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KNOWLEDGE SHARING REPORT

Ballarat Battery Energy Storage System

OPERATIONAL REPORT #3 & #4

13 TO 24 MONTHS OF OPERATION

The Consortium

Downer SPOTLESS EnergyAustralia AusNet services

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PART I Introduction

The Consortium is pleased to provide this knowledge sharing report that outlines the performance of the Ballarat Battery Energy Storage System (Ballarat System) over 13 to 24 months of operation.

The purpose of this report is to share the learnings from the 13 to 24 months of operation of the Ballarat System as part of the Consortium's obligations with ARENA and DELWP under the Knowledge Sharing Agreement. This document is intended to be released to the public and covers the following key areas:

- Operational Performance;
- Market Services;
- Network Revenue Opportunities; and
- Technical Challenges

The Ballarat System is a consortium project undertaken by the Spotless / Downer Group, Fluence, AusNet Services, and Energy Australia. The project was selected during the Victorian Government Energy Storage Initiative tender process and is one of two projects under that program to be constructed and now in operations. The Victorian Government and the Australian Renewable Energy Agency (ARENA) through the Advancing Renewables Program contributed $25 million in grant funding for this project.

The project is the first of its kind in Australia -- a standalone battery-based energy storage system being installed in front of the meter and directly connected to the transmission network -- and the first grid-scale battery-based storage system commissioned in the state of Victoria.

The Ballarat System is a 30MW / 30MWh system utilising Lithium-ion battery technology and Fluence's proprietary hardware and software controls. The system is installed at Ballarat Terminal Station (BATS) and is connected to the transmission network via the BATS No.1 transformer tertiary winding (rated at 22kV 40MVA). The Ballarat System is registered to operate as a 30MW generator, a 30MW load, and to provide regulation Frequency Control Ancillary Services (FCAS) raise and lower as well as all six contingency FCAS markets. The Ballarat Terminal Station is the central hub for the electricity transmission network in western Victoria and the location was chosen to add new capabilities at AusNet Services' existing facility to support further renewable electricity generation, in addition to over 620MW of existing local renewable energy generation.

The project was constructed in nine months during 2018 and was completed and capable of dispatching services for all eight FCAS markets and energy to the NEM on 22 December 2018. Providing capacity comparable to 6,000 residential battery storage systems at a single location, the project was designed to provide the following outcomes:

1. to enhance network stability and reduce congestion on Victoria's transmission grid through direct grid connection and participation in both Australia's National Electricity Market's (NEM) contingency and regulation Frequency Control Ancillary Services (FCAS) markets; and
2. to add a peak power resource to help manage price volatility and reliability risks during high demand periods, by providing a reliable energy source to the Australian Energy Market Operator (AEMO).

Key Achievements from the 13 to 24 months of operation include:

- The System has provided 5,611 MWh to the Energy and FCAS markets
- The System has achieved $6.65M in net revenue, with revenue in Energy markets meeting expectations and revenue in FCAS markets exceeding expectations
- The System had an overall availability of 91.05%. Availability was primarily impacted by:
  - A precautionary and temporary modification to the system State of Charge (SoC) to 75% (if this is excluded, the availability would have been 98.92%)

Key learnings from the 13 to 24 months of operation:

The consortium wants to highlight for the industry the key learnings from the 13 to 24 months of operation to assist future storage projects.

Availability

Despite the SoC restriction, availability improves as the operations and maintenance mature

Availability of the Ballarat system improved in the 13 to 24 months of operation as many of the teething issues of the new technology were resolved. The availability was again impacted by the SoC restriction, though it is anticipated that the SoC battery restriction will not be imposed in future. A Ballarat system availability without SoC restriction is expected to achieve approximately 99%.

FCAS

The Ballarat battery continues to perform strongly in the FCAS markets

The Ballarat revenue continues to be dominated by the contingency and regulation FCAS markets. Over 90% of revenue in 2020 is attributed to the FCAS markets – predominately the regulation and contingency raise markets.

Anti-islanding Scheme

Availability was impacted by anti-islanding scheme protection design

The anti-islanding scheme that was originally commissioned for the interface equipment was not suitable for the Ballarat system. Disturbances on the Transmission network caused the anti-islanding protection scheme to inadvertently operate. It is recommended that a power system dynamic study is completed prior to commissioning to ensure that the protection design is suitable for the network application.

Energy vs. Power

Maximising revenue from the system

During the 13 to 24 months of operation, the revenue generated from the Ballarat battery identified a high-power (MW), low-energy (MWhs) system provides the greatest value in revenue. This enables the battery to operate in FCAS markets and capture high priced volatile events in the Energy market. This validation is consistent with the first 12 months of operation of the Ballarat Battery system.

PART II
Operations Report

2.1 Project Overview

The Ballarat System commenced commercial operations on 22 December 2018 and is owned and operated under the following structure:

- EnergyAustralia as the Market Intermediary, operating and trading the system in the National Energy Market (NEM) in accordance with the Operating Parameters;
- AusNet Services/Mondo as the asset owner, with a service agreement with EnergyAustralia for use of the Ballarat system in the NEM in accordance according to the Operating Parameters;
- AusNet Services/Mondo contracts Fluence under a 15-year services agreement ("Term") to ensure the battery system is available for use according to the Operating Parameters; and
- AusNet Services maintains the Balance of Plant to ensure the system is available for use according to the Operating Parameters.

Operations and maintenance (O&M) responsibilities are summarised in Figure 1.

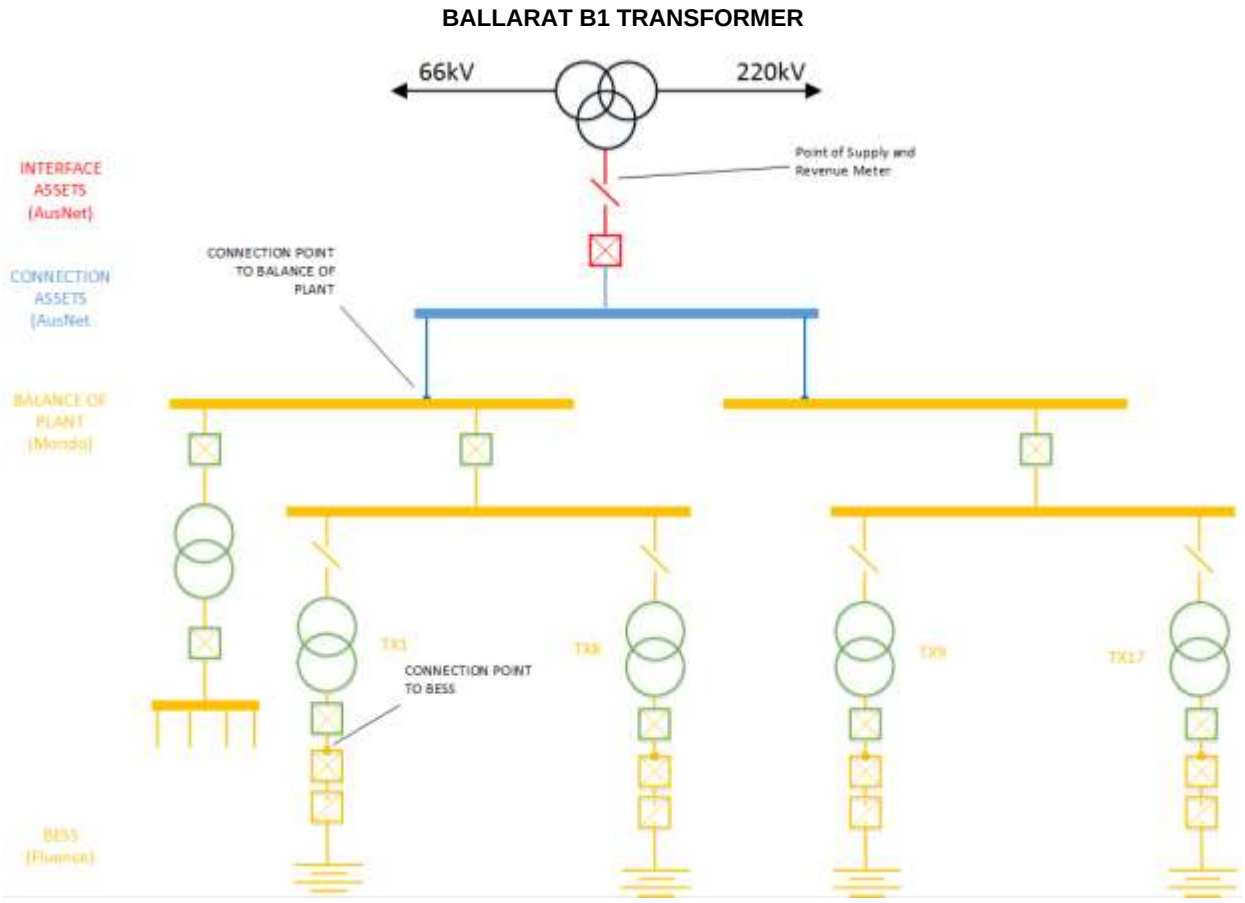

Figure 1 – O&M Responsibilities

2.2 Operating Parameter Summary

Operating parameters for the first two years of operation, from 22 December 2018 to 21 December 2020 ("Contract Year 1 and 2") of the Ballarat System are presented in Table 1. The Operational parameters for subsequent years are reduced in accordance with the nominated degradation curve.

Table 1 – Operating Parameter Summary

Parameter	Requirement – Contract Year 1	Requirement – Contract Year 2
Availability	$Availability\ (\%) = \frac{Capacity}{Rated\ Power}$ $(averaged\ over\ all\ periods)$ Where, for each Period: Capacity is the lesser of: (i) Actual Available Capacity; and (ii) $\frac{Actual\ Available\ Energy}{Usable\ Energy} \times Rated\ Power$	
Rated Power	30.38 MW	**30.38 MW**
Usable Energy	30.38 MWh	**29.07 MWh**
Round Trip Efficiency	87.17%	**86.80%**

2.3 Performance

The performance of the Ballarat System for Contract Years 1 and 2 are summarised in Table 2.

Table 2 – Key performance summary

	Actual
Availability for Contract Year 1	86.36% (Availability for Contract Year 1 excluding SoC restriction – 95.65%)
Availability for Contract Year 2	91.05% (Availability for Contract Year 2 excluding SoC restriction – 98.92%)

Other key performance parameters from the Ballarat System for Contract Years 1 and 2 and are provided in Table 3.

Table 3 – Key performance parameters

Parameter	Actual (Contract Year 1)	Actual (Contract Year 2)
Cumulative energy discharge (i.e., FCAS provisioned/energy sales for arbitrage)	7311.96 MWh	5639.1 MWh*
Deep Discharge	1 event per 24 hours 45 events during Contract Year 1	2 events maximum per 24 hours 43 events during Contract Year 2
State of Charge	34.1% average SoC in Contract Year 1 14 times at >50% SoC for 14 to 20 hours	35.4% average SoC in Contract Year 2 10 times at >50% SoC for 14 to 20 hours

**Note – Energy contributed to the NEM was 5,611 MWh*

A deep discharge event is defined as the SoC of the system during a discharge event going from greater than 80% to under 20% during the event.

For the Ballarat System there is a limit in the average SoC allowable over the course of the year due to the hardware and software installed. These limitations are identified above regarding the SoC.

2.4 Discussion Topics

The following section discusses key issues that have affected the availability and also of interest to the audience of this report during Contract Year 2 of operation, under the following categories:

- Reinstatement of SoC restriction and battery replacement
- Performance testing
- Anti-island scheme updates
- Unplanned Maintenance Activities

2.4.1. Reinstatement of State of Charge restriction and battery replacement

In June 2020, Fluence provided AusNet Services' notification of a precautionary and temporary modification (Modification) to system operation parameters. The Modification ensured the battery modules in the system did not exceed a maximum SoC of 75% of the rated system nameplate. This Modification was recommended by LG Chem (battery OEM) following a recall of certain battery modules. Targeted battery module replacement work on the Ballarat System took place from October 2020, through to November 2020, after which the SoC restriction was removed and the system returned to normal operations.

The impact of the Modification, while it was in effect, was reduced capacity and availability of the Ballarat system for trading purposes relative to the SoC restriction, as noted in Section 2.3. A restriction on the battery SoC also occurred during Contract Year 1 between April and September 2019.

2.4.2. Performance Testing

The Ballarat system is registered with AEMO as a 30MW asset. At the commencement of each year, the Ballarat system's health is assessed through a process of performance testing. This is notionally timed with the anniversary of the system's final stage of commissioning – the Ballarat system's practical completion occurred in December 2018. Due to constrained outage requirements over the summer period (December to April), annual testing for Contract Year 2 was postponed by agreement of the consortium partners until after the trading period.

Due to the postponement of testing, the Ballarat system's performance was measured and evaluated after the defined performance guarantee date for Contract Year 2. Subsequently, module degradation during the intervening period may impact the measured performance value.

The results of the performance testing – assessing power capacity (MW), available stored energy (MWh), and round-trip efficiencies (%) – are provided below in Table 4.

Table 4 – Key performance parameters

Performance Metric	Recorded Value	Result
Delivered Cores Array Power (MW)	30.24	PASS
Array Cores Energy (MWh)	29.50	PASS
Array Cores RTE (%)	93.16	PASS

2.4.3. Anti-islanding Protection Scheme

The interface plant Protection and Control Requirements (PCR) for the Ballarat Battery system is specified by the Australian Energy Market Operator (AEMO). In Contract Year 2, AusNet Services experienced multiple unexpected trip events of the interface equipment. After investigating the incidents, it was observed that disturbances on the upstream TNSP network were adversely impacting the anti-islanding protection scheme for the Ballarat Battery. The AEMO PCR requirements stipulated for the Ballarat Battery to be disconnected in the event of a loss of phase on the 22kV network. In Q1 2020, the TNSP experienced two separate high fault current disturbances on the transmission network at Ballarat – causing voltage instability for several cycles (milliseconds). As a result, the anti-islanding protection scheme inadvertently operated.

As the Ballarat Battery system is a generation connection asset, any changes in the protection and control scheme need approval from AEMO. AusNet Services proposed changes to the Protection and control settings which were reviewed and approved by AEMO. The Ballarat System availability for Contract Year 2 was reduced by approximately 0.14% due to the anti-islanding protection scheme issue.

2.4.4. Unplanned Maintenances Activities

In addition to the availability constraint due to the SoC Modification in 2.4.1, additional unplanned maintenance activities for contract year 2 are noted in Table 5 below.

Table 5 – Unplanned maintenance items for Contract Year 2

Unplanned Maintenance	Impact
Anti-islanding operation of interface connections (multiple events)	All cores impacted
Battery module adjustments and/or replacements (multiple events)	One core out of service at a time
Controller stoppages (multiple events)	All cores impacted, most were restored on same day
PCS communication timeout or fault (multiple events)	One core out of service at a time
Controller software or communications stoppage (multiple events)	One core out of service at a time
Damage during power restoration after full outage (single event)	One core out of service
Inspection alert raised by module monitoring (multiple events)	One core out of service at a time
LG module recall (single event, 2-month replacement process)	One to two cores out of service at a time
Mains supply protection event (single event)	All cores impacted

Figure 2 summarises the causes of unplanned outages and impacts on availability throughout the year. The main factor contributing to reduced battery availability was the precautionary SoC restriction (7.87%).

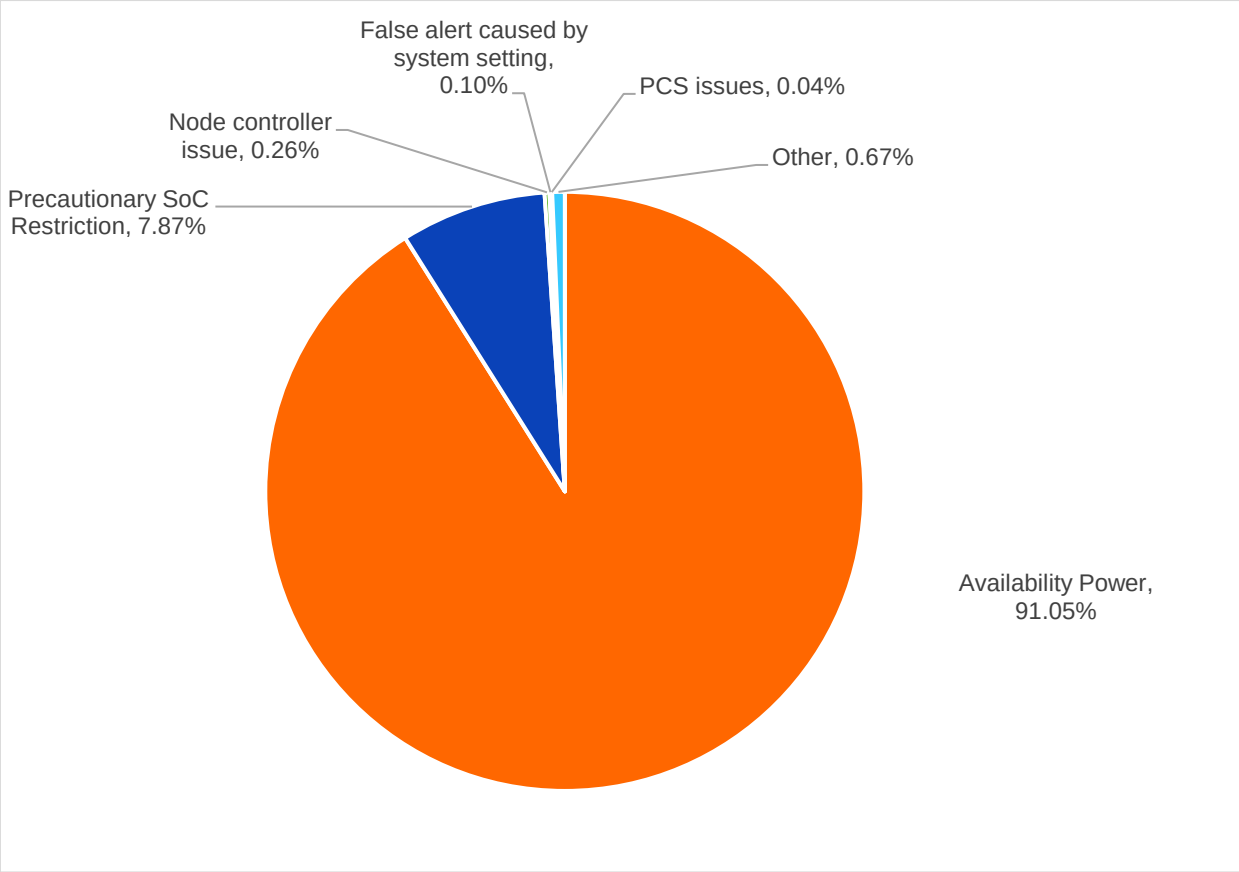

Figure 2 – Unplanned maintenance outages

PART III
Market Services

3.1 General Financial Performance

EnergyAustralia is the registered market intermediary for the Ballarat System and is therefore responsible for the bidding of the battery system with AEMO. The Ballarat System has been registered as both a generator, and a market load, along with all FCAS markets. While the primary business case for EnergyAustralia was for energy arbitrage and capacity, the Ballarat System has continued to generate greater revenues from FCAS markets.

The Ballarat Battery has been highly effective in the provision of FCAS services, which are critical in ensuring the stability of the system. As was discussed in year one, the continued high penetration of renewable energy has seen a greater requirement for FCAS and therefore sustained high FCAS prices. The VIC-SA separation event on 31 January 2020 drove increased revenue in Q1. FCAS prices were lower in the rest of the year, along with the energy market, due to mild conditions and strong renewable output.

Table 6 – Financial Performance (figures in table provided in $000's)

BALLARAT	Q1-19	Q2-19	Q3-19	Q4-19	Q1-20	Q2-20	Q3-20	Q4-20	2019	2020
Pool Revenue	836	225	416	159	310	56	143	145	1,636	654
Charging Costs	-185	-173	-313	-114	-61	-32	-83	-79	-785	-255
FCAS Revenue	497	1,158	1,993	1,578	3,362	875	915	1,104	5,226	6,257
Market Fees	-1	-1	-4	-3	-2	-2	-3	-3	-8	-11
Net Revenue (pre-tax)	1,147	1,209	2,092	1,620	3,609	897	973	1,167	6,069	6,645

3.2 Ballarat System Value Streams

The overall bidding strategy for the Ballarat System is to optimise the earnings by utilising the registered markets (Energy/FCAS), whilst giving consideration to the contractual and technical limitations of the battery system. The monthly revenue stack for the Ballarat System from January to December 2020 is shown in Figure 3. The performance of the Ballarat System in the FCAS markets, particularly the Contingency Raise FCAS and the Regulation Raise FCAS markets, has continued to exceed expectations in contract year two, despite the SoC operational restrictions.

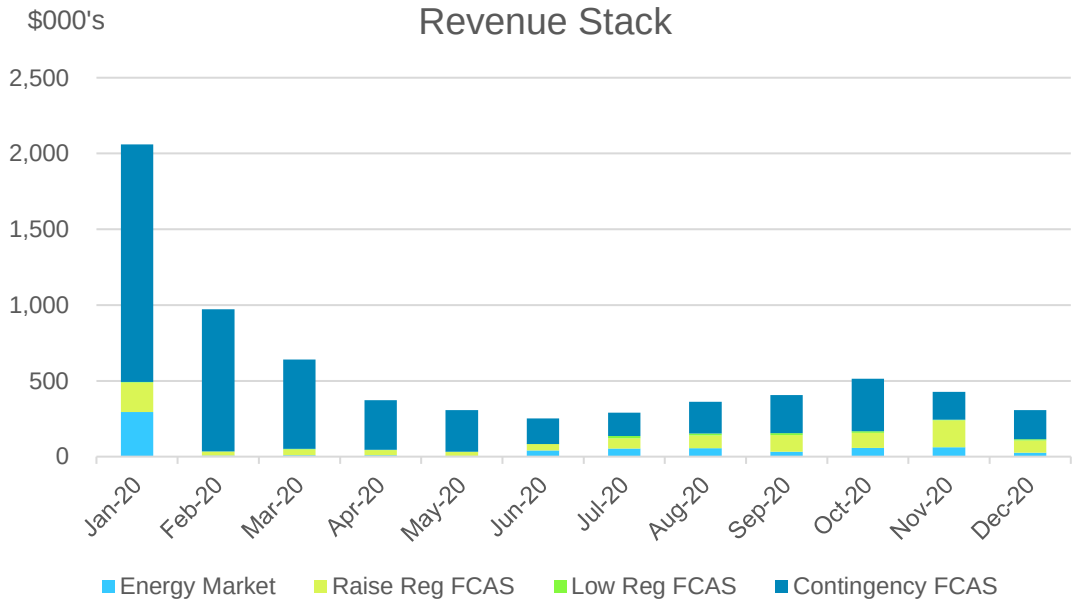

Figure 3 – Revenue summary

3.3 Energy Arbitrage Outcomes

In Contract Year 2, the Ballarat System generated most of its revenue from the FCAS markets. Consequently, the spread between the average price paid and the average price received in the wholesale energy market was relatively low in many quarters. As seen in Figure 4, a greater price spread was achieved in those months with increased arbitrage revenues including January, June, July and August. The higher energy arbitrage in January was caused by a separation event between Victoria and South Australia, which resulted in high energy market prices. The higher energy arbitrage in June, July and August were due to the steep demand shape over the morning and evening peak.

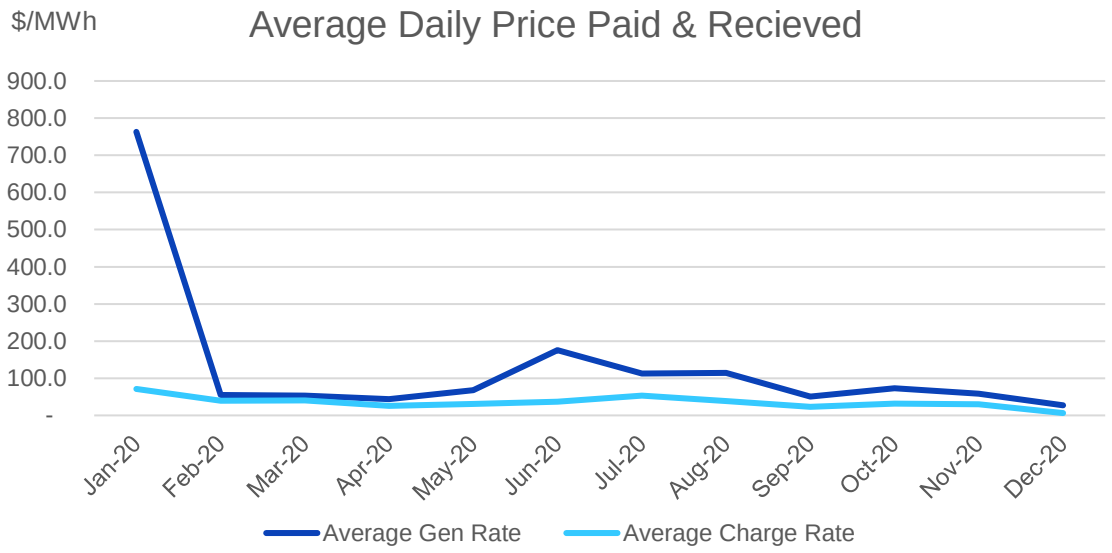

Figure 4 - Average Price Paid & Received

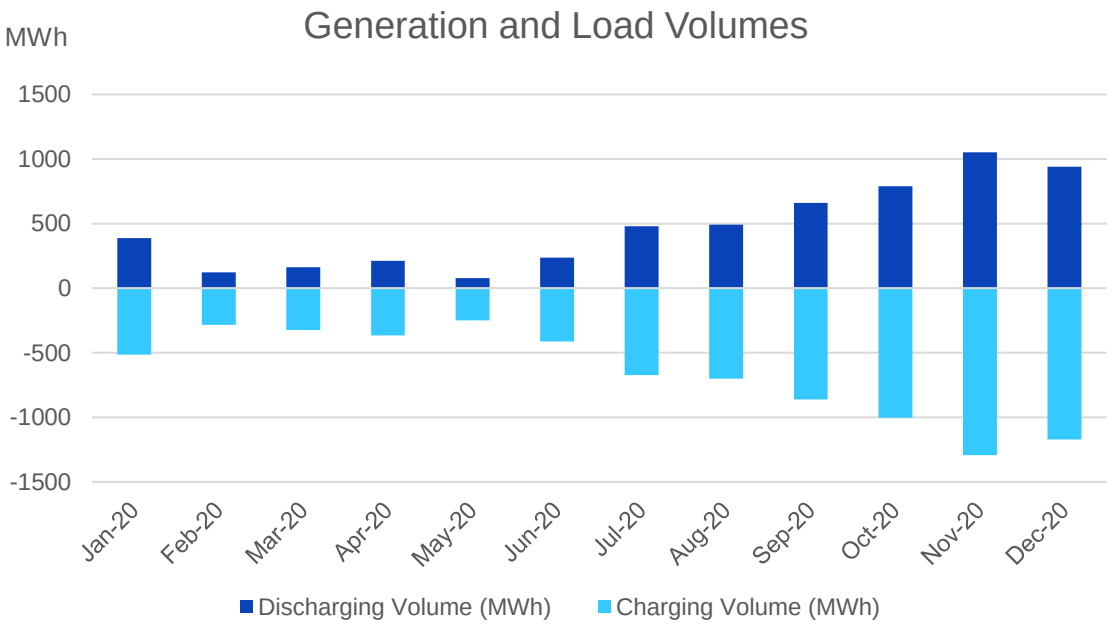

Figure 5 Generation and Load Volumes (MWh)

3.4 FCAS Services Outcomes

The Ballarat System has performed extremely well in both the regulation and contingency FCAS markets for Contract Year 2 – consistent with Contract Year 1. The Ballarat System delivered more than half of its FCAS revenue in Q1, driven by the summer volatility and corresponding high FCAS prices. Contingency Raise Services (5 seconds, 60 seconds and 5 minutes) generated the most value in the first half of 2020, whereas in the second half, value was generated in all eight FCAS markets.

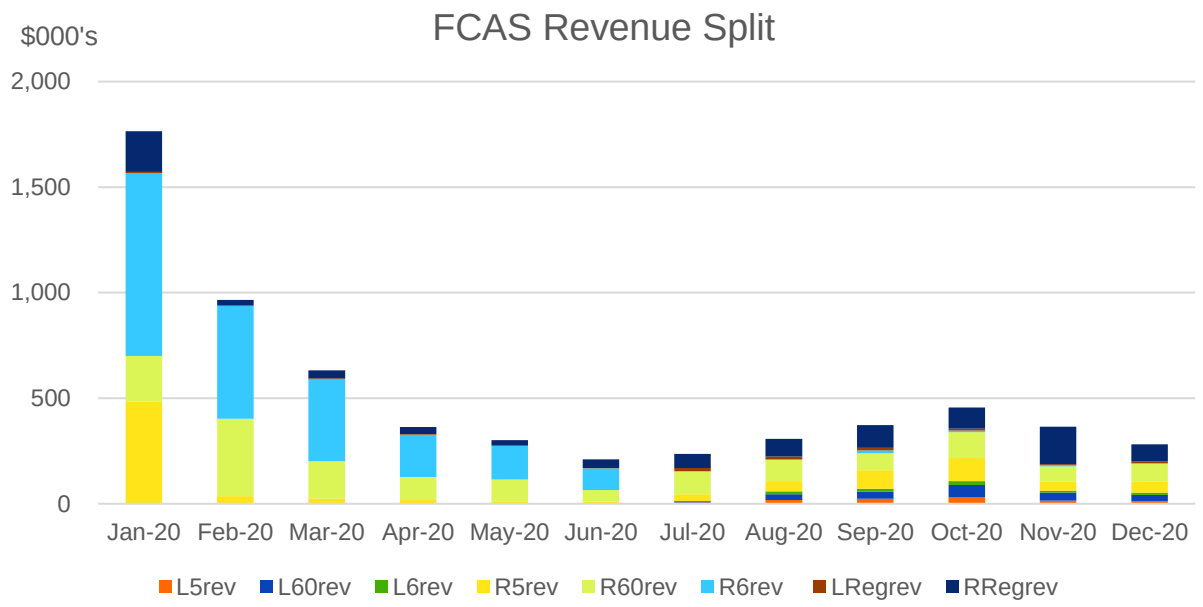

Figure 6 – FCAS revenue by market

3.5 Lessons Learnt

Many of the key lessons outlined in the contract year 1 report remain important when developing a battery project:

- If cycling limitations exist, then it is possible to maximise/extend a cycle by operating in the FCAS markets as well as the energy market;
- To date, based on the recent pricing, EnergyAustralia has had a bias towards FCAS markets compared to Energy utilisation (however several markets can be provided concurrently as paid for enablement without actual energy use).
- For the moment, from a trading perspective, a Higher Capacity (MW) batteries are more advantageous compared to a higher Energy (MWh) battery with the ability to capture the low/high prices at a higher volume and a shorter timeframe. Higher MWs also have more value in the FCAS markets.
- Trading has required additional data points to be captured to allow for further analysis, use in alerting tools, business rule validations and API calls.
- Default offers can be used to an extent but due to daily variations in price it is difficult to set and forget and fully optimise the return. The added variable is managing the SoC to optimise depending on market outcomes.

Part IV: Other Items

The following sections highlight some key performance results from the Ballarat System over Contract Year 2.

4.1 Availability

The SoC restriction on the battery in Contract Year 2 impacted the availability of the Ballarat Battery system – similar to the first 12 months of operation. Despite this, the availability of the Ballarat Battery system in year 2 of operations exceeded the availability of year 1 by approximately 5%. This considerable increase in availability enabled EA to trade the battery more frequently and with greater confidence. The increased availability is due to the rectification of several technical issues identified over the first 12 months of operations.

Following the battery replacement program completed in Contract Year 2, it is anticipated that the SoC battery restriction will not likely be imposed in future, unless further directed to by the battery module manufacturer. The Ballarat system's availability without SoC restriction is expected to achieve approximately 99%.

4.2 Energy vs. FCAS

Over the duration of Contract Year 2, the Ballarat system delivered over 5,611 MWh of energy to the National Electricity Market (NEM). The total energy is a reduction on the first 12 months of operation, whereby the Ballarat system produced over 7,311 MWh – a reduction of approximately 23%. Despite this, revenue increased for Contract Year 2 by approximately 10%. This is primarily driven by the strong financial performance in the regulation and contingency FCAS markets, as highlighted in section 3.4.

The total energy discharged threshold, as agreed by the consortium, is 7,149 MWh for contract year 2. EnergyAustralia's focus on trading the battery in the regulation and contingency FCAS markets instead of energy arbitrage in contract year 2 meant that the battery utilisation was approximately 78.5%. Utilisation in year two was down from 97.9% in contract year 1 due to market intermediary's operational changes.

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