Transgrid | Lumea

# Operations Report #3

## 2020/ARP013 Transgrid Wallgrove Grid Battery

**January to June 2023**

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The purpose of this document (Report) is to provide a summary of the third six-month period of operation of the Wallgrove Grid Battery. For simplicity and readability, rather than use the precise third six-month period of operation, the report covers the period from 1 January to 30 June 2023.

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# 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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# Contents.

# 1. Acronyms

| | |
|---|---|
| **AEMC** | Australian Energy Market Commission |
| **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 |
| **GPS** | Generator performance standards |
| **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 |
| **POD** | Power Oscillation Damper |
| **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 |
| **Syncon** | Synchronous Condenser |
| **TNSP** | Transmission network service provider |
| **UPS** | Uninterruptible power supply |
| **UTC** | Coordinated Universal Time |
| **VMM** | Virtual Machine Mode |
| **WGB** | Wallgrove Grid Battery |

*This Report summarises the operations of the Wallgrove Grid Battery (WGB) from 1 January 2023 to 30 June 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 1,414 work hours occurred onsite during the third six-month period of operations. There were no safety or environmental issues onsite.

This was the first 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. While initial results are included in this Report, the full findings will be released in early 2024.

The commercial operation of the WGB aligned with Iberdrola Australia's experience operating the Lake Bonney BESS in South Australia. A clear progression toward energy revenue and away from regulation FCAS was evident, with the WGB deriving 38 percent of its revenue in the energy market, up from 26 percent in the previous period.

The availability of the battery fell significantly through the period, through a number of unplanned outages.

*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 third 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. 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 |
| **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<br>SRG meeting #2 19/10/2021<br>SRG meeting #3 10/11/2022<br>SRG meeting #4 14/06/2023 |
| **Attendance at webinar or workshop** | ARENA smart inverters webinar participation / presentation 27/05/2021<br>Presentation in ARENA grid forming / advanced inverters webinar 09/08/2022 |
| **Project website** | Accessible via:<br>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 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

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

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

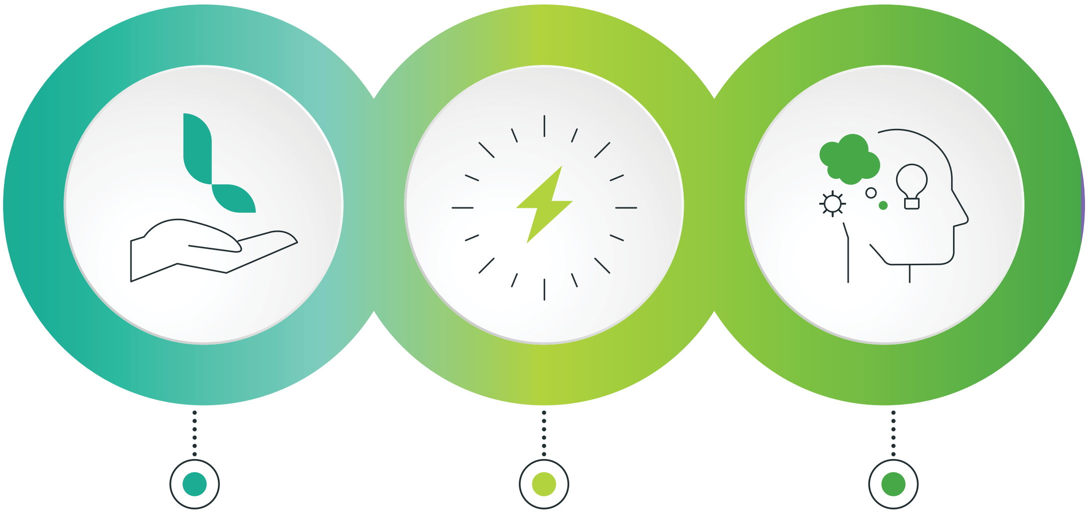
The trial will provide valuable technical information about the actual operation of the WGB, including how often it will be needed for fast frequency response and how much electricity it is able to store and dispatch under different conditions, relative to commercial demands.

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 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. VMM was enabled on 23 November 2022.

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.<br><br>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).<br><br>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.<br><br>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;<br><br>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<br><br>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<br><br>Assist in the operation of a low emissions NSW electricity system by firming Iberdrola Australia's variable renewable energy output from their portfolio<br><br>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 | 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<br>9 x 33/0.518/0.518kV coupling transformers<br>ABB SafePlus gas-insulated compact switchgear<br>500kVA 33/0.400kV auxiliary transformer<br>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:**<br>NTTTW0ZQ90 for Import B1 (Generation)<br>NTTTW0ZQ91 for export E1 (Consumption)<br>**Wallgrove Battery 132kV Check**<br>NTTTW0ZQ95 |

*Table 2 – Key technical parameters*

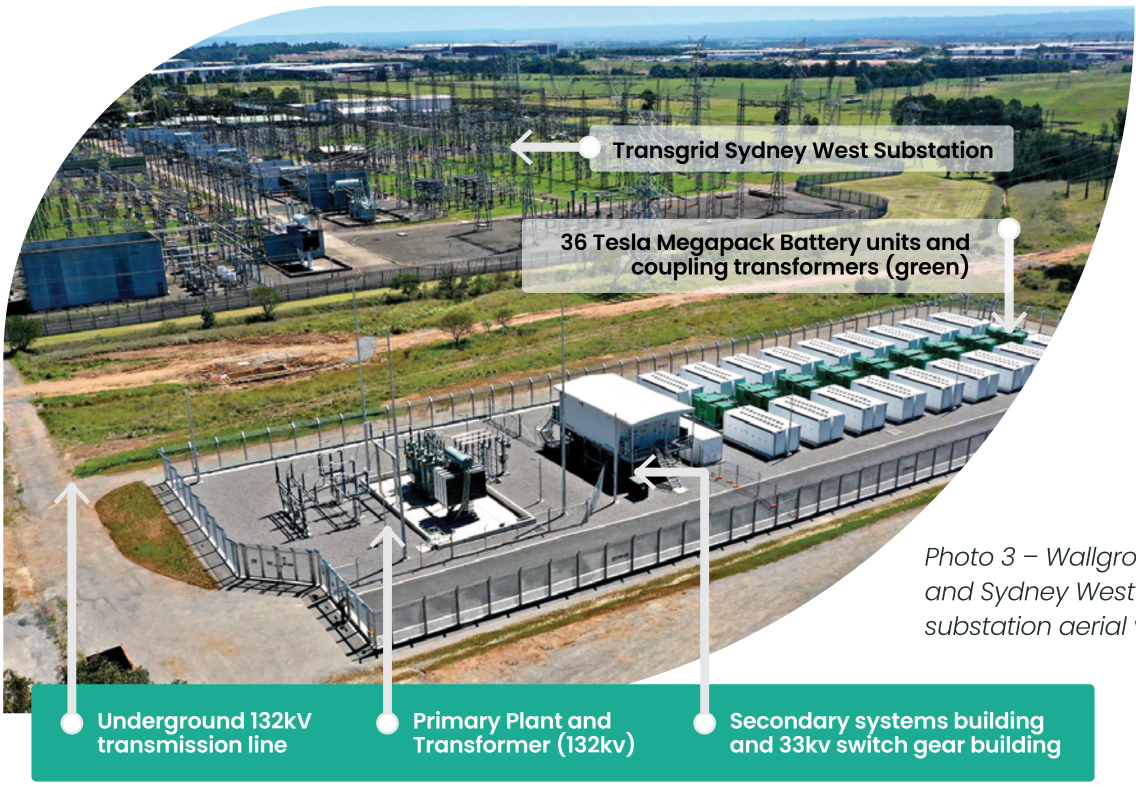



*Photo 3 – Wallgrove Grid battery and Sydney West 330/132kV substation aerial view*

Challenges in the VMM implementation process were highlighted in Operations Report #2, along with the settings that were registered. While the approval process ultimately resulted in a successful registration, the challenges encountered support ongoing efforts to continue to develop the rules for asynchronous generators emulating the behaviour of synchronous generators.

## 5.1. Performance during system disturbance

In this section of the report, the response of the WGB in three frequency events are presented and discussed. When a generator trips, the frequency drops, and the synthetic inertia should mean the WGB responds with a spike in power output to stabilise the frequency.

### 5.1.1. Event 1 - Loss of Mt Piper Unit 2

On 14 January 2023 at 19:45, Mt Piper Unit 2 synchronous generator tripped at 610MW resulting in a reduction of frequency to 49.792Hz measured by the Wallgrove power quality meter at the 132kV bus. The highest rate of change of frequency (ROCOF) for this event was estimated to be approximately –0.1325Hz/s.

The overlay of active power and frequency is provided in Figure 1 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 estimated that approximately 39MWs was released by the battery in the window denoted A (~4.78 seconds). Within this window of data, the response from the battery has three main frequency inclining phases (indicated by three arrows) between which the ROCOF has slightly changed and as a result the active power injection has been adjusted. The first phase of the BESS response occurs between 4 and 6 seconds corresponding to arrow B. In that part of the response ROCOF is calculated to be approximately -0.1 to -0.11Hz/s. The inertial energy released from the WGB to the grid is 1.46202MWs within the 1.16 seconds in which the BESS initiated the response from 0MW to the point that it returned to 0MW again, which covers the very first peak at around 5 seconds on the x axis. The response mainly corresponds to the inertial response of the battery and, as can be seen in Figure 2, the back calculated Δf-P ratio does not match with the rest of the data window. Once the active power initial response comes back down to almost pre-disturbance at around t~6 seconds, there is a second increase in active power which is more significant than the first response. In this phase, represented by arrows C and D, and with a consistent Δf-P ratio shown in Figure 2 from halfway along the x axis, the response from the BESS is assumed to be fast frequency response (FFR) because of the aggressive droop settings relative to primary frequency response (PFR).

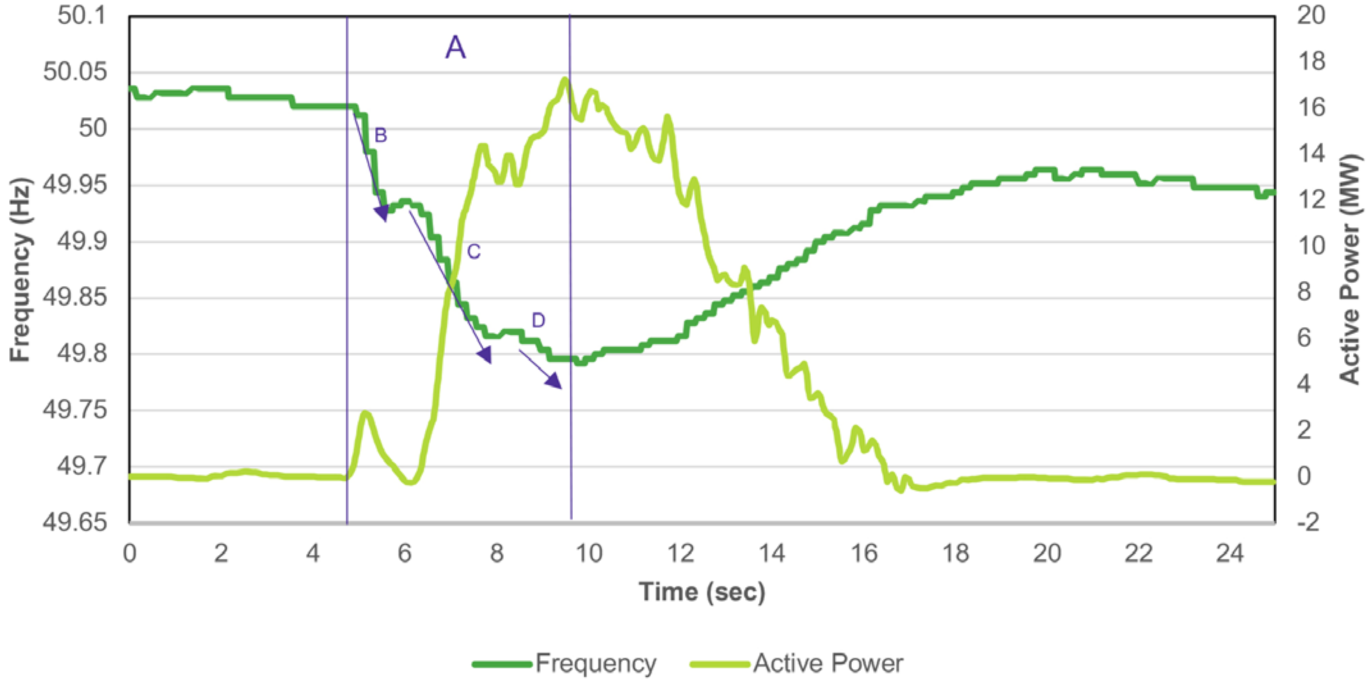



*Figure 1 - Event 1 - Active power and frequency overlay*

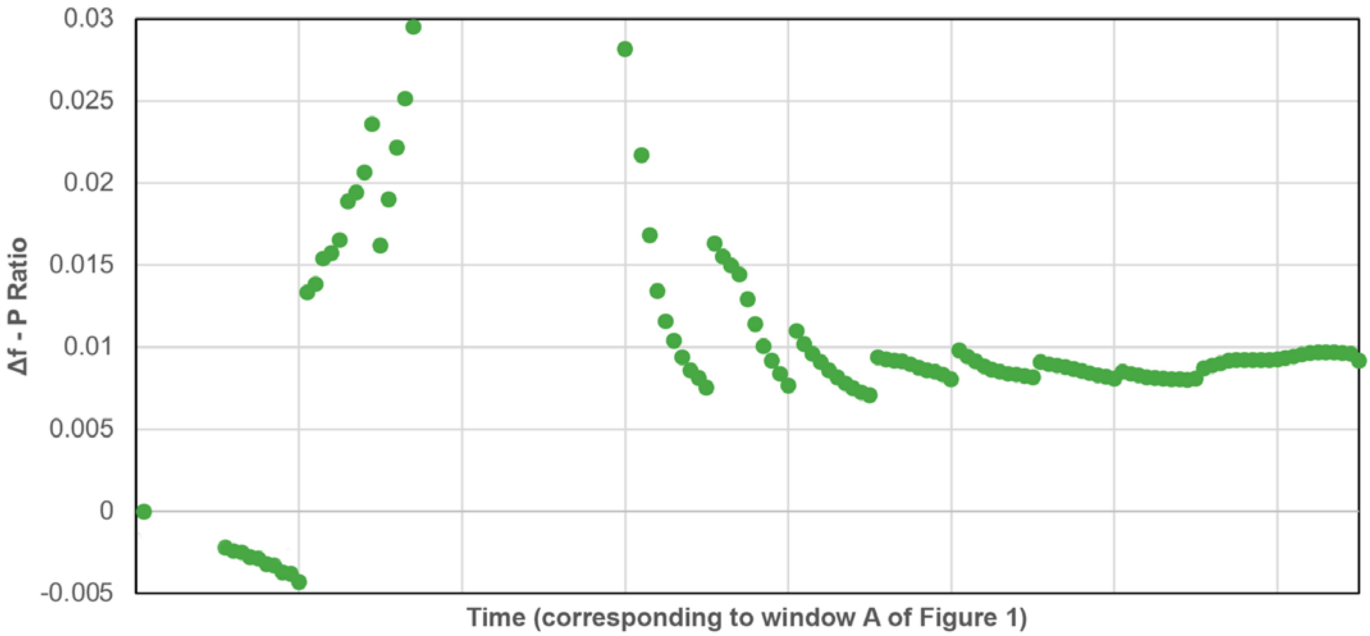



*Figure 2 – Event 1 – Δf-P calculation (each point corresponds to 20 ms)*

### 5.1.2. Event 2 - Loss of Eraring Unit 1

On 2 February 2023 at 10:40, Eraring 1 synchronous generator tripped at 660MW resulting in frequency going down to 49.777Hz measured by the Wallgrove power quality meter at the 132kV bus. The highest ROCOF for this event has been calculated to be approximately –0.2288Hz/s.

The response from the WGB appears to include an initial smaller phase and a larger phase which reaches its peak value at the end of window A in Figure 3. In the window A data, the inertial energy released to the grid is approximately 18.85MWs. 2.08MWs energy release of the response corresponds to the initial part of the response which is represented by point B. In this window, the response from the battery corresponds to the inertial response and after ~5 seconds, the response is in-line with the fast frequency response with the indicated constant Δf-P evident in Figure 4.

The consistent observation across events 1 and 2 is that the fast frequency response from the battery is more dominant than the inertial response. Subsequent reporting will communicate findings on the impact of the selected VMM parameters on this observation.

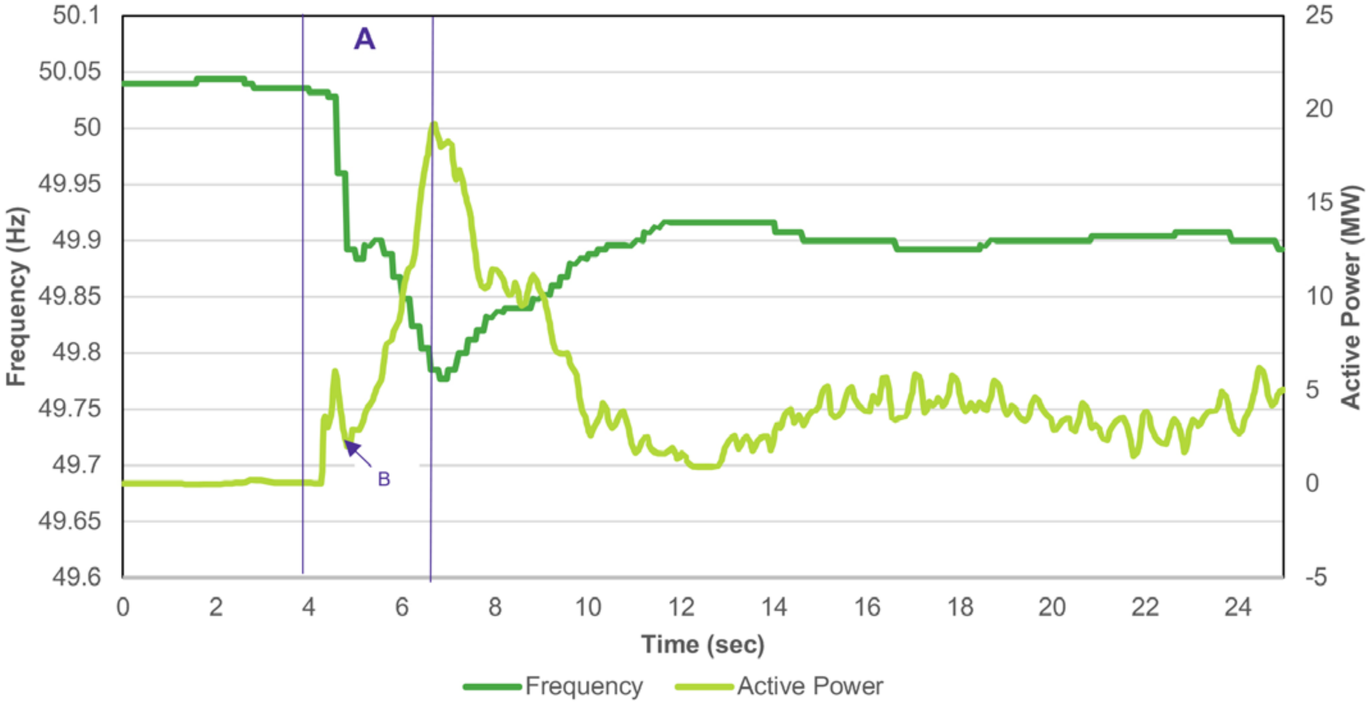



*Figure 3 – Event 2 - Active Power and Frequency overlay*

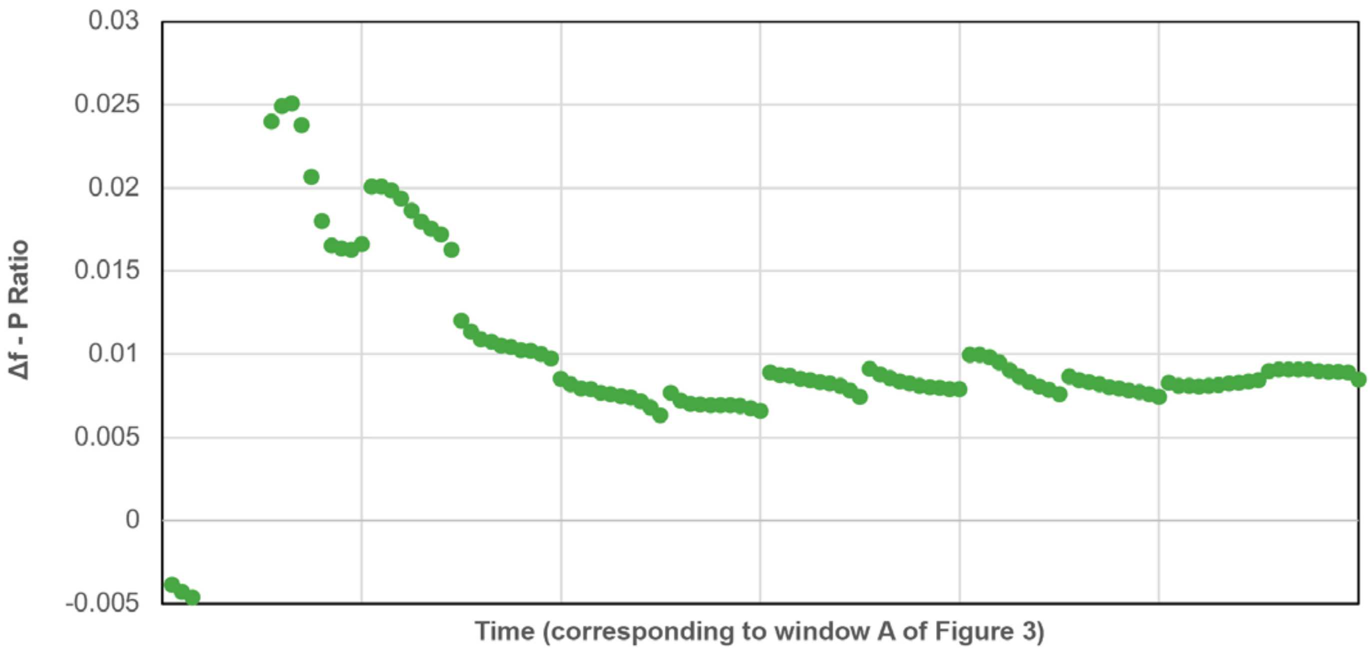



*Figure 4 – Event 2 – Δf-P calculation (each point corresponds to 20 ms)*

### 5.1.3. Event 3 - Loss of Kogan Creek

On 12 June 2023 at 12:33, Kogan Creek synchronous generator unit tripped at 759MW resulting in frequency going down to approximately 49.77Hz measured by the Wallgrove power quality meter at the 132kV bus. The highest ROCOF for this event has been estimated to be approximately –0.17Hz/s.

In window A in Figure 5, the WGB has released approximately 48.92MWs of energy to the grid of which a small portion of it, 1.41MWs, refers to the inertial response at around the 2 second mark. Beyond this point, the response is consistent with the P-f ratio observed in other events as seen in Figure 6 from data sample 60 onwards.

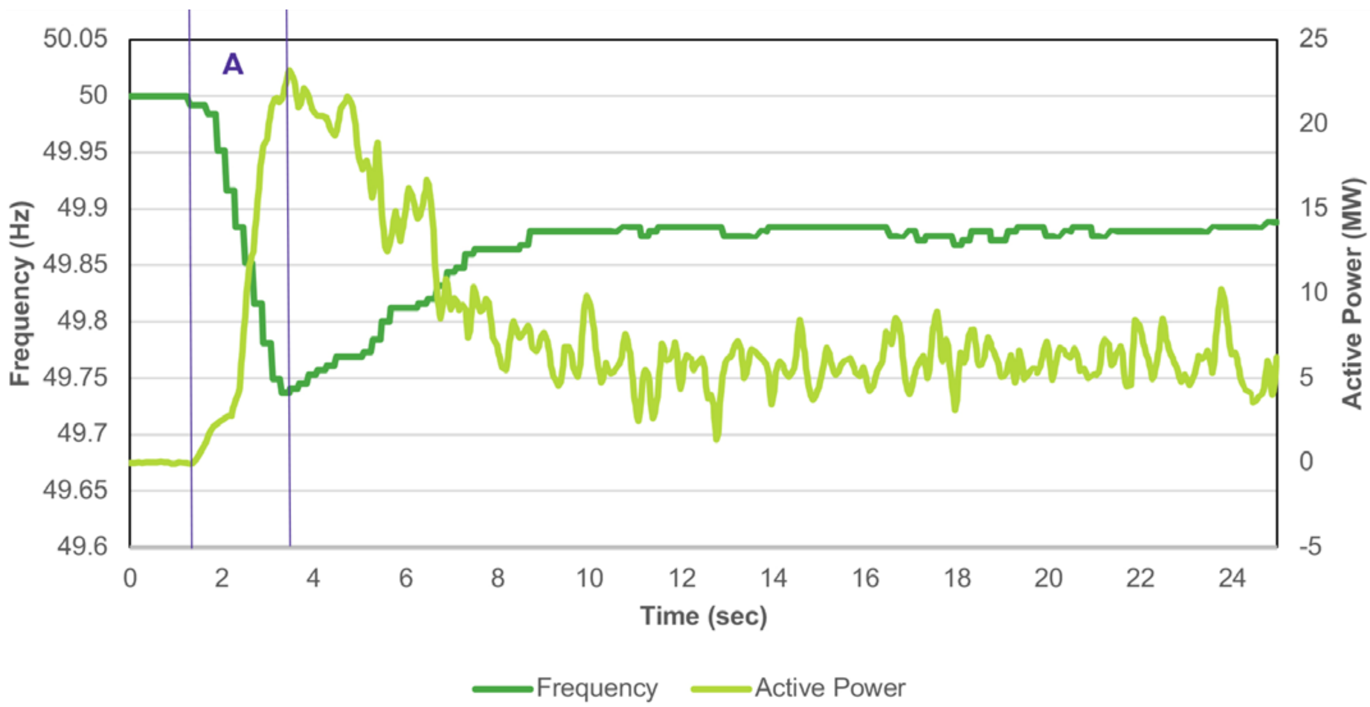



*Figure 5 – Event 3 – Active Power and Frequency Overlay*

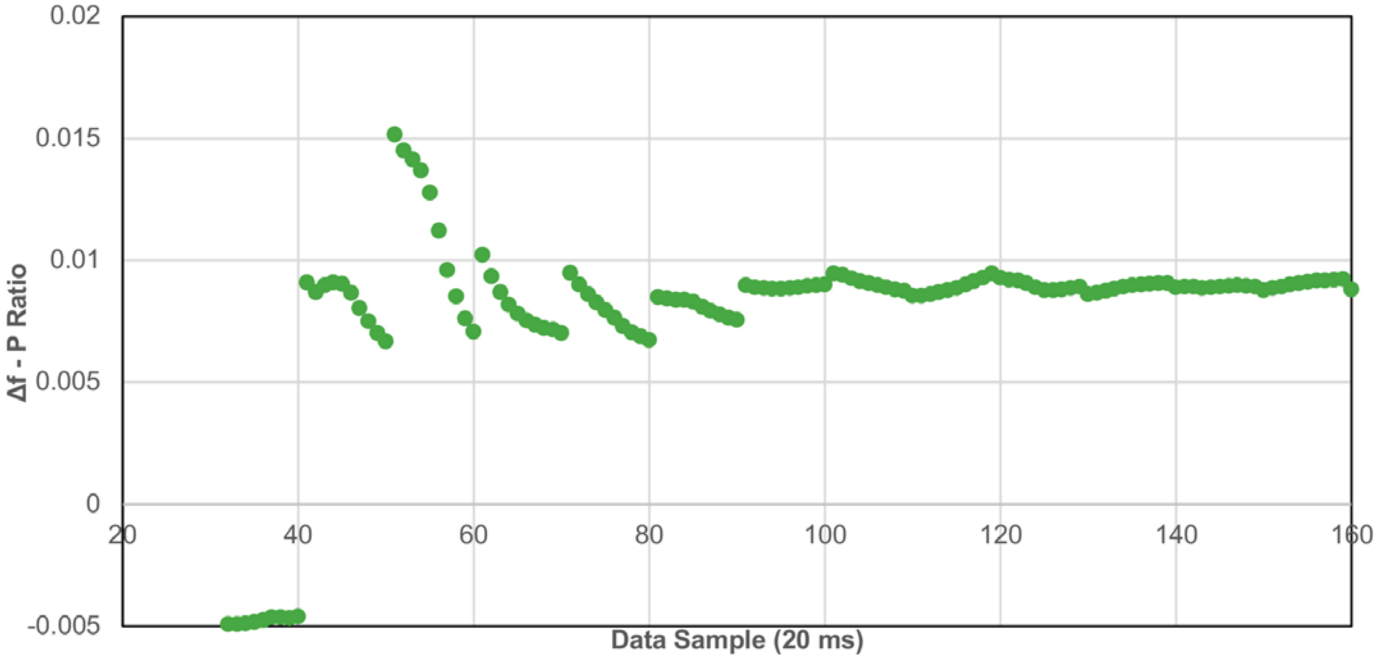



*Figure 6 – Event 3 – Δf-P Ratio Distribution from ~2-~5.2 seconds*

### 5.1.4. Pre-Post Virtual Machine Mode Enablement Comparison

While it is difficult to find a system frequency event with the exact same depth and characteristics, this section compares two responses from before and after enablement of VMM. Figure 7 compares the response between the event on 12 Sep 2022 and Event 3 discussed in section 5.1.3.

Figure 7 shows that when VMM is enabled, the response, though minor, is immediate to the ROCOF. While the battery responded to frequency events before VMM was enabled, the response commenced around 600ms after the initiation of the event. It should also be noted that the frequency control deadband in the event with VMM was in fact less sensitive than the scenario without VMM.

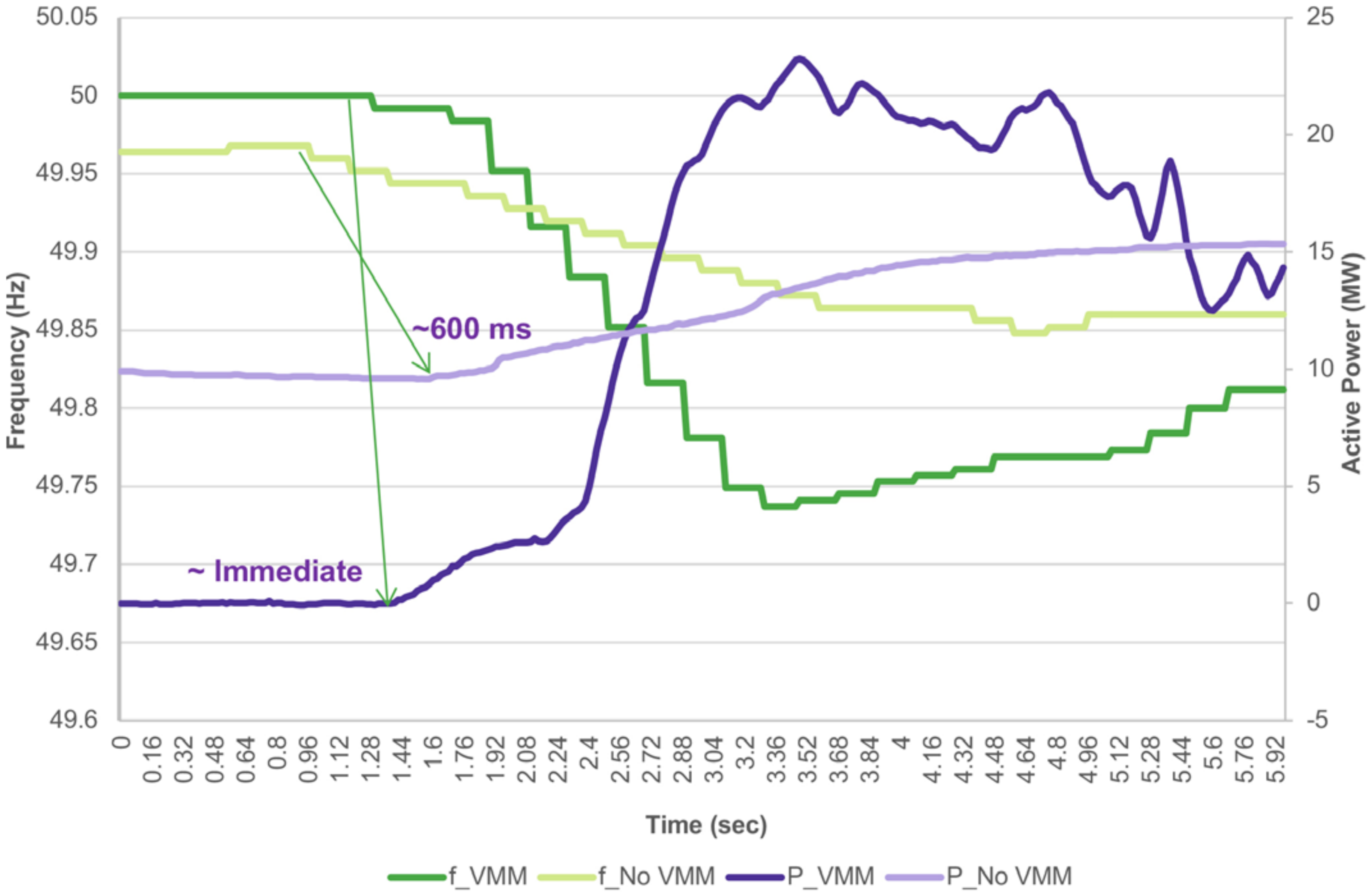



*Figure 7 – Active Power Response time to Frequency Pre-Post VMM enablement*

### 5.1.5. Conclusions

Observation and analysis is ongoing and subsequent technical reports will draw further conclusions on the performance of VMM as an inertia substitute and the relationship between the tuned parameters of VMM and the inertial response. It must be noted that the inertial response is not only a function of the inertial constant (unlike an actual synchronous generator), as other tuned parameters may be impacting the inertial response. Initial conclusions include:

1. The WGB's response to a frequency incident is dominated by the fast frequency response while it has some inertial response at the beginning of the disturbance.
2. Virtual machine mode shows much faster response than standard grid following technology.
3. As the virtual inertial response is provided by the control system of the battery, the inertial response can be affected by the control structure and filter tunings. This means that conclusions on virtual inertia response cannot be drawn exclusively from one specific model within one technology.

## 5.2. Synchronous condensers

Transgrid has also investigated the inertial responses from Synchronous Condenser (Syncon) technology, and it has been observed that Syncons, depending on their selected inertia are capable of providing the same inertial responses as synchronous generators. It should be noted that, once the inertial response of a Syncon is settled, there is no further energy that can be provided, unlike synchronous generators or BESS. An example of inertial response from one of Transgrid's Syncons is provided below in Figure 7. In this study, frequency of the network changes nearly 1.5Hz up and down. It is observed that the simulated Syncon has reached the peaks (points A and B in Figure 7) of its inertial response which is approximately 200MW within 230 ms from each step of the frequency change.

It must be noted that should the Syncon not have appropriate flywheel installed, the post disturbance oscillations may be larger than what batteries will generate as there is more flexibility in battery power electronics for controlling the active power than in a Syncon with no Power Oscillation Damper (POD).

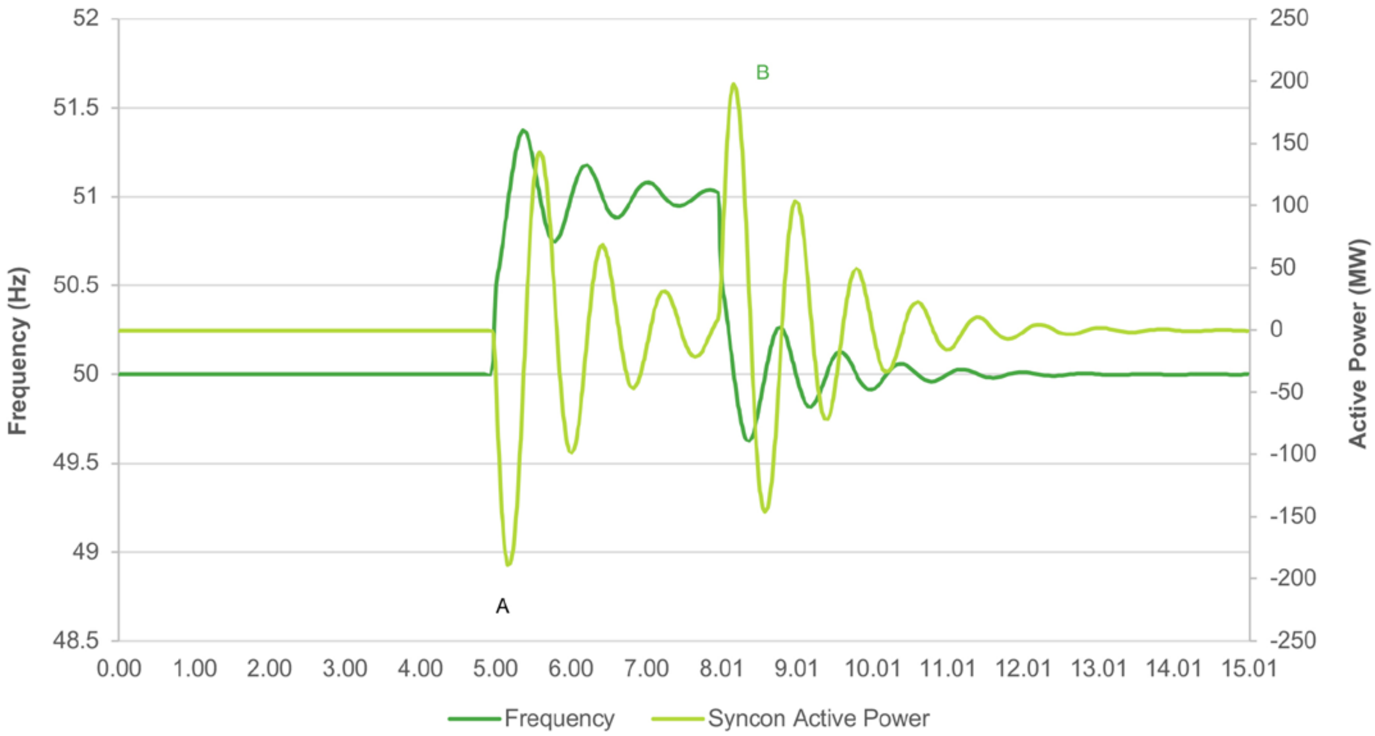



*Figure 8 – Synchronous condenser response (active power to frequency change)*

## 5.3. Energy Market Participation

When assessing the WGB's energy market participation, certain factors should be considered, as they may constrain the battery's participation.

Firstly, whenever a battery is dispatched to provide FCAS, its ability to provide energy is constrained by the capacity that it is enabled for in these FCAS markets. The regulation and contingency FCAS markets still represent a large portion of the total revenue available to a battery. As discussed further in the following sections, energy revenues are assuming a larger share of the total revenue available to a battery, but FCAS constraints on energy market participation remains material.

Secondly, the energy storage capacity of a battery constrains its short-term operations. A battery cannot charge or discharge beyond these limitations regardless of the value.

These shorter-term considerations give way to a third constraint – the cycling limitations of a battery. The number of times the battery can be charged and discharged per year has technical limitations and there are commercial considerations in the context of its warranty.

Finally, the provision of network services that a battery has committed to can impinge on operations. This, however, is not the case for the WGB, as providing inertia in the event of grid disturbance has not been found to change participation in the energy market. While MWhs of battery capacity are reserved for the provision of inertia, the operator of the battery has found that this requirement overlaps with its preferred use of the battery in a complementary way, so it does not constrain operations. This is not a universal conclusion for network services and commercial batteries but has been the experience of the WGB through its first years of operation.

## 5.4. Capacity Factor

The capacity factor[1] 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. As the battery has a 1.5 hour duration, charging and discharging once a day infers a capacity factor of 6.25%. Table 3 demonstrates that in Q2 and Q3 CY2022, when the market was extremely volatile, the battery was cycled more than once a day in pursuit of the revenues associated with that higher volatility.

| | | 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 |
| **Q1 CY2023** | Discharge | 0.50 | 95.46 |
| | Charge | 2.96 | 96.33 |
| **Q2 CY2023** | Discharge | 2.56 | 91.63 |
| | Charge | 4.36 | 92.66 |

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

1 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.

The capacity factor continues to show great variations over time, driven in part by the volatility observed within the energy markets, alongside the relative value of energy markets in comparison to the FCAS markets. This variation over time is shown in Figure 9.

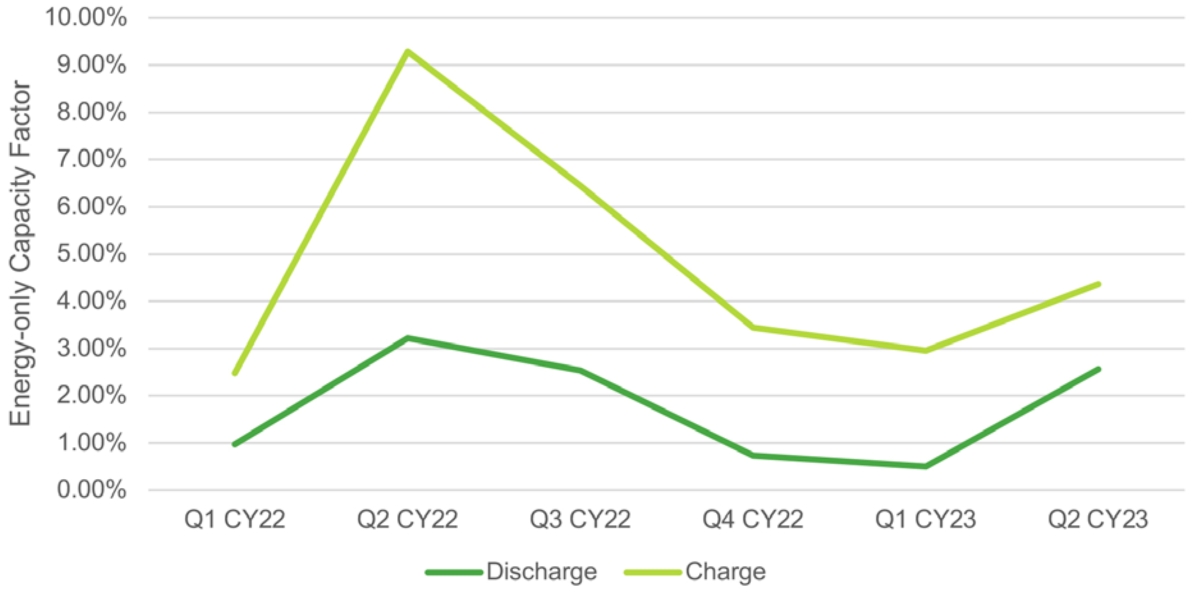



*Figure 9 – Energy-only capacity factor of the WGB for each quarter of operations*

## 5.5. 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% and 25% probability of exceedance (PoE)[2] differences between the highest and lowest value hours each day.

| | Average Daily Hour Max/ Min Difference ($/MWh) | 50% PoE Daily Hour Max/Min Difference ($/MWh) | 25% PoE Daily Hour Max/Min Difference ($/MWh) |
|---|---|---|---|
| January 2023 | 137.15 | 105.30 | 155.67 |
| February 2023 | 162.36 | 137.37 | 199.25 |
| March 2023 | 542.30 | 171.97 | 225.70 |
| April 2023 | 242.13 | 214.67 | 265.83 |
| May 2023 | 841.88 | 268.63 | 461.21 |
| June 2023 | 295.61 | 182.34 | 256.07 |

*Table 4 – Market factors for consideration for an energy arbitrage strategy – Hours of Day*

In January, February and April the gap between the average and 50% PoE daily difference highlights reduced volatility on an hourly basis. By comparison, a much higher difference than the 25% PoE in March and May (and to a lesser extent June) highlights that a small number of days in those months had extreme price differences, driving up the average difference.

If a pure arbitrage strategy was pursued, a difference of charge and discharge price higher than the above should be attainable in identical market conditions due to the ability of the battery to operate on a five-minute basis, and potentially avoiding non-economic dispatch intervals that are averaged into the above hourly values.

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

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, given the WGB's strong point of connection into the network, any MLF revenue adjustments are immaterial with a FY2022-23 MLF of 1.0010 and 1.0009 for its generation and load components respectively.

## 5.6. Negative Price Opportunities

2.7% (1,426) 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 below.

This is an important metric for energy prices as the average value can be distorted by a minimal number of extreme pricing events, so the 50% PoE is a much better indication of what normal market conditions will be than the average value under most circumstances.

| Price ($/MWh) | -1,000 to -500 | -500 to -250 | -250 to -100 | -100 to -50 | -50 to -25 | -25 to 0 |
|---|---|---|---|---|---|---|
| DIs | 11 | 1 | 2 | 303 | 625 | 484 |
| % of all DIs | 0.02 | 0.00 | 0.00 | 0.58 | 1.20 | 0.93 |

*Table 5 – Negative Price Distributions in NSW region in H1 2023*

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 H1 2023 (1,426) were less than half of those seen in H2 2022 (2,974). In line with this finding, 30 out of the 181 daily minimum hourly values in the reporting period were negative (16.6%). This was a reduction from the previous reporting period, in which 52 out of the 184 daily minimum hourly values were negative (28.3%).

## 5.7. Charging and Discharging Profiles

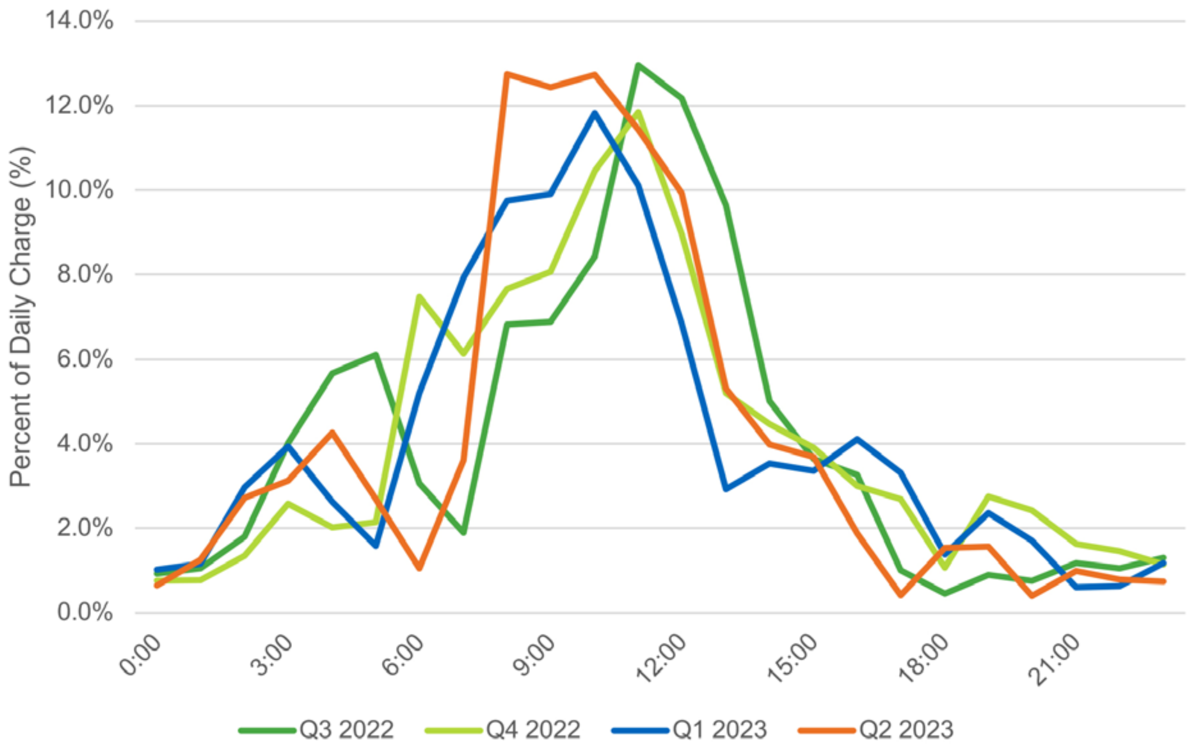



*Figure 10 – Average daily charging profile for the WGB*

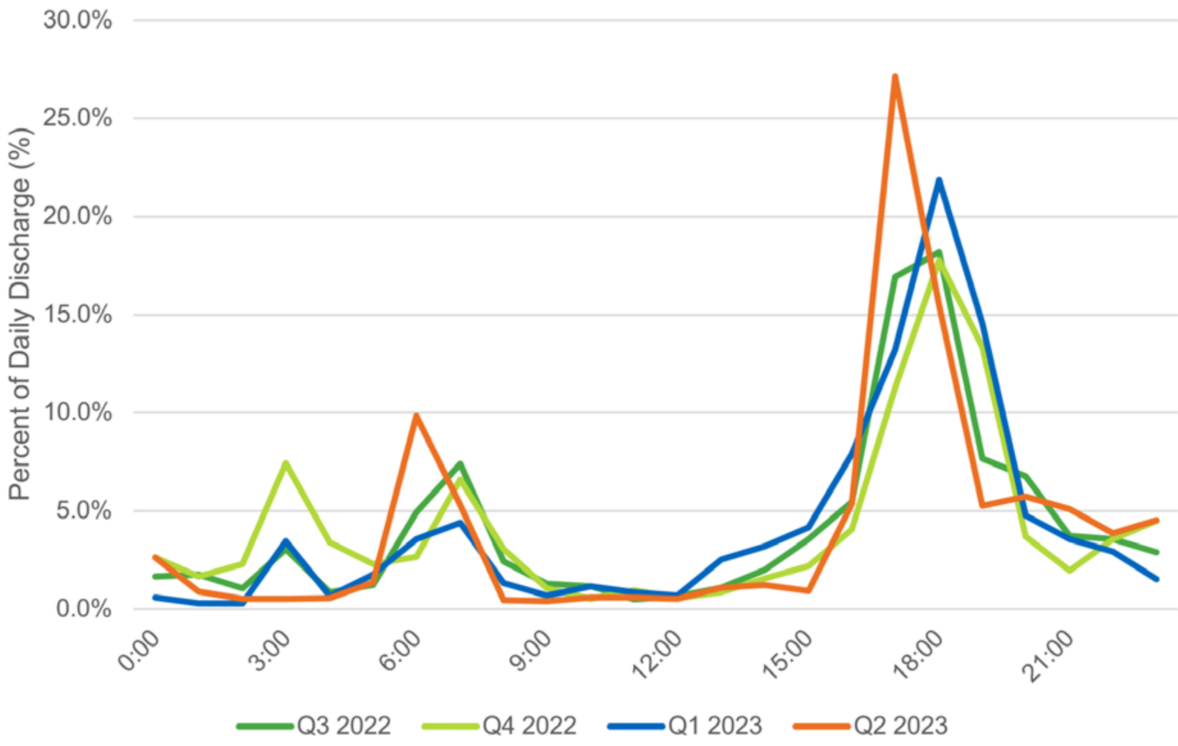



*Figure 11 – Average daily discharging profile for the WGB*

The average daily charging profile of the WGB has remained consistent with the profile seen to develop in Q3 CY2022 and continues a shift towards charging the battery predominantly throughout the middle periods of the day, and limiting the charging undertaken overnight. Similarly, there is little variation seen in the shapes of the previous and current quarters for the discharge profile aside from a slight focussing of the evening peak into a tighter distribution around the evening peak hours.

## 5.8. Provision of Regulation FCAS

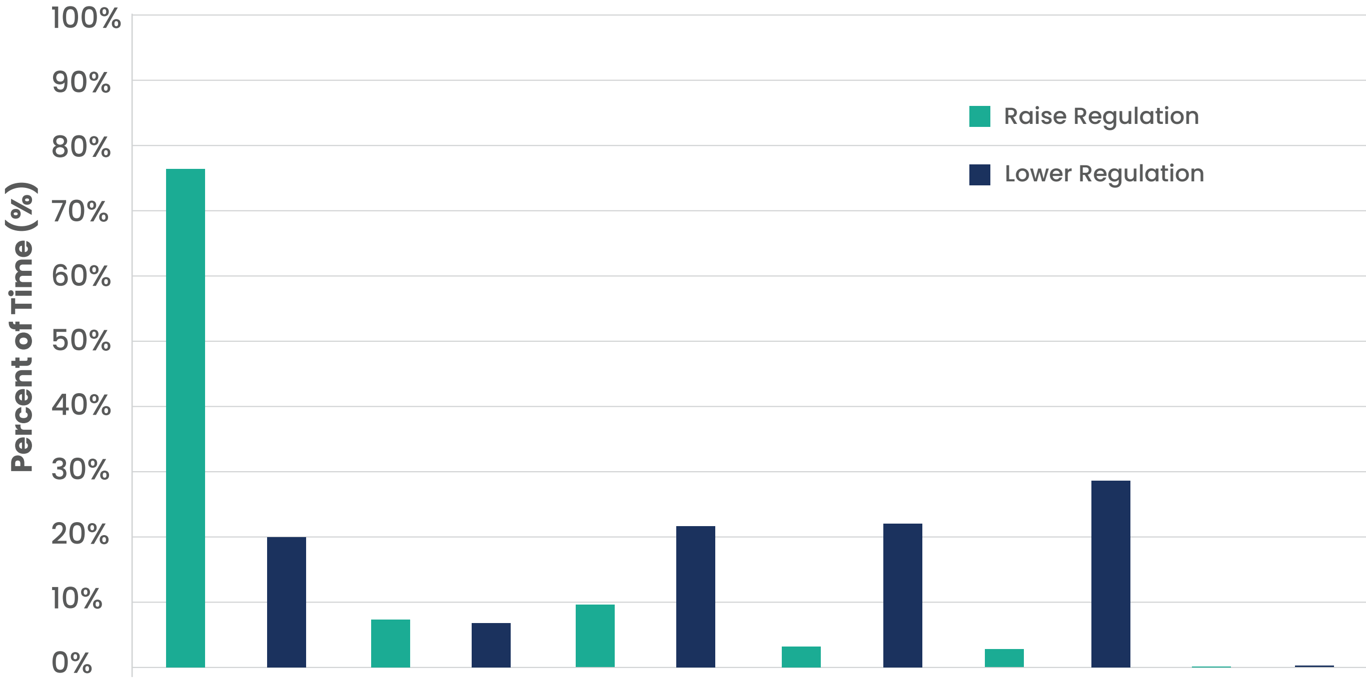
The WGB can provide three different services: energy, regulation FCAS, and contingency FCAS. These services are co-optimised, which means that they can be provided simultaneously, but they have to share the WGB's nameplate capacity. The WGB has a nameplate discharge capacity of 50MW. However, whenever the WGB is fully enabled for contingency raise, 26MW of this nameplate discharge capacity must be reserved as headroom. 26MW is the maximum registered capacity for the battery in contingency FCAS, based on the response to frequency at deviations of 50Hz +/- 0.5Hz. 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

In this report, 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.




| **MWs** | 0 | 0 | 1-23 | 1-20 | 24 | 21 | 25-49 | 22-46 | 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*

The results shown in Figure 12 aligned with Iberdrola Australia's expectation generally and are similar to the performance of the WGB throughout 2022. Changes to the enablement observed or the raise and lower regulation services for the reporting period include:

- Increased enablements of ~5% for lower regulation between 21MW to 47MW, and a subsequent reduction in the amount of non-enablement periods by ~10%
- Reduced enablements of ~5% for raise regulation between 24MW to 50MW, and a subsequent increase in the amount of non-enablement periods by ~10%

These shifts in enablement are driven by the relative values of the 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), contingency will be prioritised above regulation, so regulation FCAS enablement above the NP Cap – cFCAS will decrease. Following the same logic, increases in regulation FCAS enablement are expected when contingency FCAS has a lower economic value.

## 5.9 Provision of Contingency FCAS

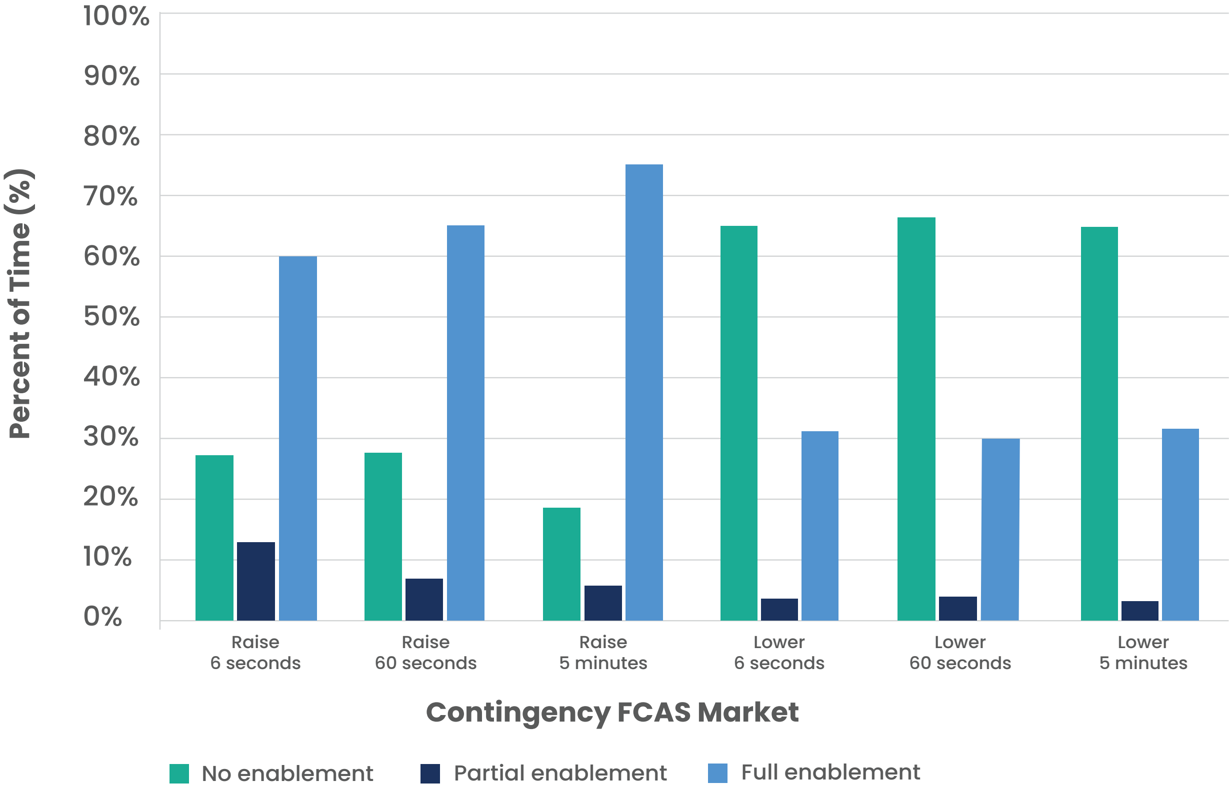



*Figure 13 – Contingency FCAS market enablement in H1 CY2023*

The contingency FCAS enablement seen above in Figure 13 is generally in line with expectations and the previous operations of the battery. The relationships discussed for regulation FCAS above are most observable in the trends seen in the contingency raise FCAS enablement as the raise FCAS markets typically have a higher value than the lower FCAS markets. The key change to the H2 2022 enablement levels is the ~10% increase in enablement across all three contingency raise FCAS markets.

To date the WGB has been able to provide different levels of enablement for contingency FCAS services between the fast (6s), slow (60s) and delayed (5min) markets. This has been due to the fast response that a battery can provide. As the battery does not ramp linearly between 0-6 seconds and reaches its full response of 26MW faster, a slightly higher average response is recorded. Under the specifications for how contingency FCAS is registered with AEMO, the increased value in the fast market is offset by a reduced response in the slow market such that the two responses average out to the physical response provided at frequency deviations +/- 0.5Hz. This results in a response between the fast and slow markets that averages the physical response (26MW) – usually 33MW of fast response and 19MW of slow response.

However, the specifications for how contingency FCAS is registered with AEMO are due to change and will standardise the registerable response to 26MW for all markets following the implementation of the Very Fast Contingency FCAS markets (discussed further in Section 7).

## 5.10 Extreme market prices capture rates

### 5.10.1 Energy market

The average energy response of the WGB during extreme energy price events within the last two reporting periods is shown in Table 6 below.

| | 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 |
| 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 |

*Table 6 – Wallgrove Grid Battery response during extreme energy price events*

In Q1 2023, the majority of high-priced intervals missed were due to the battery preferring to bid its generation capacity into the regulation raise FCAS market. During Q2 2023, the majority of high price periods were missed due to the WGB being unavailable due to an outage to undertake maintenance on Transgrid's main transformer.

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. For many of these intervals, renewable generation was covering the contracted position of Iberdrola's NSW portfolio, so the battery's state of charge was reserved from fully discharging into the energy markets during the period to ensure that it was available to discharge if the intermittent generation reduced and the contracted position became uncovered.

### 5.10.2 Frequency Control Ancillary Services Markets

As is evident in Table 7, there was limited volatility seen in the FCAS markets in H1 2023, and the WGB captured a significant portion of the only high price interval for the period.

| | DIs above $1,000/MW/h | Average enablement (% of registered capacity) |
|---|---|---|
| Raise 6 Seconds | 1 | 81% |
| Raise 60 Seconds | 0 | n/a |
| Raise 5 Minutes | 0 | n/a |
| Raise Regulation | 0 | n/a |
| Lower 6 Seconds | 0 | n/a |
| Lower 60 Seconds | 0 | n/a |
| Lower 5 Minutes | 0 | n/a |
| Lower Regulation | 0 | n/a |

*Table 7 – WGB enablement during extreme FCAS price events*

## 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 8, 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.

| Method | Round trip efficiency at 132kV transmission network connection point (%) |
|---|---|
| 23 December 2021 to 23 June 2022 | 83.2% |
| 1 July to 31 December 2022 | 81.7% |
| 1 January to 30 June 2023 | 78.2% |

*Table 8 - Round trip efficiency performance*

## 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.

## 6.3 Auxiliary Power Usage

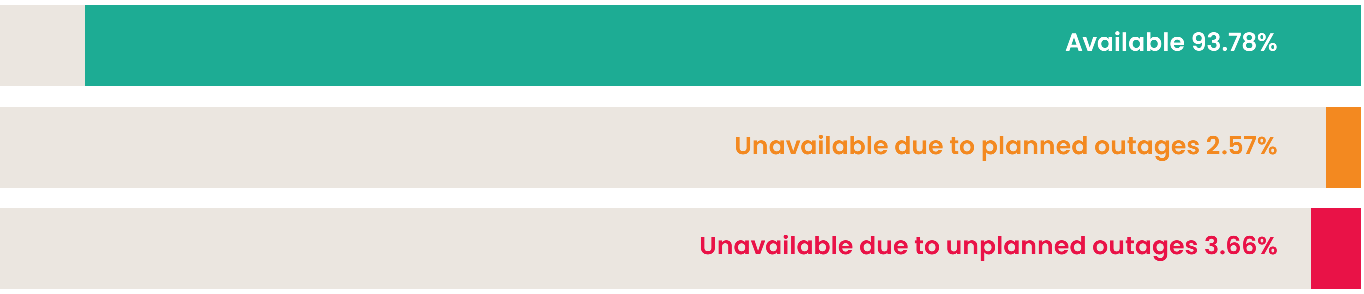
Auxiliary power usage is estimated to be 8.0kVA from observations of the auxiliary power distribution board meters over a one-hour period. The measurements were taken during the day and therefore do not account for yard lighting.

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

The availability performance from 1 January 2023 to 30 June 2023 was:




### 6.4.1 Planned Outages

| Planned outage date | Works occurred |
|---|---|
| 6 February 2023 | Transgrid Feeder 26G - Commission new IDS meter, Database upload. |
| 15-19 May 2023 | Transgrid Megapack coupling transformers Warranty Service |
| 22-26 May 2023 | Transgrid main transformer maintenance |

*Table 9 – Planned outages*

### 6.4.2 Unplanned Outages

| Unplanned outage date | Works Occurred |
|---|---|
| 19 January 2023 | Tesla megapack repair |
| 7-9 February 2023 | Tesla megapack repair |
| 18-21 February 23 | Main transformer trip |
| 23-26 June 23 | 33kV Cable sealing repair work |

*Table 10 – Unplanned outages*

*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.

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

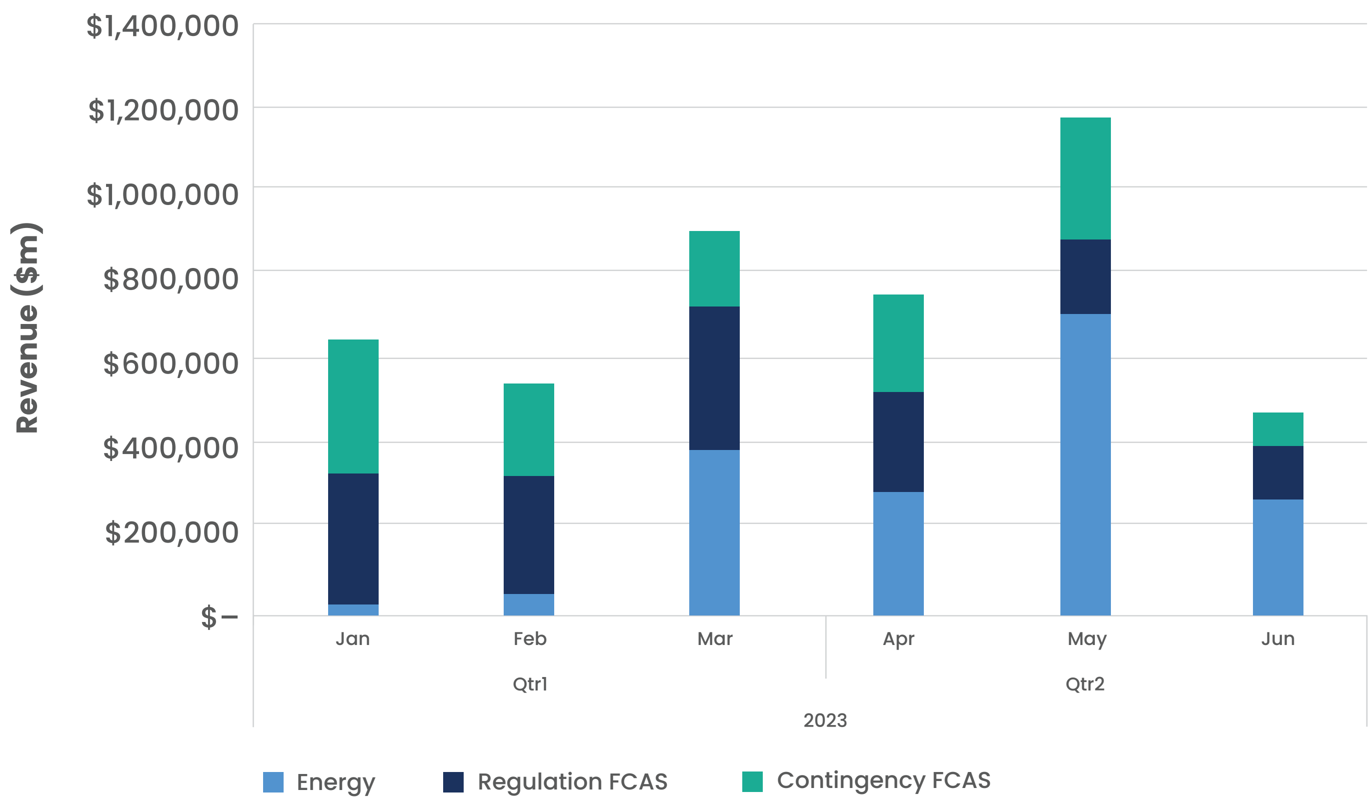



*Figure 14 – Market revenue by month*

Limited energy revenues were observed in the first few months of 2023, consistent with recent years with limited extended high temperature periods over summer and high availability of thermal generation. Increased energy market revenues were then observed in the following months, as thermal generation availability dropped with the shoulder season maintenance of plant and retirement of Liddell Power Station.

FCAS prices were comparatively consistent across both the regulation and contingency markets (with some variations seen between these two revenue streams on a monthly basis). While these revenues were seen to drop away in June, it is typical to see the FCAS revenues degrade during periods of increased thermal availability over summer and winter (outside of the shoulder seasons where maintenance is typically scheduled).

### 7.1.3 Market Revenue by Application

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

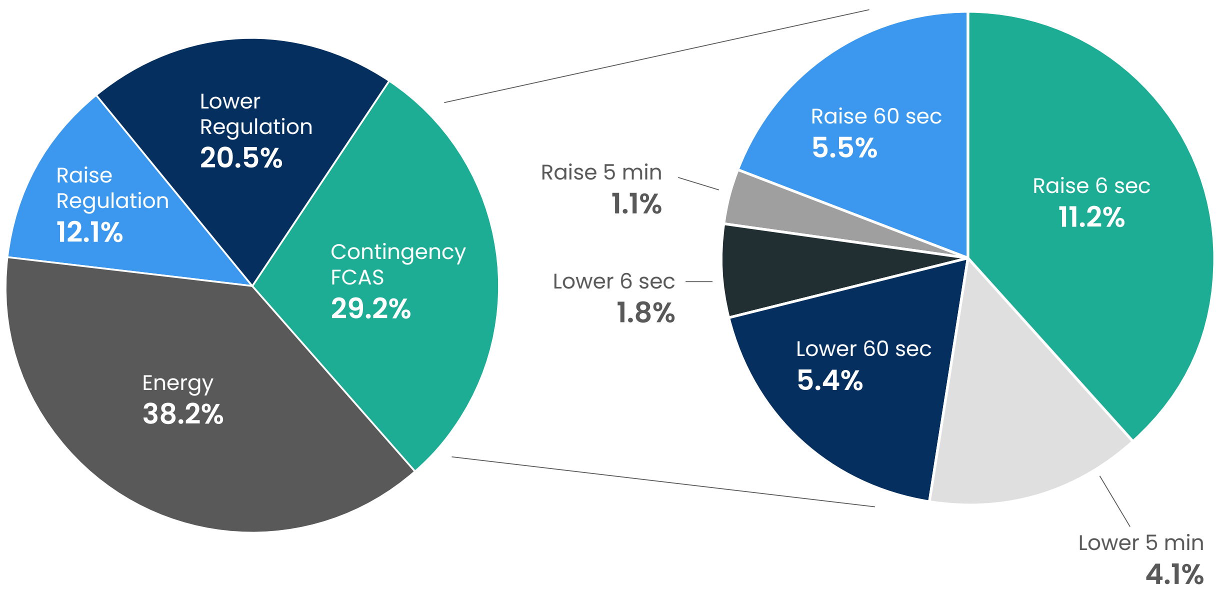



*Figure 15 – Market revenue by application for Q1 and Q2 CY2023*

The above distribution of earnings displays a similar trend to Lake Bonney BESS - that energy revenues are assuming a larger portion of the battery's total revenue.

For the Lake Bonney BESS, energy revenues have accounted for ~50% of total revenues for the previous year. Similarly, the revenue attributed to the energy market operation at the WGB has increased from 26% in the second half of 2022 to 38% for the first half of 2023.

## 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 is reflected in the historic MLFs determined for financial years 2022, 2023 and 2024 shown in Table 12.

| Financial year | WALGRVG1 (generator) | WALGRVL1 (load) |
|---|---|---|
| 2021-22 | 1.0011 | 1.0010 |
| 2022-23 | 1.0010 | 1.0009 |
| 2023-24 | 1.0010 | 1.0009 |

*Table 11 – MLF values for the Wallgrove Grid Battery*

## 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.

To accommodate the Very Fast Contingency FCAS markets, the Market Ancillary Service Specifications have been updated. As part of these changes, the registration of the existing contingency FCAS markets has been altered to limit the maximum registerable capacity to the physical response of the battery.

This change is due to the establishment of the Very Fast markets, which now allows for the speed of response for technologies like batteries to be recognised. As a result, it is expected that the WGB will be registered to provide 26MW of contingency FCAS response across all 8 markets.

There have been no safety or environmental incidents in the first 18 months of operations.

Approximately 1,414 work hours occurred on site during the reporting period, as shown in Table 12, which was much higher than previous periods.

| 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 |

*Table 12 – Work hours on site*

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