Operations Report

2020/ARP013 Transgrid Wallgrove Grid Battery

July to December 2022

transgrid.com.au | lumea.com.au

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This Project received funding from ARENA as part of ARENA's Advancing Renewables Program and from the NSW Government Emerging Energy program.

Acknowledgements.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program and was proudly supported by the NSW Government, Emerging Energy program.

Australian Government
Australian Renewable Energy Agency

ARENA

NSW GOVERNMENT

Acknowledgement of Country.

In the spirit of reconciliation Lumea acknowledges the Traditional Custodians of the lands where we work, the lands we travel through and the places in which we live.

We pay respects to the people and the Elders past, present and emerging and celebrate the diversity of Aboriginal peoples and their ongoing cultures and connections to the lands and waters of NSW.

Contents.

Contents.

1. Acronyms

AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AGC	Automatic generation control
ARENA	Australian Renewable Energy Agency
BESS	Battery energy storage system
cFCAS	Contingency frequency control ancillary services
DI	Dispatch interval
FCAS	Frequency control ancillary services
GPS	Generator performance standards
HMI	Human machine interface
LSBS	Large scale battery storage
MLF	Marginal loss factor
MMS	Market Management System
NEM	National electricity market
NER	National electricity rules
NMI	National metering identifier
NP Cap	Nameplate capacity
OEM	Original equipment manufacturer
PoE	Probability of exceedance
PPC	Power plant controller
RoCoF	Rate of change of frequency
RRP	Regional Reference Price
RTAC	Real-time automation controller
RTE	Round trip efficiency
SCADA	Supervisory Control and Data Acquisition
SoC	State of charge
TNSP	Transmission network service provider
UPS	Uninterruptible power supply
UTC	Coordinated Universal Time
VMM	Virtual Machine Mode
WGB	Wallgrove Grid Battery

Transgrid

Lumea

This Report summarises the operations of the Wallgrove Grid Battery (WGB) from 1 July 2022 to 31 December 2022.

The WGB is a 50MW/75MWh (1.5-hour duration) battery energy storage system (BESS) located adjacent to the Transgrid Sydney West 330/132kV substation (Wallgrove) in Eastern Creek, NSW. The WGB tests how well a battery can deliver services that will be needed to stabilise the grid through Australia's energy transition to a low-carbon market. It also operates commercially – Iberdrola Australia controls the battery's dispatch to participate in the frequency control ancillary services (FCAS) and wholesale energy markets.

Approximately 1,214 work hours occurred onsite during the second six months of operations. There were no safety or environmental issues onsite.

The operation of the WGB in the energy and FCAS markets aligns with Iberdrola Australia's historical experiences in operating the Lake Bonney BESS in South Australia. July achieved high energy revenues on the back of lingering volatility from the extreme pricing events that emerged through Q2 CY2022. From then, however, the period saw a correction to historical norms that bias batteries toward FCAS markets. The higher rates of enablement in FCAS meant that over the period the WGB revenue contributions were split almost in perfect quarters across energy, raise regulation, lower regulation, and contingency FCAS.

Photo 1 – Wallgrove Grid Battery and Sydney West 330/132kV substation aerial view

3.1 Purpose of Report

This Report covers the operational learnings over the second six-month period of operations for the WGB.

This Report focuses on the following areas:

- Analysis of charging behaviour, including participation in different applications (eg wholesale energy market, contingency FCAS, regulation FCAS etc)
- Technical performance such as round-trip efficiency, degradation, auxiliary power usage, equipment availability
- Financial performance (from the market participant's perspective) including a breakdown of revenue in each application, impact of loss factors, impact of curtailment, and any other factors materially impacting financial performance
- Safety and environmental performance
- Discussion on impact of any regulatory changes and any other emerging challenges and opportunities;
- Unexpected costs and potential new revenue opportunities (if any), and detail of challenges associated with accessing new revenue opportunities
- A discussion on the benefits and challenges of other innovative elements, including any other innovative elements requested by ARENA.

Virtual Machine Mode (VMM) was enabled on 23 November 2022. Observations and learnings on VMM operations will be covered in greater depth in subsequent reports when more data is available, As VMM was only enabled toward the end of the reporting period, commentary focuses on the following areas:

- Challenges in VMM implementation
- Commentary and assessment of the project's ongoing performance with respect to the testing plan (for synthetic inertia), such as how the WGB has performed during system disturbances

3.2 Distribution of Report

This Report is intended for the public domain and has no distribution restrictions.

The intended audience of this document includes:

- Project developers
- Renewable energy industry participants
- Network Service Providers
- General public
- Equipment vendors
- General electricity sector members
- Government bodies
- ARENA.

3.3 Knowledge Sharing Plan

This document represents one of the deliverables under the knowledge sharing plan that forms part of the funding agreement between Transgrid and ARENA. All documentation associated with the Knowledge Sharing Program for the Project will be available from Transgrid's Wallgrove Grid Battery project website.

The knowledge sharing deliverables completed to date are shown in Table 1.

Deliverable	Responsibility
Arena 15 min project survey	Quarterly
Lesson learnt report #1	Submitted May 2021
Lessons learnt report #2	Submitted January 2022
Stakeholder reference group meetings	SRG meeting #1 03/02/2021 SRG Meeting #2 19/10/2021 SRG Meeting #3 10/11/2022
Attendance at webinar or workshop	ARENA smart inverters webinar participation / presentation 27/05/2021 Presentation in ARENA grid forming / advanced inverters webinar 09/08/2022
Project website	Accessible via: https://www.transgrid.com.au/projects-innovation/wallgrove-grid-battery

Table 1 – Knowledge sharing deliverables

Photo 2 – Wallgrove Grid Battery looking towards Sydney West substation

4.1 About Transgrid

Transgrid operates and manages the high-voltage electricity transmission network in NSW and the ACT, connecting generators, distributors and major end users. The Transgrid network is the backbone of the NEM, enabling energy trading between Australia's three largest states along the east coast and supporting the competitive wholesale electricity market.

4.2 About Lumea

Lumea is a renewable energy infrastructure, telecommunications, and energy services business. Lumea operates in contestable markets across the NEM and is the largest connector of renewable generation in Australia to date. Lumea's mission is to help bring 40GW of renewable energy to market by 2030 using the skills, expertise and heritage as part of the Transgrid Group to help generators, large load customers and governments realise their own clean energy ambitions. Lumea is developing its own innovative projects across a variety of new energy assets and services, as well as establishing a pipeline of grid-scale batteries.

4.3 Project Context

Australia's energy system transition to distributed renewable energy is expected to accelerate in order to reach the net zero emissions targets announced by both Federal and State governments. This means the continuing reduction of coal-fired generation, with AEMO's 2022 Integrated System Plan (ISP) forecasting 14 GW reduction in the NEM by 2030 under the step change scenario[1].

The energy system transition creates technical challenges, such as ensuring the system has enough inertia. A stable and reliable network requires inertia to support the power system to resist changes in frequency. Traditionally, inertia is provided by synchronous generators, such as coal plants, but following the retirements of Liddell, Vales Point, Eraring and Bayswater Power Stations, the inertia level in NSW is unlikely to meet the double contingency secure planning level of 15,000 MWs for 93 per cent of the time[2]. One way to address this inertia shortfall is through the provision of synthetic inertia through BESS.

BESS are increasingly recognised as potential solutions to those network challenges, as well as providing storage capacity for renewable generation. AEMO anticipates that by 2050, 16GW of storage will be provided by utility-scale batteries and pumped hydro storage[3]. Furthermore, modelling indicates significant savings for NSW electricity customers from deploying BESS instead of traditional synchronous condensers to perform inertia services.

Transgrid expects that an inertia gap will be declared in NSW as existing sources of inertia, predominantly coal-fired generators, are progressively withdrawn from the market. In preparation for this event, Transgrid is investigating alternative technology solutions to establish technically and commercially

1 AEMO ISP June 2022
2 Transgrid Transmission Annual Planning Report 2022, p101
3 AEMO ISP June 2022

viable, lower-cost solutions to address the inertia gap, including its first hybrid grid-scale battery – the Wallgrove Grid Battery.

4.4 Overview of Wallgrove Grid Battery Project

The WGB is a 50MW/75MWh (1.5-hour duration) grid-scale lithium-ion Tesla battery. It is the first large-scale grid battery in NSW and the third[4] large-scale grid battery demonstration of synthetic inertia in the National Electricity Market (NEM). Located at Wallgrove, the WGB is a pilot demonstration of the viability of synthetic inertia from a battery to maintain frequency stability on the network. The WGB is also enabling Iberdrola Australia to control dispatch and participate commercially in the frequency control ancillary services (FCAS) and wholesale energy markets.

The WGB was undertaken as an innovation pilot, to build battery expertise, and to support the development of more efficient synthetic inertia technologies in different locations on the grid, including areas of higher population density. The model combines funding to maximise battery utilisation for network and commercial purposes.

The WGB can provide both network services (including inertia and fast frequency response) and market services (including energy and FCAS), and accesses corresponding regulated and unregulated revenue streams in a hybrid commercial model. Less than 5 per cent of energy storage capacity is reserved for the provision of network services. The project enables the TNSP, Transgrid, to explore this approach as a credible option to address the forecast inertia shortfall in NSW/ACT following the retirements of numerous coal-fired generation plants, including Liddell, Eraring and Vales Point Power Stations, and enable the NSW Government's plan for a reliable, affordable and sustainable electricity future that supports a growing economy.

Information is being shared as part of the trial. This information sharing will support future projects and improve understanding of battery technology as a low-cost and technically viable solution to the emerging challenges created by the transformation of the generation sector. The project also demonstrates a revenue stack and commercial arrangements that provide grid benefits cost-effectively for consumers.

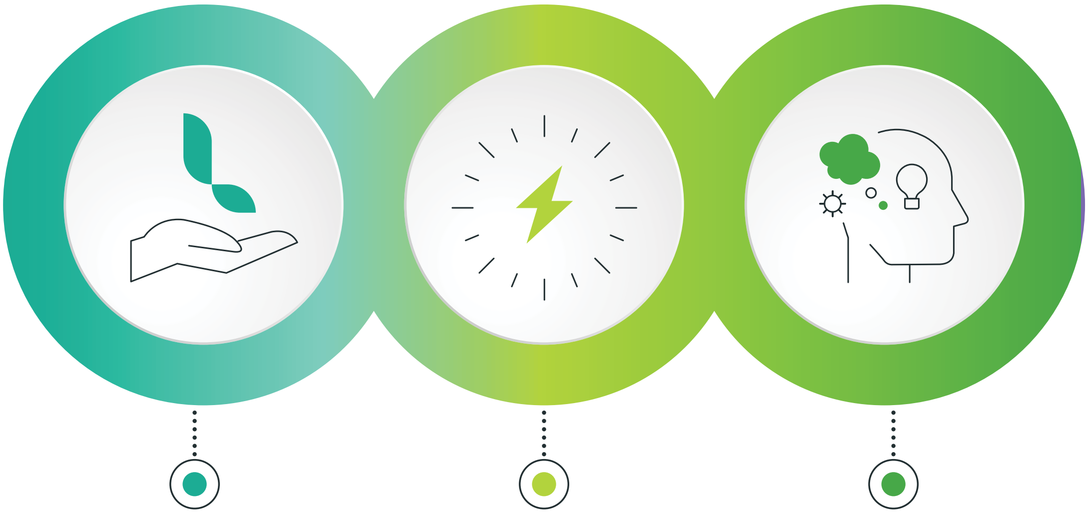
The trial will provide valuable technical information about the actual operation of the WGB, including how often it will be needed for fast frequency response and how much electricity it is able to store and dispatch under different conditions, relative to commercial demands.

As more wind and solar energy sources replace fossil fuel generation, less mechanical inertia is available on the grid, removing a natural stability buffer in the case of a grid disturbance. As these fossil fuel generators retire from the NEM, alternative solutions are needed to ensure this stability remains. The WGB will demonstrate the use of Tesla's Virtual Machine Mode (VMM) to address these stability challenges by virtually emulating mechanical inertia.

The WGB received funding from ARENA's Advancing Renewables Program and the NSW Government as part of the Emerging Energy Program. The WGB was constructed, registered, tested and commissioned successfully, and commenced Commercial Operations on 22 December 2021.

4 Wallgrove is the third BESS in the NEM to demonstrate synthetic inertia. ESCRI (30MW) and Hornsdale Expansion (150MW) are the first and second.

Project Benefits



Enhanced reliability

The battery will provide a new source of system stability services.

More affordable power

Finding lowest-cost ways to maintain frequency, while also increasing the supply of dispatchable power to the market, puts downward pressure on energy bills.

New knowledge

The trial will provide valuable technical and commercial insights which will be shared across the energy industry – helping to identify the lowest cost technology for future network needs.

4.5 Key Project Objectives

The project's objectives, as agreed with NSW Government and ARENA

ARENA	NSW Government
Supporting technical innovation: Improved understanding of the ability of FFR services and Tesla's Virtual Machine Mode to substitute for inertia and help meet Transgrid's requirement to manage RoCoF in NSW with transferable learnings across the National Electricity Market. Support inclusion of LSBS projects in the Recipient's regulatory submission: The Project will help support Transgrid's vision to include ~240 MW of LSBS projects in its revenue submission to the AER for the upcoming regulatory period (2023/24 to 2027/28). New commercialisation pathway: The Project will contribute to the development of a new commercialisation pathway for LSBS by leveraging regulated network expenditure to provide a clear pathway to commercialisation for LSBS. Improving supply chains: Relatively few LSBS projects have been installed. Supporting LSBS will improve supply chains and reduce costs for OEMs and balance of plant providers.	Enhance system reliability and security in NSW by operating in the wholesale energy and frequency control ancillary services markets in the NEM, as well as provide inertia support activities including fast frequency response and virtual inertia; Promote competition through its contracting arrangement with Iberdrola Australia which will operate the project to firm variable renewable energy generation in NSW to supply retail customers Promote diversification of electricity supply in the NSW region of the NEM by deploying a lithium-ion battery system in the NEM that is dispatchable and capable of firming variable renewable energy generation Assist in the operation of a low emissions NSW electricity system by firming Iberdrola Australia's variable renewable energy output from their portfolio Provide value to NSW and the NEM by sharing key learnings to reduce the risk and encourage further investment in utility scale battery energy storage systems in NSW.

4.6 Technical Overview

The key technical operating parameters of the WGB are shown in Table 2.

Technical parameter	Summary
Registered discharge power capacity	50 MW (at 132kV connection point)
Registered charge power capacity	47 MW (at 132kV connection point)
Nameplate storage capacity	75 MWh (at 132kV connection point)
Number of megapacks	36
System voltages	132 / 33 / 0.518 / 0.4 kV
Balance of plant	60 MVA 132/33kV power transformer 9 x 33/0.518/0.518kV coupling transformers ABB SafePlus gas-insulated compact switchgear 500kVA 33/0.400 kV auxiliary transformer 75kVA isolation transformer for street supply
Point of connection	Sydney West 330/132kV substation – Feeder Bay 2X
Metering point location	Sydney West 330/132kV substation – Feeder Bay 2X
Network connection	132kV
Substation	Sydney West 330/132kV substation
National Metering Identifiers	**Wallgrove Battery 132kV Revenue:** NTTTW0ZQ90 for Import B1 (Generation) NTTTW0ZQ91 for export E1 (Consumption) **Wallgrove Battery 132kV Check** NTTTW0ZQ95

Table 2 – Key technical parameters

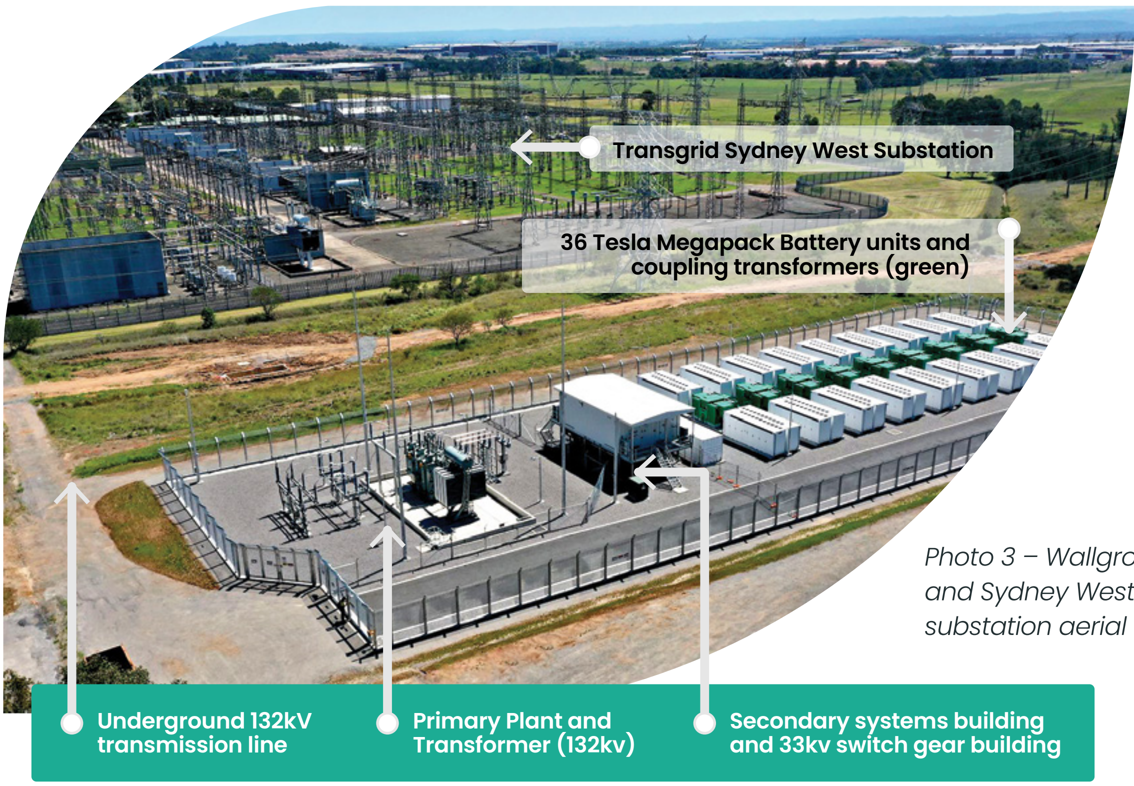


Photo 3 – Wallgrove Grid battery and Sydney West 330/132kV substation aerial view

5.1 Benefits of enabling Virtual Machine Mode (VMM)

With increasing asynchronous generation and declining inertia from synchronous machines, there is increasing potential for batteries to provide a 'virtual' or 'synthetic' inertia service. Advanced inverters of a grid-forming nature, including the system deployed at WGB, can provide a virtual machine mode that can mimic the response of a traditional rotating machine to provide an inertial response. The virtual machine is a blended mode that brings dispatchability of a current source operating in parallel with the stability benefits of a voltage source. The flexible and fast controls in an advanced inverter can replicate the response of a traditional rotating machine. As the inverter's inertial response is created by the inverter controls the response is tuneable and can be modified based on the grid's needs (unlike traditional generators that have a fixed inertial constant based on their physical characteristics). The virtual machine model is a flexible feature that can be enabled and has configurable parameters such as inertial constant that can be tuned to obtain the desired dynamic behaviour for the grid.

5.2 VMM implementation approval process

To enable VMM, Lumea proposed to alter the generating system under the 5.3.9 process of the National electricity rules (NER). At the time of commencing this process only one other battery (Hornsdale Power Reserve) had gone through a similar alteration process with AEMO. The lack of current incentive structures and the perceived, or actual, complications in connection alterations have prevented more operational batteries from undertaking a similar alteration. As such there were limited market insights on how smooth the connection alteration would be, and whether challenges would arise in relation to either specific clauses in the NER or the AEMO connection process.

During the alteration process, there were several issues that highlighted barriers that exist in connecting grid batteries with grid-forming characteristics. The most significant challenge faced was that under the 5.3.9 process, the performance standards of the existing plant effectively become the minimum standards that the plant must adhere to when alterations are made [clause 5.3.4A(b)(1A), NER Version 196]. An unintended consequence of the current access standards in Schedule 5.2 of the NER for asynchronous generation is that a project with grid-forming inverter technology is assessed against access standards that appear more suited to asynchronous generating systems that are of a grid-following nature, which can trade-off some of the benefits offered by advanced inverters with grid-forming capability. Grid-forming inverters are more analogous to synchronous machines (which are assessed differently to asynchronous generators under s5.2.5.5 due to these inherent and recognised differences). While the overall performance of the WGB improved, under certain clauses, notably s5.2.5.5, it was not able to meet the existing performance standard agreed for the grid-following configuration.

Lumea established through dialogue with AEMO and ElectraNet that this issue was not faced to the same extent by ElectraNet when they followed a similar process on the Hornsdale battery. Two reasons were deemed to be contributory:

1. ElectraNet were able to adjust some parameters to enable the battery to meet the minimum access standards for one of the clauses of the generator performance standards (GPS), specifically s5.2.5.5. This same approach was not a viable option for the WGB as the performance standards of the existing plant at WGB, and therefore the minimum standards applied to the alteration, were different to those at Hornsdale.

2 Hornsdale is located in a weaker part of the network electrically, while Wallgrove is in a stronger part of the network. The original performance standard agreed for WGB in grid-following configuration in this strong part of the network made it more challenging to replicate the same behaviour using a grid-forming configuration, due to the inherent differences between grid-following and grid-forming control systems.

The most impacted performance standard was s5.2.5.5, which has a provision to enable AEMO and the TNSP to have some discretion on the parameters of operation. Lumea and Transgrid sought external advice which provided guidance that enabled alteration of the wording of the clause along with further studies to ensure that the minimum standard could be met. The wording was ultimately presented to AEMO and received their agreement which was the critical hurdle before hold point testing could commence.

The project team identified that an existing rule change process was underway through the AEMC which would most likely address the issue being encountered. The specific AEMC page for the proposed rule change 'Efficient reactive current access standards for inverter-based resources' can be found at:
https://www.aemc.gov.au/rule-changes/efficient-reactive-current-access-standards-inverter-based-resources

The Transgrid planning team provided input which can be found at:
https://www.aemc.gov.au/sites/default/files/2023-02/230202%20Transgrid.pdf.

5.3 Final Settings

Final registered parameters:
Inertia Constant (H) = 1 MWs/MVA
Damping factor (D) = 0.9

The primary objective in determining the final settings was to demonstrate that the previously agreed GPS (negotiated for a grid-following configuration) could be met as required by the NER, although it should be emphasised that this resulted in a trade-off in performance in some areas where a more optimal tuning of the virtual machine could have been offered for provision of inertia services. When in VMM, the BESS is mimicking the behaviour of a synchronous machine, and modelling observed slower active power recovery time and reactive current settling time, which is generally consistent with the behaviour of synchronous generators compared to grid-following asynchronous inverter-based systems. These were the two items under the clause s5.2.5.5 where the performance of the grid-forming configuration was not able to meet the previously negotiated access standard for the grid-following system. Inverters with grid-forming characteristics are more analogous to synchronous machines (which are assessed differently to asynchronous generators under s5.2.5.5 due to these recognised differences).

To resolve the issue, the damping factor parameter for the machine was reduced, and an updated access standard for the above two items was negotiated by taking a holistic view and demonstrating the general performance improvements to clause s5.2.5.5 when implementing VMM.

5.4 Performance during system disturbance

On 25 December 2022 at 11:46hrs, No.2 Synchronous Condenser tripped at the Buronga 220kV switching station, resulting in the trip of Darlington Point Solar Farm. Approximately 260MW of Generation was interrupted. This caused a frequency deviation of up to about 72 mHz with ROCOF of 1.2 Hz/sec at its sharpest point (noting that due to the small size of the frequency deviation, the ROCOF may be measured differently). This frequency disturbance made the WGB generate approximately 4.5 MW inertial response as shown in Figure 1.

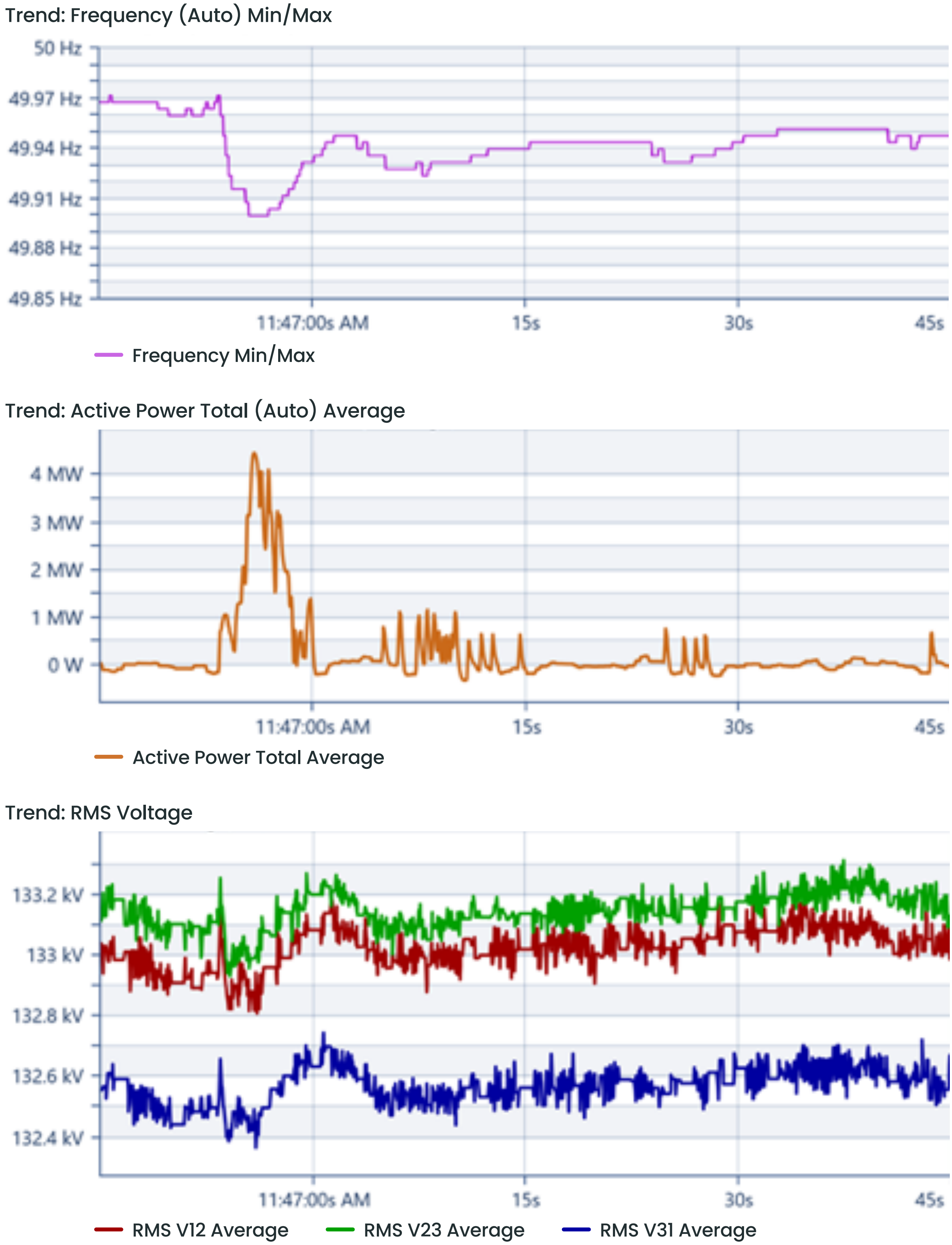


Figure 1 – WGB Inertial Response to Loss of 260 MW Generation in NSW – 25 December 2022

The overall response is generally consistent with the expectation, however it is recognised that the scale of this event was relatively minor, with frequency remaining within the Normal Operating Frequency Band throughout the full duration of the event. The behaviour of the BESS during the frequency decrease and increase continues to be assessed.

5.4.1 Power and Frequency Overlay

The overlay of active power and frequency is provided in Figure 2 to illustrate the response from the battery versus the frequency deviation on the same time stamp. As can be seen, the battery's response, unlike the response from a typical grid-following battery, is immediate to the disturbance. It is also estimated that approximately 4.1 MWs of inertia was provided by the battery for the ~2.46 seconds from the red line in Figure 2, which is the initiation of the frequency decrease to the point that the active power reaches its peak value.

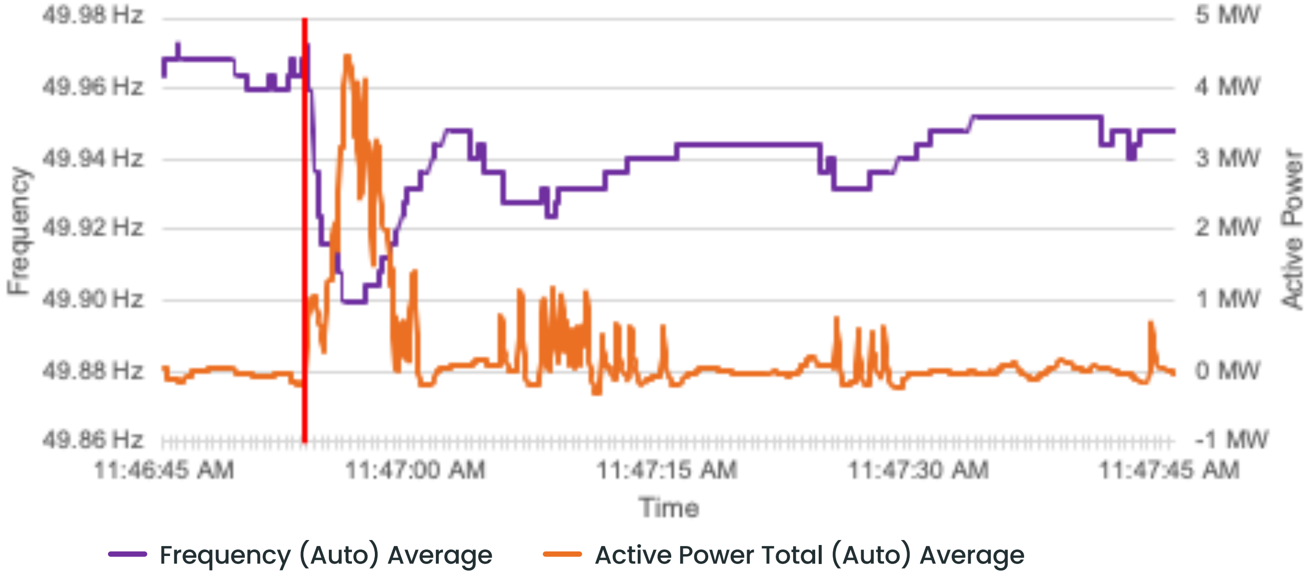


Figure 2 – System Frequency Event 25 December 2022 – Active Power and Frequency overlay

5.5 Energy Market Participation

The following factors constrain a battery's participation in the energy market, and should be considered when assessing the WGB's energy market participation:

- The regulation and contingency FCAS markets still represent the largest share of revenue available to a battery. Whenever a battery is dispatched to provide FCAS, its ability to provide energy is constrained
- The energy storage capacity of a battery constrains its short-term operations
- The cycling limitations of a battery (ie the number of times the battery can be charged and discharged per year) constrains its long-term operations.

5.6 Capacity Factor

The capacity factor[5] of the WGB throughout the reporting period is shown in Table 3, alongside the percentage of intervals in which the WGB is active in a discharge (energy, raise regulation and raise contingency) or charge (energy, lower regulation and lower contingency) market. The capacity factor calculation only considers energy generation or consumption, as distinct from the provision of other services, such as FCAS.

5 Capacity factor represents the average generation (or consumption) of a power plant across a year as a percentage of its nameplate capacity. For example, a 100MW generator with a 50% capacity factor might have run at 100MW capacity for half a year, and 0MW for the remainder of the year; or at 50MW for the entire year.

		Energy-only capacity factor (%)	Active intervals (%)
Q1 CY2022	Discharge	0.97	97.80
	Charge	2.48	98.11
Q2 CY2022	Discharge	3.22	91.98
	Charge	9.29	92.21
Q3 CY2022	Discharge	2.54	97.99
	Charge	6.44	98.65
Q4 CY2022	Discharge	0.74	96.29
	Charge	3.44	96.86

Table 3 – WGB energy-only capacity factor and active intervals in the reporting period

The data demonstrates a clear difference in the behaviour of the WGB in Q1 and Q4 when compared to Q2 and Q3, which was a product of the volatility seen in the energy market during the middle of the year.

While the energy-only capacity factor is seen to vary greatly, the active intervals for the WGB remained consistent throughout the year (subject to plant outages to undertake maintenance). This was in line with Iberdrola Australia's expectations and mirrors the operations of the Lake Bonney BESS.

5.7 Arbitrage Price Dynamics

Energy market revenue opportunities for the WGB are based upon the principle of arbitrage, being able to buy energy when prices are low (by charging) and/or selling this energy when prices are high (by discharging).

The key market factors that dictate the opportunities of the WGB in the energy market are shown in Table 4. These are the average, and the 50 per cent and 25 per cent probability of exceedance (PoE)[6] differences between the highest and lowest value hours each day. This methodology is different to the previous report due to the added volatility that 5-minute settlement brings and seeks to reflect a price differential that will be easier to capture in real-world operations.

	Average Daily Hour Max/ Min Difference ($/MWh)	50% PoE Daily Hour Max/Min Difference ($/MWh)	25% PoE Daily Hour Max/Min Difference ($/MWh)
July 2022	535.30	411.03	485.06
August 2022	232.76	227.26	268.10
September 2022	246.97	237.73	318.19
October 2022	262.11	201.37	258.76
November 2022	255.31	220.55	265.38
December 2022	223.33	165.33	193.46

Table 4 – Market factors for consideration for an energy arbitrage strategy – dispatch intervals

Considering arbitrage value on an hourly basis reduces the amount of volatility presented. If a pure arbitrage strategy was pursued, a higher difference of charge and discharge price than the above should be attainable, due to the ability of the battery to operate on a five-minute basis. That includes the potential to avoid non-economic dispatch intervals that are averaged into the above hourly values. 52 out of the 184 daily minimum hourly values in the reporting period were negative (28.3%).

The revenue earned by a BESS based on this price difference would be further eroded by round-trip efficiency losses and the potential MLF difference between the generator and load portions of the BESS. However, for Wallgrove BESS, given its strong point of connection into the network, any MLF revenue adjustments are marginal with a FY2022 MLF of 1.0010 and 1.0009 for its generation and load components respectively.

6 Probability of Exceedance (PoE) is a statistical metric that describes the probability of a particular value being exceeded

5.8 Negative Price Opportunities

5.6% of all dispatch intervals in the reporting period settled at a negative price, with the distribution of prices across a range of negative price bands shown in Table 5.

Price ($/MWh)	-150 to -100	-100 to -75	-75 to -50	-50 to -25	-25 to 0
DIs	2	26	782	1,064	1,100
% of all DIs	0.00	0.05	1.48	2.01	2.08

Table 5 – Negative Price Distributions in NSW region in H2 2022

While negative price intervals are starting to become more regular in the energy market for the NSW region of the NEM, charging through negative prices is just one of the ways a battery can earn revenue, and capturing these prices needs to be considered in the context of the overall arbitrage opportunity for energy revenue, and the co-optimisation of energy and FCAS enablement to maximise total revenue.

5.9 Charging and Discharging Profiles

The charging and discharging behaviour of the WGB in the reporting period is shown in Figures 3 and 4.

Figure 3 – Average daily charging profile for the WGB in the reporting period

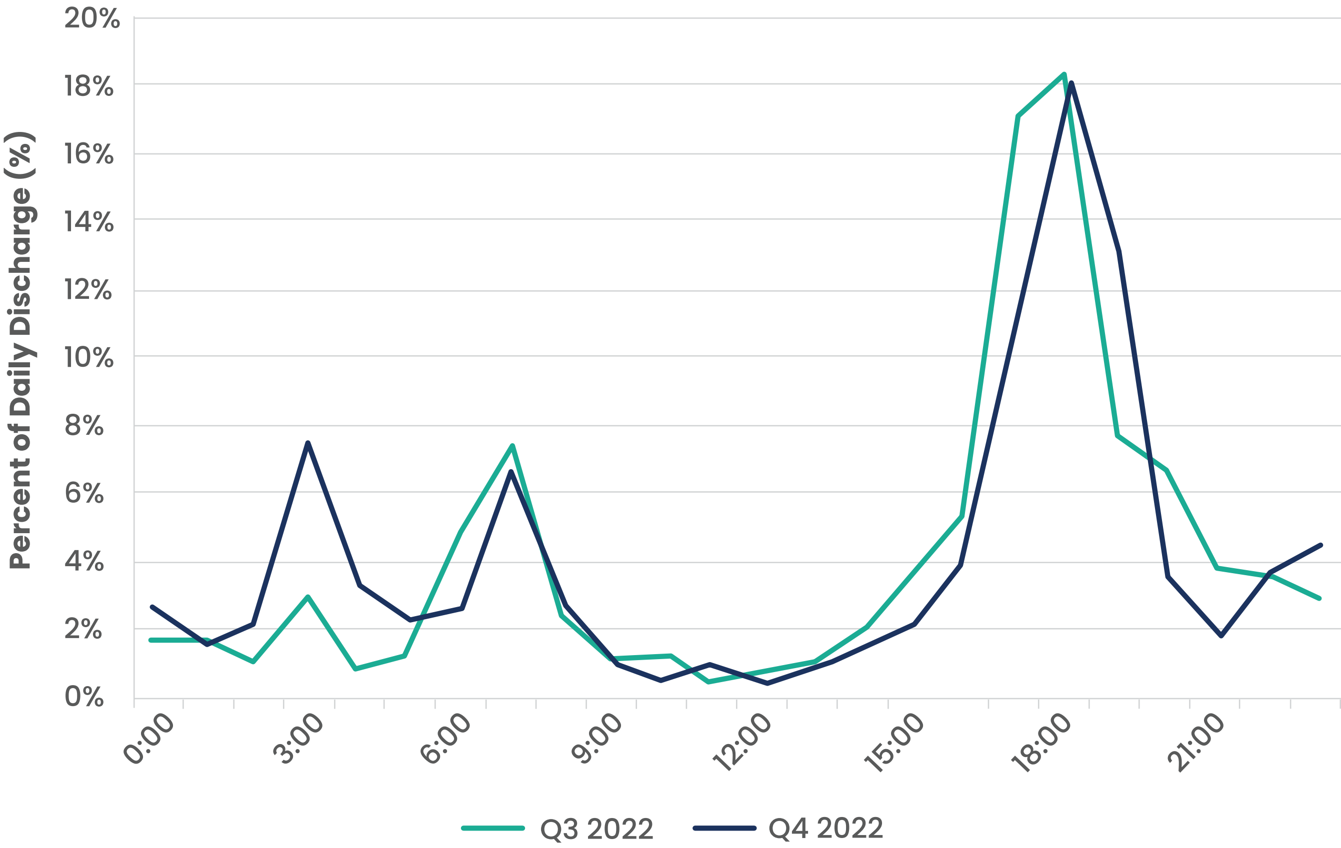


Figure 4 – Average daily discharging profile for the WGB in the reporting period.

The average daily charging profile of the WGB has remained consistent with the profile that developed in Q2 CY2022 and continues a shift towards charging the battery predominately throughout the middle periods of the day, and limiting the charging undertaken overnight. There is little variation seen in the discharge profile aside from a tighter distribution around the evening peak hours.

It is notable that despite the varied enablement for the WGB in the energy markets across the two quarters of the reporting period, the average profile of when the battery was charging and discharging into the network was consistent.

5.10 Provision of Regulation FCAS

The regulation FCAS enablement levels are reported across six categories, which reflect the provision of co-optimised services (ie contingency FCAS and energy). These categories are explained in Table 6.

	Raise regulation	Lower regulation	Comment
No enablement	0MW	0MW	
>0MW and <(NP Cap – cFCAS)	1 to 23MW	1 to 20MW	
NP Cap - cFCAS	24MW	21MW	No impact on contingency FCAS. This indicates the WGB is providing the maximum possible amount of contingency FCAS (26MW), and is using all its leftover capacity to provide regulation FCAS.
>(NP Cap – cFCAS) and <NP Cap	25 to 49MW	22 to 47MW	Some impact on contingency FCAS. This indicates the WGB is providing less contingency FCAS in order to provide more regulation FCAS.
NP Cap	50MW	47MW	WGB is only providing regulation FCAS (not providing any contingency FCAS or energy). This indicates the WGB has stopped providing contingency FCAS and is using all its capacity to provide regulation FCAS.
>NP Cap	>50MW	>47MW	WGB is providing regulation FCAS and energy in the opposite direction. This indicates the WGB has been dispatched to fully prioritise regulation FCAS over contingency FCAS.

Table 6 – Regulation FCAS category capacities

The WGB can provide three different services: energy, regulation FCAS, and contingency FCAS. These services are co-optimised, which means that they can be provided simultaneously, but they have to share the WGB's nameplate capacity. The WGB has a nameplate discharge capacity of 50MW. However, whenever the WGB is fully enabled for contingency raise, 26MW of this nameplate discharge capacity must be reserved as headroom. This leaves only 24MW for the provision of regulating raise FCAS and energy (in the same dispatch interval). Conversely, enabling the WGB for more than 24MW of regulating raise impacts the amount of contingency raise that can be enabled in the same interval. Dispatch for energy (discharge) further reduces the amount of regulating raise and/or contingency raise that can be provided in the same interval, whereas dispatch for energy (charge) would increase it.

The WGB is registered for 50MW in the regulating raise market, and 47MW in the regulating lower market, reflecting the WGB's asymmetric nameplate capacities (50MW discharge / 47MW charge).

Fully enabling the WGB for contingency FCAS requires 26MW of capacity in both directions. This means that whenever the WGB is providing the maximum possible amount of contingency FCAS, it can simultaneously provide:

- 50MW nameplate discharge capacity – 26MW required for cFCAS = 24MW of regulating raise
- 47MW nameplate charge capacity – 26MW required for cFCAS = 21MW of regulating lower

The levels of regulation FCAS enabled for the WGB throughout the reporting period is displayed in Figure 5.

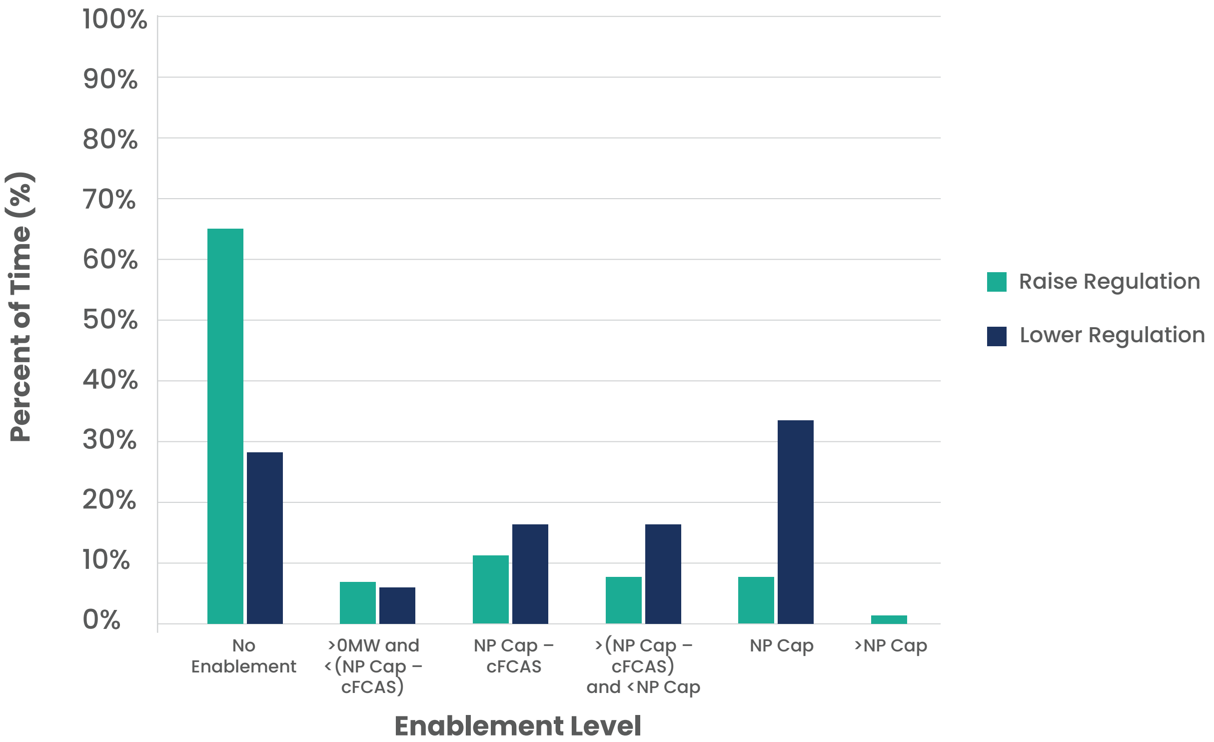


Figure 5 - Regulation FCAS market enablement in Q3 and Q4 CY2022

The results shown in Figure 3 are aligned with Iberdrola Australia's expectation generally and are similar to the performance of the WGB through the first half of 2022. The exception is lower regulation FCAS above 21MW, i.e. in the last three categories. Q3 and Q4 saw greater value available in the lower contingency FCAS markets, leading to a preference for enablement on those markets.

5.11 Provision of Contingency FCAS

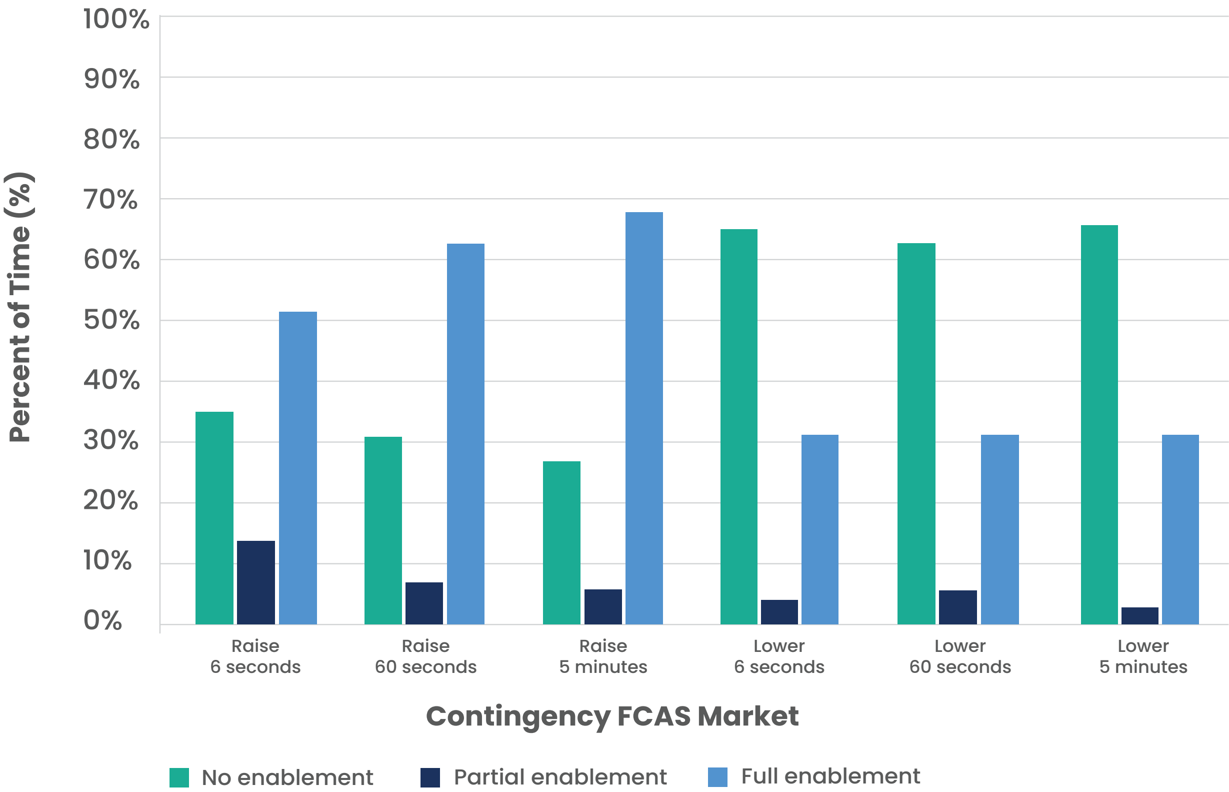


Figure 6 – Contingency FCAS market enablement in Q3 and Q4 CY2022

Similar to the regulation FCAS enablement distributions, the contingency FCAS enablement in Figure 4 is generally in line with expectations and the previous operations of the battery. As noted previously in commentary on lower regulation enablement, the corresponding increase in lower contingency enablement can be observed in the above graph, with a ~10% increase in full enablement across all lower contingency markets in comparison to the first half of the year.

5.12 Extreme market prices capture rates

5.12.1 Energy market

The average energy response of the WGB during extreme energy price events in the second half of the year is shown in Table 7.

	Dispatch interval ranges	# of periods	Average energy response (MW)
Q3 CY2022	DI above $1,000/MWh	55	15.24
	DI below $-500/MWh	0	n/a
Q4 CY2022	DI above $1,000/MWh	10	7.87
	DI below $-500/MWh	0	n/a

Table 7 – Wallgrove Grid Battery response during extreme energy price events

The average energy responses shown above are consistent with past experiences. It is important to emphasise that a level of detail is missed when only considering the energy response without the context of the market conditions or co-optimisation with the regulation FCAS markets.

Most of these prices were only marginally above $1,000/MWh. For an energy-constrained asset like a battery, these pricing periods can be extremely difficult to bid the battery into, as the forecast price into the future at times of high-price volatility can typically suggest that even higher prices may eventuate, and that the optimal decision at the time would be to conserve the battery's state of charge to discharge for greater returns later.

An additional consideration for the dispatch of the WGB is the operational performance of Iberdrola Australia's other assets at the time. If renewable generation is covering the contracted position of our NSW portfolio, it is typical for the battery state of charge to be reserved during volatile market periods to ensure that it is available to discharge if the intermittent generation reduces and the contracted position becomes uncovered.

5.12.2 FCAS markets

	DIs above $1,000/MW/h	Average enablement (% of registered capacity)
Raise 6 Seconds	4	0%
Raise 60 Seconds	0	n/a
Raise 5 Minutes	0	n/a
Raise regulation	4	0%
Lower 6 Seconds	0	n/a
Lower 60 Seconds	0	n/a
Lower 5 Minutes	0	n/a
Lower regulation	1	0%

Table 8 – WGB enablement during extreme FCAS price events

As evidenced in the table, the WGB did not capture any of the high price FCAS events in the reporting period. There were two reasons for this result, either the extreme price event occurred during the maintenance period of the battery, or it was coincidental with higher prices in the energy market, which meant the battery was dispatched into the energy market to maximise revenue.

6.1 Round-Trip Efficiency

Round-trip efficiency (RTE) is the proportion of the energy put into the battery that can be retrieved. It is calculated as the ratio of energy exported / energy imported through a given point (eg the inverter terminals, or the grid connection point), over a given duration. The RTE of the WGB throughout this time is shown in Table 9.

The WGB is connected directly to the transmission network, and the RTE is measured at the transmission network connection point. The RTE therefore includes losses in the 132/33kV power transformer.

Method	Round trip efficiency at 132kV transmission network connection point (%)
Operational performance estimate from 1 July 2022 to 31 December 2022	81.7%

Table 9 - Round trip efficiency performance

6.2 Operational Performance Estimate

The operational RTE performance can be estimated as follows:

RTE = (total energy exported - start state of charge (SoC) + end SoC) / total energy imported

For Q3 and Q4 CY2022[7]:

- Start SoC = 37 MWh
- End SoC = 25 MWh
- Total energy exported = 10,631 MWh
- Total energy imported = 12,996 MW
- RTE = (10,631 – 37 + 25) / 12,996 = 81.7%

Note that the difference between the RTE test result vs operational RTE performance estimate reflects the difference between test conditions vs operational conditions, rather than any material deterioration in RTE performance since commissioning. For example, auxiliary and standby losses have a much bigger impact on RTE when ambient conditions during operation are outside the range of standard test conditions.

6.3 Energy Retention

An energy discharge capacity test was conducted prior to the end of the first year of operations. Approximately 90MWh was discharged at the time of this test, however it is recognised that the BESS was not charged fully to 100% state of charge at the commencement of this test. The performance test prior to COD achieved 95.1MWh discharged, which suggests degradation was no greater than 5.7% in the first operating year, and likely better than this value as it is recognised that the system was not fully charged at the commencement of the energy discharge capacity test.

6.4 Auxiliary Power Usage

Auxiliary power usage is estimated to be 8.0kVA from observations of the auxiliary power distribution board meters over a one-hour period. The measurements were taken during the day and therefore do not account for yard lighting.

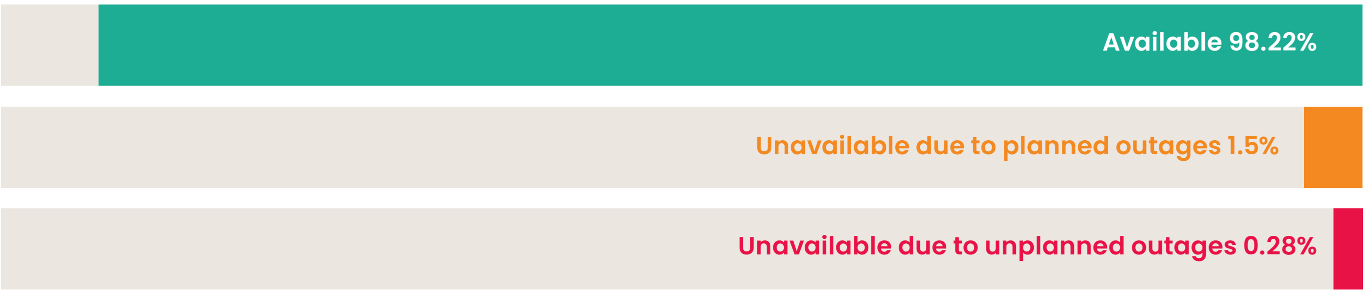
This is a marginal increase on original operations, as a new server was installed for Iberdrola inside the auxiliary services building. The auxiliary power distribution board supplies power to the following:

- BESS protection, control, and communication systems
- Secondary systems – uninterruptible power supply (UPS)
- BESS security systems
- Switch room and auxiliary services building and light power and fire detection systems
- Power transformer auxiliary supply
- Yard light and power.

7 This data is available at https://www.transgrid.com.au/projects-innovation/wallgrove-grid-battery

6.5 Availability

Availability performance for 1 July 2022 to 31 December 2022 was:



6.5.1 Planned Outages

The planned outages that occurred during the reporting period are shown in Table 10.

Planned outage date	Works occurred
Multiple	Tesla maintenance
4, 14, 21-23 November 2022	Implementation of VMM and 6 point droop
8 December 2022	Installation of Instability Detection System
19 December 2022	Energy Retention Testing

Table 10 – Planned outages

6.5.2 Unplanned Outages

The WGB has performed exceptionally well with only one minor event to report on. The impact of unplanned outages for the reporting period was approximately 0.28%.

Unplanned outage date	outage
12 July 2022	WGB unable to recharge due to AGC outage

Table 11 – Unplanned outages

6.6 Other Technical Performance Issues After Commercial Operations

6.6.1 Automatic Generation Control Outages

The operation of the WGB is highly dependent on communications systems, including AEMO's automatic generation control (AGC) signal which controls the dispatch of the battery in the energy and regulation FCAS markets.

In June 2022, during the height of the energy crisis, Iberdrola Australia was required to discharge the WGB during the market suspension but then it was unable re-charge it due to the over-constrained dispatch price settling above the highest energy load bid that the BESS could provide ($15,100/MWh). As a result, the WGB was discharged to a very low state of charge (SoC).

This caused the WGB site controller to disable AGC mode. This was by design, to prevent the WGB from being dispatched when it did not have sufficient stored energy to participate in the market. Unfortunately, this also made it impossible for Iberdrola Australia to re-charge the battery via the normal dispatch process (ie via AGC), meaning the only way to re-charge was via manual dispatch.

A new AGC outage occurred on 12 July 2022, with the WGB out of service for approximately five hours. The logic was subsequently updated in mid-July to prevent any further AGC lockouts. No AGC related un-planned outages have occurred since.

Commentary and data presented in this section are from Iberdrola Australia's perspective, unless noted otherwise.

7.1 Market Revenue

7.1.1 Data Sources

The revenue figures shown below are compiled by Transgrid using operating data for the battery from AEMO's public Market Management System (MMS) database at www.nemweb.com.au (which has not been verified for accuracy) and AEMO's settlement procedures for the applicable revenue sources. The presented revenue results for the battery may not reflect actual outcomes due to errors in underlying data or due to contract positions held by Iberdrola Australia. Accordingly, this information should not be used as an indication of the net revenues earned by Iberdrola Australia from the battery's operations.

In August 2022 the figures returned from AEMO's database contradicted Iberdrola's internal calculations. The inconsistency is assumed to relate to an event on 10 August 2022 where a scheduling error resulted in high volumes of contingency FCAS trading at the price cap for 13 dispatch intervals. The prices were subsequently revised, but the data remains artificially high. Iberdrola's calculations are therefore assumed to be more correct and have been used in the follow graphs.

Energy revenue = MWh exported * Energy Regional Reference Price (RRP) * Marginal Loss Factor (MLF)

(with MWh imported reflecting a negative MWh export)

FCAS revenue = MW enabled * FCAS RRP / 12

MWh imported/exported is derived from nemweb.com.au/Reports/Current/Causer_Pays/

FCAS enablement is obtained from nemweb.com.au/Reports/Current/Next_Day_Dispatch/

Prices are obtained from nemweb.com.au/Reports/Current/Public_Prices/

MLFs are obtained from nemweb.com.au/Reports/Current/Marginal_Loss_Factors/

7.1.2 Market Revenue by Month

The revenue earned by the WGB for each month is provided in Figure 7.

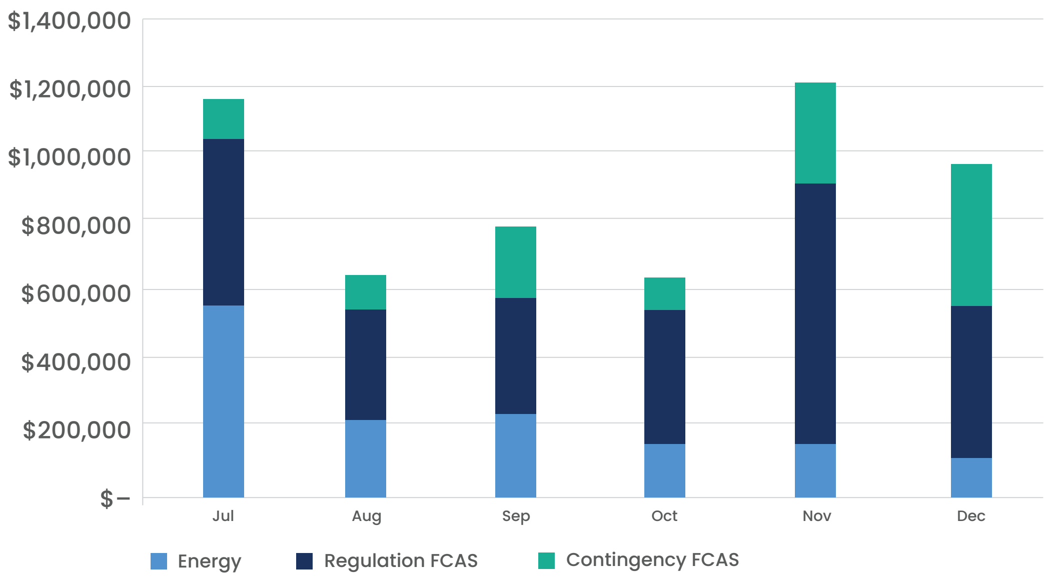


Figure 7 – Market revenue by month

The escalated energy market volatility of Q2 CY2022 continued into July with increased revenues realised from energy before the market returned to the levels seen at the start of CY2022. This is evidenced by the much lower portion of overall revenue earned in the final months of the year.

In contrast with the variation in energy market revenues, regulation and contingency FCAS markets have remained relatively consistent throughout the reporting period. The exception is the increased regulation FCAS revenues seen in November driven by higher average raise regulation prices.

7.1.3 Market Revenue by Application

The revenue earned by the WGB for each application is shown in Figure 8.

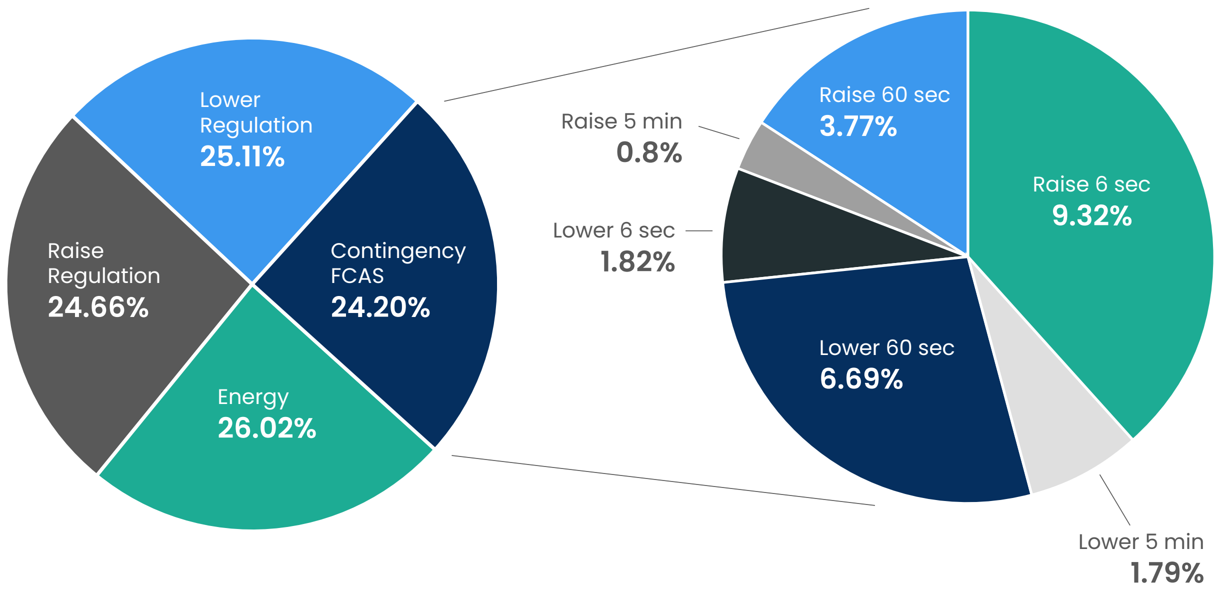


Figure 8 - Market revenue by month – 1 July 2022 to 31 December 2022

Earning at the WGB was split evenly between the energy, raise and lower regulation markets and the six contingency FCAS markets. This distribution is a return to historical convention for the distribution of revenues for batteries in the NEM.

For comparison, typical revenue distribution for Iberdrola Australia's Lake Bonney BESS during its two years of operation were about 25 per cent of revenue from the energy market, 45 per cent from the regulation FCAS markets, and 30 per cent from the contingency FCAS market.

7.2 Factors Materially Affecting Market Revenues

7.2.1 Marginal Loss Factors (MLFs)

Given that the WGB is adjacent to the regional reference node of the NSW region, long-term stability of the generator and load MLFs were expected to have negligible impact on the revenues generated by the battery in the energy market. This was reflected in the first two MLFs reported for financial years 2022 and 2023 shown in Table 12.

Financial year	WALGRVG1 (generator)	WALGRVL1 (load)
2021-22	1.0011	1.0010
2022-23	1.0010	1.0009

Table 12 – MLF values for the Wallgrove Grid Battery

7.2.2 Curtailment Impacts

As with the MLFs for the WGB, the strong point of connection has limited any curtailment risks for the operations of the battery to date.

7.3 Future Revenue Opportunities

Iberdrola Australia continues to be an active participant in a number of rule change requests and market design proposals under consideration by the Australian Energy Market Commission (AEMC). These include the introduction of system security services that were previously identified as new market opportunities for dispatchable generators (and batteries in particular) such as the WGB.

The determination by the AEMC on the establishment of two new markets (the very fast raise contingency service and very fast lower contingency service) to deliver FFR services in the NEM is the first of these new markets to be realised, planned for October 2023.

7.3.1 Primary Frequency Response Incentive Arrangements

Iberdrola Australia also remains an engaged participant in the discussions around the future arrangements for the provision of primary frequency response and whether incentives should be established to encourage a market response. The WGB remains well positioned to participate flexibly for any future requirement or incentive regime.

7.3.2 System Security Services

A number of rule change requests for the introduction of new system security markets have been made to the AEMC, including:

- a FFR ancillary service market for raise and lower responses measured within a timeframe of 0.5-2 seconds from the frequency excursion event (completed – new FFR market commences October 2023)
- an operating reserve (OR) market for generators that can provide a dispatchable response within 30 minutes, with a 15-minute call time (draft determination due June 2023)
- a ramping service ancillary service market for raise and lower responses that operate over a 30-minute period (draft determination due June 2023)
- an inertia spot market that would replace the current mechanism whereby inertia is procured by TNSPs (pending initiation).

There should be no barriers for the WGB participating in these markets if/when they are established. The WGB would be able to provide the required responses within either short-term or medium-term timeframes (subject to operational state of charge limitations).

Major considerations for Iberdrola Australia utilising the WGB to participate in future markets such as these are the enablement constraints with other market services and the potential energy throughput due to enablement.

There have been no safety or environmental incidents in the first year of operations.

Approximately 1,214 work hours occurred on site during the second six months of operations, as shown in Table 13. The total hours include Transgrid and Tesla employees and subcontractors. Tesla conducted yearly routine maintenance along with ongoing corrective and preventative maintenance activities during this operational period. The hours observed on site are higher due to Tesla's proactive work on site and TransGrid's continuous project improvements including the successful implementation of VMM, 6 point droop, and installation of an instability detection system.

Operational period	Approximate work hours onsite
1 July 2022 – 31 December 2022	1,214

Table 13 – Work hours on site

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