Battery Storage and Grid Integration Program

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Evaluation of FCAS Capabilities of a V2G Capable EV Charger – A Case Study

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Executive Summary

V2G is a promising technology that can provide frequency control ancillary service (FCAS) in Australian National Energy Market [1]. However, the capabilities of V2G technology to deliver FCAS services are still unproven at technical level. This report aims to be a “first look” at the technical capabilities of the V2G technology for delivering FCAS services. The experimental tests are undertaken on a “Wallbox Quasar” charger using the DERlab grid simulator facility at the Australian National University (ANU). This report presents a series of experimental test results on the charger’s technical capabilities to deliver FCAS services. These tests were undertaken against both the AS4777.2:2020 and UK G99 standards.

This suite of tests was undertaken as part of the Realising Electric Vehicle-to-Grid Services (REVS) project in the DERlab at ANU. This project examines V2G’s capability to deliver FCAS services using a 51-vehicle fleet of EVs deployed across the Australian Capital Territory (ACT). This report mainly focuses on FCAS capabilities of the charger against the AEMO market ancillary service specifications [2].

These tests are performed between 10/2021 and 03/2022. The experimental test data is recorded using the ANU-developed point-on-wave (POW) meter and a power meter identical to the one that has been deployed as part of the standard REVS installation at other sites. It is important to note that the charger (wallbox quasar) unit that was used for these tests is a slightly earlier production unit that does not comply with AS4777.2:2020 due to hardware grounding issues however, the firmware is AS4777.2:2020 compliant. The charger has been assessed against the AEMO Market Ancillary Service Specification (MASS).

The methodology and tests that have been performed to demonstrate the charger’s capabilities are presented in **Section 3** and **Section 4** respectively. Results are discussed in **Section 5**. More detailed experimental test results are provided in **Appendix E**.

The test results in this report show that the charger ramps very slowly and takes more than 300 seconds to respond to the multiple FCAS fast raise events when the charger is configured with AS4777.2:2020 standard. This is longer than the 6 second response time required by the MASS. Therefore, the charger in its current configuration cannot provide all contingency FCAS services. The ramp rate limitation is caused by the vendor’s implementation of sections 3.3.4.2, 4.5.3.2.2 & 4.5.3.3.2 of AS/NZS 4777.2:2020 [3]. This standard specifies inverters must limit their active power ramp rate (W_{Gra}) to 16.67% of the rated power output per minute (60 seconds). AS/NZS 4777.2:2020 specifies that W_{Gra} ramp rate must be applied when frequency is within the continuous operation range which is 49.75 Hz - 50.25 Hz for Australia A. As shown in **Table 4**, the FCAS raise services trigger when the frequency drops below

49.85 Hz and this frequency overlays within the 49.75 Hz which is the lower limit of the continuous operation range. This implies that the charger responds to the W_{Gra} ramp rate limit imposed by AS/NZS 4777.2:2020 instead of responding to FCAS events as per AEMO MASS requirements. Other AS/NZS 4777 compliant inverters already participate in FCAS markets, therefore the issue could be in the manufacturer's implementation of the AS/NZS 4777 standard rather than the standard itself.

This response speed is not a hardware limitation. When the charger is reconfigured for the UK G99 standard, the charger ramped far quicker and the charger responds to all FCAS services within 4.5 seconds of the contingency frequency event. This means that the charger is capable to respond within 6 seconds for all FCAS services when configured with UK G99 standard.

For both G99 and AS/NZS 4777.2:2020 standard configurations, there is time delay of around 14 seconds for the charger to ramp back down to its initial operating point after the event. This delay is caused by the JetCharge controller. A new revision of the JET charge controller firmware is expected to resolve this issue before V2G capable chargers are installed. The results also show that the frequency and power data recorded by POW meter are less noisy as compared to the power meter data. The additional FCAS tests results as described in **Appendix E.2.4** are drawn from the power meter data. A summary of the test results is presented in **Table 1**. Within the current architecture even where capable fast services are at the limits of the charger's capability. Response time is around 4 seconds which is likely too slow for participation in future faster frequency markets.

Table 1: Charger capabilities for delivering contingency FCAS services in Australian National Electricity Market

<table>
<tr><th>FCAS services</th><th>Configured with AS4777.2:2020</th><th>Configured with UK G99</th></tr>
<tr><td>Fast raise service</td><td rowspan="3">Not capable</td><td rowspan="3">Capable</td></tr>
<tr><td>Slow raise service</td></tr>
<tr><td>Delayed raise service</td></tr>
<tr><td>Fast lower service</td><td rowspan="3">Capable</td><td rowspan="3">Capable</td></tr>
<tr><td>Slow lower service</td></tr>
<tr><td>Delayed lower service</td></tr>
</table>

1. Introduction

A bidirectional EV charger is a four-quadrant converter. It facilitates V2G operation by enabling discharge of EV batteries to grids. This enables the EV to provide a range of grid services including FCAS [4]. EV uptake is increasing, which will lead to a large number of vehicles throughout Australian power grids over the coming years. This creates scope for V2G to deliver FCAS services in the Australian National Electricity Market (NEM). However, it is very important to examine the technical capabilities of the bidirectional charger to deliver the FCAS services in NEM. In the REVS project, there will be 51 Nissan LEAF EVs deployed across Australian Capital Territory (ACT) to test and deliver frequency control ancillary services (FCAS) to NEM. To facilitate FCAS, a total of 51 Wallbox bidirectional chargers having vehicle to grid (V2G) capability will be installed in ACT government facilities.

2. Purpose

The purpose of the document is to present experimental results of the EV charger to demonstrate its technical capabilities to deliver all six contingency FCAS to NEM through a series of laboratory tests. The laboratory tests of the EV charger examine the following:

- Can the charger provide FCAS services when it is configured to AS4777.2:2020 standard?
- Can the charger provide FCAS services when it is configured to international standard i.e. UK G99?

3. Methodology

The experimental test system is shown in Figure 1. This is physically located at the DERlab at the Australian National University (ANU). A full 4-quadrant grid simulator is used to supply the bidirectional EV charger that connects the EV via CHAdeMO port. The system comprises of the following hardware:

- FCAS control system
- Bidirectional EV charger (Wallbox Quasar)
- High speed power meter (SATEC EM3250)
- Grid simulator (Regatron)
- Ethernet network
- POW meter/picomu

The grid simulator is used to supply the bidirectional EV charger that connects the EV via a CHAdeMO port. FCAS contingency services are provided by the FCAS controller that initiates the requests for the EV charger to modulate the charging or discharging session based on the local frequency.

The FCAS controller communicates with the bidirectional EV chargers and power meter using MODBUS-TCP on a Local Area Network (LAN). The power meter provides power measurements at a rate of 256 samples/cycle and updating its internal MODBUS registers every 20 ms. The bidirectional EV charger exposes data on its internal MODBUS registers every 1 sec. Apart from the power meter, the experimental test data is recorded using point-on-wave (POW) meter to compare the results from power meter. The bidirectional charger is capable of charging and discharging the EV at a maximum rate of 7.2 kW on a single-phase connection. The detailed specifications of the hardware and software used in REVS are provided in **Appendix B**. The FCAS controller is discussed in **Appendix C**.

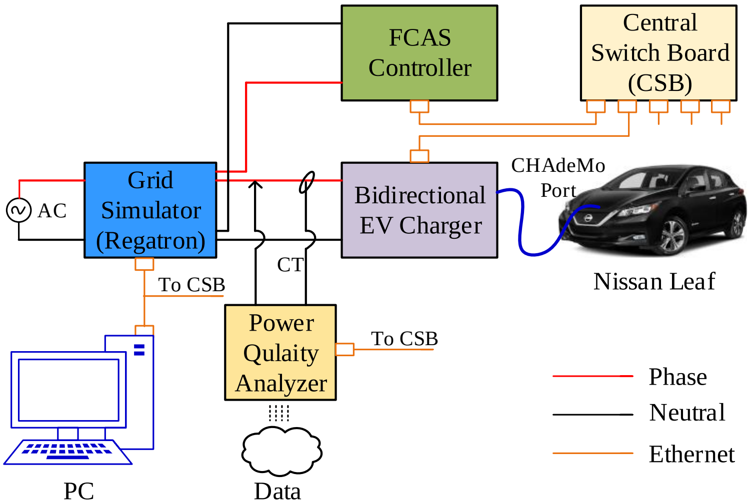

Figure 1: Experimental system for EV charger's FCAS capability tests.

4. Test Performed

Table 2 shows the list of tests that are conducted in ANU DERlab to assess the FCAS capabilities of the bidirectional charger to deliver FCAS services. Test 7 is to observe what happens if the EV charger is plugged-in, when there is a FCAS event in progress. The SOC limit test (test 8) was performed to observe what happens if the SOC of the battery exceeds 90% as the allowable SOC range was set to 30%-90% for participating FCAS events.

Table 2: FCAS capability tests

Tests	FCAS services	Test profiles
Test 1	Fast/slow/delayed FCAS Lower	**Figure 10**
Test 2	Fast/slow/delayed FCAS Raise	**Figure 11**
Test 3	Fast/slow/delayed combined FCAS Raise + Lower	**Figure 12 (a)**
Test 4	Fast/slow/delayed combined FCAS Raise + Lower	**Figure 12 (b)**
Test 5	Fast/slow/delayed FCAS lower	**Figure 8**
Test 6	Fast/slow/delayed FCAS raise	**Figure 9**
Test 7	Charger plugged-in while FCAS event is in progress	**Figure 8 and Figure 10**
Test 8	SOC limit test (>90%)	**Figure 8**

5. Charger capabilities for delivering FCAS services

Table 3 shows the charger's performance against required response time defined by AEMO market ancillary service specification. It is clear that the charger's response time much more than this should be when it is configured to AS4777.2:2020 standard. This implies that the charger is not capable of delivering raise FCAS services in NEM with its current firmware.

Table 3: Charger's performance against required response time defined by AEMO market ancillary service specification

<table>
<tr><th>FCAS services</th><th>Required response time</th><th>Response time when configured with AS4777.2:2020</th><th>Response time when configured with UK G99</th></tr>
<tr><td>Fast raise</td><td>6 sec</td><td rowspan="3">>300 sec</td><td rowspan="6">4.5 sec</td></tr>
<tr><td>Slow raise</td><td>60 sec</td></tr>
<tr><td>Delayed raise</td><td>300 sec</td></tr>
<tr><td>Fast lower</td><td>6 sec</td><td rowspan="3">5 sec</td></tr>
<tr><td>Slow lower</td><td>60 sec</td></tr>
<tr><td>Delayed lower</td><td>300 sec</td></tr>
</table>

However, the charger response time is measured to be 4.5 sec for delivering all contingency FCAS services when the charger is configured to international standard, for example UK G99. Although the charger is working well with the UK G99 standard, there are technical limitations for network operators to allow connections of the noncompliant EV chargers to Australian power networks.

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Appendix A Background

A.1. Background Studies

V2G service is an emerging technology that is being developed because it allows higher utilisation of EV batteries. The global rise in electric vehicle sales is expanding the potential of V2G services [4]. This promises financial and non-financial benefits for stakeholders such as EV owners, electricity system and wider communities, as described in [1].

Most EVs have large batteries that are not utilised for driving for much of the day. They are parked for many hours and connected to charger even after the EVs are fully charged. To achieve better utilisation, EVs can be utilised to provide V2G services to make them prepared for participating in FCAS markets [5]–[7]. In Australia, FCAS markets are divided into two parts: regulation and contingency services [2] . REVS project is demonstrating the contingency FCAS services. AEMO has defined six types of FCAS contingency services as presented in **Table 4** [12]. “Raise” services require generators to increase output in response to decrease in local frequency and the “Lower” services require generators to decrease output in response to increase in local frequency. The raise and lower services are both divided into three categories based on the response time requirements: fast, slow, and delayed as shown in **Table 4**.

Table 4: Specifications for contingency FCAS response time in the Australian national energy market [2]

Service type	Response time (s)	Duration (s)	Trigger (Hz)
Fast raise service	6	60	f < 49.85
Fast lower service	6	60	f > 50.15
Slow raise service	60	300	f < 49.85
Slow lower service	60	300	f > 50.15
Delayed raise service	300	600	f < 49.85
Delayed lower service	300	600	f > 50.15

An example of contingency frequency control is shown in **Figure 2** where the system returns to the standard operating frequency band (FB) within 5 minutes from the contingency event. The objective of fast raise and fast lower services is to capture the fall or rise in grid frequency due to a contingency event. Contingency events such as sudden loss of generators or loads cause the grid frequency leave the standard operating band. Fast raise services alter generation output quickly to counteract the disturbance – reducing generation on frequency increase or increasing it in frequency decline.

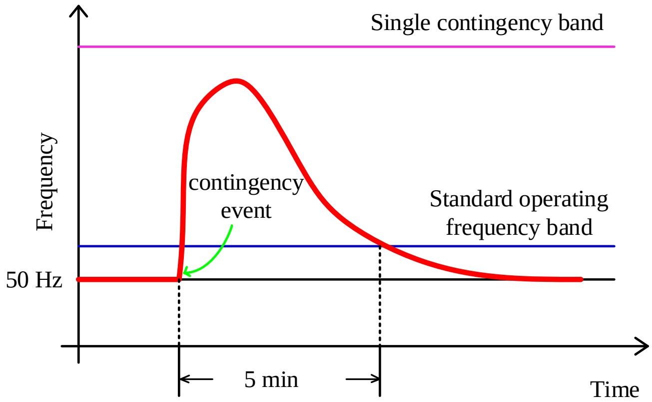


Figure 2: Contingency frequency control [12]

Fast services act within six (6) seconds to arrest rapid changes in grid frequency. Slow services take over where fast services leave off and act to restore frequency to within normal bounds. Once grid frequency recovers, it is not required to provide FCAS contingency services. For example, if frequency recovers above 49.9 Hz or below 50.1 Hz within six seconds from contingency event, FCAS service providers are not required to deliver slow or delayed services. Similarly, recovery between six seconds and 60 seconds from the contingency event means FCAS service providers are not required to deliver delayed services. FCAS contingency services are controlled locally. Service providers must automatically respond to frequency deviations following contingency events. FCAS service providers must register with the Australian Energy Market Operator (AEMO) and submit FCAS bids every 5 minutes through AEMO's market management systems. FCAS bids represent the amount of active power service providers can either supply to the grid or consume from the grid in the time period defined by the FCAS bands in **Table 4**. The provision of FCAS services is enabled by bidirectional chargers which is an integral part of the control systems [8], [9]. These bidirectional chargers are classified as multiple mode inverter in AS/NZS 4777.2:2020.

Introducing the Realising Electric Vehicle-to-grid Services (REVS) trial

This report has been developed as part of the REVS trial. In an Australian first, the Realising Electric Vehicles-to-grid Services (REVS) project demonstrates how commercially available electric vehicles (EVs) and chargers can contribute to energy stability by transferring power back and forth into the grid, as required.

EVs will inject power back into the grid during rare events (to avoid possibility of blackouts) and EV owners will be paid when their vehicles are used for this service.

Employing 51 Nissan LEAF EVs across the ACT as part of the ACT government and ActewAGL fleet, the REVS project seeks to support the reliability and resilience of the electricity grid, unlocking economic benefits making electric vehicles a more viable and appealing transport option for fleet operators.

The REVS consortium covers the whole electricity and transport supply chains including ActewAGL, Evoenergy, Nissan, SG Fleet, JET Charge, ACT Government and the Australian National University. Together the consortium will produce a roadmap with recommendations that will accelerate the deployment of V2G nationally.

The project has been endorsed by the Australian Renewable Energy Agency (ARENA) and has received funding as part of ARENA's Advancing Renewables Program.

REVS is underway and will publish a final report in late 2022.

https://secs.accenture.com/accenturems/revs/

A.2. Single line diagram of ANU DERlab

Figure 3 shows the single-line diagram (SLD) of the ANU DERlab. The EV charger will be connected at the connection point 1 (CP 1) to perform the test. These connection points can be directly connected to the evoenergy network or to the grid simulator installed at ANU DERlab.

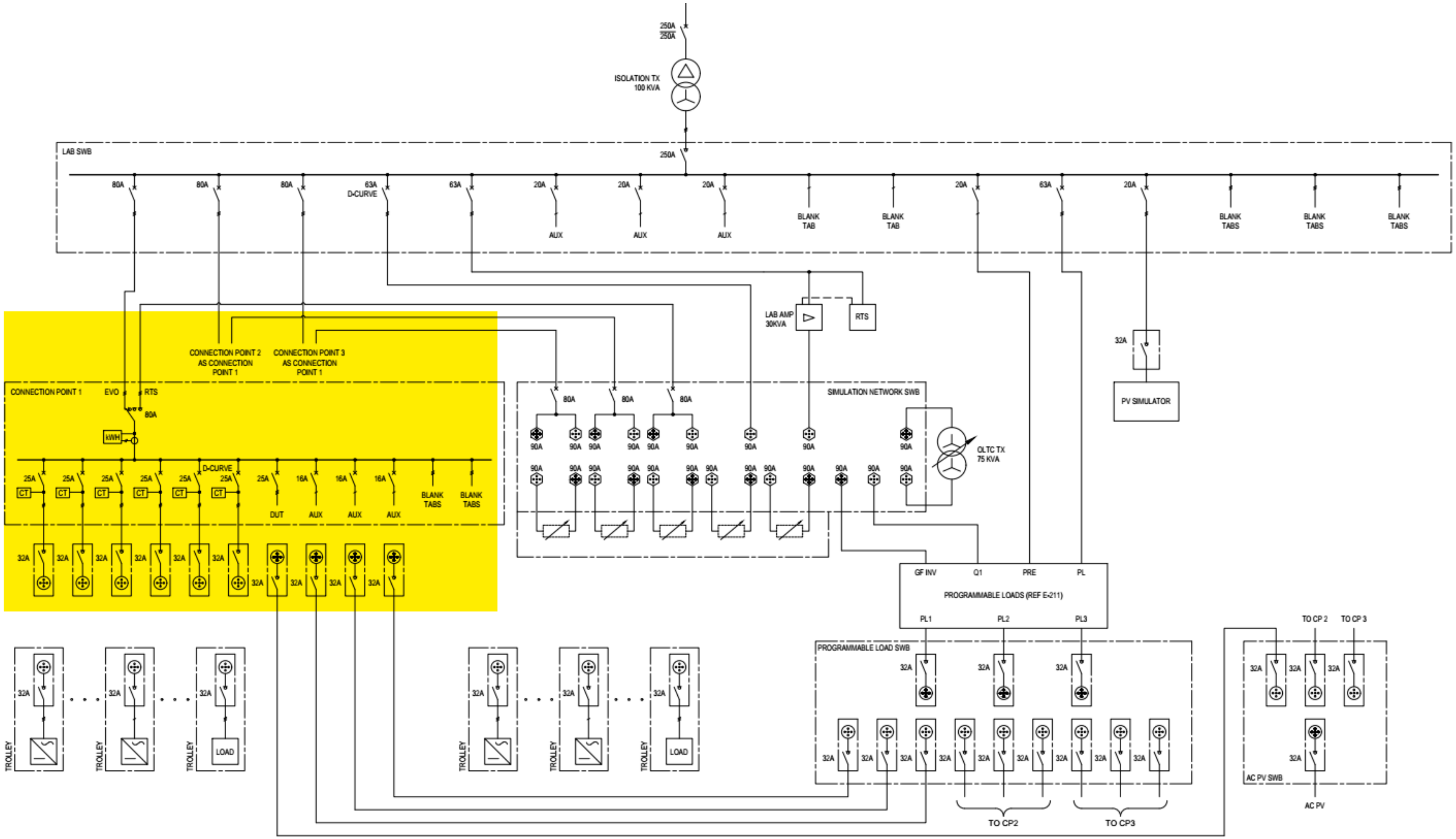


Figure 3: Single-line diagram of ANU DERlab

Appendix B Hardware and Software

B.1.1. Experimental test set-up

The laboratory setup of the EV charger in the ANU DERlab is shown in **Figure 4**. The laboratory setup comprises of a grid simulator, a V2G capable "Wallbox Quasar" EV charger mounted on a pole, a Nissan LEAF EV with CHAdeMO port and measurement devices. The technical specifications of the EV and hardware used for laboratory testing and measurements are presented below:

Figure 4: EV charger's testing setup in the ANU DERlab.

B.1.2. V2G capable wallbox quasar

Wallbox quasar is a DC bidirectional EV charger to directly charge and discharge the EVs through its CCS or CHAdeMO port. The charger is generally controlled using the Wallbox App. The technical specification is shown in **Table 5**.

Table 5 Technical specifications of wallbox quasar

Manufacturer	Wallbox
Model	DC charger
Connector type	CCS or CHAdeMO
Maximum power	7.4 kW (single phase)
AC voltage	230 V AC ±10%
DC voltage	150 V – 500 V
Maximum current	32 A (Charging current configurable from ± 6 A to ± 32 A)
Rated frequency	50 Hz

B.1.3. Nissan LEAF

The specification of the Nissan LEAF EV is shown in **Table 6**.

Table 6 Technical specifications of 2021 white Nissan LEAF sedan

Manufacturer	Nissan
Model	2021 WHITE NISSAN SEDAN
Battery	
Type	Laminated lithium ion
Voltage	350 V
Capacity	40 kWh
Charging	
On-board charger	6.6 kW
CHAdeMO port	50 kW
Charging time (6.6 kW on-board charger)	Around 7.5 hrs to charge from alert to 100% at 32 A
Charging time (50 kW rapid charger)	Around 60 min to charge from 20% to 80%.

B.1.4. Grid simulator

The frequency disturbance will be created using the Regatron grid simulator at ANU DER Lab. During the duration of contingency FCAS test, the bi-directional charger will be responsive to the signal created by this grid simulator. The technical parameters of the Regatron grid simulator is given in **Table 7**.

Table 7 Technical specifications of Regatron grid simulator

Manufacturer	Regatron
Model	TC.ACS.30.528.4WR.S.LC
AC lineside ratings	
Line voltage	3 x 360 – 528 VAC
Line frequency	48 – 62 Hz
Input current	3 x 54 Arms
AC loadside ratings	
Power range	0-30 kVA
Voltage range	0 – 305 Vrms (L-N)
Frequency range	0 – 1000 Hz

Current range	3 x 0 – 43 A

B.1.5. Measurement devices

The key parameters of assessing the tests capabilities are the active and reactive power flow between the grid and the EVs. Thus, the active and reactive power at the connection points (1 or 2 or 3) in DER Lab will be recorded for each test. Furthermore, for the verification of frequency measurement capabilities within the defined conditions as well as for post-test analysis, grid frequency will be measured at the connection point.

In the REVS project, power measurements are made using power meter. It provides power measurements at a rate of 256 samples/cycle and updating its internal MODBUS registers every 20 ms. The bidirectional EV charger exposes data on its internal MODBUS registers every 1 sec. The experimental data is also captured by the point-on-wave (POW) meter operating at 62 kHz and post analysed to compare the result from power meter. The measurements with POW meters allow users to visualise real-time measurement data and waveforms directly form controlled PC.

Power meter

The technical specification of the SATEC power meter is presented in **Table 8**. Further measurement accuracy details are shown in **Table 9**.

Table 8 Technical specifications of SATEC power meter

Manufacturer	SATEC
Model	eXpertPRO DIN EM3250
Power supply	
Rated input:	85-332VAC 50/60Hz, 40-290VDC
Over-voltage withstands:	1000 VAC continuous, 2000 VAC for 1 second
Voltage inputs	
Operating range	10VAC (L-L) to 1000VAC (L-L)
Current inputs	
Magnitude	1A-5A secondary (standard)
Operating range	continuous 10A RMS
Overload withstands	15A RMS continuous, 200A (25 x Imax) RMS for ½ second
Sampling rate	256 samples/cycle

For the purpose of post-test analysis, other parameters as given below may need to be recorded at the connection point.

- Voltage
- Current
- Power factor
- Reactive power

Table 9 Measurement accuracy details of the power meter (EM3250)

Parameter	Full Scale @ Input Range	Accuracy			Range
		% Reading	% FS	Conditions	
Voltage	120VxPT @ 120V 400VxPT @ 690V	0.1	0.02	10% to 120% FS	0 to 1,150,000 V Starting voltage 1.5-5.0% FS (selectable)
Line current	CT	0.1	0.02	For In = 5A 1% to 200% FS For In = 1A 5% to 200% FS	0 to 50,000 A Starting current 0.1% FS
Active power	0.36×PT×CT @ 120V 1.2×PT×CT @ 690V	0.2	0.02	|PF| ≥ 0.5	-10,000,000 kW to +10,000,000 kW
Reactive power	0.36×PT×CT@ 120V 1.2×PT×CT @ 690V	0.2	0.04	|PF| ≤ 0.9[1]	-10,000,000 kvar to +10,000,000 kvar
Apparent power	0.36×PT×CT @ 120V 1.2×PT×CT @ 690V	0.2	0.02	|PF| ≥ 0.5[1]	0 to 10,000,000 kVA
Power factor	1.000		0.2	|PF| ≥ 0.5, I ≥ 2% FSI	-0.999 to +1.000
Frequency		0.002		VL-N > 25V	40 Hz to 70 Hz
Total Harmonic Distortion, THD V (I), %Vf (%If)	999.9	1.5	0.2	THD ≥ 1%, V ≥ 10% FSV and V_{L-N} > 25V, I ≥ 10% FSI	0 to 999.9
Total Demand Distortion, TDD, %	100		1.5	TDD ≥ 1%, I ≥ 10% FSI, V_{L-N} > 25V	0 to 100
Active energy Import & Export		Class 0.2S under conditions as per IEC 62053-22:2003			0 to 999,999,999 kWh
Reactive energy Import & Export		Class 0.5S under conditions as per IEC 62053-24:2015			0 to 999,999,999 kvarh
Apparent energy		Class 0.2S under conditions as per IEC 62053-22:2003			0 to 999,999,999 kVAh

Point on wave (POW) meter/picomu

The POW meter or simply picomu provides raw data and calculated data for current, voltage and power. The raw data is sampled at maximum of 64000sps to minimum of 2000sps. Each of those samples has a time stamp of 1µs. A photograph of the POW meter connected to ANU DERlab switchboard is shown in **Figure 5**.

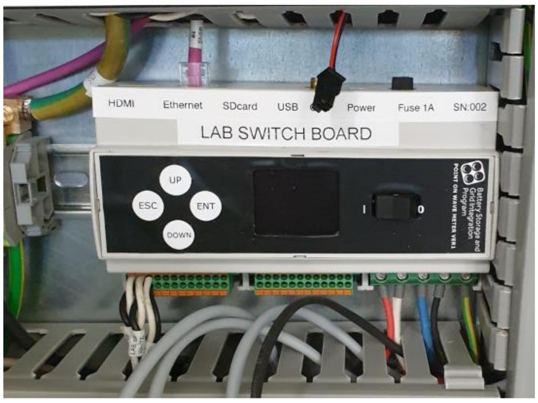


Figure 5: POW meter.

B.1.6. Software Interface

The software for grid simulator is installed in the computer to change set points and to interface with the grid simulator. This is used to define appropriate set points to generate FCAS test profiles for fast, slow and delayed FCAS services. These tests profiles are applied to the EV charger. The tests data is recorded by power meter and POW meter and is analysed to interpret the behaviour of EV charger. The software interface of the grid simulator is shown in **Figure 6**.

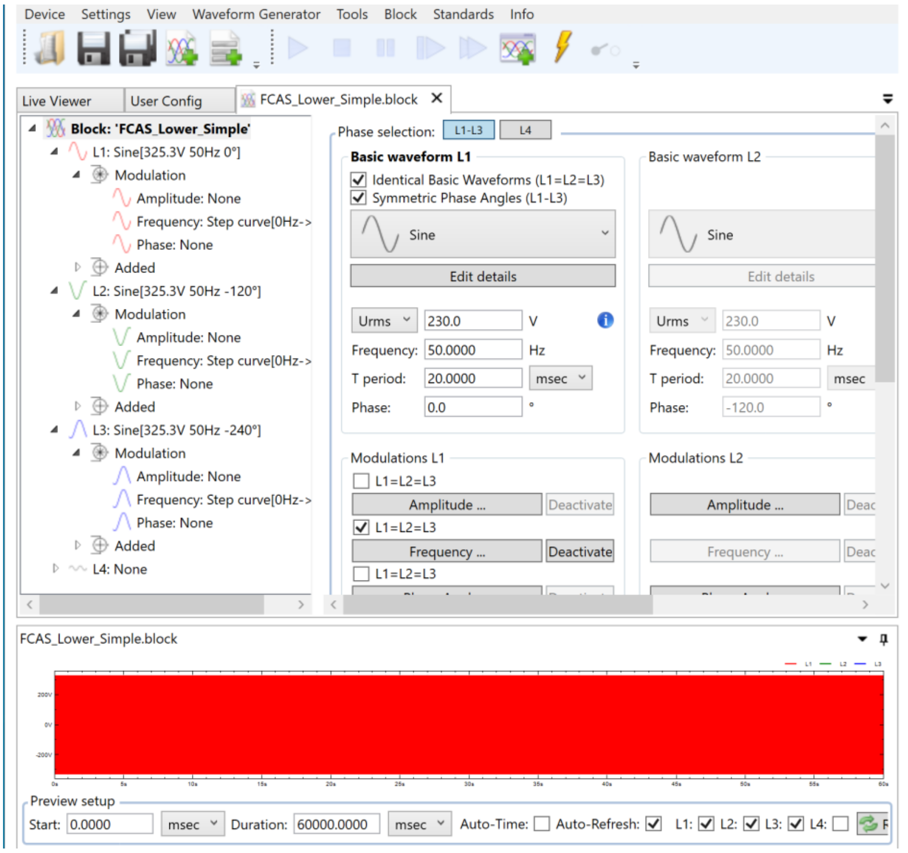


Figure 6: ACS control interface of a grid simulator interface.

Appendix C FCAS Controller

C.1. Overview of FCAS controller

The bidirectional EV charger do not have inherent capability to respond to the FCAS events. In the REVS project, JET Charge has developed an external control box to connect to the EV charger which is named as "FCAS controller" in this report. The purpose of this FCAS controller is to detect frequency disturbance in the grid and control bidirectional EV chargers to respond for FCAS events. The FCAS controller modulates EV charging in response to local frequency in line with the market ancillary service specification [2] to assist with stabilising the grid frequency. The FCAS controller is able to provide all six FCAS contingency services. In response to an FCAS lower event (f > 50.15Hz), the FCAS controller causes the bidirectional EV charger with plugged in EVs to switch to charge mode, while for an FCAS raise event (f < 49.85Hz), it causes the bidirectional EV charger with plugged in EV to switch to discharge mode respectively. The EV charger ramps output power within 6 s of the contingency and continues to maintain this output for at least 60 s and up to 10 minutes for fast, lower and delayed services respectively [2]. The set-points of FB for frequency detection are set as follows. This event can last for up to 10 minutes or until the frequency has stabilized to within the FB specified in (1).

$$49.85Hz < FB < 50.15Hz \tag{1}$$

The program flow of the proposed coordinated control algorithm for the FCAS controller are summarized as below:

Step 1: Initialize FB as (49.85 Hz < *f* < 50.15 Hz).

Step 2: Read frequency from the power quality analyser.

Step 3: Check FB. Start EV charging/discharging if conditions are false; go to Step 2 if conditions are true.

Step 4: Log voltage, current, frequency and power data for 60 s and 300 s for contingency services.

Step 5: Check FB. Stop EV charging/discharging if conditions are true; go to Step 4 if conditions are false.

C.2. State transitions rules

The state of charger (SOC) of the EV batteries determines whether or not an EV can participate in FCAS markets. For the EVs to qualify to participate in the FCAS event, the SOC must be within the specified limits. In the REVS trial, this range is set to $30\% \leq SOC \leq 90\%$ in the FCAS controller. If the SOC is outside of this specified boundaries, the FCAS controller causes the bidirectional EV charger with plugged in EV to switch to either charge or discharge mode to reach the threshold. Once this is reached, the EV qualifies to participate.

In order to provide the fastest reaction time possible and be able to constantly monitor SOC, EV which is plugged in is set to keep the connection with bidirectional chargers active at all times. As a result, the connector is locked and the charger is set to operate in remote control mode. Hence all the user interaction is automatically disabled on the EV charger. As a consequence, this may prevent an EV driver from unlocking the connector on certain EVs such as Nissan LEAF. To solve this issue, an RFID card tap action has been implemented. Once the RFID card is tapped, the EV charger stops the charging session and unlocks the connector. For this to happen, The FCAS controller and the EV charger must be both online, RFID is not verified for authorisation. Another viable workaround that can be applied to Nissan LEAF specifically is to plug in Type2 charging cable not connected to any charger to its AC charging port, which should trigger a release for the DC charging CHAdeMO port.

Outside of FCAS events, the FCAS controller automatically keeps SOC of the EV that is plugged-in at a level which qualifies an EV to participate in any upcoming FCAS event as well as provides a driver enough charge to drive off if required. The detailed state transitions rules based on FCAS triggers are presented in **Table 10**. This shows that the action of the FCAS controller depends on the SOC values and event triggers. For example, if there is an event for FCAS lower services when the battery SOC is over 90%, the FCAS controller prevents the EV charger to provide FCAS lower services to limit the SOC.

Table 10 State transitions rules of V2G charger

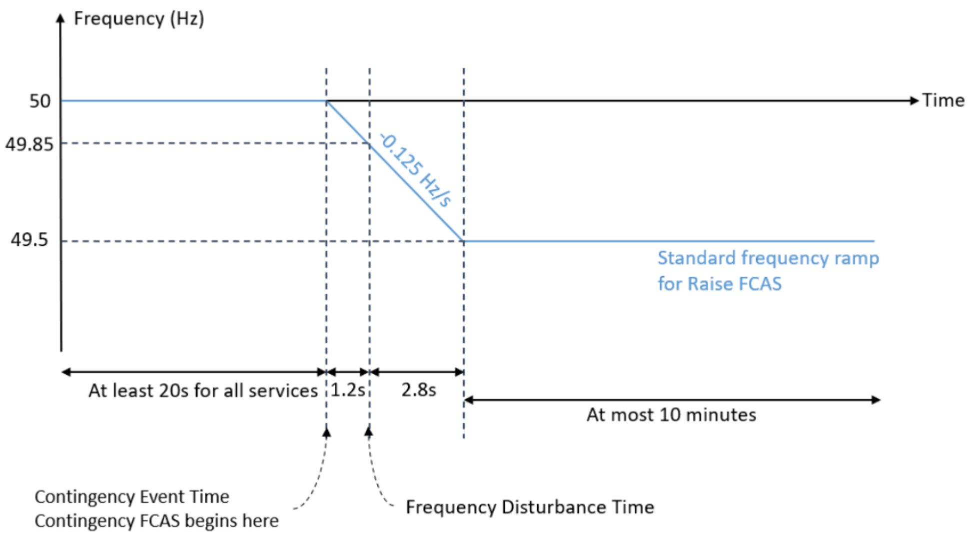
Battery SOC range & conditions	Trigger	Action
SOC > 90%	FCAS lower	Unable to participate in FCAS lower services
SOC ≤ 90%	FCAS lower	Provide FCAS lower service and charge the battery until frequency returns to the nominal value
SOC > 85%	EV Plugged in or FCAS raise finished or FCAS lower finished	Provide FCAS raise or lower services as required. Once these are finished, discharger the battery 80%
75% ≤ SOC ≤ 85%	EV Plugged in or FCAS raise finished or FCAS lower finished or Charged to 80% or	Provide FCAS raise or lower services as required. Once these are finished, set the output to 0 kW and keep the connection active

	Discharged to 80%	
SOC < 75%	EV Plugged in or FCAS raise finished or FCAS lower finished or SOC updated	Provide FCAS raise or lower services as required. Once these are finished and charge the battery to 80%
SOC ≥ 30%	FCAS raise	Provide FCAS raise service and discharge the battery until frequency returns to the nominal value
SOC < 30%	FCAS raise	Unable to participate in FCAS raise services
FCAS event in progress	EV plugged in	Set the output to 0 kW until the event finishes and keep the connection active

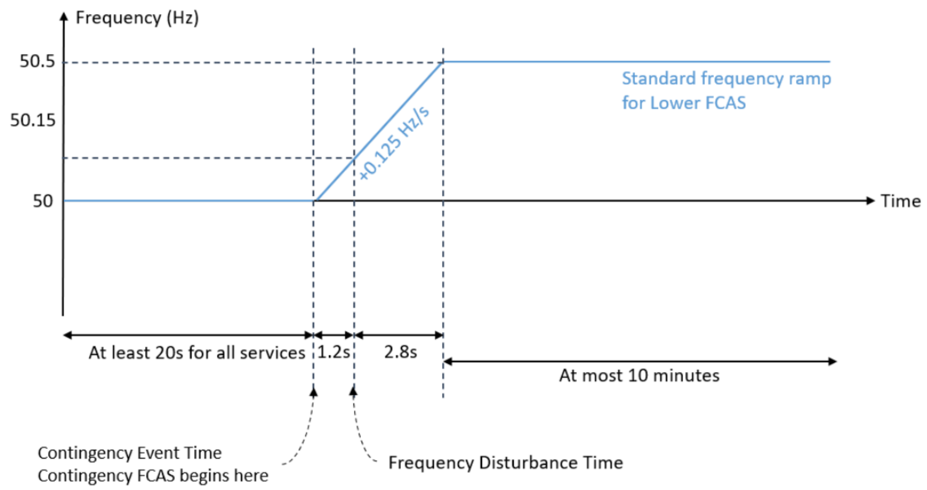
Appendix D Test Profiles

D.1. Standard frequency ramp

The standard frequency ramp is a linear change in local frequency from one level to another at the applicable frequency ramp rate and then it is sustained as shown in Figure 7. The standard frequency ramp for FCAS raise service is shown in Figure 7 **(a)** where the frequency ramp rate is −0.125 Hz/s. This means that the frequency drops from 50 Hz to 49.5 Hz at −0.125 Hz/s and then continues to maintain 49.5 Hz for a period of time. Figure 7 **(b)** shows the standard frequency ramp for FCAS lower service.



(a)



(b)

Figure 7: Standard frequency ramp other than Tasmania defined by AEMO [2], (a) raise FCAS, (b) lower FCAS service

The frequency rises from 50 Hz to 50.5 Hz at a ramp rate of +0.125 Hz/s and then continues to maintain 50.5 Hz for a period of time.

In the REVS project, the specifications of the standard frequency ramp are used to develop the FCAS test profiles to assess the FCAS capabilities of the bidirectional EV chargers. These are presented **Appendix D.2** and **D.3**.

D.2. Simple FCAS Capabilities

Figure 8 and Figure 9 show the example test profiles for simple/single FCAS lower and raise service respectively. For FCAS lower service, as shown in Figure 8, the frequency rises from 50 Hz to 50.25 Hz with a ramp rate of +0.125 Hz/s and maintains the frequency at 50.25 Hz for a period of time. The frequency returns to nominal frequency of 50 Hz with a ramp rate of −0.125 Hz/s and maintains this frequency for at least 120 seconds to upload the FCAS data. As shown in Figure 9, the frequency drops to 49.75 Hz with a ramp rate of −0.125 Hz/s and returns back to 50 Hz at t_3. **Table 11** shows the time duration of the example test profiles as shown in Figure 8 and Figure 9.

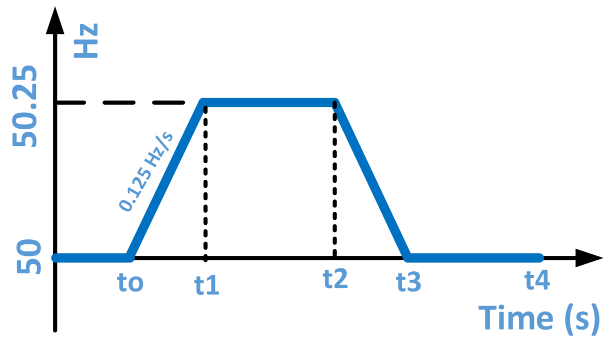


Figure 8: An example test profile for simple FCAS lower service

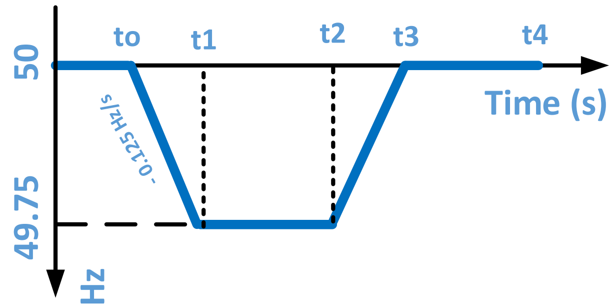


Figure 9: An example test profile for simple FCAS raise service

Table 11 : Time duration for simple FCAS capability tests.

	Services	t0(s)	t1(s)	t2(s)	t3(s)	t4(s)
Figure 8 FCAS Lower	Fast	0	2	50	52	172
	Slow	0	2	180	182	342
	Delayed	0	2	480	482	602
Figure 9 FCAS Raise	Fast	0	2	50	52	172
	Slow	0	2	180	182	342
	Delayed	0	2	480	482	602

D.3. Multiple FCAS Capabilities

The test profiles for multiple FCAS are essentially drawn from the simple/single FCAS test profiles. The example test profile for multiple FCAS lower service shown in Figure 10, is essentially a combination of two simple FCAS lower service test profiles. The frequency starts to rise at t_0 from 50 Hz to 50.25 Hz with a ramp rate of +0.125 Hz/s and maintains the frequency at 50.25 Hz for a period of time, t_2. The frequency returns to nominal frequency of 50 Hz at t_3 with a ramp rate of −0.125 Hz/s. The frequency again rises from 50 Hz to 50.25 Hz at +0.125 Hz/s at t_5, maintains this frequency up to t_6 and finally returns back to 50 Hz at t_7 with a ramp rate of −0.125 Hz/s.

An example test profile for multiple FCAS raise service is shown in **Figure 11**. The frequency starts to drop at t_0 from 50 Hz to 49.75 Hz with a ramp rate of −0.125 Hz/s and returns to nominal frequency of 50 Hz at t_3 with a ramp rate of +0.125 Hz/s. The frequency again drops from 50 Hz to 49.75 Hz at −0.125 Hz/s at t_5 and finally returns back to 50 Hz at t_7 with a ramp rate of +0.125 Hz/s.

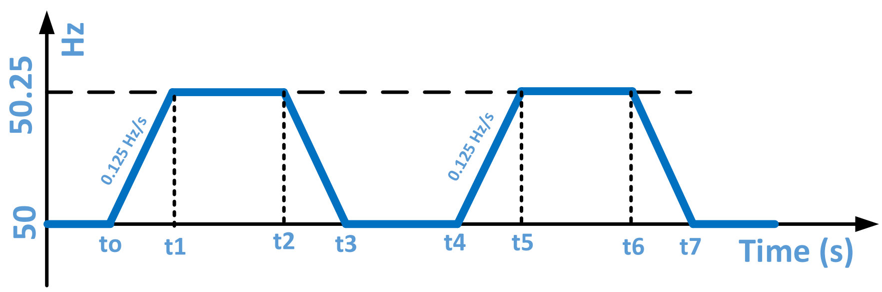


Figure 10: An example test profile for multiple FCAS lower service

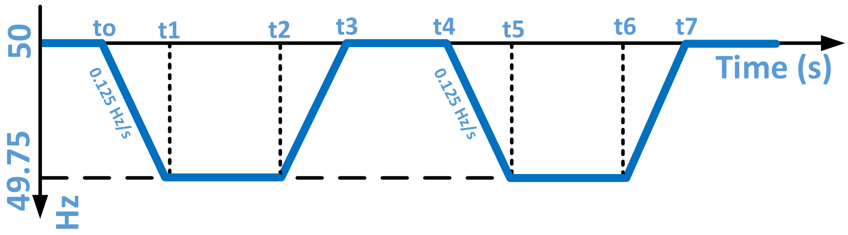


Figure 11: An example test profile for multiple FCAS raise service

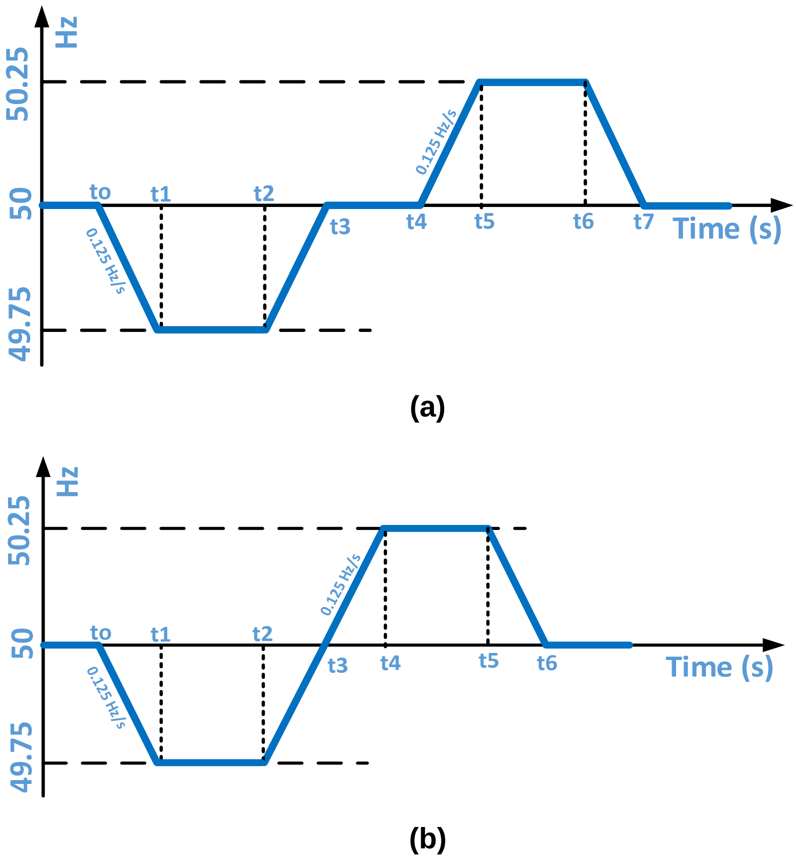


Figure 12: Example test profiles for combined FCAS raise and lower service

The example test profiles for combined multiple FCAS raise and lower service are shown in Figure 12. Figure 12 **(a)** shows that the frequency starts to drop at t_0 from 50 Hz to 49.75 Hz with a ramp rate of −0.125 Hz/s and returns to nominal frequency of 50 Hz at t_3 with a ramp rate of +0.125 Hz/s. Then, the frequency starts to rise from 50 Hz to 50.25 Hz at +0.125 Hz/s at t_5 and finally returns back to 50 Hz at t_7 with a ramp rate of −0.125 Hz/s. The only difference in Figure 12 **(b)** is that frequency does not return and sustain at 50 Hz from time t_3 to t_4, however, the frequency starts to rise from 49.75 Hz to 50.25 Hz with a ramp rate of +0.125 Hz/s and then returns back to 50 Hz at t_6. The time duration of the test profiles is shown in

Table 12.

Table 12 : Time duration for multiple FCAS capability tests.

	Services	t0(s)	t1(s)	t2(s)	t3(s)	t4(s)	t5(s)	t6(s)	t7(s)
Figure 10 FCAS Lower	Fast	0	2	50	52	172	174	242	244
	Slow	0	2	180	182	342	344	652	654
	Delayed	0	2	480	482	602	604	1212	1214
Figure 11 FCAS Raise	Fast	0	2	50	52	172	174	242	244
	Slow	0	2	180	182	342	344	652	654
	Delayed	0	2	480	482	602	604	1212	1214
Figure 12 **(a)** Combined FCAS	Fast	0	2	50	52	172	174	242	244
	Slow	0	2	180	182	342	344	652	654
	Delayed	0	2	480	482	602	604	1212	1214
Figure 12 **(b)** Combined FCAS	Fast	0	2	50	52	54	242	244	N/A
	Slow	0	2	180	182	184	652	654	N/A
	Delayed	0	2	480	482	484	1212	1214	N/A

Appendix E Experimental Test Results

E.1. Test results with AS4777.2:2020 standard

This section presents the V2G charger's response to deliver FCAS services when the charger is configured with AS4777.2:2020 standard. The charger power is represented by blue curve and frequency is represented by red curve. The experimental response of the charger for multiple FCAS fast services are discussed in **Appendix E.1.1**. The charger response to FCAS events also depend on the SOC of the EV battery and the charger follows the state transitions rules described in **Table 10**. During these tests SOC was varied from 75% to 85%. For simplicity of understanding, the positive value of power indicates input power (vehicle charging) and negative power indicates output power (vehicle discharging) throughout this report. All the experimental tests data are recorded by POW meter except some additional FCAS tests shown in **Appendix E.2.4**, where the data is recorded by the power meter. This provides us a comparison on the performance of POW meter and power meter.

E.1.1. Multiple FCAS fast service

Figure 13 shows the charger's response to multiple FCAS fast lower service with AS/NZS 4777.2:2020. As the SOC is 78%, the EV charger stops battery to charge to full power but maintains active connection to respond to FCAS events. As the frequency goes up to 50.25 Hz around 60 sec, the charger allows the battery to charge at full power (5.8 kW[1]). The charger again returns back to idle state and keeps connective active when frequency returns to 50 Hz as the SOC is 78%. Similar response is observed when there is another FCAS lower event occurs around 240 sec. In both FCAS events, the charger takes 5 sec to reach zero to full power, thus satisfies the response time requirements defined by MASS for FCAS fast lower services. However, there is time delay of around 14 s for the charger to ramp back down to its initial operating point after the event. This delay is caused by the JetCharge controller. A new revision of the JET charge controller firmware is expected to resolve this issue before V2G capable chargers are installed.

[1] The 5.8 kW limit was because the maximum charge/discharge current was set at 25 A in the tested unit

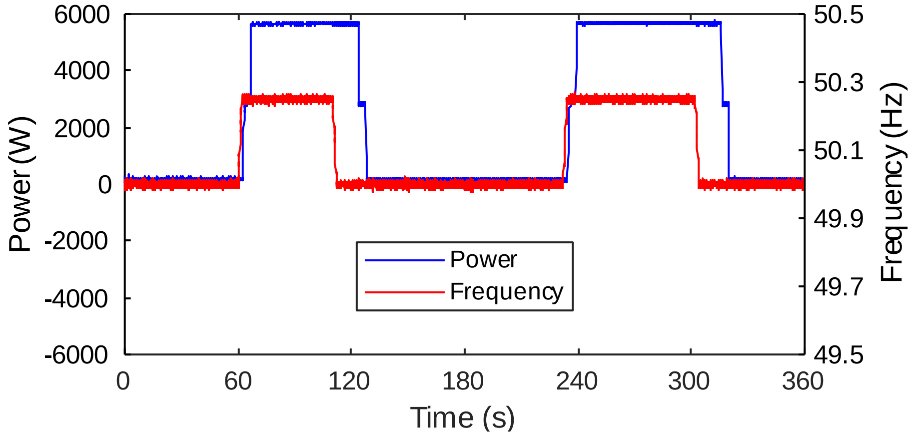


Figure 13: *V2G charger's response to multiple FCAS fast LOWER service with AS/NZS 4777.2:2020.*

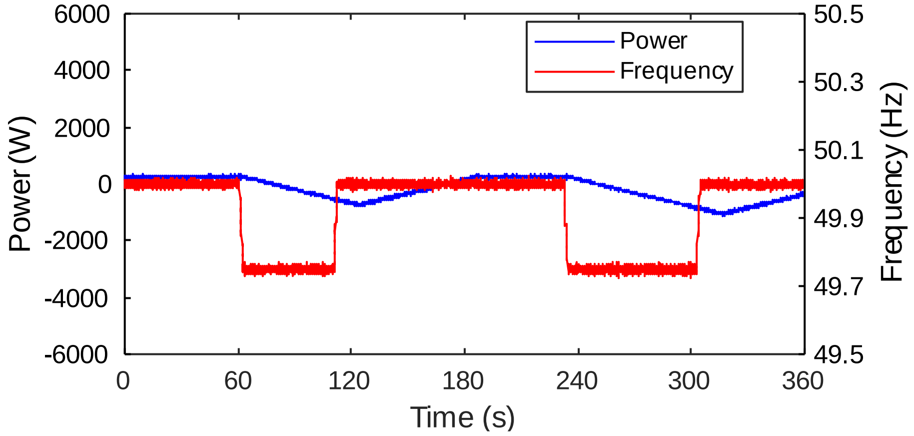
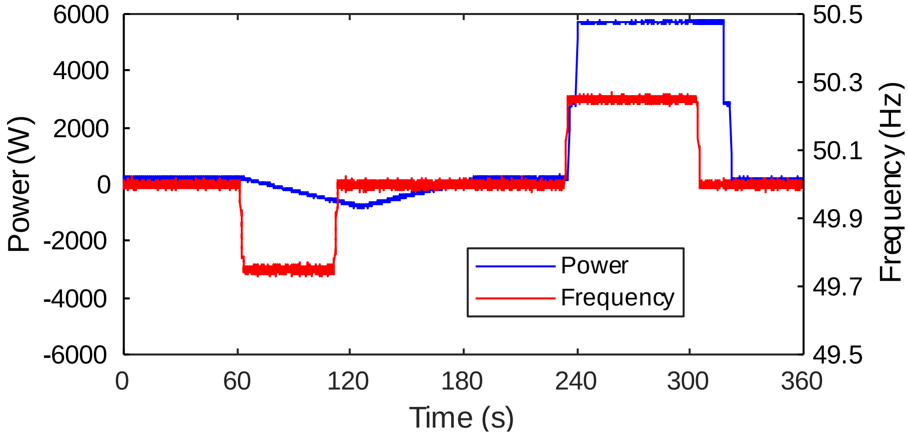
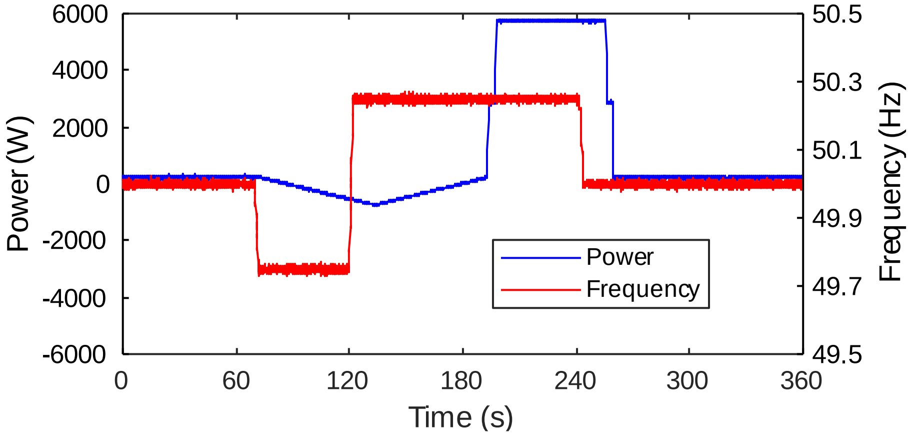


Figure 14: *V2G charger's response to multiple FCAS fast RAISE service with AS/NZS 4777.2:2020.*

Figure 14 shows the charger's response to multiple FCAS fast raise service with AS/NZS 4777.2:2020. The test result revealed that the charger was responding far too slowly when operating in the Australian standard (AS/NZS 4777.2:2020) mode. When the frequency dropped to 49.75 Hz at 60 sec, the charger ramped at 920 W/minute for raise services (where the charger must export power). This means that the charger takes 6 minutes (360 sec) to export 5.5 kW power. As a result, the charger does not meet the response time requirements defined in the MASS. To provide all contingency FCAS raise services, the charger must respond within 6 sec from the contingency frequency event.



(a)



(b)

Figure 15: *V2G charger's response to combined FCAS fast RAISE and LOWER service with AS/NZS 4777.2:2020.*

Figure 15 shows charger's response to combined FCAS fast raise and lower service with AS/NZS 4777.2:2020. Similar to the results in Figure 14, the charger is responding too slowly when providing FCAS fast raise services as shown in Figure 15. However, the charger responds to FCAS lower services within 6 sec when frequency goes up from 50 Hz to 50.25 Hz around 240 sec as shown in Figure 15 **(a)**. The charger responds to FCAS fast lower services but very slowly for the test profile as shown in Figure 15 **(b)**.

The ramp rate limitation during V2G operation is caused by the vendor's implementation of sections 3.3.4.2, 4.5.3.2.2 & 4.5.3.3.2 of AS/NZS 4777.2:2020 [3]. This standard specifies inverters must limit their active power ramp rate (W_{Gra}) to 16.67% of the rated power output per minute (60 s). This implies that the charger takes 6 minutes to ramp power from zero to rated power or vice versa. AS/NZS 4777.2:2020 specifies that W_{Gra} ramp rate must be applied when frequency is within the continuous operation range which is 49.75Hz - 50.25Hz for Australia A. As shown in **Table 4**, the FCAS raise services trigger when the frequency drops below 49.85 Hz and this frequency overlays within the 49.75 Hz which is the lower limit of the continuous operation range. This implies that the charger responds to the W_{Gra} ramp rate limit imposed by AS/NZS 4777.2:202 instead of responding to FCAS event as per MASS requirements.

Table 13 shows the assessment of charger's capability to provide FCAS fast services against MASS requirements when it is configured with AS/NZS 4777.2:2020.

Table 13 Assessment of charger's capabilities to deliver multiple FCAS fast services with AS4777.2:2020

Service type	Test profile applied	Required response time (s)	Measured response time (s)
Multiple fast lower service	Figure 10	6	5
Multiple fast raise service	**Figure 11**	6	Undetermined
Combined fast lower and raise service	Figure 12 **(a)** Figure 12 **(b)**	6	Undetermined

This slow ramp between 49.85 Hz and 49.75 Hz does not meet the requirements in the AEMO MASS specification. Therefore, the charger would not be able to provide significant amounts of FCAS raise services with current performance when configured with AS/NZS 4777.2:2020 standards. Therefore, we configured the charger back to UK G99 standard for conducting rest of the experimental tests. The results for fast, slow and delayed FCAS services are discussed in **Appendix E.2**.

E.2. Test results with UK G99 standard

It seems that the slow response speed of the charger with AS4777.2:2020 standard during FCAS raise services is not a hardware limitation. When the charger is reconfigured for the UK G99 standard [10], the charger output power ramped far quicker for FCAS raise services. The experimental results of the charger's response to all contingency FCAS services with UK G99 standard are described below.

E.2.1. Multiple FCAS fast service

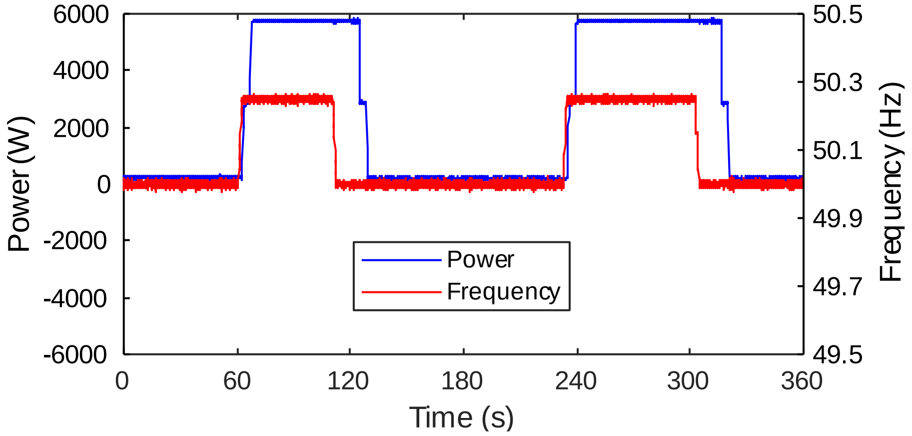


Figure 16: *V2G charger's response to multiple FCAS fast LOWER service with UK G99.*

Figure 16 shows charger's response to multiple FCAS fast lower service with UK G99. When the frequency went up to 50.25 Hz at 60 sec, the charger ramped at 1.27 kW/s for lower service and consumed imported power up to 5.7 kW within 4.5 sec of the contingency frequency event. This means that the charger is capable to respond within 6 sec for FCAS fast lower service.

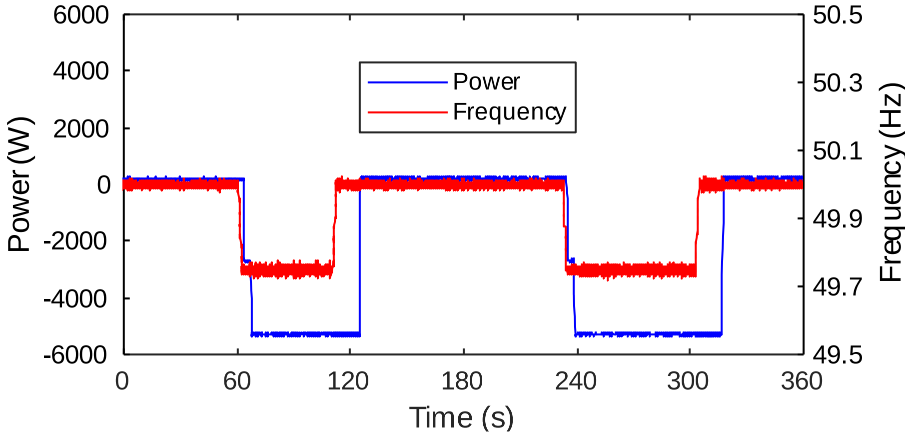
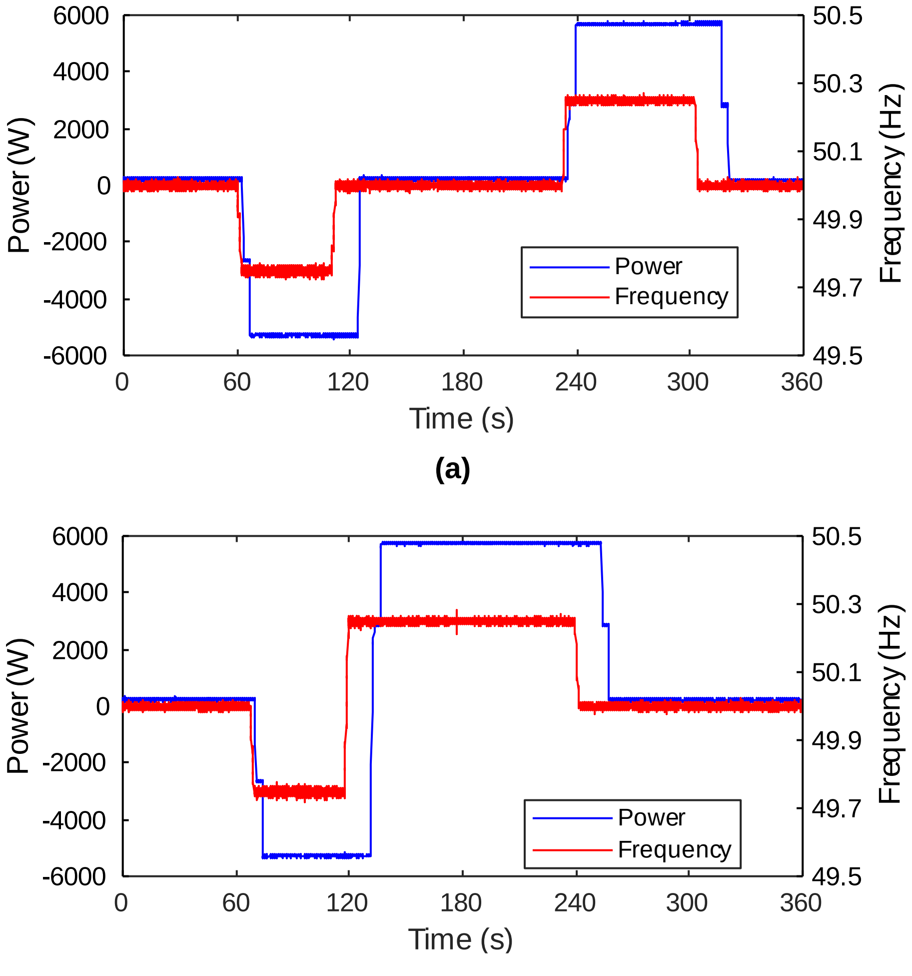


Figure 17: *V2G charger's response to multiple FCAS fast RAISE service with UK G99.*

Figure 17 shows charger's response to multiple FCAS fast raise service with UK G99. When the frequency dropped to 49.75 Hz at 60 sec, the charger ramped at 1.22 kW/s for raise services and delivered rated exported power up to 5.5 kW within 4.5 sec of the contingency frequency event. This implies that the charger is capable to respond within 6 sec for FCAS fast raise service.



(b)

Figure 18: ***V2G charger's response to combined FCAS fast RAISE and LOWER service with UK G99.***

Figure 18 shows charger's response to combined FCAS fast raise and lower service with UK G99. When the frequency dropped to 49.75 Hz at 62 sec, the charger ramped at 1.22 kW/s for raise services and delivered rated exported power (blue curve) up to 5.5 kW within 4.5 sec of the contingency frequency event. During fast FCAS lower services when the frequency went up to 50.25 Hz around 240 sec (Figure 18 **(a)**) and 120 sec (Figure 18 **(b)**), the charger ramped at 1.27 kW/s and consumed imported power up to 5.7 kW within 4.5 sec of the contingency frequency event.

Table 14 shows the assessment of charger's capability to provide FCAS fast services with MASS requirements when it is configured to operate with UK G99 standard. This means that the charger is capable to respond within 6 sec for combined fast FCAS raise and lower services under UK G99 standard.

Table 14 Assessment of charger's capabilities to deliver multiple FCAS fast services with UK G99

Service type	**Test profile applied**	**Required response time (s)**	**Measured response time (s)**
Multiple fast lower service	Figure 10	6	4.5
Multiple fast raise service	**Figure 11**	6	4.5
Combined fast lower and raise service	Figure 12 **(a)** Figure 12 **(b)**	6	4.5

E.2.2. Multiple FCAS slow service

Figure 19 shows charger's response to multiple FCAS slow lower service with UK G99. When the frequency went up to 50.25 Hz at 60 sec, the charger ramped at 1.27 kW/s for slow lower service and consumed imported power up to 5.7 kW within 4.5 sec of the contingency frequency event. When there is a second FCAS lower events at 400 sec, charger ramped at the same ramp rate as before and consumed imported power up to 5.7 kW within 4.5 sec. This means that the charger is capable to respond within 6 sec for multiple FCAS slow lower service.

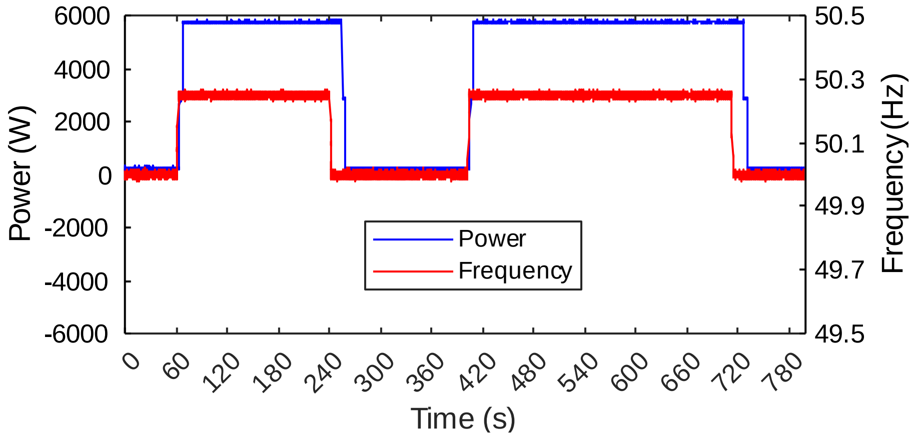


Figure 19: *V2G charger's response to multiple FCAS slow LOWER service with UK G99.*

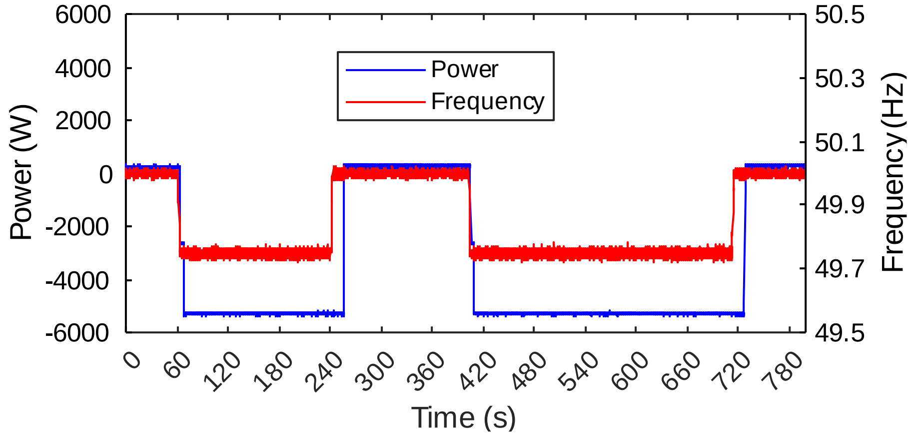
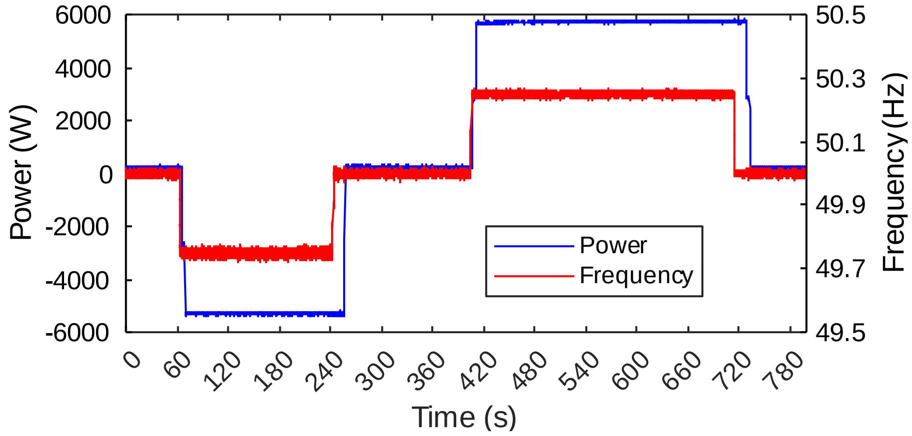
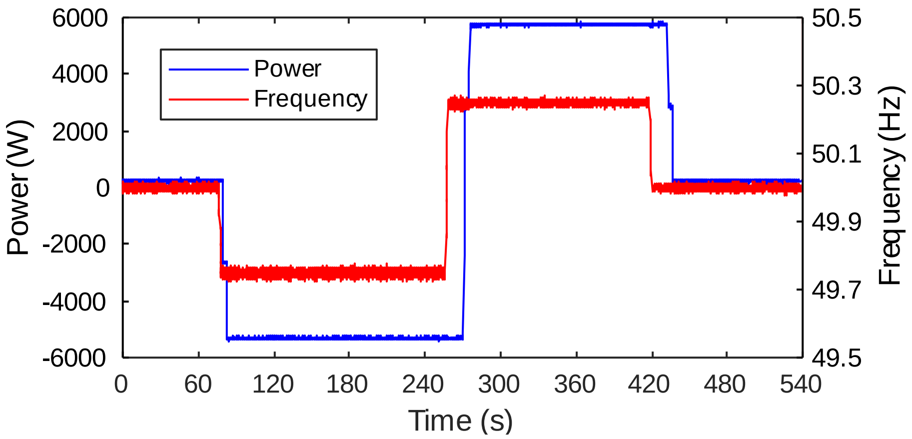


Figure 20: *V2G charger's response to multiple FCAS slow RAISE service with UK G99.*

Figure 20 shows charger's response to multiple FCAS slow raise service with UK G99. When the frequency is dropped to 49.75 Hz at 63 sec, the charger ramped at 1.22 kW/s for raise services and delivered rated exported power up to 5.5 kW within 4.5 sec of the contingency frequency event. When there is a second FCAS raise events at 400 sec, charger ramped at the same ramp rate as before and delivered exported power up to 5.5 kW within 4.5 sec. This implies that the charger is capable to respond within 6 sec for multiple FCAS slow raise service.



(a)



(b)

Figure 21: *V2G charger's response to combined FCAS slow RAISE and LOWER service with UK G99.*

Figure 21 shows charger's response to combined FCAS slow raise and lower service with UK G99. When the frequency dropped to 49.75 Hz at 62 sec (Figure 21 **(a)**) and 80 sec (Figure 21 **(b)**), the charger ramped at 1.22 kW/s for raise services and delivered rated exported power up to 5.5 kW within 4.5 sec of the contingency frequency event. During slow FCAS lower services when the frequency went up to 50.25 Hz around 400 sec (Figure 21 **(a)**) and 260 sec (Figure 21 **(b)**), the charger ramped at 1.27 kW/s and consumed imported power up to 5.7 kW within 4.5 sec of the contingency frequency event.

Table 15 shows the assessment of charger's capability to provide FCAS slow services against MASS requirements when it is configured to operate with UK G99 standard. This means that the charger is capable to respond within 6 sec for combined slow FCAS raise and lower services under UK G99 standard.

Table 15 Assessment of charger's capabilities to deliver multiple FCAS slow services with UK G99

Service type	**Test profile applied**	**Required response time (s)**	**Measured response time (s)**
Multiple slow lower service	Figure 10	60	4.5
Multiple slow raise service	**Figure 11**	60	4.5
Combined slow lower and raise service	Figure 12 **(a)** Figure 12 **(b)**	60	4.5

E.2.3. Multiple FCAS delayed service

Figure 22 shows charger's response to multiple FCAS delayed lower service with UK G99. When the frequency went up to 50.25 Hz at 63 sec, the charger ramped at 1.27 kW/s for lower service and consumed imported power up to 5.7 kW within 4.5 sec of the contingency frequency event. When there is a second FCAS delayed events at 680 sec, charger ramped at the same ramp rate as before and consumed imported power up to 5.7 kW within 4.5 sec. This means that the charger is capable to respond within 6 sec for multiple FCAS delayed lower service.

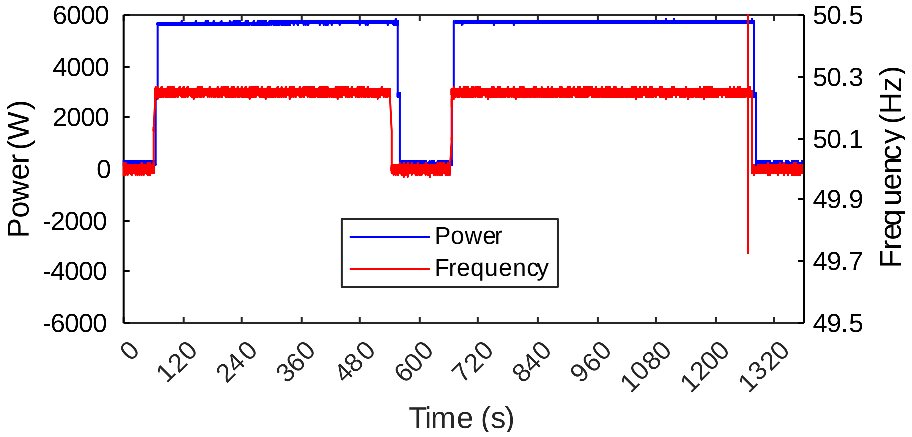


Figure 22: *V2G charger's response to multiple FCAS delayed LOWER service with UK G99.*

Figure 23 shows charger's response to multiple FCAS delayed raise service with UK G99. When the frequency dropped to 49.75 Hz at 63 sec, the charger ramped at 1.22 kW/s for raise services and delivered rated exported power up to 5.5 kW within 4.5 sec of the contingency frequency event. When there is a second FCAS raise events at 680 sec, charger ramped at the same ramp rate as before and delivered exported power up to 5.5 kW within 4.5 sec. This implies that the charger is capable to respond within 6 sec for multiple FCAS delayed raise service.

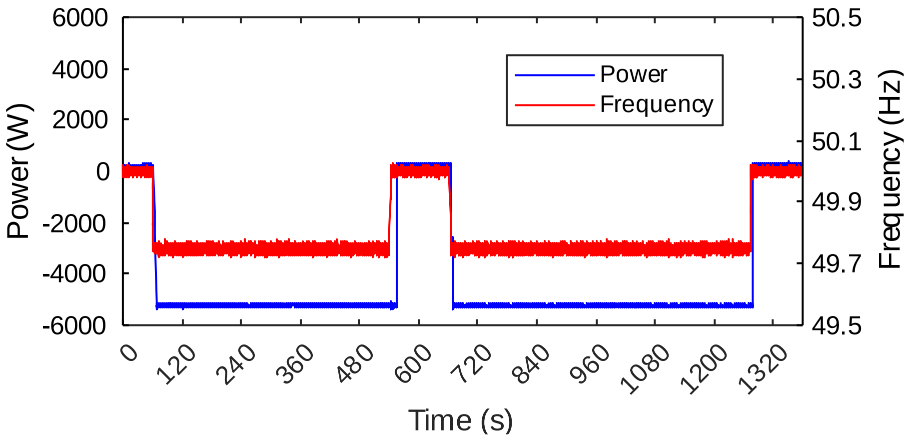
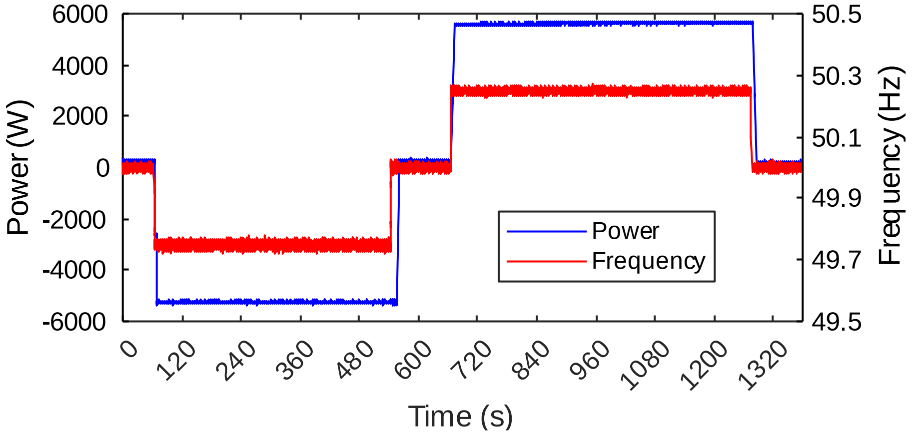
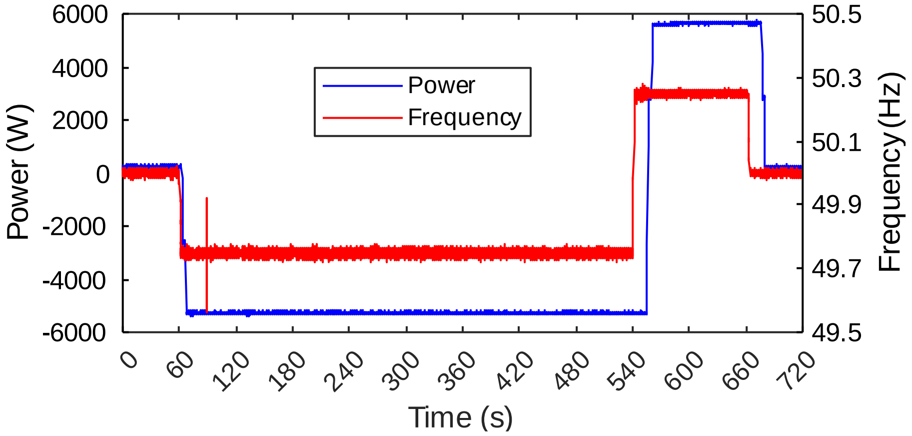


Figure 23: ***V2G charger's response to multiple FCAS delayed RAISE service with UK G99.***



(a)



(b)

Figure 24: ***V2G charger's response to combined FCAS delayed RAISE and LOWER service with UK G99.***

Figure 24 shows charger's response to combined FCAS delayed raise and lower service with UK G99. When the frequency dropped to 49.75 Hz at 63 sec (Figure 24 **(a)**) and 60 s (Figure 24 **(b)**), the charger ramped at 1.22 kW/s for raise services and delivered rated exported power up to 5.5 kW within 4.5 sec of the contingency frequency event. During delayed FCAS lower services when the frequency went up to 50.25 Hz around 680 sec (Figure 24 **(a)**) and 540 sec (Figure 24 **(b)**), the charger ramped at 1.27 kW/s and consumed imported power up to 5.7 kW within 4.5 sec of the contingency frequency event.

Table 16 shows the assessment of charger's capability to provide multiple FCAS delayed services against MASS requirements when it is configured to operate with UK G99 standard.

This means that the charger is capable to respond within 6 sec for combined delayed FCAS raise and lower services under UK G99 standard.

Table 16 Assessment of charger's capabilities to deliver multiple FCAS delayed services with UK G99

Service type	Test profile applied	Required response time (s)	Measured response time (s)
Multiple delayed lower service	Figure 10	300	4.5
Multiple delayed raise service	**Figure 11**	300	4.5
Combined delayed lower and raise service	Figure 12 **(a)**	300	4.5
	Figure 12 **(b)**		

E.2.4. Additional FCAS capability tests

In the REVS project, we performed some other tests additional to multiple FCAS tests. These additional tests are conducted to verify some operational states of the charger based on the SOC of the EV battery. One of the interesting cases were considered to observe the charger's response when the SOC is over 90%. We are also interested to observe what happens if the EV charger is plugged-in when a FCAS event is progress. In order to do these additional tests, we purposefully conducted the tests so that the charger provides FCAS lower services. All these additional tests were conducted with UK G99 standard.

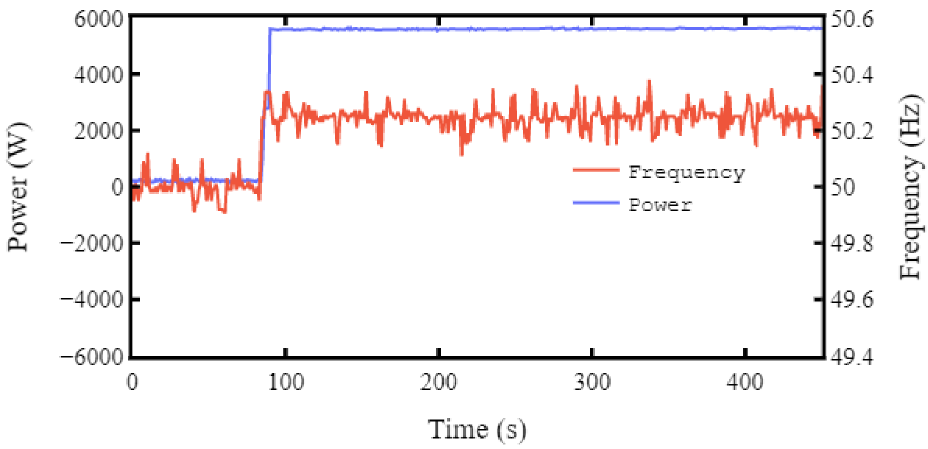


Figure 25: Charger's response to simple FCAS lower service (SOC at start = 80% and SOC at finish = 83%)

Figure 25 shows the charger's response to simple FCAS lower service (SOC at start = 80% and SOC at finish = 83%). As the SOC is 80% when the charger is plugged-in, the charger goes to idle state and keeps the connection active. When there is a FCAS lower event at 90 sec, the charger continues charging to respond to the FCAS event.

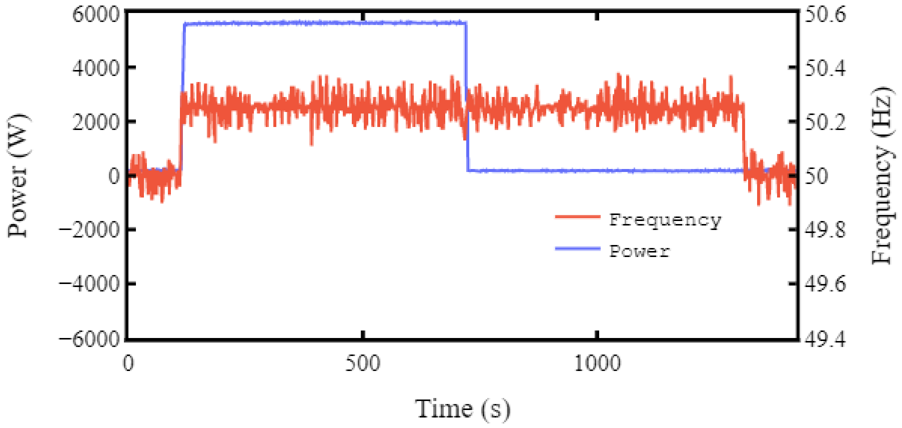


Figure 26: Charger's response to simple FCAS lower service (SOC at start = 83% and SOC at finish = 85%)

Figure 26 shows the charger's response to simple FCAS lower service (SOC at start = 83% and SOC at finish = 85%). The charger keeps connection active and it responds to FCAS lower events at 120 sec and continues charging. However, after 10 mins the charger stops charging and returns back to idle state (SOC is below 85%) because the FCAS events should not be last for more than 10 minutes.

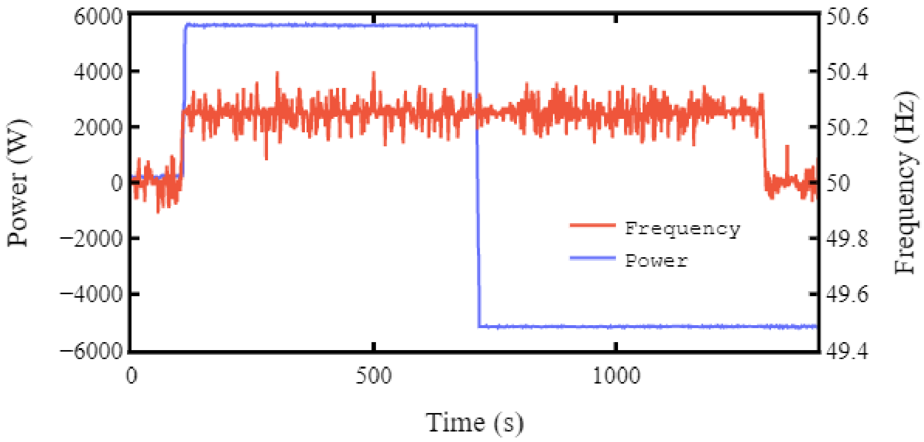


Figure 27: Charger's response to simple FCAS lower service (SOC at start = 85% and SOC at finish = 85%).

Figure 27 shows the charger's response to simple FCAS lower service (SOC at start = 85% and SOC at finish = 85%). The charger keeps connection active and it responds to FCAS lower events at 120 sec and continues charging for at least 10 minutes because the FCAS events should not be last for more than 10 minutes. After this time, the charger stops charging and the starts discharging to grid this time because the SOC increases to 88% due to FCAS lower events.

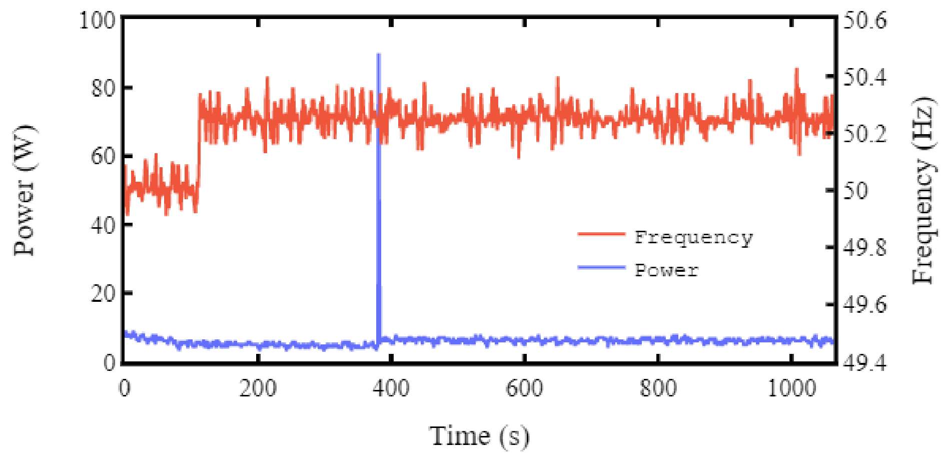


Figure 28: Charger's response to simple FCAS lower service (SOC at start = 85% and SOC at finish = 85%).

Figure 28 shows the charger's response to simple FCAS lower service (SOC at start = 85% and SOC at finish = 85%). This test is to observe what happens if the EV charger is plugged-in, when there is a FCAS event in progress. The FCAS lower event occurs at 120 sec and frequency went up to 50.25 Hz. The EV charger is plugged-in at 370s, the FCAS control system does not respond to the FCAS event.

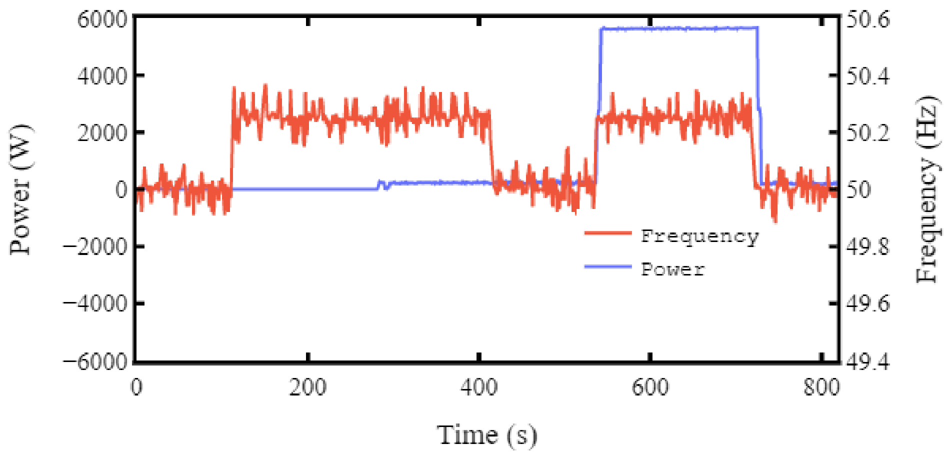


Figure 29: Charger's response to multiple FCAS lower service (SOC at start = 84% and SOC at finish = 84%)

To better understand the charger's response if it is plugged-in during FCAS event is in progress, we have considered multiple FCAS test profile as shown in Figure 29. The result shows that the FCAS control system does not respond to the FCAS event that occurs at 120 sec, when the EV charger is plugged-in at 274 sec. As the EV charger is now plugged-in, it responds to the next FCAS event that occurs at 540 sec, the charger responds to the FCAS lower service and continues charging the battery. After FCAS event finishes, the charger returns back to idle state and keeps connection active since the SOC is 84%.

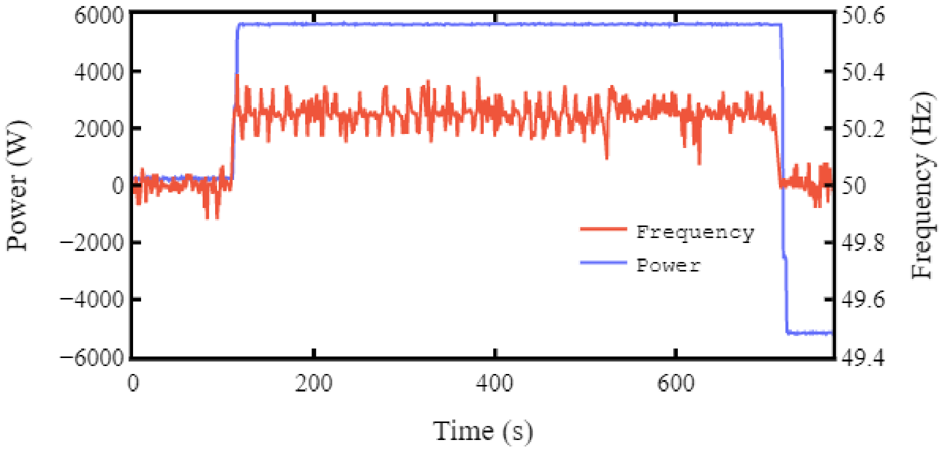


Figure 30: Charger's response to FCAS lower service (SOC at start = 84% and SOC at finish = 85%)

Figure 30 shows the charger's response to simple FCAS lower service (SOC at start = 84% and SOC at finish = 85%). The charger keeps connection active and it responds to FCAS lower events at 130 sec and continues charging the EV battery. However, the charger automatically starts discharging the EV battery when the FCAS event finishes because the SOC of the battery was above 85%. This allows the SOC of the battery to reduce that makes the EV ready to accept next FCAS events.

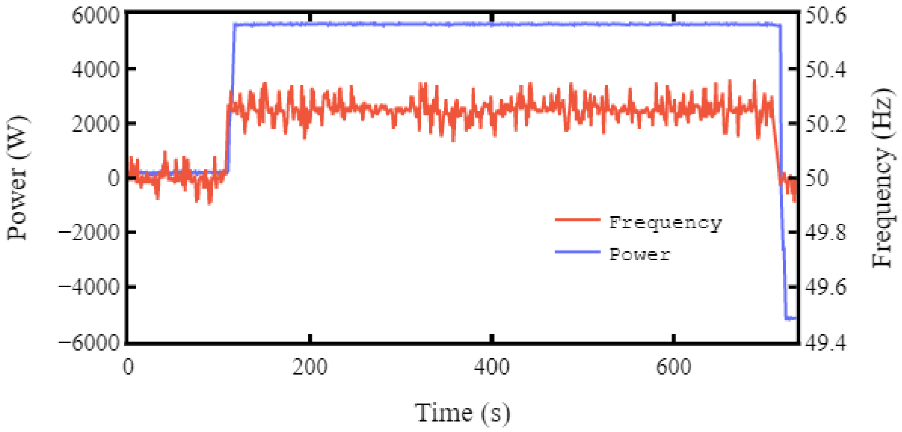


Figure 31: Charger's response to FCAS lower service (SOC at start = 85% and SOC at finish = 88%)

Figure 31 shows the charger's response to simple FCAS lower service (SOC at start = 85% and SOC at finish = 88%). In this case, the charger's response is similar to Figure 30.

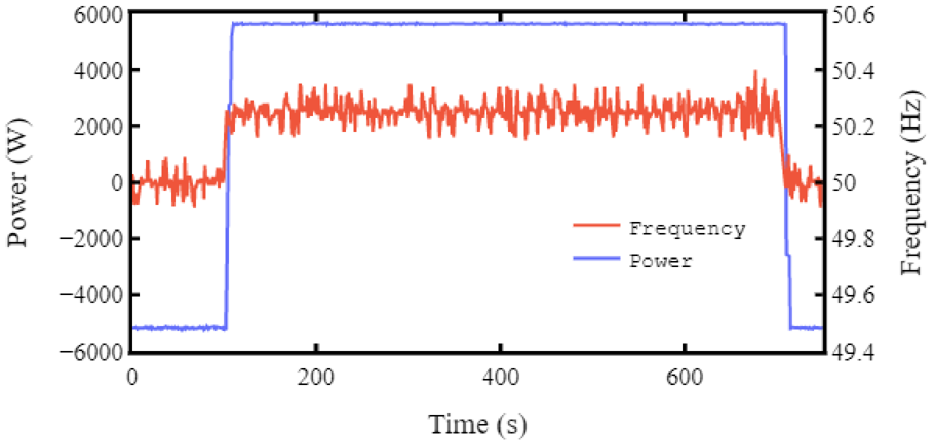


Figure 32: Charger's response to FCAS lower service (SOC at start = 88% and SOC at finish = 90%)

Figure 32 shows the charger's response to simple FCAS lower service (SOC at start = 88% and SOC at finish = 90%). The charger starts discharging the EV battery when it is plugged-in as the SOC is above 85%. However, the charger responds to the FCAS lower event that occurs at 110 sec and continues charging the EV battery until the FCAS event finishes. The charger then again returns back to discharging mode as the SOC is 90%.

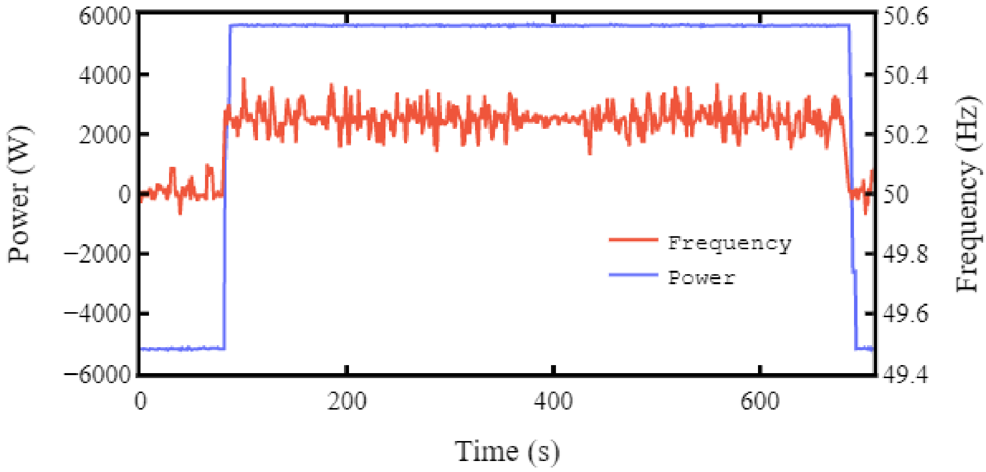


Figure 33: Charger's response to FCAS lower service (SOC at start = 90% and SOC at finish = 91%)

Figure 33 shows the charger's response to simple FCAS lower service (SOC at start = 90% and SOC at finish = 91%). The charger's response was similar to Figure 32. However, the SOC of the battery reaches to 91%.

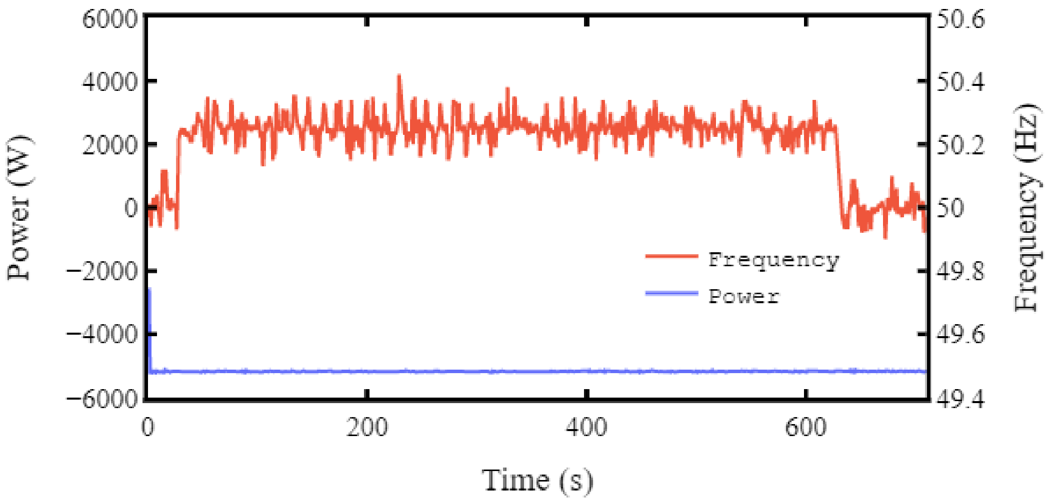


Figure 34: Charger's response to FCAS lower service (SOC at start = 91% and SOC at finish = 90%)

Figure 34 shows the charger's response to simple FCAS lower service (SOC at start = 91% and SOC at finish = 90%). The test was performed to observe what happens if the SOC of the battery exceeds 90% as the allowable SOC range was set to 30%-90% for participating FCAS events. The result shows that as SOC is above 90% when the EV charger is plugged-in, the FCAS control system does not respond to the FCAS event that occurs at 30 sec, however, it causes the charger to continue discharging the EV battery to reduce the SOC below 90%. Therefore, the charger cannot participate to FCAS markets until SOC of the battery drops below 90%.