Gannawarra Energy Storage System

Final Knowledge Sharing Report

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Disclaimer

The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Glossary of Terms

Acronym	Meaning
AC	Alternating Current
AEMO	Australian Energy Market Operator
API	Application Programming Interface
ARENA	Australian Renewable Energy Agency
BSSA	Battery Storage Services Agreement
DELWP	The Victorian Government's Department of Environment, Land, Water and Planning
DLF	Distribution Loss Factor
DUOS	Distribution Use of System
Edify	Edify Energy Pty Ltd and its related entities
EPC	Engineering, Procurement and Construction
FCAS	Frequency Control Ancillary Services
GESS	Gannawarra Energy Storage System
GSF	Gannawarra Solar Farm
LLV	Large Low Voltage
MLF	Marginal Loss Factor
NEM	National Electricity Market
NMI	National Metering Identifier
Project	GESS
RCR	RCR Tomlinson Limited
RRN	Regional Reference Node
SCADA	Supervisory Control and Data Acquisition
SOC	State-of-Charge
ST	Subtransmission
TUoS	Transmission Use of System
WIRCON	Wircon Energie 9 GmbH and its related entities

Project partners

GESS would not have been possible without the support of DELWP as part of its Energy Storage Initiative, ARENA as part of its Advancing Renewables Program or WIRCON as 50-50 joint venture co-investors. GESS's other project partners Tesla and EnergyAustralia also worked tirelessly to turn the project from concept to reality.

INTRODUCTION

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1 Introduction

This Final Knowledge Sharing Report concludes the knowledge sharing activities and deliverables under the Funding Agreement with DELWP and ARENA, and also forms a key part of ARENA's Advancing Renewables Programme objectives.

The report summarises all knowledge previously shared, with a focus on the following:

- Technical performance;
- Financial performance in comparison to business case;
- Safety and environmental performance;
- Operational regimes and key events;
- Overall lessons learned; and
- Summary of project risks and treatment.

The report is public with an intended audience that includes:

- Developers;
- Renewable energy industry;
- General public;
- Vendors;
- General electricity sector; and
- Governments.

1.1 Knowledge sharing activities to date

To date, a number of knowledge sharing activities for GESS have taken place as listed in Table 1.

Table 1 Knowledge sharing activities to date

Activity	Details
Industry presentations	• RenewEconomy / Informa Conference; June 2018 • All Energy Conference; October 2018 • Baker McKenzie panel seminar; October 2018 • AEMO Advanced Systems Integration Group (ASIG) meeting; October 2018 • ARENA Insights Forum; November 2018 • Australian Solar + Energy Congress and Expo; December 2018 • Clean Energy Summit; July 2019
Reports and other published materials	• ARENA's GESS video, November 2018[1] • AEMO Emerging Generation and Energy Storage (EGES) stakeholder paper response; December 2018[2] • Energy Magazine Article; February 2019[3]

[1] https://youtu.be/tEUiqYu28OA
[2] https://www.aemo.com.au/-/media/Files/Electricity/NEM/Initiatives/Emerging-Generation/Submissions/Edify-Energy_20181204.pdf
[3] https://www.energymagazine.com.au/exploring-the-retrofit-model-and-offtake-agreements-for-battery-integration/

	• ARENA Insights Spotlight: Gannawarra Energy Storage System (GESS) An interview with Edify Energy, April 2019[4] • DELWP's GESS media release and video, July 2019[5] • Project Summary Report, September 2019 • Operational Project Report #1 and #2, August 2020 • Energy Magazine Article; November 2020[6] (also published in the May 2021 issue of Utility Magazine) • Operational Project Report #3 and #4, July 2021
Site visits	• Construction visit; August 2018 • Completion visit; June 2019[7]

1.2 About Edify Energy

Edify is a leading 100% Australian owned renewable energy company, with significant experience in developing, project financing and delivering renewable and storage projects across Australia. Edify has under construction, or brought into operation, six large-scale solar farms (640MW_{AC} / 770MW_{DC}) and a 25MW / 50MWh lithium-ion battery.

The Edify business model supports the full lifecycle of energy project development and operation, including greenfield development, project structuring and financing, construction management and a full asset management offering, including trading, reporting and managing operations and maintenance personnel. Edify's philosophy is to ensure that its interests are as closely aligned with investors and project stakeholders as possible. For this reason, in addition to providing long-term asset management services, Edify seeks to maintain an equity interest in its projects, resulting in best-in-class assets.

The Edify management team has in excess of 130 years' experience in the power and renewables sector internationally, raised and deployed around $3 billion in capital, brought over 40 solar and wind projects into commercial operation and overseen the construction and operation of a collective operational portfolio of more than 1.7GW. Edify operates as a team across Australia in capital cities and in towns close to the project sites, maintaining a strong connection with the communities in which the solar power and storage plants operate.

Table 2 outlines the projects that Edify has developed, structured, financed and managed the construction of to date. All projects are operational and under Edify's asset management function.

As is noted in Section 1.4 below, GSF and GESS required the creation and registration of a network in order to enable the connection arrangement for these two assets. Edify is one of very few energy companies that has overcome many of the challenges presented in the energy sector's transition in that, in addition to the GESS / GSF network, Edify has developed, structured, financed and has under construction or operation renewable assets, a battery, harmonic filters and a synchronous condenser.

[4] https://arena.gov.au/assets/2019/04/gannawarra-energy-storage-system.pdf
[5] https://www.energy.vic.gov.au/media-releases/australias-largest-integrated-battery-and-solar-system
[6] https://www.energymagazine.com.au/co-locating-renewables-and-batteries-assessing-the-operational-implications/
[7] https://reneweconomy.com.au/edify-energy-celebrates-completion-of-gannawarra-big-battery-73122/, https://www.abc.net.au/news/2019-06-14/australias-largest-solar-and-battery-farm-opens-in-kerang/11209666

Table 2 Edify Energy's Australian development and transaction experience

Project	Capacity	Location	Status	Comment
Whitsunday Solar Farm	58MW_{AC} 69MW_{DC}	Collinsville, QLD	• Operational • Commissioned 2018	• Received ARENA funding • Secured largest Solar 150 Support with QLD Government • Original debt funding with CBA, CEFC and NORD LB
Hamilton Solar Farm	58MW_{AC} 69MW_{DC}	Collinsville, QLD	• Operational • Commissioned 2018	• Short-term PPA with ERM Power for full output • Original debt funding with CBA, CEFC and NORD LB
Daydream Solar Farm	150MW_{AC} 180MW_{DC}	Collinsville, QLD	• Operational • Commissioned 2018	• PPA with Origin Energy for full output • Equity funding with BlackRock • Original debt funding with CBA, CEFC and Natixis
Hayman Solar Farm	50MW_{AC} 60MW_{DC}	Collinsville, QLD	• Operational • Commissioned 2019	• Merchant project • Equity funding with BlackRock • Original debt funding with CBA, CEFC and Natixis
Darlington Point Solar Farm	275MW_{AC} 330MW_{DC}	Darlington Point, NSW	• Operational • Commissioned 2020	• PPA with Delta Electricity for portion of output • Equity funding with Octopus Investments • Original debt funding with CBA and Westpac
Gannawarra Solar Farm	50MW_{AC} 60MW_{DC}	Kerang, NSW	• Operational • Commissioned 2018	• PPA with EnergyAustralia for full output • First large-scale solar farm in Victoria • Original debt funding with CBA, CEFC and NORD LB
Gannawarra Energy Storage System	25MW / 50MWh lithium-ion battery	Kerang, NSW	• Operational • Commissioned 2019	• Grant funding provided by ARENA and VIC Government • Long-term services agreement with EnergyAustralia • One of the largest co-located solar farm and battery facilities in the world

1.3 About EnergyAustralia

EnergyAustralia provides gas and electricity to more than 2.5 million residential and business customer accounts in Victoria, New South Wales, the Australian Capital Territory, South Australia and Queensland. EnergyAustralia is dedicated to building an energy system that lowers emissions and delivers secure,

reliable and affordable energy to all households and businesses. To support this, EnergyAustralia owns, contracts and operates an energy generation portfolio that includes coal, gas, battery storage, demand response, solar and wind assets. Combined, these assets comprise 4,500MW of generation capacity. EnergyAustralia, which has its headquarters in Melbourne, is a wholly-owned subsidiary of CLP Group, one of the largest publicly-owned integrated power businesses in the Asia Pacific. Read more about us here: www.energyaustralia.com.au

1.4 Project overview

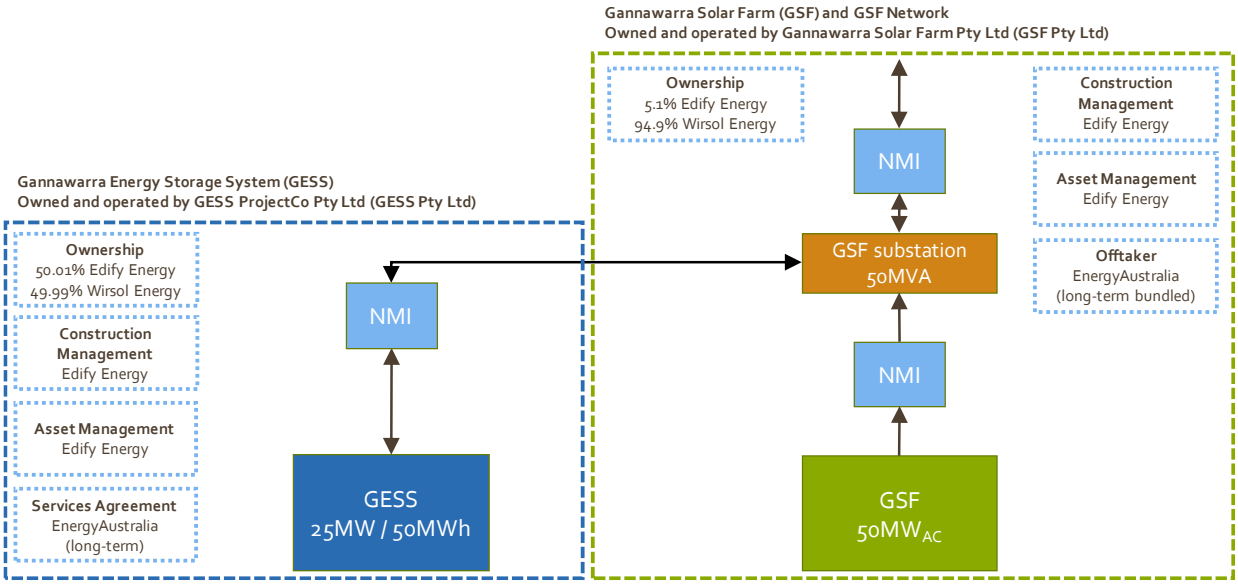
GESS is a 25MW / 50MWh battery that is integrated with Victoria's first large-scale solar farm – GSF (being a 50MW$_{AC}$ solar farm). GESS was developed and structured by Edify and financed by ARENA and DELWP as providers of $25 million in grant funding with Edify in a consortium with WIRCON as 50-50 joint venture co-investors. Tesla was the battery provider, RCR the EPC contractor and EnergyAustralia is the long-term operator of GESS under a novel BSSA.

Now complete and commissioned, GESS is:

- The first integrated utility scale renewable energy and battery system in Victoria and among the first in Australia;
- The first retrofit of a battery to an existing or under-construction solar farm in Australia;
- Among the largest integrated renewable energy and battery systems in the world; and
- A pioneering project for all consortium members and the broader electricity sector given its importance in identifying necessary reforms to bring batteries and other storage technologies to market.

Figure 1 indicates the commercial relationships for GESS and how they interact with GSF. In addition to developing and being a majority owner of GESS, Edify also acts as asset manager and oversaw the construction of GESS, in a similar way to its role in GSF. Importantly, EnergyAustralia holds a long-term offtake position with GSF, that complements its operational role for GESS under the BSSA.

Figure 1 Commercial arrangements for GESS and its interaction with GSF

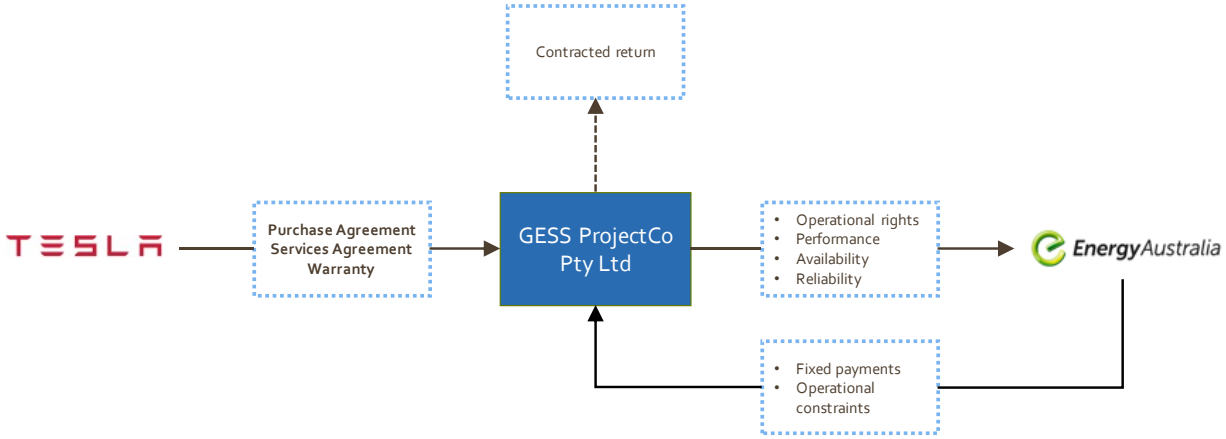


1.4.1 EnergyAustralia as operators

The revenues of GESS are wholly captured in the novel long-term BSSA between GESS and EnergyAustralia. The BSSA entitles EnergyAustralia to full operational rights over GESS, as they relate to charge and discharge decisions in both energy and FCAS markets. Accordingly, EnergyAustralia is the beneficiary of all market-linked revenues from GESS, which it receives in exchange for making fixed payments to GESS.

The BSSA also provides EnergyAustralia with battery performance, availability and reliability commitments, subject to operational constraints, mainly relating to cycling frequency and depths and dispatch capacity limits relating to sharing a connection with the co-located solar farm. The battery purchase agreement provides GESS with performance, availability and reliability commitments from Tesla. Figure 2 outlines these arrangements.

Figure 2 Structure of the novel long-term services agreement with EnergyAustralia



PERFORMANCE

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2 Performance

2.1 Technical performance

Figure 3 and Figure 4 indicate some high-level metrics relating to the technical performance of GESS over its first two years of operation. These can be summarised as follows:

- An average round-trip efficiency of 85.0% (as measured at the connection point of the facility, so accounting for balance of plant losses) has been observed, with month-to-month fluctuations over a few % either side of this average (note that these values, albeit indicative, were not undertaken under standard test conditions, so cannot be considered for the purposes of warranted positions);
- Availability has been high and on average in excess of 99.2%, with minor variations observable each month within a relatively tight band (with the exception of the first month of operations, where a SCADA data collection issue during this period distorts the actual availability);
- The cycle duty of the system has averaged at 0.93 full charge / discharge cycles per day, with values as high as 1.27 and as low as 0.46 observed in some months; and
- This cycle duty has a seasonality relationship, where higher use has been observed during the shoulder seasons leading into and out of summer, rather than during the summer months.

Figure 3 Round-trip efficiency and usage over two-year operational period

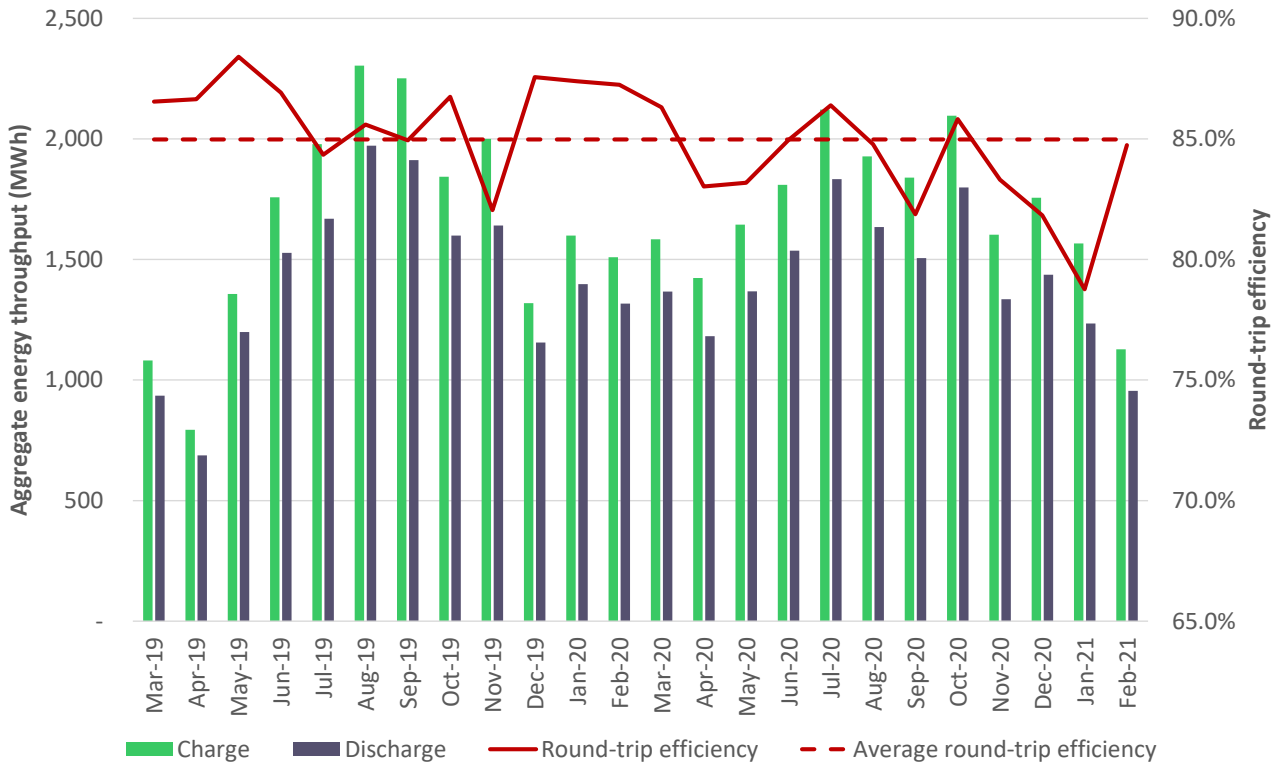
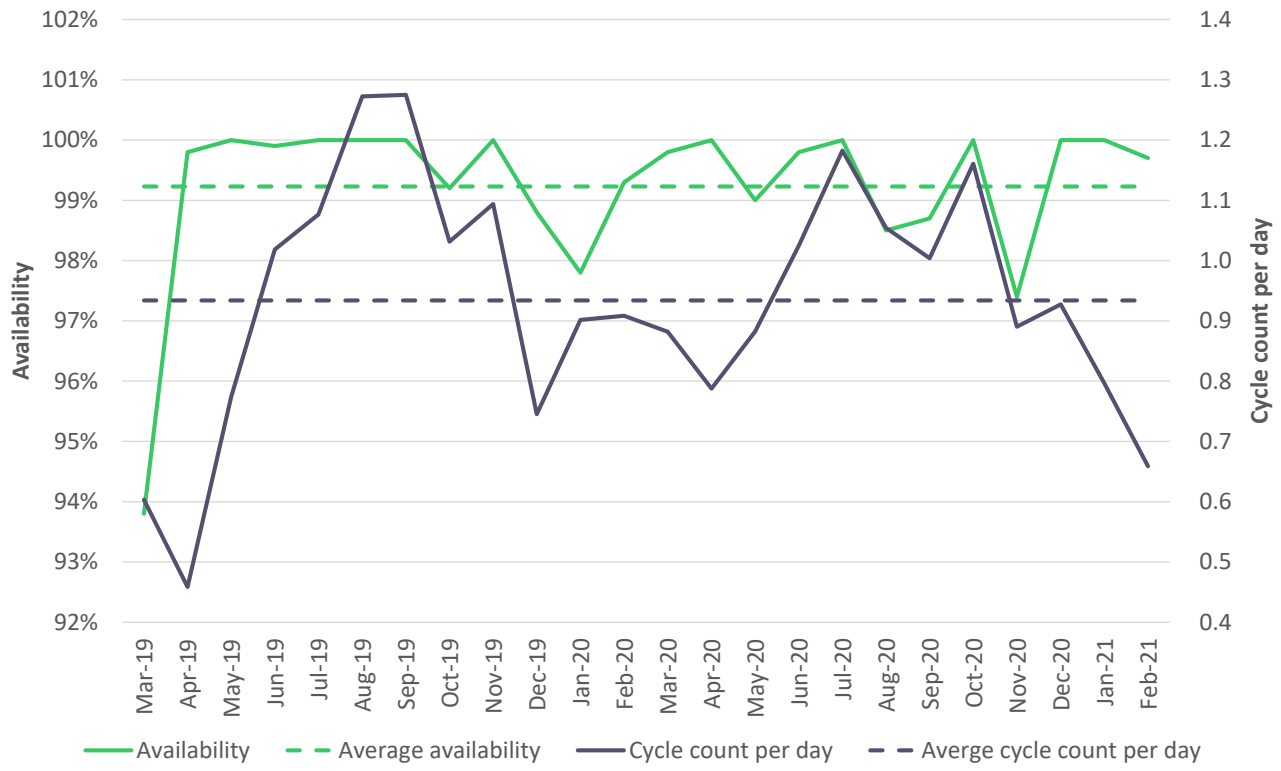


Figure 4 Availability and daily cycle count over two-year operational period



2.2 Financial performance

Figure 5 and Figure 6 outline the financial performance of GESS for its first two years of operations, with Figure 7, Figure 8, Figure 9 and Figure 10 providing some market and operational context to this financial performance. Findings can be summarised as follows:

- Average monthly net-revenues of $281k has been recorded over the project's first two years of operations, with a high degree of fluctuation with monthly net-revenues as high as $1.152m and as low as $20k recorded within the period;
- Following the first few months of operation (and its registration to offer regulation FCAS services), raise regulation FCAS has been the dominant revenue source, comprising 65% of total, where 33% is attributable to the energy market (noting the project was not registered for contingency FCAS during its first two years of operations);
- The net-revenue profile outcomes can be observed through changes to energy and FCAS prices over the same period, where both energy and FCAS tracked significantly lower in the second 12-month period, compared to the first;
- Notwithstanding the considerable change in prices, the operational profile has remained relatively consistent, where an early morning and middle of the day charge strategy has been employed to meet morning and evening peak prices; and
- This early morning charging strategy at a fixed 10MW (outside of solar hours) is despite incurring DUOS charges (see Section 2.2.1), owing to slightly lower power prices in this early morning period compared to during solar hours.

Figure 5 Net-revenue breakdown over two-year operational period

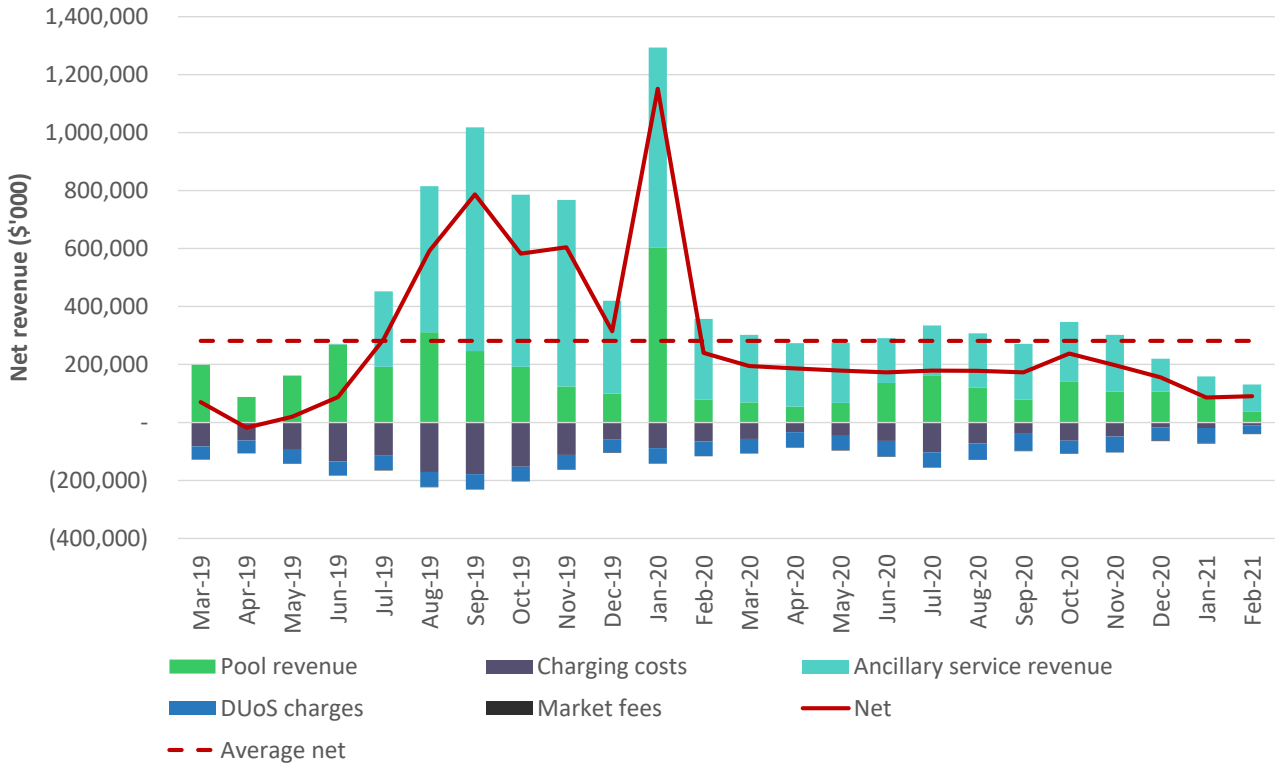


Figure 6 Revenue breakdown over two-year operational period

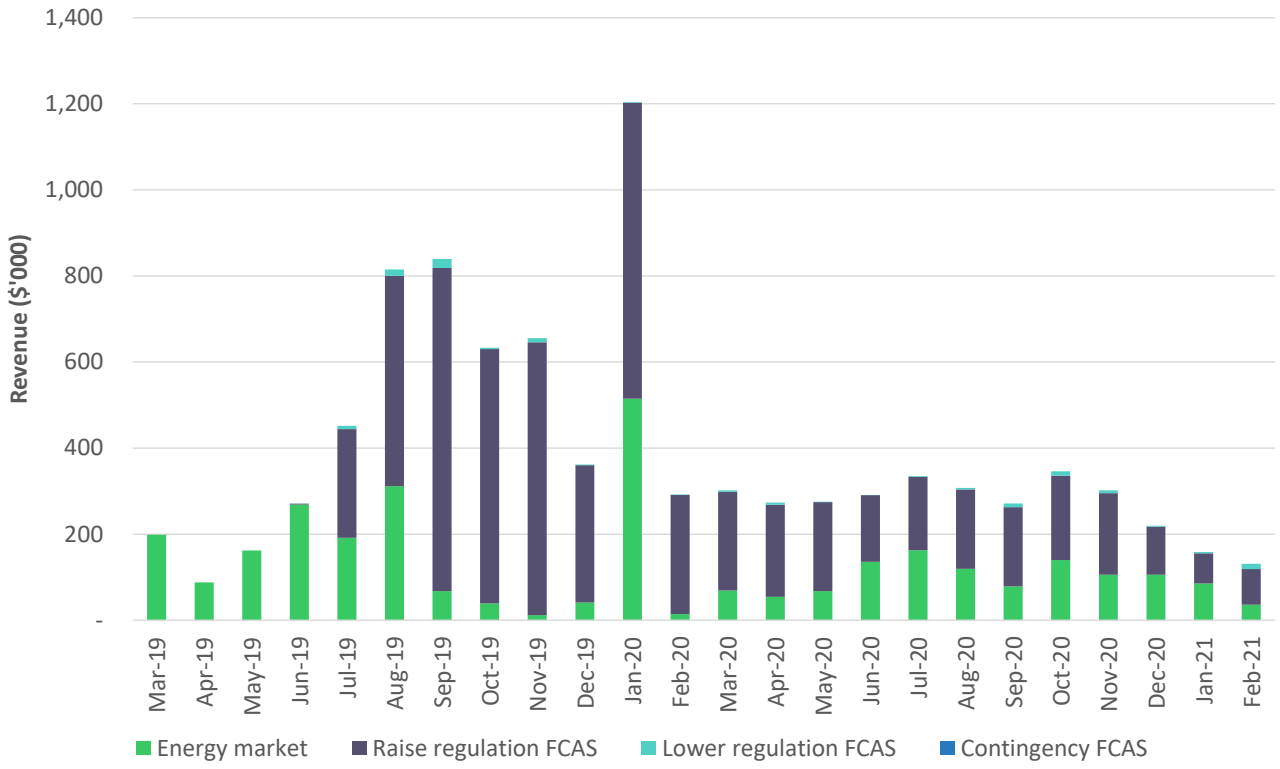


Figure 7 Average VIC trading interval prices by half-hour period and month over two-year operational period

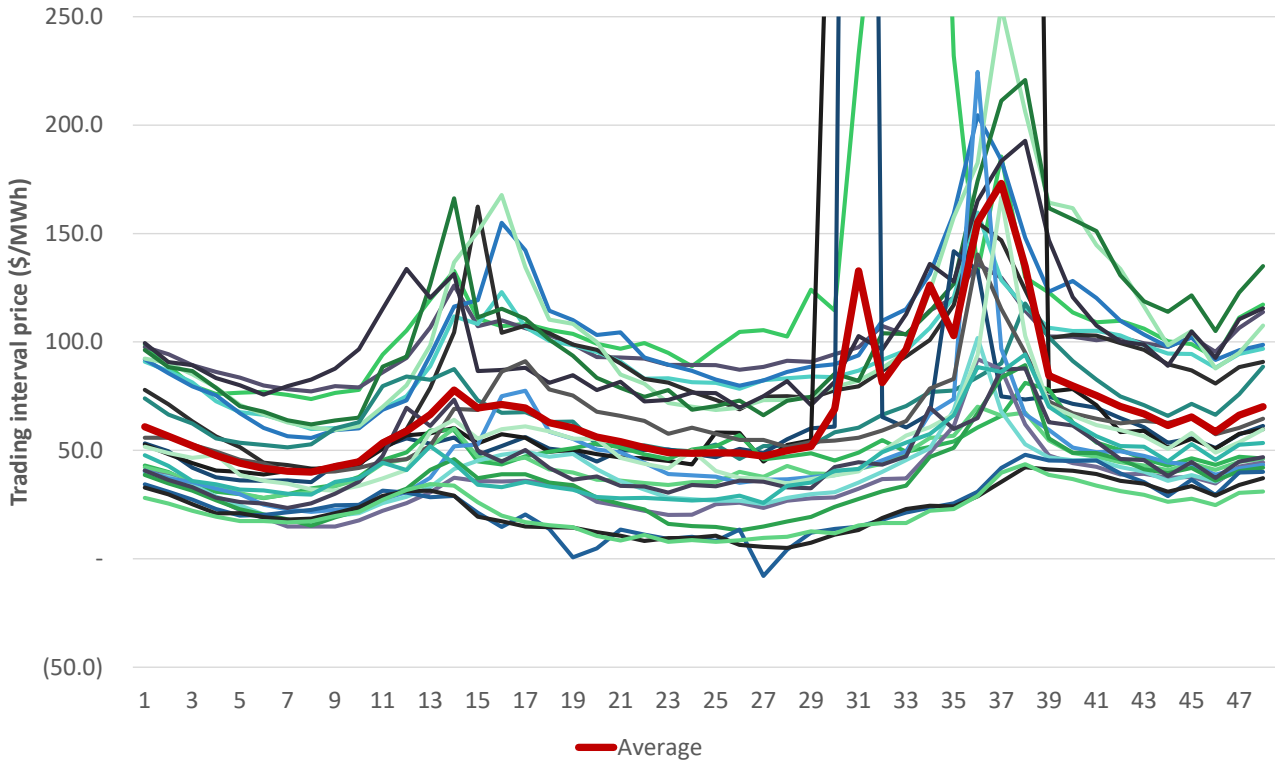


Figure 8 Average VIC trading interval prices by month over two-year operational period

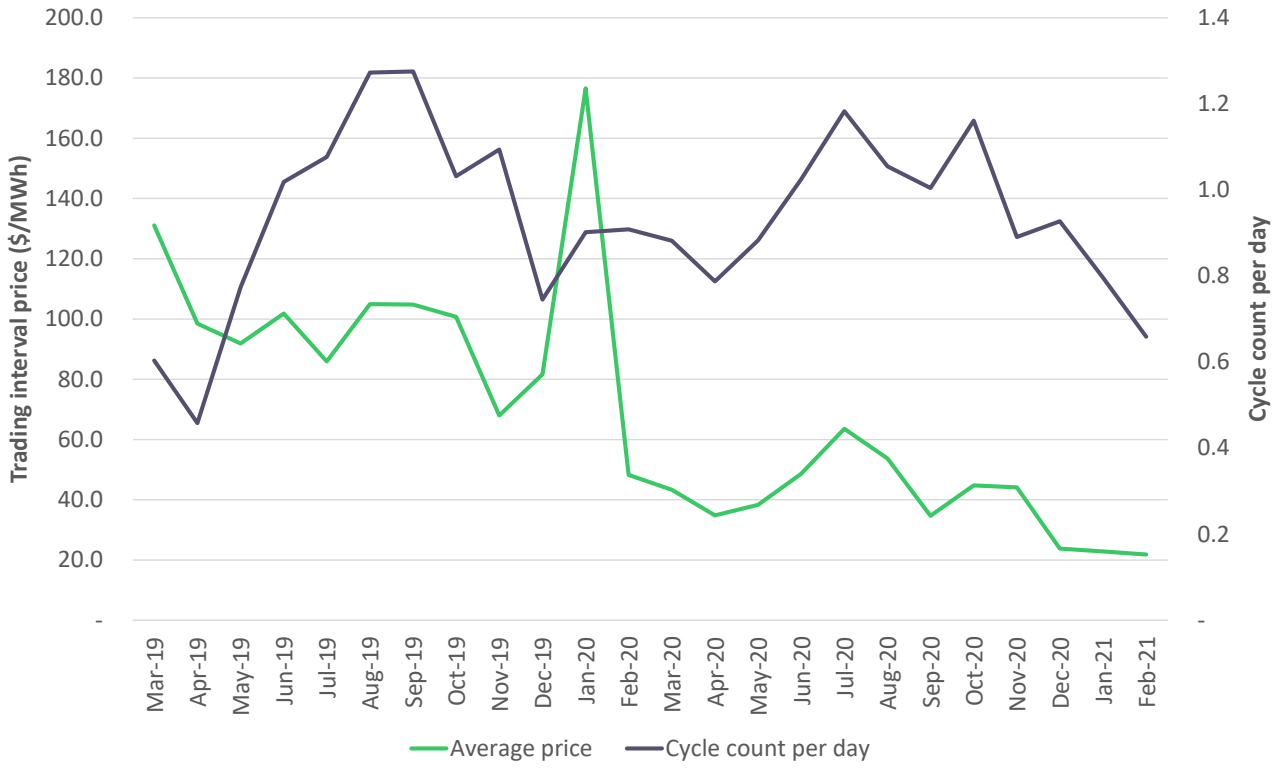


Figure 9 Average interval FCAS prices by month and service over two-year operational period

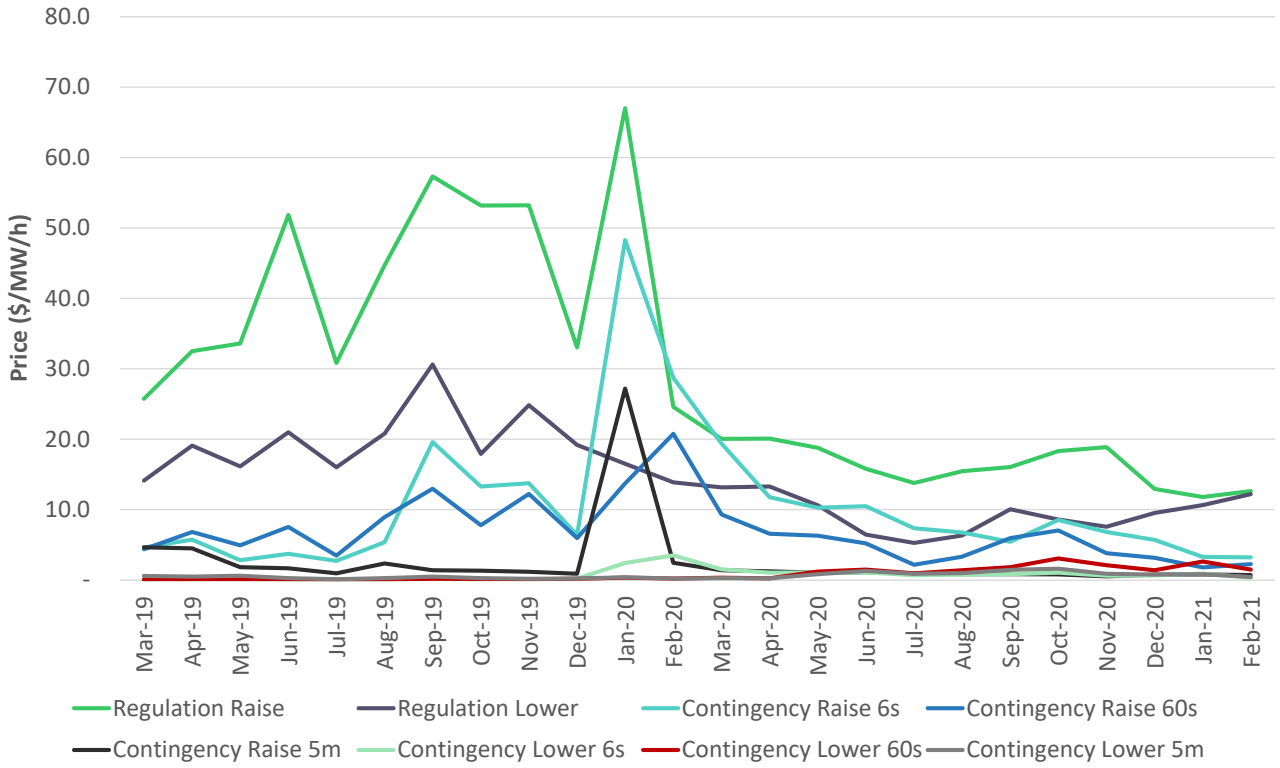
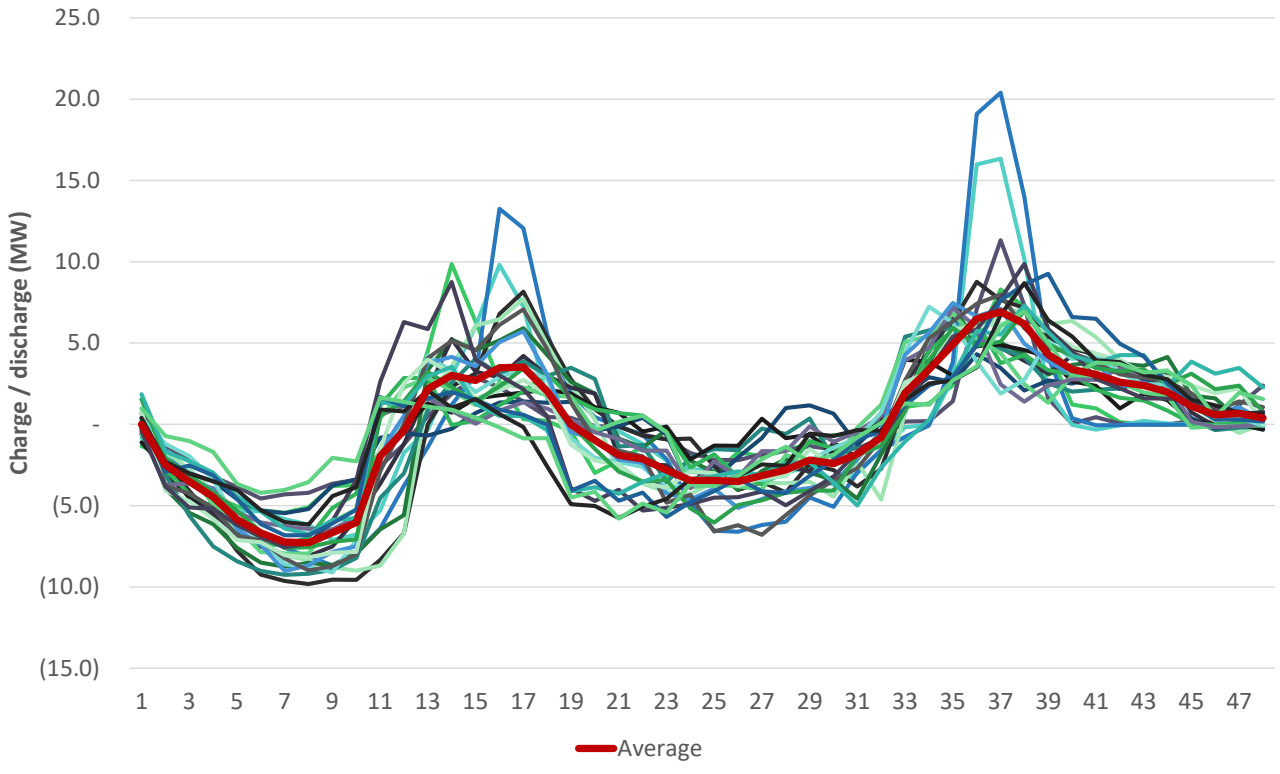


Figure 10 Average GESS operational profile by half-hour period and month over two-year operational period



2.2.1 Network charges and charging implications

The registered network that provides the interface for GSF and GESS with Powercor is subject to DUOS charges imposed by Powercor. As GESS is the primary source of load, most of these DUOS charges flow through to GESS. The network tariff allocated to the combined system is the Subtransmission class, which is usually reserved for subtransmission customers (not generators). Prior to the connection of GESS, GSF was subject to the Large Low Voltage tariff class, where maximum overnight loads for auxiliary power consumption were low (in the order of 150kW) so this was not a material cost impost. In contrast, the fixed and demand charges now imposed on GESS are considerable Table 3 outlines the tariffs for each of the ST and LLV Powercor tariff classes applicable over the first two years of operations.

Table 3 Powercor ST and LLV tariffs for 2019[8], 2020[9] and HY 2021[10]

Charge	Subtransmission	Large Low Voltage
2020		
Fixed ($ p.a.)	252,000	8,200
Demand ($/kVA p.a.)	24.16	107.83
Peak usage (c/kWh)	2.58	4.19
Off-peak usage (c/kWh)	0.78	2.22
2020		
Fixed ($ p.a.)	262,600	8,800
Demand ($/kVA p.a.)	26.26	119.99
Peak usage (c/kWh)	2.80	4.67
Off-peak usage (c/kWh)	0.85	2.47
HY 2021 (January to June 2021)		
Fixed ($ p.a.)	250,000	8,000
Demand ($/kVA p.a.)	18.36	112.43
Peak usage (c/kWh)	1.75	3.85
Off-peak usage (c/kWh)	0.62	2.11

[8] https://media.powercor.com.au/wp-content/uploads/2018/12/20154518/Network-Tariff-Schedule-2016-2019.pdf
[9] https://media.powercor.com.au/wp-content/uploads/2019/11/13093923/Powercor-Pricing-Proposal-2020.pdf
[10] https://media.powercor.com.au/wp-content/uploads/2020/11/26113637/Powercor-HY-2021-Pricing-Proposal-min.pdf

2.2.2 Marginal and distribution loss factors

The application of losses to reference settlement for GESS back to the RRN is subject to one MLF and two DLFs – one for the Gannawarra Solar Farm Network and one for Powercor's Distribution Network[11] – for its generation and load. Given the short electrical distance between the interface of Powercor's network and GESS's metering point, the AER has determined that a DLF of 1.0 is appropriate for the Gannawarra Solar Farm Network. The MLFs and DLFs for the first two years of operation are indicated in Table 4.

Table 4 MLF and DLFs for the reporting period

Loss factor	Generation	Load
FY 2018-19		
MLF	1.0070	1.0311
Powercor DLF (DLF_1)	0.9860	0.9860
Gannawarra Solar Farm Network DLF (DLF_2)	1.0000	1.0000
MLF x DLF_1 x DLF_2	0.9929	1.0167
FY 2019-20		
MLF	0.9643	1.0191
Powercor DLF (DLF_1)	0.9951	0.9951
Gannawarra Solar Farm Network DLF (DLF_2)	1.0000	1.0000
MLF x DLF_1 x DLF_2	0.9596	1.0141
FY 2020-21		
MLF	0.9793	0.9823
Powercor DLF (DLF_1)	0.9901	0.9901
Gannawarra Solar Farm Network DLF (DLF_2)	1.0000	1.0000
MLF x DLF_1 x DLF_2	0.9696	0.9726

2.3 Safety and environmental performance

GESS recorded no safety or environmental incidents in its first two years of operation. This is not unexpected due to the nature of the facility as well as the workplace health and safety policies adopted on site. As a company Edify is always targeting zero incidents for our sites.

During the design of the battery system, elimination of risk has been adopted wherever possible, which is the first principal of risk control. This has been done by eliminating the need for intervention by staff in the operation of the facility as far as possible. The site is designed for fully unmanned operations meaning that

[11] Reference NMI: 6203935735 with DLF code KGS

staff only attend site to respond to faults or to conduct preventative maintenance inspections. This avoids the majority of safety and environmental risk with the facility.

Where staff are required to go to site, the operations and maintenance contractor responsible for oversite of safety on the site has safety procedures in line with best industry practice. This includes ensuring that correct isolations are in place for works to be undertaken and using lock-out procedures to prevent unintended re-energisation. The O&M contractor reviews the work plans of any Tesla staff coming to site to maintain the batteries which are maintained under a services agreement.

The safety record of the facility is also in large part to the inherent safety architecture aspects of the battery system that includes:

- Individual cell testing prior to module assembly to ensure flawed cells are not introduced into the battery system;
- Pods (collection of cells) are fully sealed to prevent thermal spread and have dedicated management systems that monitor individual cells to ensure they are operated within safe parameters;
- Packs (racks of 16 pods) are contained in weather-proof steel enclosures with monitoring and operation optimised to reduce the risk of cascading failure of pods;
- Compliance with national and international safety standards; and
- Exceedance of standards related to fire safety and propagation resistance to thermal runaway within individual cells.

Tesla technicians perform all preventative maintenance and inspections of the battery system which ensures that any issues are identified before they become a safety or environmental concern.

With two consecutive 12-month periods of no recorded safety or environmental incidents at GESS, its performance in this regard has been high.

2.4 Operational regimes

2.4.1 Services provided

As outlined in Section 1.4.1, EnergyAustralia is the registered market intermediary for GESS and is therefore responsible for the bidding of the battery system with AEMO. GESS has been registered as both a Scheduled Market Generator and a Scheduled Market Load in the NEM, and since July 2019 has been registered in the regulation FCAS markets. For this reason, for its first two years of operations, GESS's primary use case was energy arbitrage and providing regulation FCAS services.

Contingency FCAS is an additional revenue opportunity for GESS and one that will give EnergyAustralia an additional tool to maximise value of the battery while keeping within contractual limitations on cycles and SOC. During its first two years of operations, GESS was not registered to provide contingency FCAS services, but will do so in the future.

In its first two years of operations, GESS did not provide additional non-market services, however in accordance with the agreed performance standards and the capability of the plant, it has potential to offer fast-responding services, which will include the new very fast contingency FCAS products. Otherwise, GESS is designed to:

- Maintain its connection point power factor at unity whilst both charging and discharging, and regulate power factor in co-ordination with GSF and in a manner that helps to support network voltages during faults;
- Provide continuous uninterrupted operation within the frequency range 49.5-50.5Hz and in doing so provide support during the period of containment after a generation or load contingency event has occurred and contingency markets have recovered and stabilised the system frequency; and

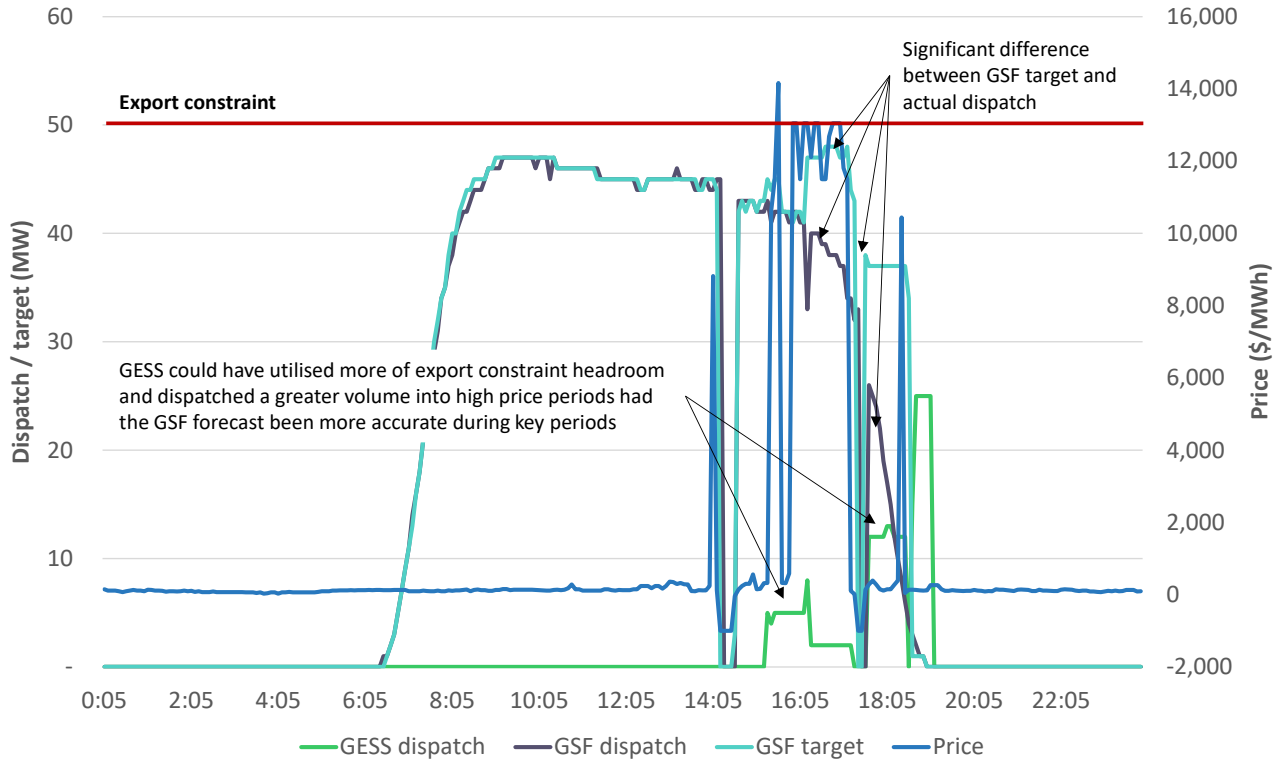
- Utilise control system settings that are capable of providing for automatic increases or reductions in active power for frequency excursions outside the normal operating frequency band, as well as ensuring power system oscillations are adequately damped.

2.4.2 Constraints on operation

As described in Section 1.4, GESS is located within a registered network that is shared with GSF. This registered network is in-turn connected to Powercor's distribution network. The combined connection point of GSF and GESS has a rating of 50MW to which GSF has priority access. Whilst the shared grid connection point and capacity was efficient from a design perspective, it does mean that GESS is effectively constrained to utilising headroom in this connection point from unutilised solar output, which therefore requires accurate real-time knowledge of GSF's output and what headroom is available for GESS.

This constraint can lead to inefficient outcomes, to the extent that solar farm output is inaccurately forecast, resulting in underutilised headroom through the connection point that could have been taken up by GESS. Figure 11 outlines one such example of this during a high price day in 2019. These inefficiencies are particularly prevalent at the beginning and end of the day as the solar output rapidly increases and curtails. Improved real-time information systems (including API links) and accurate forecasting of solar output is therefore a key consideration to optimise battery output for battery and renewable generation systems that share a connection point.

Figure 11 Impact of forecast error on GESS dispatch on 1 March 2019



LESSONS LEARNED

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3 Operational lessons learned

Between the Project Summary Report and the two Operational Reports, GESS has already provided the sector with a number of development, regulatory, delivery and operational learnings, particularly in relation to coordinated battery and renewable plant arrangements. This report should therefore be read in conjunction with these previous reports to provide the reader with the project's full breadth of findings.

A summary of the key lessons learned from an operational perspective for the project's first two years of operations are as follows:

- The shared network infrastructure does not preclude the battery system from performing effectively across the readily accessible markets of energy and FCAS;
- Performance in the energy market has been in line with expectations and was assisted by highly volatile days, where the supply / demand balance was tight;
- Regulation FCAS performance has exceed expectations and has been the stand-out revenue generating performer for the asset since becoming registered in June 2019;
- The facility is not yet providing contingency FCAS services, but this is simply because it has not yet been registered to do so and is not related to any physical capability limitations or the nature of its connection;
- The approach to trading has been to manage the SOC of the battery around the timing of peak demand periods, which is adjusted by season, and to determine the number of cycles / energy dispatched based on the typical spread in prices in the period;
- Concurrent regulation FCAS participation has been used effectively to amplify the revenue potential of individual cycles and to improve the effective cost of charging;
- The two major constraints on operations that GESS experiences, that may be in contrast to other battery systems in the NEM is 1) the application of DUOS charges by Powercor (being distribution network connected); and 2) the management of the 50MW substation headroom constraint around the output of the solar farm;
- Batteries connecting to the distribution network face significant demand-based charges which can result in sub-optimal trading decisions and therefore underutilisation of storage assets. This is mitigated in part by 1) the option to charge during solar hours in the case of the co-located arrangement of GESS and GSF; and 2) access to avoided TUOS payments, which in turn are subject to the accessibility of this revenue stream when managing connection constraints of co-located facilities;
- Despite the significant financial burden that the application of DUOS charges means for charging outside of solar hours, GESS has to this point in time still found it optimal to perform a lower capacity (10MW) charge overnight as this correlates with the lowest price periods and allows the battery to have an available SOC to capture some morning price peaks;
- The primary challenge in managing the substation headroom constraint relates to inaccuracies in the forecast of GSF, where a forecast that is higher than actual can result in underutilised headroom that could have been used by GESS, particularly during tight network events; and
- It is expected that a transition to a more accurate self-forecasting (and away from a reliance on AEMO's forecast) will mitigate these challenges, as will the movement to more coordinated IT system interfaces;
- GESS has performed strongly from a technical perspective, with high rates of availability and no safety or environmental incidents to report.