Operations Report#4

2020/ARP013 Transgrid Wallgrove Grid Battery

July to December 2023

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The purpose of this document (Report) is to provide a summary of the fourth six-month period of operation of the Wallgrove Grid Battery. For simplicity and readability, rather than use the precise six-month period of operation, the report covers the period from July to December 2023.

The Report has been prepared by NSW Electricity Networks Operations Pty Limited (ACN 609 169 959) as trustee for NSW Electricity Networks Operations Trust (ABN 70 250 995 390) trading as Transgrid (Project Owner).

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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.

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1. Acronyms

AEMO	Australian Energy Market Operator
ARENA	Australian Renewable Energy Agency
BESS	Battery energy storage system
cFCAS	Contingency frequency control ancillary services
DI	Dispatch interval
FCAS	Frequency control ancillary services
FFR	Fast frequency response
GPS	Generator performance standards
LSBS	Large scale battery storage
MLF	Marginal loss factor
NEM	National electricity market
NER	National electricity rules
NMI	National metering identifier
NP Cap	Nameplate capacity
OEM	Original equipment manufacturer
POD	Power Oscillation Damper
PFR	Primary frequency response
PoE	Probability of exceedance
PPC	Power plant controller
ROCOF	Rate of change of frequency
RRP	Regional Reference Price
RTE	Round trip efficiency
SCADA	Supervisory Control and Data Acquisition
SoC	State of charge
Syncon	Synchronous Condenser
TNSP	Transmission network service provider
VMM	Virtual Machine Mode
WGB	Wallgrove Grid Battery

2. Executive Summary

This Report summarises the operations of the Wallgrove Grid Battery (WGB) from 1 July 2023 to 31 December 2023.

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 543 work hours occurred onsite during the fourth six-month period of operations. There were no safety or environmental issues onsite.

This was the second full reporting period in which Tesla's Virtual Machine Mode (VMM) was enabled and could be observed responding to disruptions in the network. Transgrid technical personnel continue to observe the performance of the battery to understand the potential of virtual inertia to provide network services as synchronous generation retires, and in doing so Transgrid is now meeting the main objective of its funding agreement with ARENA.

The commercial operation of the WGB changed materially through the period with the introduction of the very fast contingency FCAS markets in October. The trend away from regulation FCAS remained evident.

There were no unplanned outages in the period, and the availability over the six-months was close to 99 per cent.

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

3. Purpose and Distribution

3.1 Purpose of Report

This Report covers the operational learnings over the fourth 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.

VMM was enabled on 23 November 2022. Observations and learnings on VMM operations focuses on:

- Commentary and assessment of the project's ongoing performance 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. Documentation associated with the Knowledge Sharing Program for the Project is available on the Wallgrove Grid Battery project websites (details in Table 1).

Table 1 – Knowledge sharing deliverables

Deliverable	Responsibility
Arena 15 min project survey	Quarterly
Lesson learnt report #1	Submitted May 2021
Operations reports	Every six months for the first two years of operation
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 SRG meeting #4 14/06/2023
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 Presentation to ARENA 'Dispatch' 16/08/2023 Participation in ARENA's Insight Forum March 2024
Project website	Accessible via: https://www.transgrid.com.au/projects-innovation/wallgrove-grid-battery https://www.lumea.com.au/projects/wallgrove-grid-battery/

Photo 2 – Wallgrove Grid Battery looking towards Sydney West substation

4. Project Summary

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 40 GW 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

The energy 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 15,000MWs for 93 per cent of the time[1]. One way to address this inertia shortfall is through the provision of synthetic inertia through BESS.

BESS are increasingly recognised as a potential solution to network challenges, with the additional benefit of providing storage capacity so the grid can access renewable generation when the sun isn't shining, and the wind isn't blowing. The Australian Energy Market Operator (AEMO) anticipates that by 2050, 14GW of storage will be provided by utility-scale batteries.[2]

As existing sources of inertia, predominantly coal-fired generators, are progressively withdrawn from the market, Transgrid is investigating alternative technology solutions to establish the technical and commercial viability of lower-cost solutions to address the inertia gap, including its first hybrid grid-scale battery – the Wallgrove Grid Battery.

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[1] Transgrid Transmission Annual Planning Report 2022, p101

[2] AEMO ISP June 2022

4.4 Overview of Wallgrove Grid Battery Project

The WGB is a 50MW/75MWh (1.5-hour duration) grid-scale lithium-ion battery. It became the first large-scale grid battery in NSW. Located at Wallgrove, the WGB is a pilot demonstration of the viability of synthetic inertia from a battery to support frequency stability on the network. Iberdrola Australia controls dispatch of the WGB and participates 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 synthetic inertia technologies in different locations on the grid, including strong areas of the grid. Transgrid embarked on the WGB project to explore synthetic inertia using specialist firmware to mimic the "swing equation" that governs the rotor dynamics of a synchronous machine. This product is manufactured by Tesla and, when configured to deliver synthetic inertia, is described as operating in virtual machine mode (VMM).

The project commenced commercial operations in December 2021, and has operated with its synthetic inertia capability enabled since November 2022. The project has generated valuable technical information about how often it is needed for fast frequency response, how it performs as a source of inertia in the event of grid disturbance, and how much electricity it stores and dispatches under different conditions.

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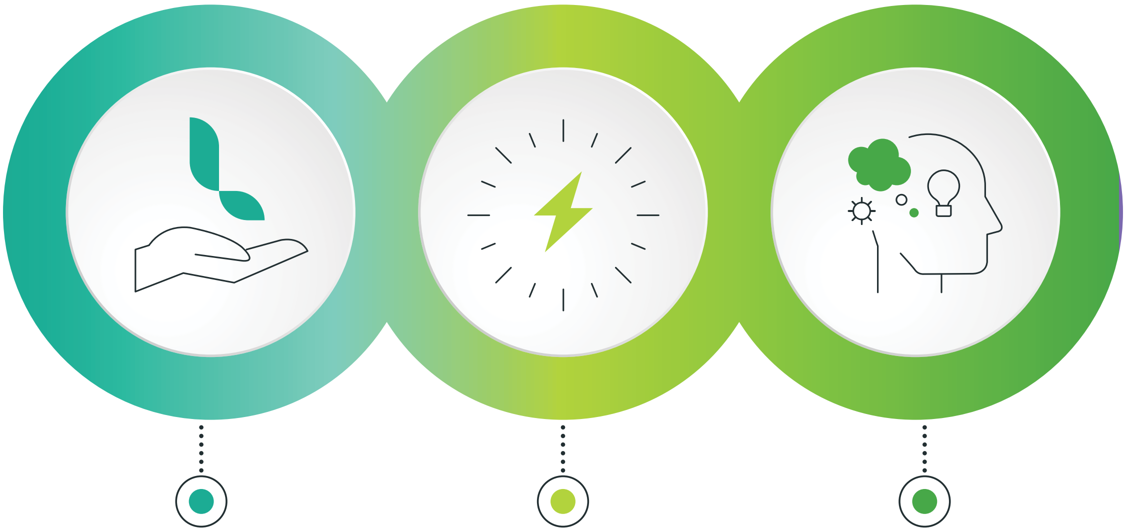
3 Wallgrove is the third BESS in the NEM to demonstrate synthetic inertia. ESCRI (30MW) and Hornsdale Expansion (150MW) are the first and second.

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 Fast frequency response (FFR) services and Tesla's Virtual Machine Mode to substitute for inertia and help meet Transgrid's requirement to manage Rate of Change of Frequency (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 ~240MW 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

Table 2 – Key technical parameters

Technical parameter	Summary
Registered discharge power capacity	50MW (at 132kV connection point)
Registered charge power capacity	47MW (at 132kV connection point)
Nameplate storage capacity	75MWh (at 132kV connection point)
Number of megapacks	36
System voltages	132 / 33 / 0.518 / 0.4kV
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 33/0.400kV 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

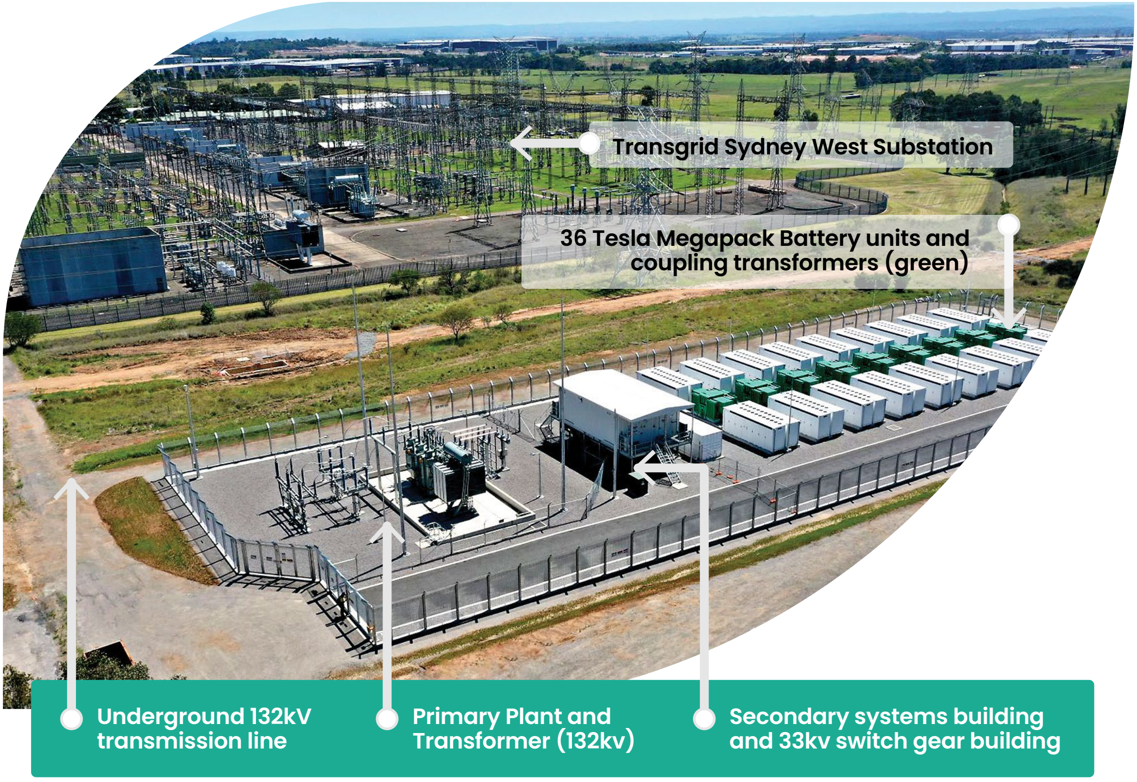


Photo 3 – Wallgrove Grid battery and Sydney West 330/132kV substation aerial view

5.1. Performance during system disturbance

5.1.1. Event 1 – Loss at Eraring

On 17 August 2023 at 15:56 hrs, Eraring unit 1 operating at 668 MW tripped, resulting in frequency going down to approximately 49.86 Hz measured by the Transgrid power quality meter at the 330kV bus of the Eraring Power Station. The highest ROCOF for this event was reported in AEMO's quarterly report as –0.3 Hz/s. This event is associated with a Low Voltage Ride Through (LVRT), so the analysis focuses on the related aspects of the performance.

Figures 1–4 present the voltage, active power and reactive power overlays of the WGB and a NSW synchronous unit which was further away from the fault location, and therefore experienced a shallower voltage response due to the increased electrical distance.

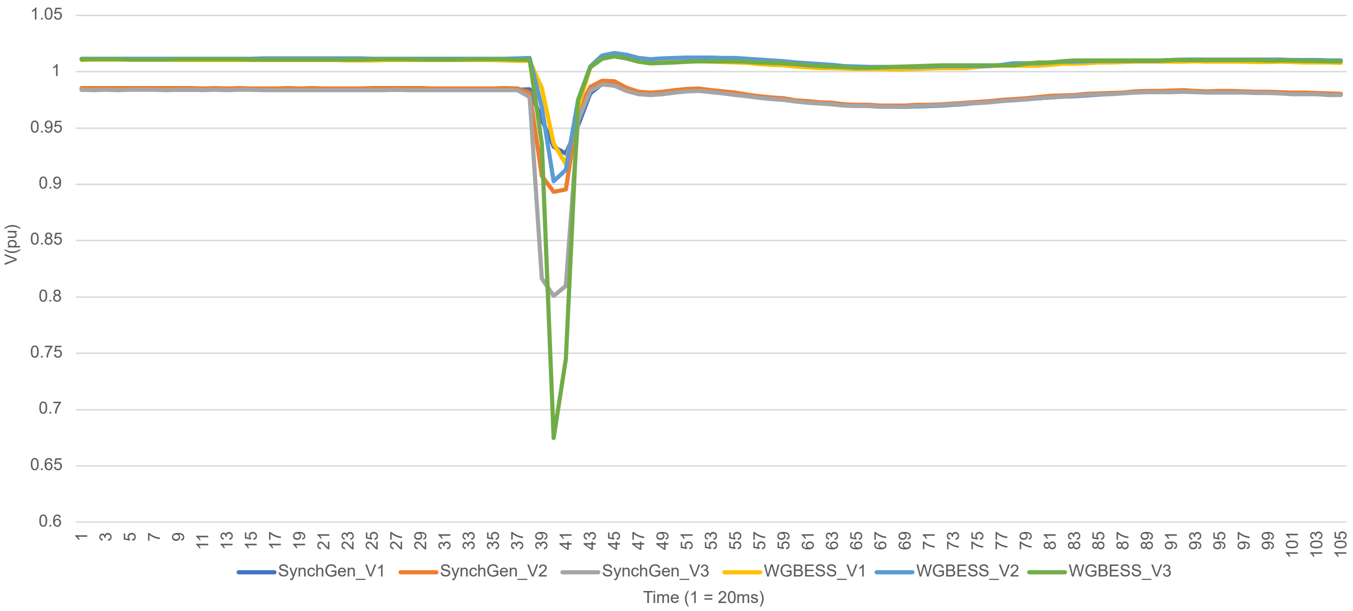


Figure 1 – Eraring Trip Phase Voltage Overlay – NSW synchronous generator and WGB

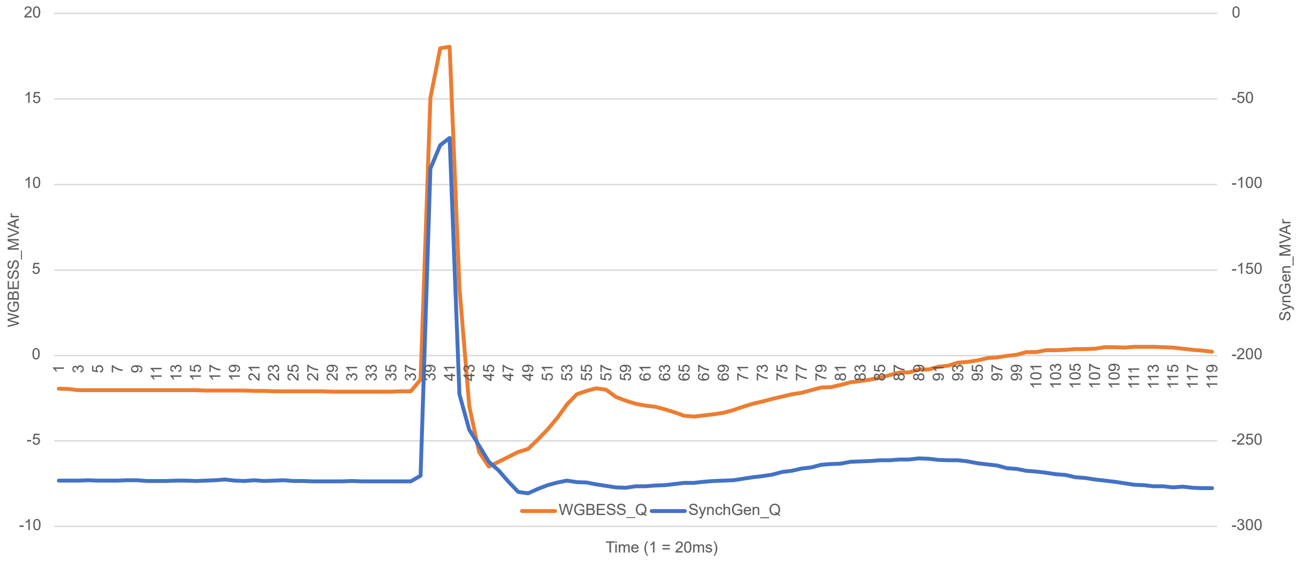


Figure 2 – Eraring Trip Reactive Power Overlay – NSW synchronous generator and WGB

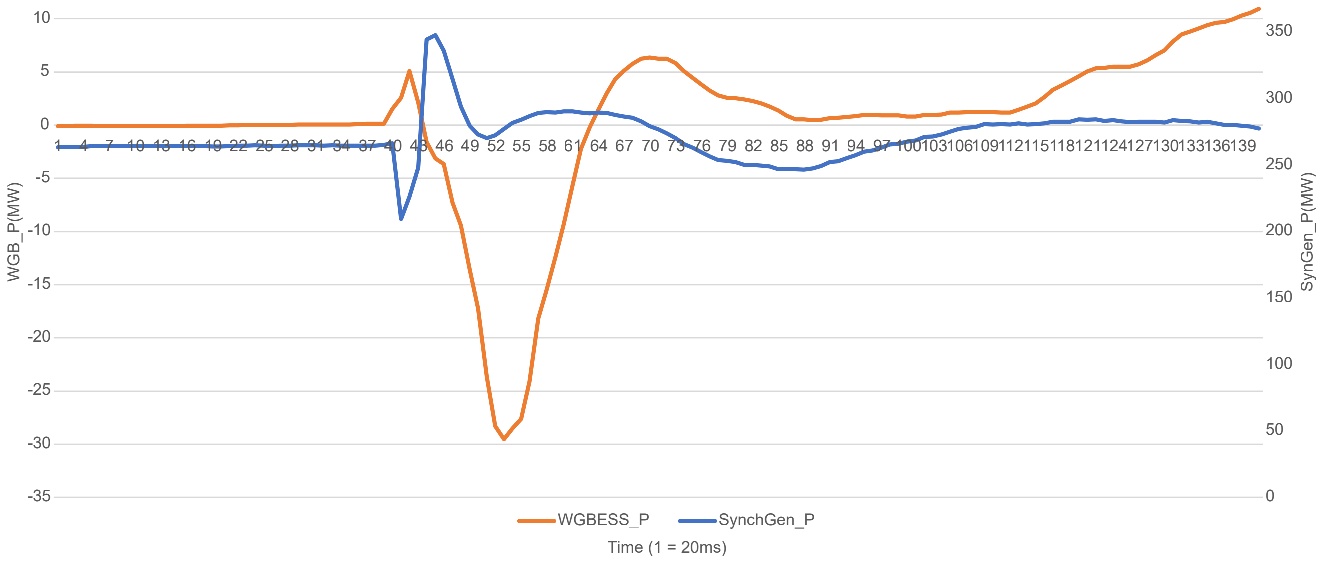


Figure 3 – Eraring Trip Active Power Overlay – NSW synchronous generator and WGB

During this event, both generator's phase voltage drops below 0.9 pu. This means that the WGB would have triggered its LVRT. This can be observed by the sharp reactive power response from the reactive current injection. However, unlike the synchronous generator, WGB had a major negative power swing (60% of its rating) as the frequency is ramping down towards its nadir, which would amplify rather than counter the drop in frequency. Figure 4 illustrates this observation of active power and grid frequency.

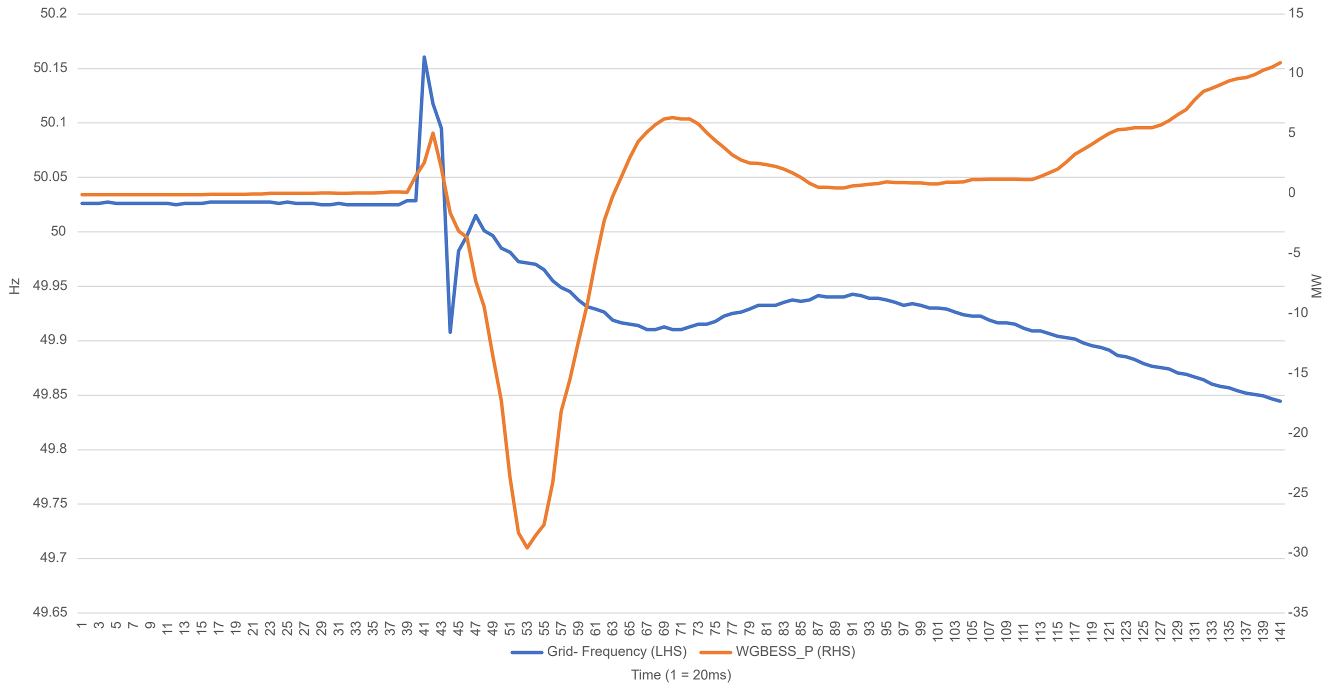


Figure 4 – Eraring Trip – Active Power and Grid Frequency

It must be acknowledged that the frequency measurement may have been slightly inaccurate due to the unbalanced voltages during the first few cycles of the event. However, beyond the few cycles at the beginning of the fault, the frequency measurement is accurate.

5.1.2. Event 2 – Loss at Loy Yang

On 17 December 2023 at 05:22 hrs, Loy Yang unit 4 tripped while generating at 556 MW resulting in frequency going down to 49.82 Hz reported by AEMO and measured as 49.824 Hz by the Power Quality meter at 132kV busbar at Wallgrove. The highest ROCOF for this event has been estimated to be approximately –0.16 Hz/s at the steepest part of the disturbance. There is a 0.03 Hz discrepancy between estimated ROCOF by AEMO and estimated ROCOF using the power quality monitoring of WGB, but it does not impact the findings.

To help to interpret the behaviour of the WGB in responding to the disturbance, Figure 5 divides the time between the occurrence of the event and the frequency nadir into three phases. The phases are illustrated by windows of data: A, B and C. Window A has the fastest ROCOF, then the ROCOF reduces through B, before increasing until about 2.2 seconds from the event when the nadir is reached at the end of C. If the small active power disturbances are discarded, the active power response is directly proportional to ROCOF.

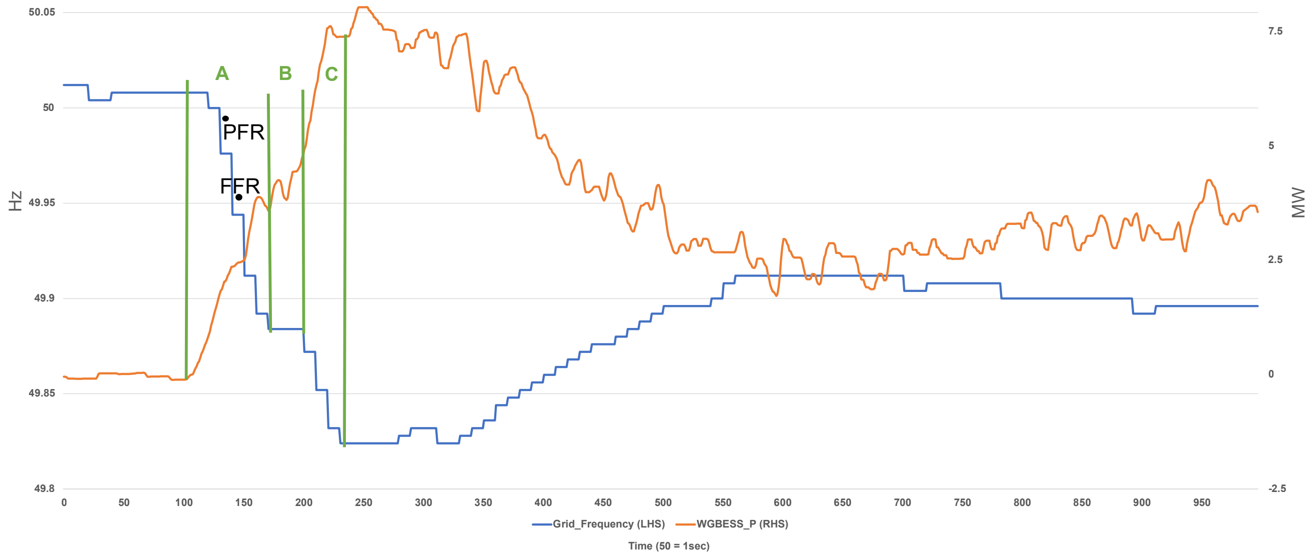


Figure 5 – Loy Yang Trip – Active Power and Grid Frequency

The active power response increases with an increase in the deviation of frequency and it reduces with the decrease in the deviation of frequency. This pattern is seen over the whole captured window of data. In other words, active power is almost 'anti-phase' with frequency across the transient and the steady state (i.e. the peak power injection occurs at the frequency nadir). While this makes the estimation of inertial response more challenging, it also indicates that the frequency response is more dominant than the inertial response.

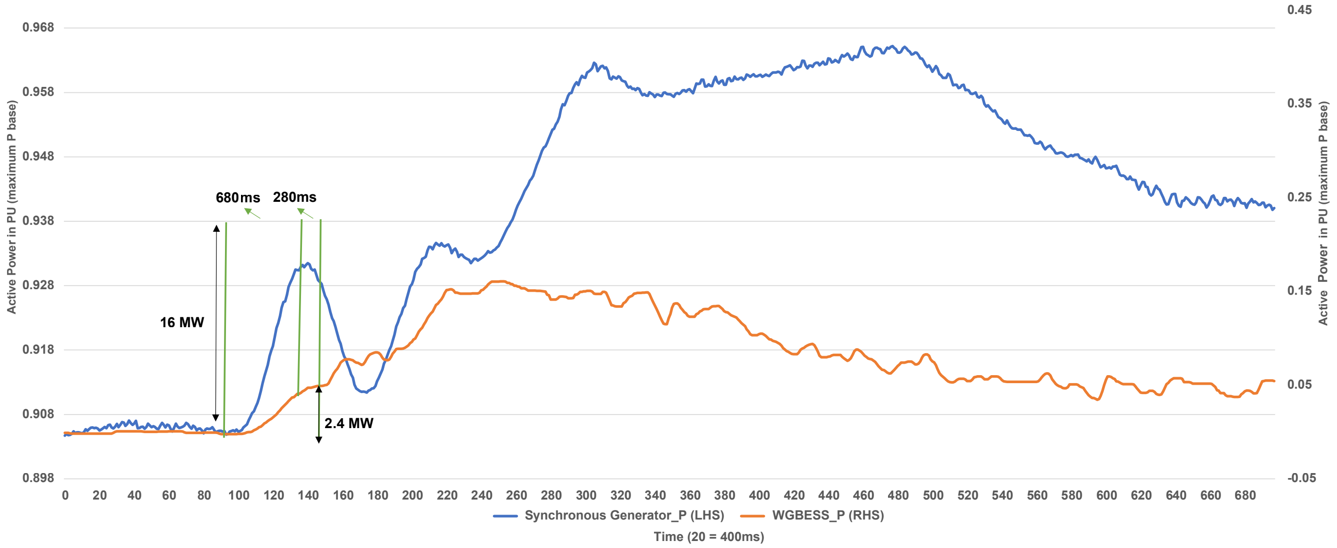


Figure 6 – Loy Yang Trip – Active Power Overlay – NSW synchronous generator and WGB

Table 3 provides the amount of energy in MW.s that the battery provided in four different windows of time from the beginning of the event to communicate the effectiveness of the energy injected by the battery at different points in time. This detail expands on Figure 6, which graphically contrasts how active power was provided by the WGB relative to a synchronous generator.

Table 3 – Loy Yang – Energy released by the source of power in frequency disturbance

Energy Provided in Loss of Loy Yang by	**200 ms**	**500 ms**	**1000 ms**	**2000 ms**
Wallgrove Grid Battery	0.036 MW.s	0.3622 MW.s	1.545 MW.s	5.58 MW.s
	0.00055 MW.s /MVA	0.0055 MW.s /MVA	0.023 MW.s /MVA	0.086 MW.s /MVA
Proportion of 2-second response	0.6%	6.5%	27.7%	100%
NSW Synchronous Machine	0.462 MW.s	3.54 MW.s	10.887 MW.s	18.55 MW.s
	0.0059 MW.s /MVA	0.0045 MW.s /MVA	0.014 MW.s /MVA	0.023 MW.s /MVA
Proportion of 2-second response	2.4%	19.1%	58.7%	100%

We see that normalised ratio of the MW.s over the total rating of each generator (e.g. (MW.s)/MVA) is slightly higher for the synchronous machine in the first 200ms, then higher for the WGB in the following time periods.

The "proportion of 2-second response" demonstrates that the proportion of the energy provided by the synchronous machine earlier in the response is relatively greater than the battery. While it is not a scope of work for this project, the industry would benefit from further exploration on the criticality of the rate of change of response within 1-2 seconds of the frequency disturbance at a much larger scale.

5.1.3. Event 3 – Loss at Bayswater

On 31 December 2023 at 20:40 hrs, Bayswater unit 1 synchronous generator tripped while generating at 505 MW resulting in frequency going down to 49.81 Hz and the recovery back to normal operating frequency band after 5 seconds.

Four windows – A, B, C and D – are provided in Figure 7 to track the response of the WGB against the frequency change. Like the previous events, the active power response from WGB commences (Window A) prior to observation of any measurable frequency change as captured at the power quality meter of the WGB.
As previously discussed, this inherent response is beneficial to the grid, compared to a standard grid following battery's response with PFR or FFR. While the relationship between active power and frequency is similar to the Loy Yang event, differences in the 'anti-phase' behaviour are evident in all windows, particularly A and D.

In Figure 7, the set thresholds for triggering PFR and FFR are also illustrated by the two black dots to indicate the point on the active power curve that the responses from these controllers applied.

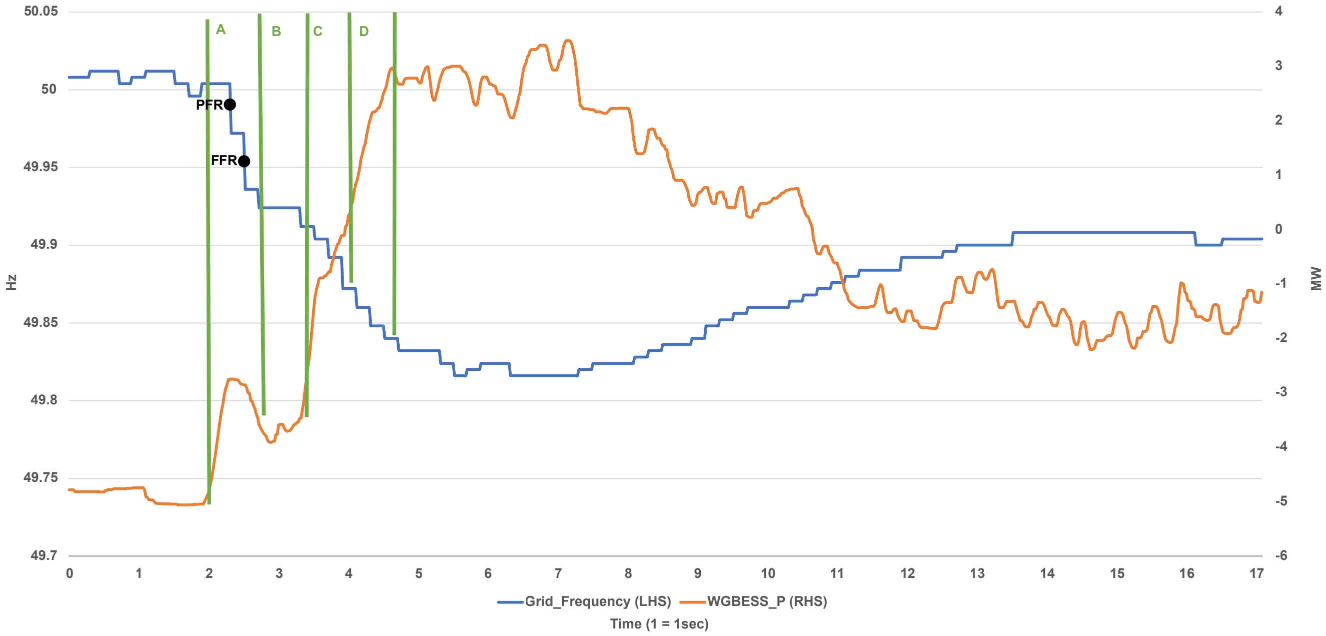


Figure 7 – Bayswater Trip – Active Power and Grid Frequency

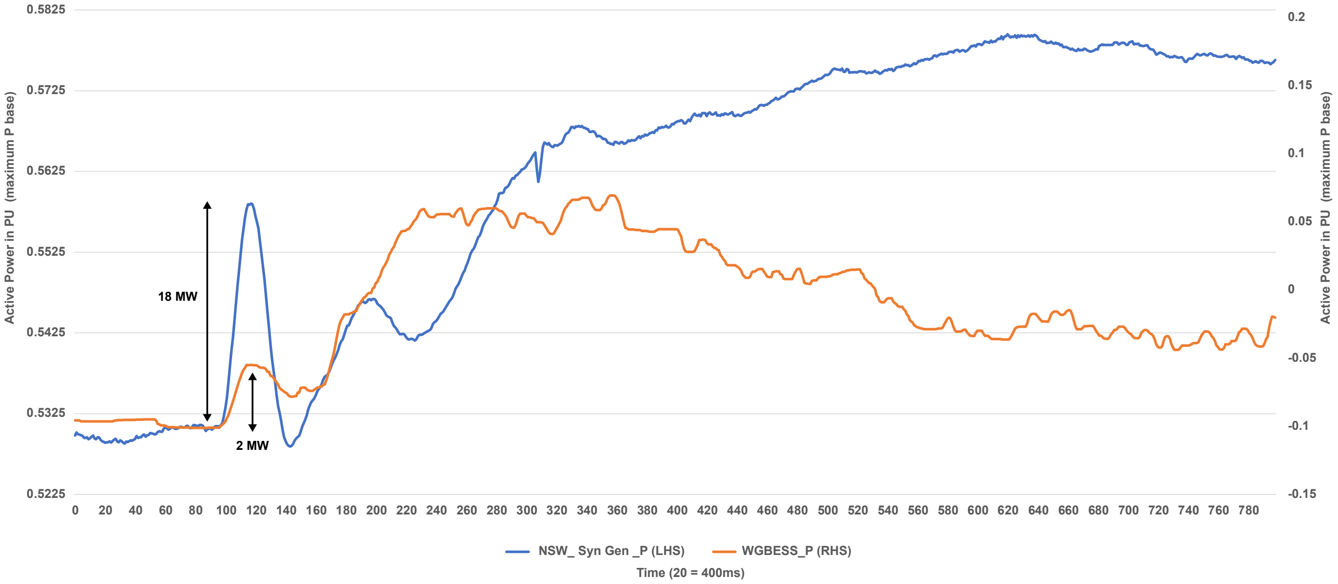


Figure 8 – Bayswater Trip – Active Power Overlay – NSW synchronous generator and WGB

The active power injections of a NSW synchronous generator and the WGB follow different profiles as demonstrated in Figure 8. The below table provides the amount of energy (MW.s) that the battery has provided in different windows of time from the beginning of the event to observe the effectiveness of the energy injected by the battery at different points in time.

Table 4 – Bayswater – Energy released by the source of power in frequency disturbance

Energy Provided in Loss of Bayswater Unit	200 ms	500 ms	1000 ms	2000 ms
Wallgrove Grid Battery	0.098 MW.s	0.67 MW.s	1.53 MW.s	4.32 MW.s
Proportion of 2-second response	2.3%	15.5%	35.4%	100%
NSW Synchronous Machine	0.62 MW.s	5.36 MW.s	7.8 MW.s	12.7 MW.s
Proportion of 2-second response	4.9%	42.2%	61.4%	100%

5.1.4. Operational performance conclusions

(i) The immediate response from the battery, even before the frequency deviation commences (at the beginning of the windows marked 'A'), can be considered as evidence that the controller is following the ROCOF not the magnitude of frequency deviation, as intended by VMM's design.

(ii) Virtual machine mode operation shows faster response than standard grid following technology which aids grid operation in the event of frequency disturbance. However, the VMM installed at Wallgrove is slower in providing effective active power response in an event, relative to observations shared from synchronous generators over the first 2 seconds.

(iii) In multiple points of the frequency trend, the direction of active power is not as per ROCOF polarity. This can mean that the BESS controller may be attempting to satisfy both inertial response and absolute frequency deviation. Alternatively, this can be a sign that additional factors within the controller make the ROCOF and active power change fail to build a linear and predictable relationship, unlike a synchronous generator. As a result, if synthetic inertia from batteries is to replace the inertial response from the synchronous generator, care must be taken to understand all the non-linearities and conditions which the controllers may have embedded in.

5.2. Energy Market Participation

The major change through the period was the introduction of the new very fast FCAS contingency markets on 9 October 2023. Iberdrola Australia registered for both the raise and lower 1-second markets. As part of this registration process, Iberdrola Australia updated the existing droop settings of WGB to have tighter deadbands which allowed for 27MW of contingency FCAS to be registered across all 8 contingency FCAS markets (an increase of 1MW for all existing services).

When analysing performance, it should be noted that Iberdrola Australia considers how to use the WGB across the energy market and ten FCAS markets in the context of its generation portfolio and customer load requirements, and in the context of constraints on operation, such as the warrantied cycling limits and the requirement to reserve energy for synthetic inertia.

5.2.1. Performance in the new markets

The revenues earned by WGB throughout H2 2023 across the energy and FCAS markets are shown in Figure 9.

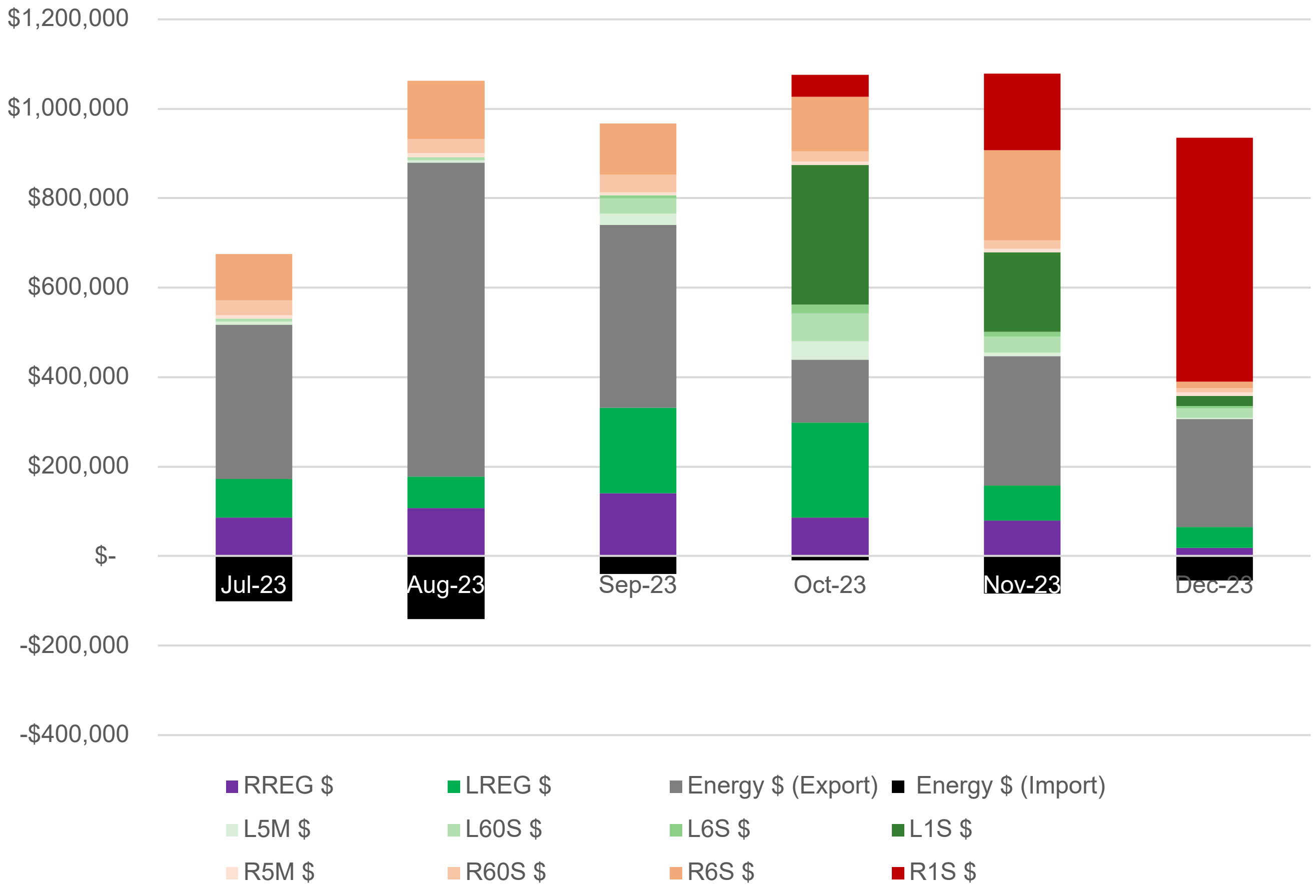


Figure 9 – Monthly revenue by service

This period included the first ~3 months of operations of the very fast contingency FCAS markets (established on 9 October 2023). During this period, AEMO has progressively increased the procured volume of very fast contingency FCAS in accordance with the schedule outlined in Table 5.

Table 5 – Very Fast FCAS procurement schedule

Date	Very Fast Raise (MW)	Very Fast Lower (MW)
9 October 2023	50	50
6 November 2023	100 (+50MW)	50
20 November 2023	150 (+50MW)	75 (+25MW)
4 December 2023	175 (+25MW)	100 (+25MW)
18 December 2023	225 (+50MW)	100
12 February 2024	225	125 (+25MW)
18 March 2024	250 (+25MW)	125
15 April 2024	325 (+75MW)	200 (+75MW)

The first three months of the new markets produced strong initial prices for Iberdrola Australia, with both WGB and Lake Bonney BESS registered to participate in these markets from the first day of implementation. The financial revenues earned from these markets are discussed further in Section 7 Financial Performance.

5.2.2. Cost of market entry

Participation in the new markets came with limited expense to WGB for implementation, with the BESS already capable of providing a fast response to frequency deviations outside of the Normal Operating Frequency Band. Costs for participation were limited to AEMO registration fees and the modelling works associated with proving the performance of the plant as part of the FCAS registration process.

5.3. 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).

Figure 10 demonstrates the relationship between the volatility in the energy market and the revenue generated, by profiling the 1.5hr spread against the amount of energy revenue realised by WGB.

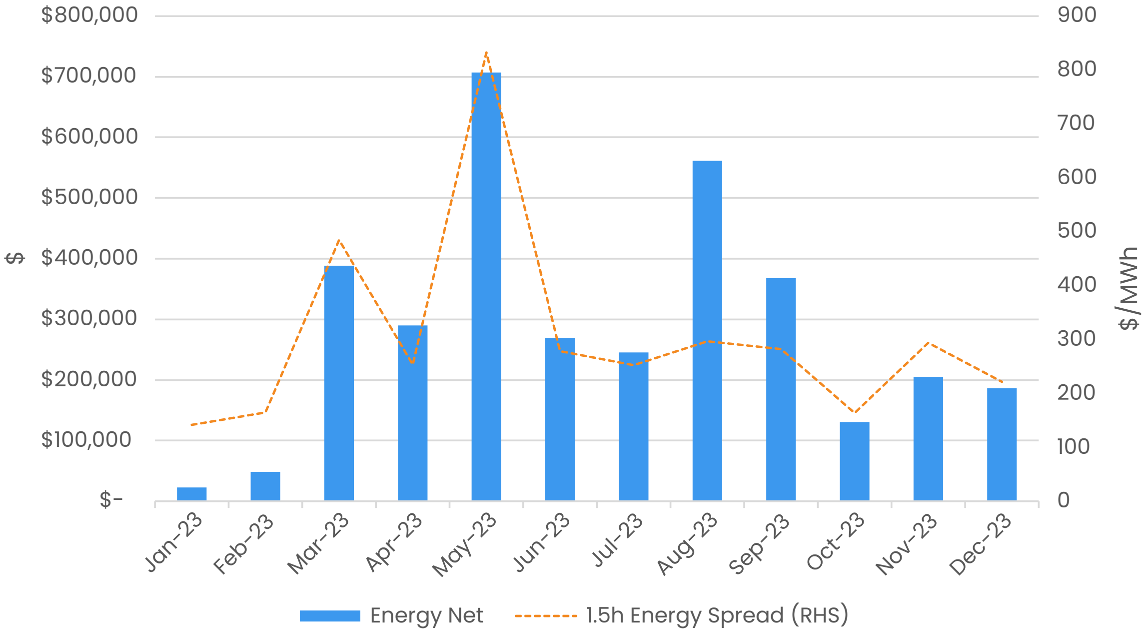


Figure 10 – Energy revenue and market volatility

While it is important to consider the broader context of bidding behaviour across the portfolio, there are a couple of obvious exceptions to the generally strong correlations between spread and energy revenue. These are in January and February 2023 when a comparatively smaller proportion of the intra-day energy spread opportunity was realised as revenue; and August and September, when a relatively larger proportion of energy revenue was realised considering the amount of volatility.

This can be explained through the consideration of several factors, including:

(i) Price Spread Dynamics: For August, which saw increased cycling above the energy price spread trend, this can be explained by assessing the average diurnal energy price. This highlighted that the arbitrage opportunity in August existed for both the morning and evening peaks in a more pronounced fashion, leading to the battery capturing energy arbitrage revenue twice a day on average. This relationship within the reporting period for August is shown in Figure 11, below.

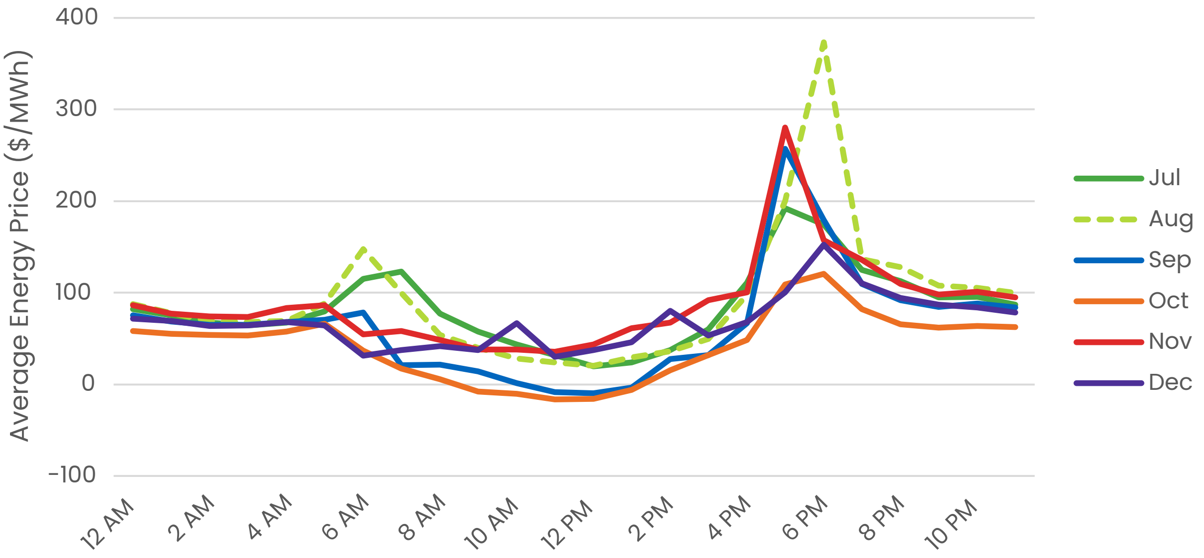


Figure 11 – Average daily energy price per month in H2 2023

(ii) Cycling of the battery: These variations in cycling can be reflective of a number of factors such as the availability of Iberdrola Australia's other operational assets, the comparative value of other markets and the price spread dynamics noted above. As is detailed further in Section 5.9 – Net energy revenue and equivalent full cycles, the WGB will cycle more or less than average over any given period of time (day, week, month, etc.).

(iii) Price Spread Requirement for Arbitrage: For January and February, which shows reduced cycling compared to the energy spread, it should be noted that if the energy spread becomes too low, the linear trend of the graph will no longer apply as the battery will be able to derive greater revenues in other markets in a more pronounced way as energy arbitrage becomes more marginal compared to available FCAS revenues.

5.4. Negative Price Opportunities

In H1 2023, 2.7% of all dispatch intervals (1,426) in the reporting period settled at a negative price, with the distribution of prices across a range of negative price bands shown in Table 3 below.

In H2 2023, that changed to 9.9% of all dispatch intervals (5,263) in the reporting period settling at a negative price, with the distribution of prices across a range of negative price bands shown in Table 3 below.

Table 6 – Negative price distributions in NSW region in 2023

	Price ($/MWh)	-1,000 to -500	-500 to -250	-250 to -100	-100 to -50	-50 to -25	-25 to 0
January – June 2023	DIs	11	1	2	303	625	484
	% of all DIs	0.02	0.00	0.00	0.58	1.20	0.93
July – December 2023	DIs	0	0	0	1,172	2,241	1,850
	% of all DIs	0	0	0	2.21	4.23	3.49

Charging through negative prices is one of the ways in which a battery can earn revenue, but capturing these prices needs to be considered against the overall arbitrage opportunity for energy revenue, and the co-optimisation of energy and FCAS enablement to maximise total revenue.

Notably, the number of negative price intervals in H2 2023 (5,263) was significantly higher than those seen in H1 2023 (1,426) and H2 2022 (2,974). The majority of these negative price intervals occurred during September and October (1,263 and 1,594 negative intervals respectively). In addition, the negative intervals are highly concentrated around 'shallow negative prices', with 87% of the negative price intervals within the distribution of prices ranging between -$100/MWh to -$50/MWh being above -$60/MWh.

These 'shallow' negative intervals are not seen to have a notable impact on the average energy spread seen in Figure 10, above – with the energy spread remaining relatively consistent throughout the entire year despite the ~270% increase in negative price intervals occurring. This again highlights that an increase in negative price occurrences do not guarantee an increase in arbitrage revenue even if the BESS is being paid to charge, with the volatility in the intra-day prices the key driver of arbitrage value.

5.5. Extreme Market Prices Capture Rates

The average energy response of the WGB during extreme energy price events within the reporting period is shown in Table 7.

Table 7 – Extreme price response for WGB in 2023

		# of periods	Average energy response (MW)
Q1 CY2023	DI above $1,000/MWh	20	9.91
	DI below -$500/MWh	9	0.00
Q2 CY2023	DI above $1,000/MWh	75	22.35
	DI below -$500/MWh	2	-34.00
Q3 CY2023	DI above $1,000/MWh	24	48.92
	DI below -$500/MWh	0	n/a
Q4 CY2023	DI above $1,000/MWh	18	20.43
	DI below -$500/MWh	0	n/a

The above results highlight the difficulty in assessing the revenue for a battery as a stand-alone asset instead of as part of an overall portfolio. The majority of high-priced intervals in Q1 2023 were missed due to the battery preferring to bid its generation capacity into the regulation raise FCAS market.

At the same time, renewable generation was covering the contracted position of our NSW portfolio, so the battery's state of charge was reserved from fully discharging into the energy markets during this period to ensure that it was available to discharge if the intermittent generation declined and the contracted position became uncovered.

During H2 2023, and particularly Q3 2023, the dispatch of the battery during periods of extreme energy price events was well aligned with expectations. This was due to the high-price events not occurring concurrently with comparably high FCAS prices, such that WGB could optimise revenue purely by discharging into the energy market. The reduction in average response in Q4 2023 is mainly due to the sporadic nature of a number of these energy price spikes, which would only occur for one interval at a time and were generally not forecast in the pre-dispatch prices.

5.6. Provision of Regulation FCAS

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. Up until the introduction of the very fast FCAS markets, whenever the WGB was fully enabled for contingency raise, 26MW of this nameplate discharge capacity would be reserved as headroom, leaving only 24MW for the provision of regulating raise FCAS and energy (in the same dispatch interval). However, since the re-registration of WGB to account for the new very fast contingency FCAS markets, its registered contingency FCAS response across all 8 markets was increased to 27MW.

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). Over the reporting period, fully enabling the WGB for contingency FCAS required either 26MW or 27MW (pre and post very fast contingency FCAS registration) of capacity in both directions. This means that whenever the WGB is providing the maximum possible amount of contingency FCAS, it can simultaneously provide:

Pre – Very Fast Contingency FCAS Registration

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

Post – Very Fast Contingency FCAS Registration

- 50MW nameplate discharge capacity – 27MW required for cFCAS = 23MW of regulating raise
- 47MW nameplate charge capacity – 27MW required for cFCAS = 20MW of regulating lower

In all, the regulation FCAS enablement levels are reported across six categories, which reflect the provision of co-optimised services across regulation and contingency FCAS as well as energy.

WGB's enablement in the raise and lower regulation FCAS markets during the reporting period is shown in Figure 12 and Figure 13 for periods before and after the commencement of the very fast contingency FCAS market (9 October 2023).

Table 8 – Regulation FCAS enablement breakdown

Pre-Oct 9 MW	0	0	1-23	1-20	24	21	25-49	22-46	50	47	>50	>47
Post-Oct 9 MW	0	0	1-22	1-19	23	20	24-49	21-46	50	47	>50	>47
Category	No enablement		>0MW and <(NP Cap – CFCAS)		NP Cap – cFCAS		>(NP Cap – cFCAS) <NP Cap		NP Cap		>NP Cap	
Indication	Battery is idle or being used exclusively for energy or contingency FCAS		Some regulation is provided but contingency can be maximised and energy can be provided		Regulation FCAS has no impact on contingency		Regulation FCAS is being prioritised and is reducing the amount of contingency FCAS provided		Only providing regulation FCAS		Providing regulation FCAS and energy in the opposite direction	

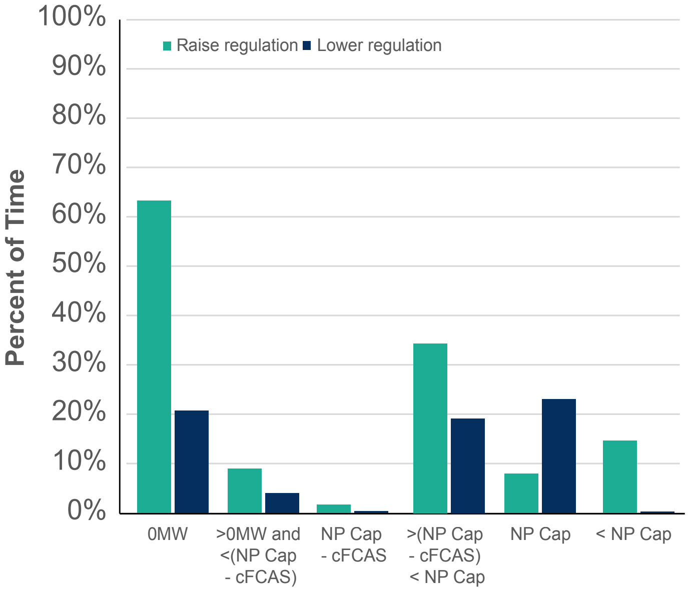


Figure 12 – Regulation FCAS market enablement pre 9 Oct

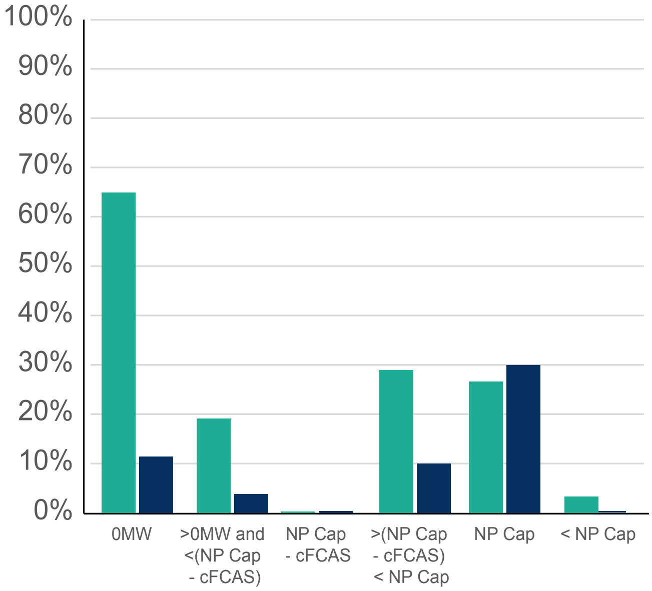


Figure 13 – Regulation FCAS market enablement post 9 Oct

Enablements above the NP Cap – cFCAS category are generally driven by the relative values of the comparable raise or lower contingency FCAS markets, and not caused by any interactions of the raise and lower regulation services against each other. As a general rule, if contingency FCAS markets have a higher economic value (factoring the impact of cycling attributable to each service), regulation FCAS enablement will decrease, with increases in regulation FCAS enablement expected when contingency FCAS has a lower economic value.

Additionally, enablement at and below the NP Cap – cFCAS category is generally driven by the relative values of the regulation FCAS and energy markets, where if the energy markets have a higher economic value, the BESS will prioritise dispatch (and cycling of the BESS) in the energy market over the regulation FCAS markets.

The results shown in Figures 12 and 13 align with Iberdrola Australia's expectations, with the following characteristics seen when comparing regulation FCAS enablement pre- and post- the establishment of the very fast contingency FCAS markets:

- Non-enablement of regulation FCAS pre- and post- establishment was consistent across both the raise and lower markets;
- Enablement of regulation FCAS <NP Cap – cFCAS level was seen to shift towards the NP Cap – cFCAS enablement post- establishment, which was more related to a shift in the comparable value of the energy and regulation FCAS markets (with more energy revenue seen in Q3 2023);
- Lower regulation FCAS enablement at the NP Cap level was seen to reduce as the lower contingency FCAS partial and full enablement levels were seen to increase across all of these markets.

5.7. Provision of Contingency FCAS

WGB's enablement in the raise and lower contingency FCAS markets during the reporting period is shown in Figure 14 and Figure 15 for periods before and after the commencement of the very fast contingency FCAS market (9th October 2023).

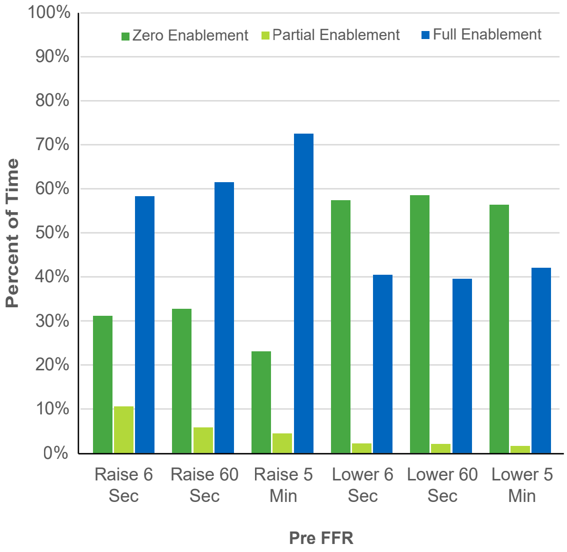


Figure 14 – Contingency FCAS market enablement pre FFR

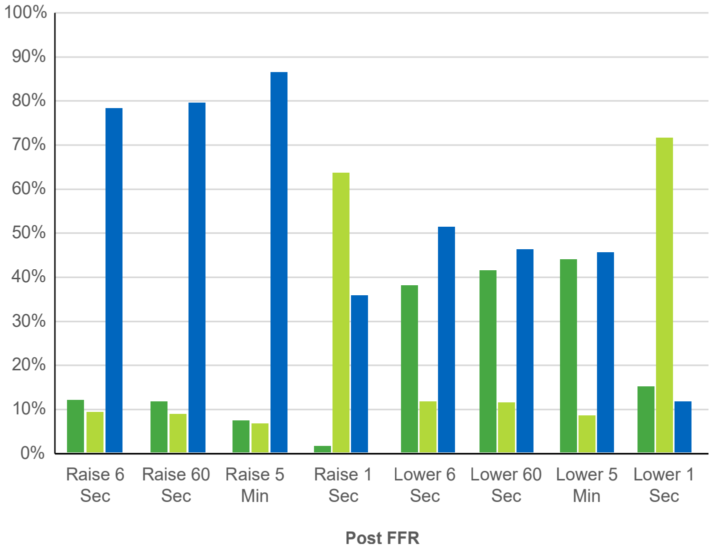


Figure 15 – Contingency FCAS market enablement post FFR

Similar to the regulation FCAS enablement distributions, the contingency FCAS enablements seen in Figures 14 and 15 are generally in line with expectations and the previous operations of the WGB.

Notable changes in line with other trends seen within this reporting period for contingency FCAS enablement include:

- A strong increase in contingency FCAS enablement across both the raise and lower markets from pre- to post- establishment, coinciding with the reduced energy market revenue opportunities seen in Q4 2023 compared to Q3 2023;
- A significant portion of the very fast contingency FCAS enablement for both raise and lower services was seen to be partial enablement, which is related to the relatively small market size of these services, even when compared to the other contingency FCAS markets.

Historically, the WGB was able to provide different levels of enablement for contingency FCAS services between the fast (6s), slow (60s) and delayed (5min) markets, due to the fast response that a battery can provide, allowing for a higher value to be registered for the fast response above the physical response that the battery provides.

However, the specifications for contingency FCAS registration with AEMO standardised to 27MW for all markets following the implementation of the Very Fast Contingency FCAS markets as part of the overall rule changes to accommodate these new markets.

5.8. Contingency FCAS enablement during extreme FCAS price events

Table 9 – The average market enablement of WGB during extreme FCAS price events.

	DIs above $1,000/MW/h	**Average Enablement (% of registered capacity)**
Raise 6 Seconds	7	14%
Raise 60 Seconds	0	n/a
Raise 5 Minutes	0	n/a
Raise Regulation	2	0
Lower 6 Seconds	0	n/a
Lower 60 Seconds	0	n/a
Lower 5 Minutes	0	n/a
Lower Regulation	0	n/a
Raise 1 Second	0	n/a
Lower 1 Second	0	n/a

As shown in Table 9, there was limited volatility in the FCAS markets in general – with the FCAS volatility seen in both the Raise 6 Seconds and Raise Regulation markets coinciding with extreme energy price events, with energy dispatch prioritised in these scenarios. A single high-price interval in Raise 6 Seconds occurred when energy prices were of lower value, and WGB was fully enabled for this service during the dispatch interval.

5.9. Net energy revenue and equivalent full cycles

A key consideration in battery operations is managing the cycling constraints. Through the course of 2023, WGB discharged an aggregate of ~20,000MWh of energy, equivalent to ~270 full cycles of the nameplate storage capacity of WGB.

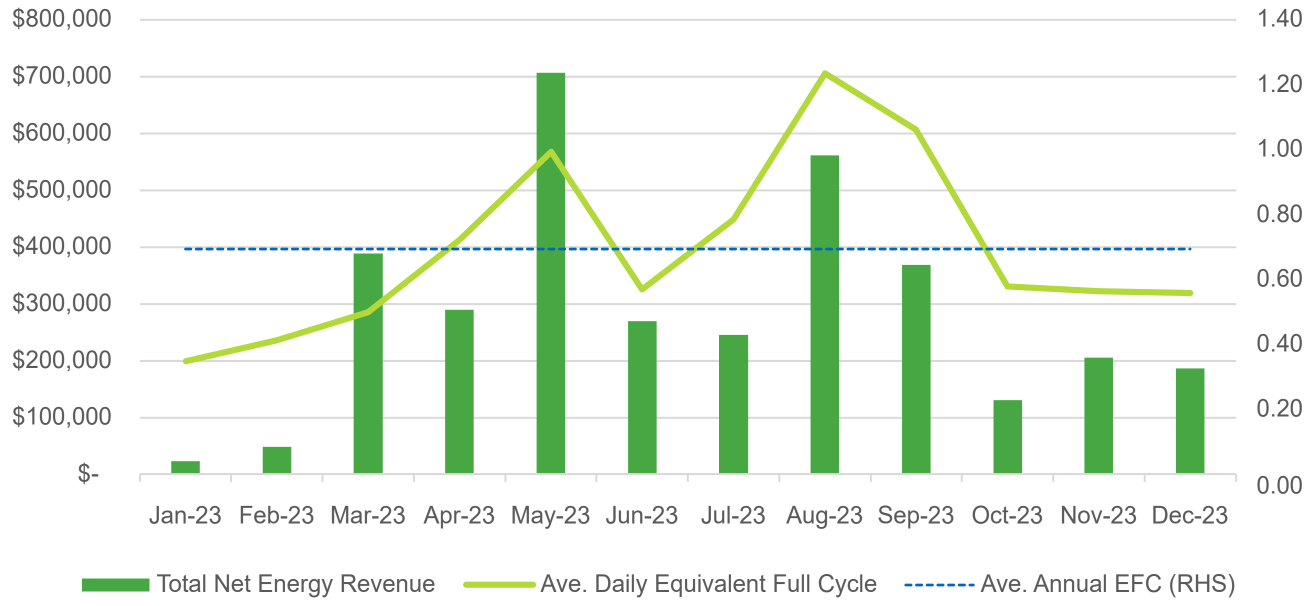


Figure 16 – Net energy revenue and equivalent full cycles

The cycling of WGB throughout 2023 was in line with Iberdrola Australia's expectations, with the completed number of cycles within the limits of the WGB cumulative cycle threshold to ensure storage degradation warranty limits are applicable. Variations in cycling over the year are typically driven by changes in energy market arbitrage dynamics, regulation FCAS market opportunities and general market volatility (which allows for increased revenues relative to the number of cycles incurred).

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 its operation is shown in Table 10, though it should be noted that these results are not the outcome of a specific test for RTE, and are instead a general outcome that is impacted by operational realities. When the battery is notionally idle, it will continue to use energy for site services such as cooling, lighting and communications, meaning that periods of underutilisation will skew the RTE results negatively.

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.

Table 10 – Round trip efficiency performance

Operational period	Round trip efficiency at 132kV transmission network connection point (%)
1 January 2022 to 30 June 2022	83.6%
1 July to 31 December 2022	81.7%
1 January to 30 June 2023	78.4%
1 July to 31 December 2023	81.9%

6.2 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.

An annual discharge test was not performed at the end of the second year, as both Lumea and Iberdrola were satisfied that the BESS capacity remained above the warranted minimum energy retention.

6.3 Auxiliary Power Usage

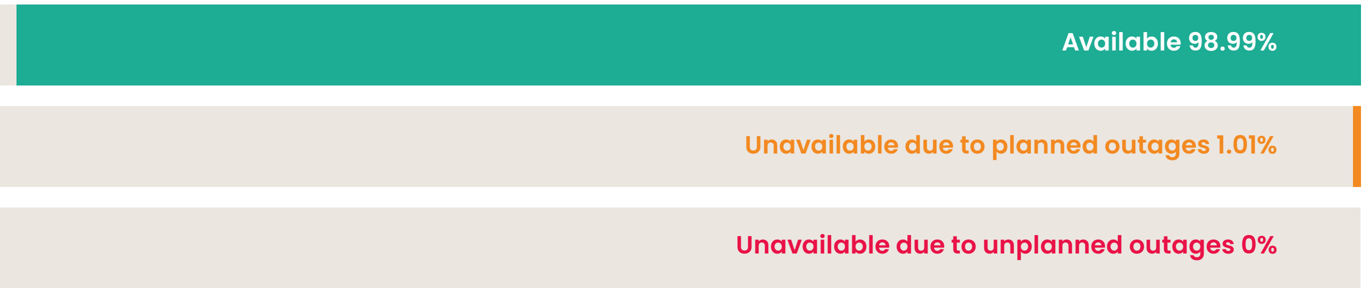
Auxiliary power usage is estimated to be 8.0kVA from observations of the auxiliary power distribution board meters over a one-hour period. The measurements were taken during the day and therefore do not account for yard lighting.

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.

6.4 Availability

1 July 2023 to 31 December 2023 and the different elements of the chart to 98.99% available, 1.01% planned outage, and 0% unplanned:



6.4.1 Planned Outages

Table 10 – Planned outages

Planned outage date	Works occurred
7-11 August 2023	Megapack maintenance works, cable partial discharge testing and IDS meter testing
27-28 September 2023	Control and SCADA works

6.4.2 Unplanned Outages

No unplanned outages in the period.

7. Financial Performance

7.1 Market Revenue

The market revenues for WGB in its first two years of operation are outlined in Figure 17.

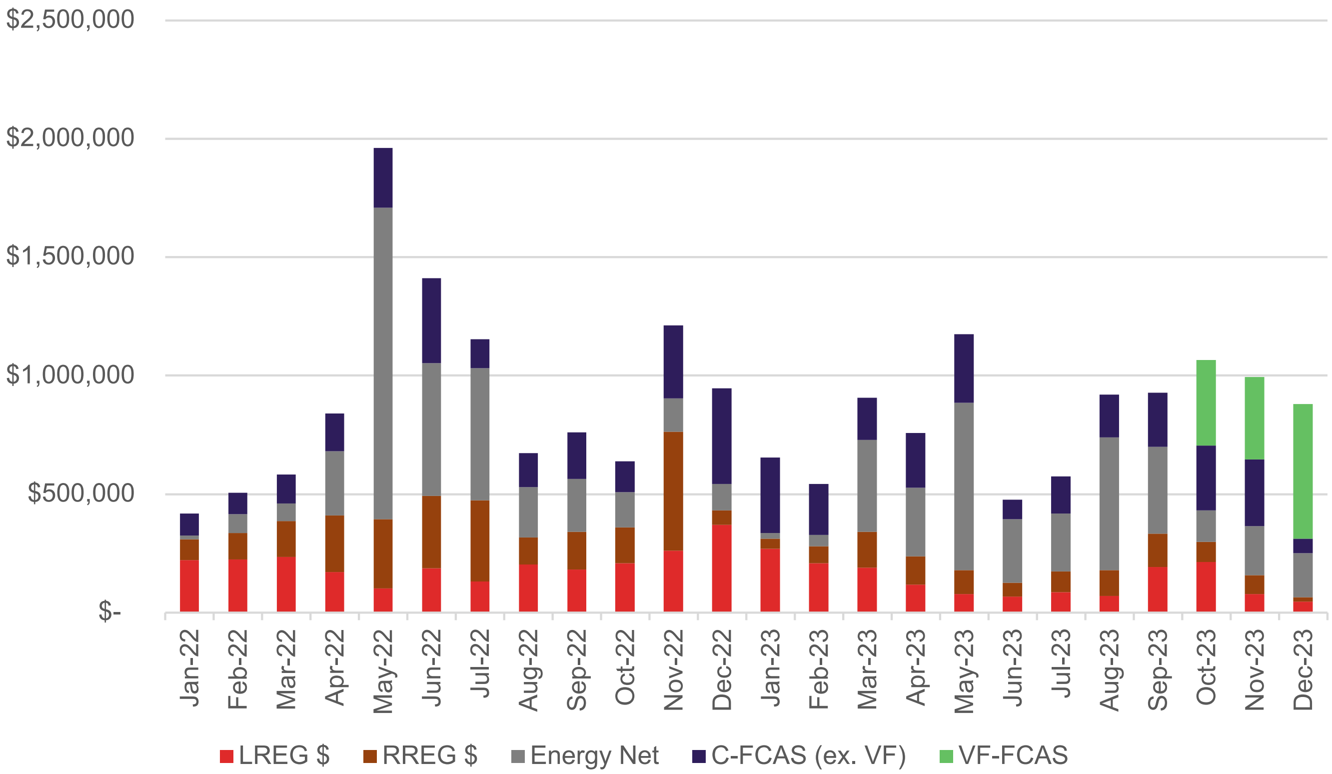


Figure 17 – Monthly revenue by market

Key points of interest in the performance over the first two years of operation are:

- Capturing revenue in periods of increased market volatility is crucial to the overall financial performance of BESS projects, with large amounts of revenue available across short timeframes.
  - This in turn highlights the importance of ensuring that a battery is flexible enough to operate with a higher capacity factor during these volatile periods (e.g. no daily cycle limits) and has a high system availability (given that these events may occur at unpredictable times based on external shocks to the market).
- Generally, higher revenue opportunities have been seen to occur during the shoulder periods in the electricity market (outside of Summer and Winter periods) where thermal generators are traditionally taken offline for maintenance works.
  - Similarly, there have been limited revenue opportunities seen in the first two years of operations for WGB during the Summer quarter (January to March) with comparably mild summer conditions experienced in these two years.
- Flexibility in the BESS to participate in new markets from their implementation is key to capturing any initial market opportunities, as seen with the revenues earned in the first few months of the very fast contingency FCAS markets.

7.2. Market revenue by application

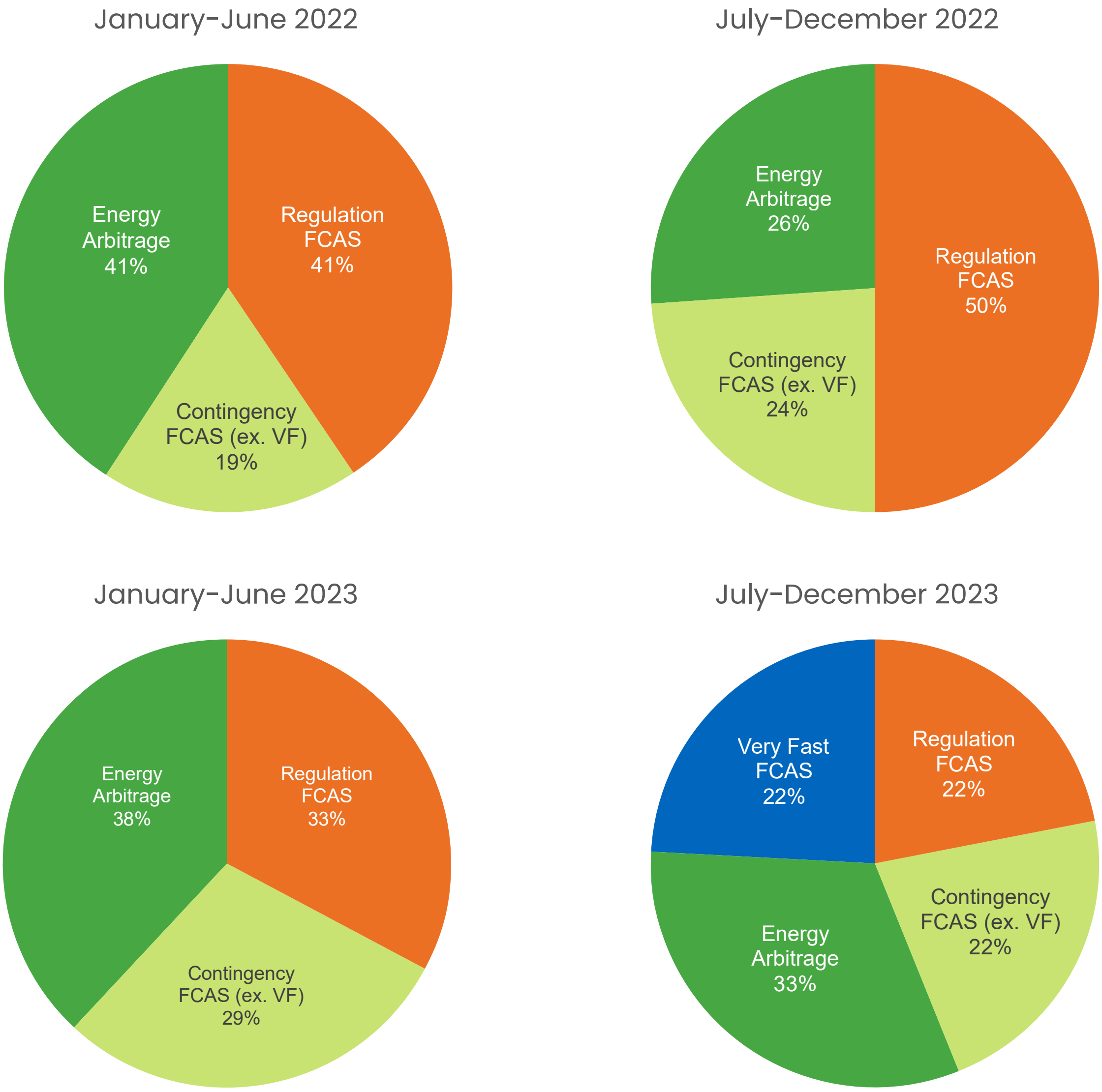


Figure 18 – Proportions of revenue contribution over the first two years of the project

Analysis of the four operational periods comprising Figure 18 demonstrates that proportionally the regulation FCAS revenue share is declining. This decrease in regulation FCAS market revenues, as shown in Table 12, ties back to increased energy price spreads around the NEM market suspension in June 2022. While the composition is volatile, the aggregate revenues earned across all markets were relatively stable through the first two years of operation.

Table 12 – Revenue contributions over the first two years of the project.

Service ($m)	**January – June 2022**	**July – December 2022**	**January – June 2023**	**July – December 2023**
Contingency FCAS Very Fast FCAS	1.1	1.3	1.3	1.2 13
Regulation FCAS	2.3	2.7	1.5	1.2
Energy	2.3	1.4	1.7	1.7
Total	**5.7**	**5.4**	**4.5**	**5.4**

7.3. Marginal Loss Factors

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 is reflected in the historic MLFs determined for financial years 2022, 2023 and 2024 shown in Table 13.

Table 13 – MLF values for the Wallgrove Grid Battery

Financial Year	WALGRVG1 (generator)	WALGRVL1 (load)
2021-2022	1.0011	1.0010
2022-2023	1.0010	1.0009
2023-2024	1.0010	1.0009

7.4. Data Sources

The revenue figures shown 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.

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/

8. Safety and Environmental Performance

There have been no safety or environmental incidents in the first 24 months of operations.

Approximately 543 work hours occurred on site during the reporting period.

Table 14 – Work hours on site

Operational period	Approximate work hours onsite
1 January 2022 – 30 June 2022	1,040
1 July 2022 – 31 December 2022	1,214
1 January 2023 – 30 June 2023	1,414
1 July 2023 – 31 December 2023	543

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