charging cable to be unlocked on demand had to be developed for the Trial. This included an RFID card that allow the user to unlock charging cable from the vehicle on demand by “tagging off” RFID card over the Quasar RFID reader.

7 V2G Inverter Classification & SAPN Network Requirements

EVE Assets underwent a consultation process with SAPN to determine a suitable network connection pathway for the Trial. Although at commencement of the Trial, the Quasar V2G units were certified to AS4777.2020 there were non-compliances identified by SAPN in related to the Volt-VAR settings following a detail review of certification test reports by SAPN.

Following consultation with SAPN, a letter of dispensation in September 2022 was granted by SAPN to permit the Quasar V2G units to be installed for the Flinders University trial on the basis the firmware updates to adjust Volt-VAR settings would be made by Wallbox in the future. The Volt-VAR settings adjustments were subsequently updated in Quasar firmware and commissioned for the Flinders University trial in May 2024.

During the consultation process, SAPN had advised the V2G system would be classified as a Battery Energy Storage System (BESS), acting as both a load and generation device and therefore its operation would be governed by the following SAPN technical standards:

- TS132 – Low Voltage Embedded Generation Connection Technical Requirements, and;
- TS134 – Communication Systems (inc. SCADA) for Embedded Generation

The V2G system capacity contributed to the overall University generation capacity (i.e. added onto the existing PV generation system capacity) and therefore SAPN control and monitoring requirements would be governed according to “SAPN SCADA (Simplified)” technical criteria according to TS134 (i.e. < 5MW total generation capacity, AS4777.2 compliant).

Since the University EMS was already controlling the existing solar PV inverters on site under the SAPN technical standards, the V2G units would be augmented into the EMS.

The release of AS4777.1-2024 (following release of ISO 15118-2022) including provisions for Vehicle to Grid charging for AC & DC connections should be provide a basis to simply network connection pathways by network operators in the future.

8 Smart AC charging System

There are 10 x 7.4kW AC chargers installed at University Carpark 3 and 5 x 7.4kW AC chargers installed at Carpark 2. The AC chargers use tethered Type 2 cable to support long-stay EV charging for fleet, students and staff. The 10 x 7.4kW AC chargers at Carpark 3 are supplied from EV-DB-CP3 (fed from South Ridge MSB MSB.SS) and connected to the University IT network via fibre optic connection to network switch inside the Solar Shed. The 5 x 7.4kW AC chargers at Carpark 2 are supplied from MDB (fed from South Ridge MSB “MSB.SS”) and connected to the University IT network via Cat6 data connection to network switch inside Solar Shed.

The smart AC charger is managed via the University EMS and apply the following protocols (Table 7). The AC charge operates is managed based on the net renewable generation (and corresponding site demand) with University network i.e. high net PV generation (or low site demand) will increase AC charge rate and low net renewable generation (or high site demand) will reduce the AC charge rate. This allows the AC charging system to maximise use of free, zero emission excess solar PV generation during the day, which provides a compelling commercial and environmental proposition for users.

AC charging stations were free to users to remove the usage barriers with revenue generated from energy credits (i.e. renewables sponge / demand reduction). There is opportunity to introduce charging tariff for users in future trials. This would include lower charging tariffs to encourage usage during higher renewables and lower energy pricing intervals and higher charging tariffs during low renewables and higher energy pricing intervals. Due to the lower charging volumes from AC charging it is anticipated that any difference in tariff pricing difference during the day would be small. In the future, should AC charging volume increases the tariff pricing differences (and incentive for users) may also increase.

Table 7 - Smart AC Charging Protocol

<table>
<tr><th>Use Case</th><th>Action</th></tr>
<tr><td>High net solar PV generation - University</td><td rowspan="4">Set AC charger to maximum rate (7.4kW)</td></tr>
<tr><td>Low site electrical demand - University</td></tr>
<tr><td>Solar PV curtailment – University</td></tr>
<tr><td>Renewable energy curtailment – SAPN (no site electrical demand constraint)</td></tr>
<tr><td>High site electrical demand - University</td><td>Reduce AC charger to minimum rate (1.4kW)</td></tr>
</table>

Load shed event – University	Set AC charger to 0kW rate

9 DC fast charger

DC fast chargers are controlled using the University EMS.

The EMS monitors the power draw from the DC fast chargers against the available capacity from the University network and increases the DC charger load incrementally from its minimum charge rate to maximum charge rate. In the event the DC charger load approaches its set capacity limit the charge rate is maintained and step-up sequence is halted. If spare capacity becomes available (i.e. EV disconnected, site load reducing, PV generation increasing) the step-up sequence will resume.

If the DC charger exceeds its set capacity limit or site load shedding is initiated the EMS will instruct the DC charger to step down from its current charge rate to its minimum charge rate.

If the University network demand is still in exceedance the DC charger will be disabled until spare capacity in the network becomes available.

9.1 Time of Use Tariff (ToU)

The public DC charger operates with Time of Use (ToU) tariff, set as follows:

- 0.72 c/kWh, 5pm-10pm
- 0.65 c/kWh all other times

The high tariff reflects a higher pricing period where network demand is high and proportion of low-cost renewables in the network is lower. The low tariff reflects a lower pricing period where network demand is low and the proportion of low-cost renewables in the network is higher. The DC charger is publicly accessible 24/7 and therefore does not limit when charging occurs during a 24-hour period.

It was found most of the charging activity occurred within the low tariff period between 10am-4pm. There was a significant drop-in charging activity after 5pm which coincides with the start of the high tariff period (

Figure 16). It was not possible to determine the proportion of charging sessions that were by the public and fleet users.

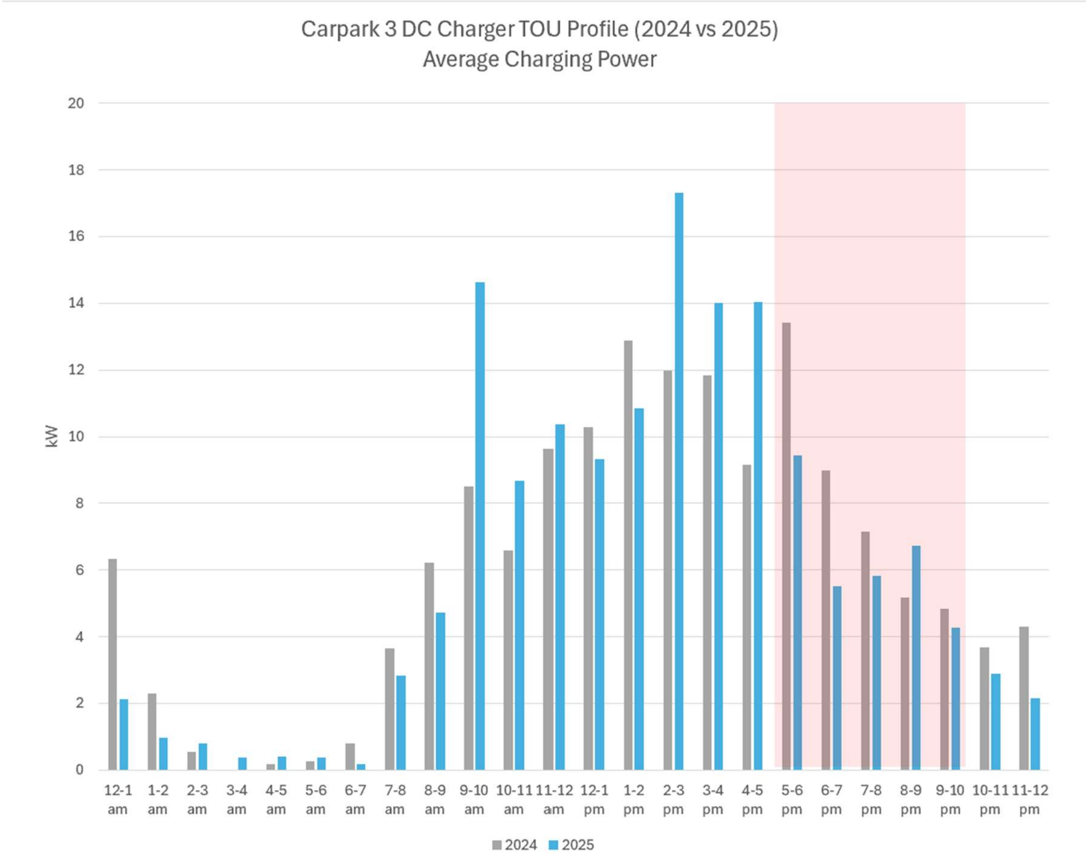

Figure 16 – DC Charger Output – ToU Tariff

10 Key Highlights & Conclusions

- The energy market within Australia has also undergone unprecedented changes with phasing out of coal and gas-fired power generation and augmentation of renewable energy sources into the national grid. South Australia currently generates over 70% of its electricity from renewable sources. This offers a prodigious opportunity for EV fleet operators to maximise use of lower cost renewable energy and support the grid during periods of high network demand.

- V2G technology provides a technology to support mass vehicle electrification for business fleets at lower charging costs. The commerciality of the technology will improve as V2G enabled EVs approach price parity with equivalent ICE vehicles.

- V2G technology must be supported in a controlled and managed manner via VPP software that can be augmented into existing energy management systems (i.e. private use or via network operators), with clear hierarchy of control defined as it relates to network operator requirements, site-level and fleet operator requirements.

- EV charging manufacturers will often offer some kind of smart integration service designed to control the speed of charging and discharging, however experience shows that off the shelve versions of these often do not enough flexibility to cater for the requirements of anything but the most basic domestic install. Consulting and working with local knowledgeable integrators is critical for positive outcome.

- A major barrier to unlocking V2G technology is in ratification of technical standard which support CCS2 charging standard. The release of AS4777.1-2024 (following release of ISO 15118-2022) which includes provisions for Vehicle to Grid charging for AC & DC connections should act as catalyst to improve market for V2G technologies and simplify connection pathways by network operators for V2G technology in the future.