Broken Hill Battery Energy Storage System

Project Knowledge Sharing Report #2

(Milestone 3)

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The purpose of this document is to provide a summary of the initial development, construction and commissioning phases of the Broken Hill Battery Energy Storage Project.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.

Australian Government
Australian Renewable Energy Agency

ARENA

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Acronyms and Abbreviations

Acronym/abbreviation	Definition
AC	Alternating Current
AEMO	Australian Energy Market Operator
AGC	Automatic Gain Control
ARENA	Australian Renewable Energy Agency
BESS	Battery Energy System
BHBESS	Broken Hill Battery Energy Storage System
BMS	Building Management System
CAPEX	Capital Expenditure
CP	Conditions Precedent
DC	Direct Current
DPE	Department of planning and Environment
EIS	Environmental Impact Statements
EOI	Expression of Interest
EPC	Engineering, Procurement and Construction
FCAS	Frequency Control Ancillary Services
GFM	Grid Forming
GPS	Generator Performance Standards
HP	Hold Point
ITC	Inspection and Testing Certificate
ITP	Inspection and Testing Plans
kV	kilovolts
LSBS	Large Scale Battery Storage
MCC	Mechanical Completion Certificate
MOD	Modified Development Consent
Ms	Milli second
MVA	Mega Volt Amperes
MVAr	Mega Volt Ampere (reactive)
MW	Megawatts
MWh	Megawatt Hour
NEM	National Electricity Market
NER	National Electricity Rules
NOE	Notice of Energisation
NSP	Network Service Provider
OEM	Original Equipment Manufacturer
OFSC	Office of the Federal Safety Commissioner
PCS	Power Conversion System
p.u	Per Unit
POC	Point of Connection
PPC	Power Plant Controller

SCADA	Supervisory Control and Data Acquisition
SCR	Short Circuit Ratio
SMIB	Single Machine Infinite Bus
SoC	State of Charge
SSAT	Small Signal Analysis Tool
SVC	Static var compensator
TNSP	Transmission Network Service Provider
UNSW	University of New South Wales
UPS	Uninterruptible Power Supply
V	Volts

1. Document Purpose and Distribution

1.1. Purpose of Document

This document is a public report issued as part of the Knowledge Sharing commitments of AGL for the Broken Hill Battery Energy Storage System (BHBESS) Project, in accordance with the Funding Agreement between AGL and the Australian Renewable Energy Agency (ARENA), which has contributed funding support through its Advancing Renewables Program.

Broken Hill BESS involves a 50 MW / 50 MWh voltage source inverter (grid-forming) Battery Energy Storage System (BESS) at Broken Hill, Central West New South Wales.

This Project Knowledge Sharing Report focusses specifically on providing a detailed overview of the initial development, construction, and commissioning phases of the Broken Hill BESS project, highlighting challenges and lessons learnt, including:

- Journey to Conditions Precedent (CP) satisfaction date.
- Construction, commissioning and achieving commercial operations.
- Testing.
- Project applicability and next steps.

Over the course of the Project, a wide range of Knowledge Sharing work is being undertaken, including delivery of a range of reports, presentations, meetings, and site visits.

Access to the full list of Knowledge Sharing resources as well as operational information and data is available at the Project Portal, at https://www.agl.com.au/about-agl/how-we-source-energy/broken-hill-battery-energy-storage-system?zcf97o=vlx3ap.

1.2. Intended Distribution

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

2. Introduction

2.1. Project Overview

The Broken Hill Battery Energy Storage System (BHBESS) is a 50 MW / 50 MWh large scale battery energy storage system located approximately 200 m from Transgrid's Broken Hill substation in New South Wales. It is connected to the Broken Hill substation via a 22 kV underground transmission cable.

The EPC contractor, Fluence/Valmec has procured inverters from EPC Power that have grid-forming and islanding functionality. For the initial installation, the inverters were configured to switch from grid-forming to grid-following mode during a system fault to assist the BESS to meet the technical requirements specified in s5.2.5 of the National Electricity Rules (NER) implemented in October 2018.

Following the AEMO review of these technical requirements in March 2023, the requirements have been relaxed. Consequently, a 5.3.9 process is underway to retrospectively modify the functionality of the inverters to remain in grid-forming mode throughout a system fault.

This Project Knowledge Sharing report is a key requirement under Milestone 3 of the Funding Agreement between AGL and ARENA. It covers the journey and lessons learnt during the initial development, construction, and commissioning phases of the Broken Hill BESS project.

Section 1 describes the Report's purpose, the intended audience and any distribution restrictions. This section also includes a link to the on-line portal where all Project Knowledge Sharing information is located.

Section 2 provides an overview of the Project and key project objectives.

Section 3 provides a summary of the journey to conditions precedent (CP) satisfaction date, including the grid connection process, procurement, key commercial considerations and securing finance and key challenges and lessons learnt.

Section 4 provides an overview on the construction, commissioning and commercial operation activities.

Section 5 outlines the testing conducted and the key insights.

Section 6 provides an overview of the key lessons learnt.

Section 7 outlines the project applicability and next steps.

2.2. Project Objectives

Real world experience with the grid-forming battery at Broken Hill is expected to provide greater insight into how such inverters can overcome the voltage stability concerns that have been raised with grid-following inverters.

Early generation inverters have been grid-following, acting as current sources which have been known to interact with the grid (particularly with nearby SVCs) to produce sub-synchronous voltage oscillations. These oscillations cause the most concern when they continue for extended periods (hours) without attenuation in weaker parts of the grid.

Weaker parts of the grid typically are more electrically remote from the main system and get less support to maintain a stable voltage waveform. During a severe fault in such locations, the voltage waveform will inevitably be quite distorted. The corollary is that voltage disturbances at weak grid locations have little impact on the main grid.

Modelling performed by UNSW on its testbench has confirmed that the voltage source mode of operation employed by grid-forming inverters can mitigate sub-synchronous oscillations in the remoter parts of the grid where many wind farms and solar farms are expected to connect.

The project objectives are listed below:

- Accelerate commercialization of large-scale battery storage (LSBS) with grid-forming inverters in weak-grid areas.
- Provide a cost-effective alternative to expensive grid-supporting equipment like synchronous condensers.
- Improve system strength to reduce investment risks in renewable energy projects.
- Inform key stakeholders, including Transmission Network Service Providers (TNSPs) and AEMO, about grid-forming inverters as a credible source of system strength.
- Assess the need for standardized performance specifications for grid-forming inverters and methods to measure their contribution to system strength.

2.2.1. Black Start Capability

AGL has registered BHBESS to support black start capability for a loss of grid power. Transgrid is responsible for restoring the power system in the vicinity of the BHBESS following the operating protocol and nominated communications channels.

No external supply is required to safely shut down the BHBESS and the shutdown will be almost instantaneous when loss of grid occurs. In emergency situations, uninterruptible power supply systems (UPS) will back up the critical control systems. An AC UPS with 3 hours capacity inside the Control Room Building will provide safe shutdown and reliable operation of complete SCADA system. Battery Management System (BMS) and PCS (Inverter) has a UPS with a duration of between 20 minutes to 1 hour. A 110V DC supply standalone system with 4 hours backup time will provide control, monitoring, protection, and indication of high and low voltage plant/equipment and that includes 22 kV Line Protection Relays and 22 kV Ring Main Unit Relays.

On the other hand, generating units (i.e., inverter units) in a shutdown sequence will restore service as soon as external supply becomes available. The design is to restart generating units within 10 minutes when operating within the control parameters. Generating unit controls and monitoring system require restart and initiation sequence to complete (approximately 15-20 minutes), independent of a safe shutdown procedure prior to shutdown sequence.

If external supply is made available within 30 minutes, the generating units can start instantaneously.

However, if external supply is not made available within 30 minutes, it will take 60 minutes to start the generating unit. If external supply is lost, the system can still function up to 30 minutes from the UPS backup power.

2.2.2. Project Objectives Achieved

BHBESS successfully completed all hold point commissioning tests and received approval of unconstrained full output (50 MW) operation from AEMO and Transgrid on 21st August 2024. After final hold point testing (HP2) it was participating in the energy market with full output, following AEMO dispatch targets and operating in AGC mode. During hold point 1 (HP1) and hold point 2 (HP2) testing, the battery's performance was evaluated through various dynamic tests, such as the voltage reference step test and reactive power step test, and it was found to show robust performance in line with GPS compliance. This serves as a strong example of BHBESS providing system strength support in a weak grid area, considering its location in a very remote part of the network.

The successful operation of BHBESS can pave the way for the commercialization of large-scale battery storage (LSBS) equipped with grid-forming inverters in weak-grid areas, offering a cost-effective alternative to traditional grid-supporting equipment like synchronous condensers. BHBESS is also participating in Transgrid's expression of interest (EOI) for providing system strength support in the Broken Hill area. BHBESS is now planned to go through the 5.3.9 process to enhance the core capabilities of grid-forming (GFM) inverters as defined in the recently published AEMO voluntary specifications.

3. Journey to Conditions Precedent (CP) satisfaction date

3.1. Grid Connection Process

The connection application for BHBESS was not a condition precedence (CP) in the funding agreement with ARENA. Due to the time limitation, AGL elected to continue with its Final Investment Decision (FID) before lodging the connection application and include this activity in the post FID activities.

3.2. Procurement

AGL evaluated multiple contracting strategies for the project before making the Final Investment Decision (FID). It was concluded that an Engineering, Procurement, and Construction (EPC) arrangement would be the most suitable approach for the Broken Hill Battery Energy Storage System (BESS). As a result, AGL conducted a closed tender process, inviting only known and pre-qualified suppliers. A key factor in the prequalification of vendors was their ability to provide a grid-forming solution for the Broken Hill BESS.

The selected Original Equipment Manufacturer (OEM), Fluence, did not possess the required accreditation from the Office of the Federal Safety Commissioner (OFSC). Consequently, AGL awarded the EPC contract to the consortium of Fluence and Valmec (Altrad) for the design, procurement, and construction of the Broken Hill BESS.

Additionally, a project agreement was executed between AGL and Transgrid for the extension of the existing 220 kV switch bay and the connection of the BESS to the Broken Hill Substation.

3.3. Key Commercial Considerations and Securing Finance

A comprehensive financial model for the Broken Hill Battery Energy Storage System (BESS) was developed and reviewed by multiple stakeholders, including ARENA. External financing was not required for the Broken Hill Project, as AGL opted to fund the project through its balance sheet and annual capital expenditures (CAPEX).

3.4. Key challenges and Lessons Learnt

One of the primary challenges in meeting the Conditions Precedent (CPs) was to demonstrate that the project would be able to achieve its defined objectives, particularly the grid-forming capability of the system. To address this, multiple studies were conducted by the University of New South Wales (UNSW) and EPC Power, the inverter's Original Equipment Manufacturer (OEM). Given that this was an emerging technology at the time of the Broken Hill BESS development, understanding the requirements and predicting system behaviour posed significant challenges.

4. Construction, Commissioning and Achieving Commercial Operations

4.1. Overview of construction, commissioning, and commercial operation activities

4.1.1. Construction

The Broken Hill BESS project was awarded as an Engineer Procure Construct (EPC) contract to the Consortium of Fluence and Valmec. The Consortium developed the concept designs into detailed construction documentation for review and approval by AGL prior to commencing procurement and construction. AGL reviewed the construction documentation packages to ensure that safety, operational and quality requirements of the contract were met. The design review process allowed for AGL comments to be incorporated into the construction documentation prior to procurement to make sure compliance issues were identified early.

The Consortium divided the project into a primary process component and a balance of plant component. The primary process component consisted of the batteries and inverters, on which the Fluence control system has direct operational control of. The remainder of the plant was allocated as balance of plant components, such as transformers, cables, switchyard, and switchgear. As per the Consortium Agreement between the two companies, Valmec has been responsible for the Balance of Plant (BOP) equipment design and installation, to allow Fluence to focus on its specialty of batteries and inverter integration.

During the construction process, the Consortium divided the site into discrete physical areas to enable different workgroups to focus on different construction stages at different times within the discrete areas. For example, at times there were civil works occurring on one half of the site while electrical installations were occurring on the other half of the site. This physical delineation of areas improved safety by keeping different types of resources and machinery separate from each other.

4.1.2. Pre-Commissioning (ITPs and ITCs)

Pre-commissioning is the process of verifying that the electrical plant is mechanically complete, fully electrically connected, and safe to power up and energise. The goal of the pre-commissioning process is to energise the electrical plant safely to handover to the commissioning team to undertake hold point testing of the plant prior to operational handover. To achieve this the plant was divided up into functional subsystems such as switchyard, protection, cables, transformers, inverters, batteries, switchboard etc and Inspection and Testing Plans (ITPs) and Certificates (ITCs) templates were designed to ensure all required tests before energisation were covered. AGL reviewed the Consortium's proposed ITPs and ITCs to ensure that all testing to verify safety to energise were covered. These included mechanical tests (such as hold down bolting, panels secured, conduits cleaned, cables connected and tight etc), offline test set injection of electrical tests (insulation integrity tests, voltage withstand tests, transformer characteristics etc) as well as protection and control system checks. Protection and control systems checks are performed with the protection and control systems live but the primary high energy systems de-energised. The protection and control system checks are performed to verify that the systems are ready for energisation, and that they will adequately control and protect the plant when primary energy is connected.

AGL witnessed most of the ITP and ITC testing, and signed off on all of the completed forms, including signing off on each individual equipment items clearance to energise using a Mechanical Completion Certificate (MCC) process. This provided an independent and client-supported process to ensure that all construction, pre-commissioning and asset owner requirements were demonstrated before energisation. In instances where AGL was not satisfied with the pre-commissioning test results or coverage, AGL recommended further testing or evidence prior to signing.

An important element of pre-commissioning was the coordination of the testing with the TNSP Transgrid, who owns the substation where the facility connects to. AGL and Transgrid shared protection testing results from both sides of the connection point and carried out joint commissioning testing to ensure that the connection to the transmission substation was also adequately protected according to the design.

Initial energisation of the plant was carefully coordinated with all parties to make sure that all people were aware that plant that was previously de-energised will now be energised. This is an important element of a project, where it transitions from dead plant to live plant. This project used 24-hour Notice of Energisation (NOE) processes as well as boundary isolations between live plant and construction plant. Boundary isolations provide two physical air gaps between construction and energised plant instead one physical airgap typically used in operations. This improves the safety to construction workers and means that construction can continue without isolation certificates.

4.1.3. Commissioning (Performance and Reliability)

Refer to section 5 for commissioning testing of performance and reliability.

4.1.4. Commercial Operations

Broken Hill BESS will be operated commercially in the Energy, Regulatory frequency control ancillary services (FCAS) and Contingency FCAS markets.

4.2. Planning and Environmental approvals

- Modified Development Consent:

The original Environmental Impact Statement (EIS) for the project was prepared based on an above-ground transmission line concept. In 2022, after further design and consultation with Transgrid, there was a need to change the design to an underground transmission cable. Consequently, AGL conducted further assessments and prepared a Modification Report for the review of the Department of Planning and Environment (DPE). This report was approved by the DPE, and Modified Development Consent (MOD 1) was issued by the Department in July 2022.

- Staging of Secondary Approvals:

Due to the extended timeframe required for the completion of consultations on secondary management plans with external stakeholders, AGL requested that the DPE approve the staging of secondary approvals (management plans) as per the following stages:

- Stage 1: construction of the BESS
- Stage 2: construction of the transmission line and connection works; and
- Stage 3: operation of the project.

This request was approved by the Department in December 2021.

- Extension of time for Fire Safety Study:

Due to the delay in the approval of the Fire Safety Study, AGL requested the Planning Secretary to approve an extension of time for the approval of the Fire Safety Study. Consequently, the condition was amended from "required prior to commencing construction" to "required prior to the delivery of battery components to the site."

- Extension of Construction Working Hours:

To expedite the construction of the battery, AGL requested the Planning Secretary to approve out-of-hours construction work. Consequently, the construction working hours were extended from ‘8:00 AM to 1:00 PM on Saturdays’ to ‘7:00 AM to 6:00 PM on Saturdays’ and from ‘not permitted on Sundays and NSW public holidays’ to ‘8:00 AM to 1:00 PM on Sundays and NSW public holidays.

4.3. Community consultation and safety

The location of the BESS in an industrial estate was ideal. With near neighbours being businesses, the community consultation involved visiting each business and sharing contact details of key Project personnel. The EPC built relationships with the nearby businesses, and AGL does not foresee any ongoing issues. There were some design changes with the fencing on one boundary that required engagement with that business. This was resolved and all parties were satisfied with the outcome.

5. Testing

Broken Hills Battery Storage System (BHBESS) completed Hold Point 0, Hold Point 1 and 2 testing from 8th February to 10th February; 19th March to 5th April and from 14th May to 22nd May respectively. These hold-point tests were to demonstrate the compliance of the plant with the generator performance standard (GPS) issued by AEMO.

5.1. Aim of the test

In accordance with the National Electricity Rules (NER) S5.5.7[1], AEMO has published Power System Model Guidelines[2]. Under the condition described in the Rules, the Generator is required to assess the performance of BHBESS in terms of Generator Performance Standards (GPS) as per the NER S5.7.3. The Generator is also required to validate the BHBESS models and design data to R2 status in accordance with NER S5.5.2.

As a result, three hold points tests have been developed and proposed to assess the GPS compliance as listed in Table 5.1

Table 5.1: BHBESS commissioning sequence and hold points

Hold point	Date	Discharge/Charge at hold point (MW)	Minimum discharge/charge (MW)	Max. no. of BESS units in service
0	8th to 10th February 2024	+/- 3.0	+/- 2.4 (80%)	2
1	19th March to 5th April 2024	+/- 25	+/- 20 (80%)	22
2	14th to 22nd May 2024	+/- 50	+/- 45 (90%)	44

[1] National Electricity Rules (NER), ver 186
[2] Power System Model Guidelines, ver 1.0, Jul 2018

During the testing phases, Hold Point 0 and Hold Point 1 evaluated the performance of a single inverter with half of the plant units online to ensure stable operation and assess any impact on power system stability or security. Hold Point 2 involved similar tests but with all units in service to demonstrate the overall plant performance.

It is important to note that BHBESS operated under N-1 conditions during the commissioning period, with only one 22/220 kV transformer in service. The grid impedances provided by Transgrid for fault level calculations at 220 kV were as follows:

- Grid resistance, R = 0.078480 per unit (based on a 100 MVA base)
- Grid reactance, X = 0.410983 per unit (based on a 100 MVA base)

The agreed test under N-1 conditions included:

1. In voltage droop control mode, apply a +/- 5% step change in voltage reference setpoint as per test procedure outlined in AEMO R2 test guidelines[3] for N-1 system outage tests (HP3_WFSOT/HP3_SFSOT)
2. In reactive power control mode, apply a +/- 10 MVAr step change in reactive power reference setpoint as per test procedure outlined in AEMO R2 test guideline for N-1 system outage tests (HP3_WFSOT/HP3_SFSOT)

The size of the step changes was adjusted based on pre-test simulations to prevent any unnecessary disturbance in the surrounding network.

5.2. Methodology description

5.2.1. Measurement equipment

To ensure high-quality test results, BHBESS has been equipped with high-speed response capture meters devices, installed at various locations, including the 220 kV busbar and the 22 kV point of connection (POC). The meters are capable of capturing data at high speeds, with sampling rates of up to 1,024 samples per cycle for detailed analysis.

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[3] GPS Compliance Assessment and R2 Model Validation Test Plan Template for Inverter-based Generation Technologies, AEMO, February 2020.

To guarantee the accuracy of the meter reading, all equipment used in the tests had been calibrated, and the calibration certificates have been submitted to AEMO and TNSP.

5.2.2. Reactive power set point step test (Qref test), local control

On May 16, 2024, the BESS reactive power control step test under Hold Point 2 (HP2) was conducted with a state of charge (SoC) of approximately 80%. Prior to the test, 44 units were operational under Fluence PPC's active power and reactive control. According to the test details outlined in the agreed test plan, the BHBESS PPC applied a ±10 MVAr step change to the reactive power setpoint.

Prior to the test, the reactive power control setpoint (Qref) was configured to 0 MVAr, and the active power control setpoint was set to +33.32 MW[4] (discharging). The ramp rate limits for both active and reactive power were disabled on the controller before applying the reactive power step change. Following this, the BHBESS PPC adjusted the active power setpoint to -40 MW (charging) to conduct the step test in the charging direction.

The applied test changes are summarised in the table below:

Table 5.2: Applied test changes

SoC	Discharging, Pref = +33.32 MW	Charging, Pref = -40MW
High, 80%	Qref = +/- 10 MVAr	Qref = +/- 10 MVAr

5.2.3. Voltage droop control set point step test (local control)

The BESS voltage droop control set point step test was conducted on May 16, 2024. Prior to the test, all 44 units were operational under Fluence PPC, managing both active power and voltage droop control. To mitigate system constraints and avoid unnecessary voltage disturbances in

[4] +33.332MW was requested by NSP due to system constraint

the surrounding network, the step size was reduced to ±2.5%. The active power and reactive power ramp rate limits were disabled on the PPC.

The tests were performed at both low state of charge (SoC) of 21% and high SoC of 80%, assessing performance in both charging and discharging modes. Initially, the active power setpoint (Pref) was set to +40 MW (discharging), and the voltage droop control setpoint (Vref) was set to 1.02 pu before applying the step change. The tests were then repeated in the charging direction with the active power setpoint (Pref) adjusted to -40 MW to evaluate the BHBESS responses.

The step changes were applied as the table below:

Table 5.3: Applied step changes

SoC	Discharging, Pref = +40MW	Charging, Pref = -40 MW
High, 80%	Vref = +/- 0.025 pu	Vref = +/- 0.025 pu
Low, 80%	Vref = +- 0.025 pu	Vref = +/- 0.025 pu

5.3. Results and any key insights and learnings

5.3.1. Reactive power set point step test (Qref test), local control

The tests outlined in the section 5.2.3 have been completed as planned. The reactive power response closely followed the reference set point, though some delay was observed between the command set point and the meter reading. This delay is likely due to interactions between the PPC, inverter and battery.

At steady state, following the step change, the reactive power remained stable and constant. Although some oscillations were noted in the voltage response during the steady state, they remained within the 10% tolerance band specified in the test plan. These oscillations are likely attributed to interactions with grid elements on the 22 kV transmission lines, such as the SVC and nearby wind farms, which were actively regulating voltage and opposing changes caused by the reactive power adjustments. To further investigate the root cause of these oscillations, a small signal model (SSAT) is recommended.

The rise time and settling time meet the requirements specified in GPS clause S5.2.5.13 for voltage and reactive power control under NER rules. Figures 5.3.1.1 and 5.3.1.2 below, depict the data recorded at the 22 kV point of connection (POC).

Figure 5.3.1.1: Reactive power step test, (Qref: 0 à 10 MVAr), high SoC, high output (discharging), result at POC

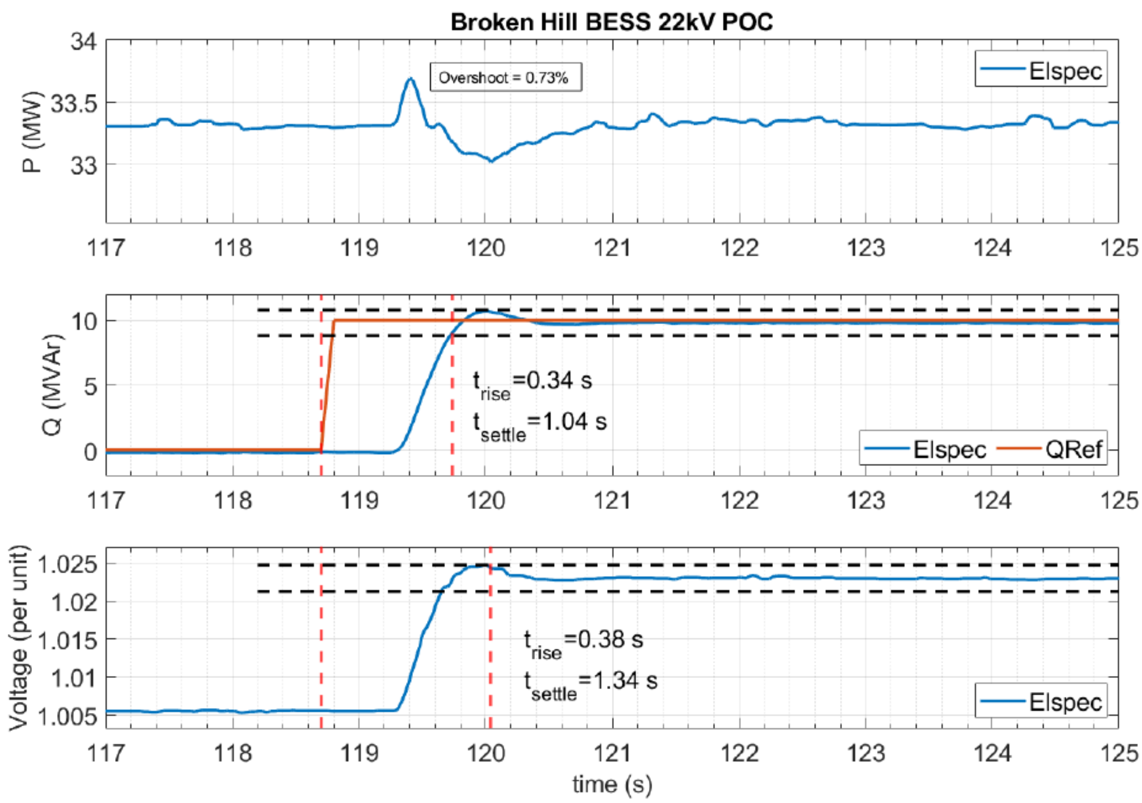


Figure 5.3.1.2: Reactive power step test (Qref: 0 à 10MVAr) under high SoC, high output (charging), result at POC

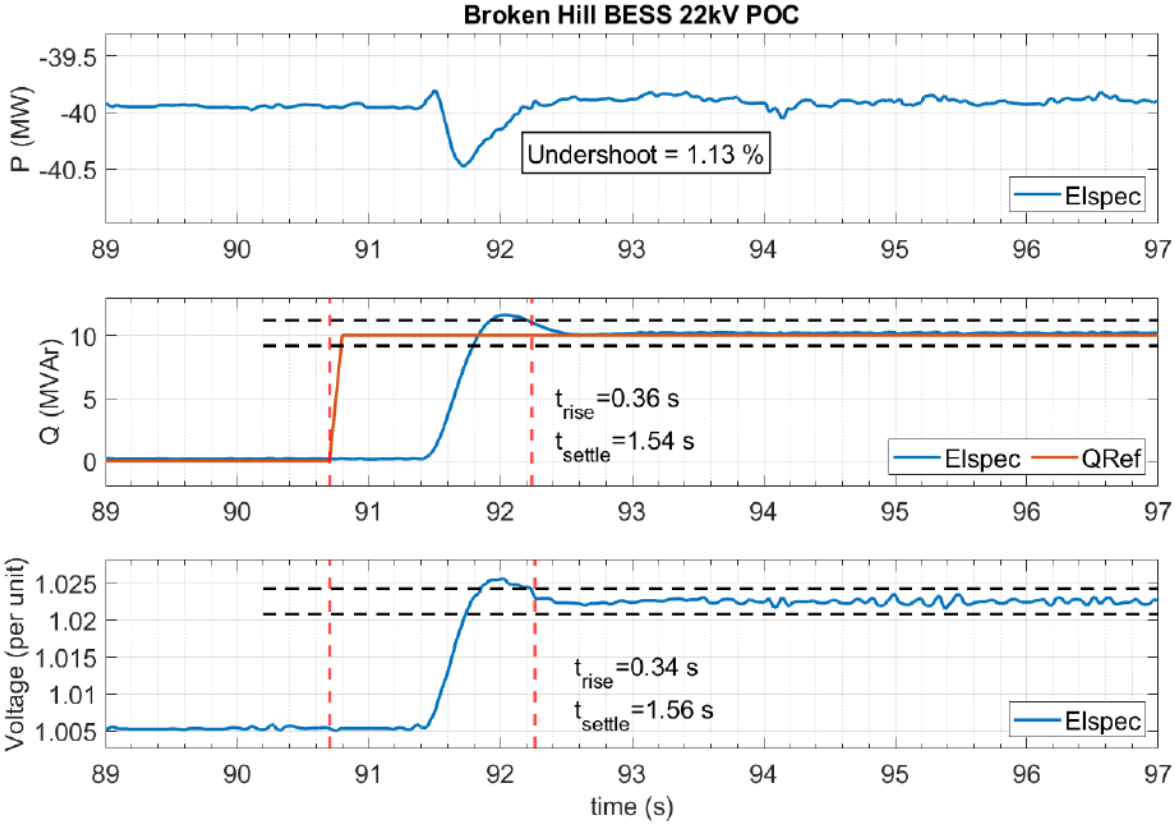
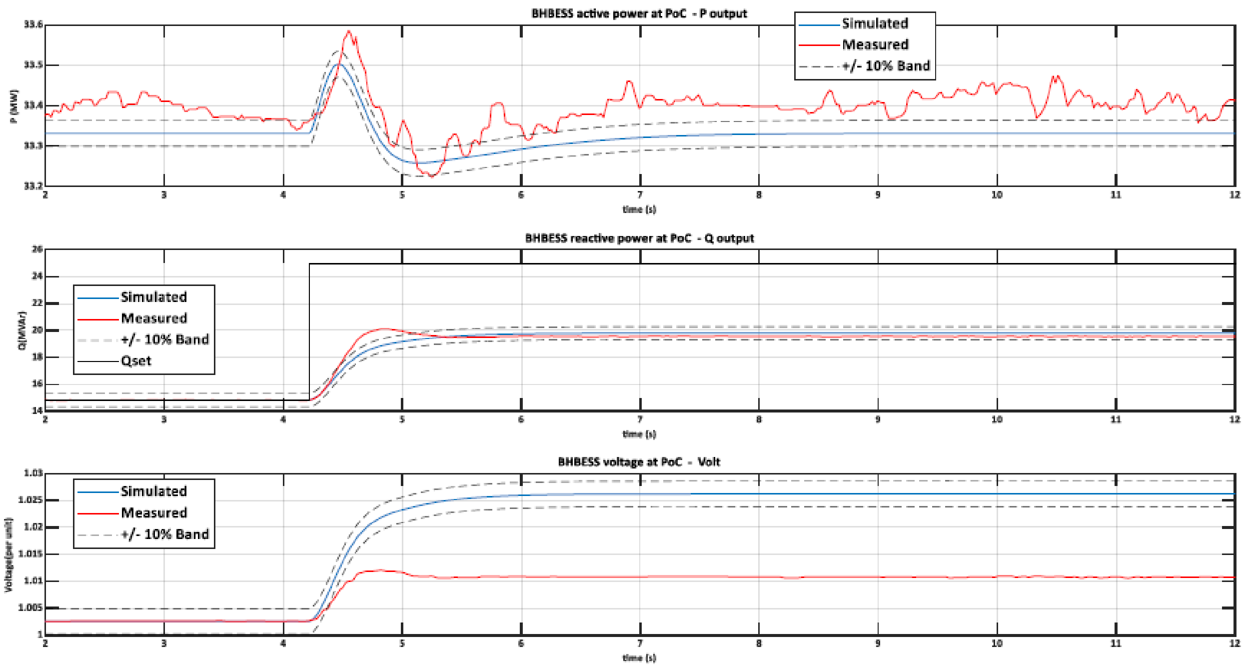


Figure 5.3.1.3 below displays an overlay of the BHBESS step test measurements and simulation results for the reactive power step test. The plot indicates a strong correlation between the active power response at the point of connection (POC) and the simulation. The measured reactive power appropriately adhered to the BHBESS reactive limit (Q limited to 19.75 MVAr), even though the Qref set point was 25 MVAr. The steady-state responses were within the ±10% tolerance specified by AEMO requirements, except for the voltage response. This discrepancy is likely due to interactions with the 22 kV transmission elements, such as the SVC and nearby wind farms, which are designed to counteract voltage disturbances in the network.

Figure 5.3.1.3: Model overlay simulation, reactive power step test (Qref: 15 à 25 MVAr), high SoC, discharging, result at POC



5.3.2. Voltage droop control set point step test (Vref test), local control

The tests conducted in the previous section were completed successfully, and the results meet the acceptance criteria outlined in the test plan. Although some oscillations were observed, the damping ratio of approximately 0.1 indicates that the response is adequately damped, thus satisfying the damping requirements specified in the National Electricity Rules (NER). The oscillations in the voltage signal during the steady state are likely due to interactions with grid elements on the 22 kV transmission lines, such as the SVC and nearby wind farms, which regulate voltage and counteract disturbances. To pinpoint the root cause, a small signal model (SSAT) is recommended for a detailed analysis of each control element at low frequencies.

Figures 5.3.2.1 and 5.3.2.2 below illustrate the BHBESS response to voltage step changes. Although some oscillations are present, they are considered adequately damped with a damping ratio of around 0.1, as per NER requirements. The rise time and settling time for both reactive and active power comply with the specifications of GPS clause S5.2.5.13 under NER rules.

Figure 5.3.2.1: Voltage step test (Vref: 1.02 à 0.995 pu), high SoC, high output, discharging

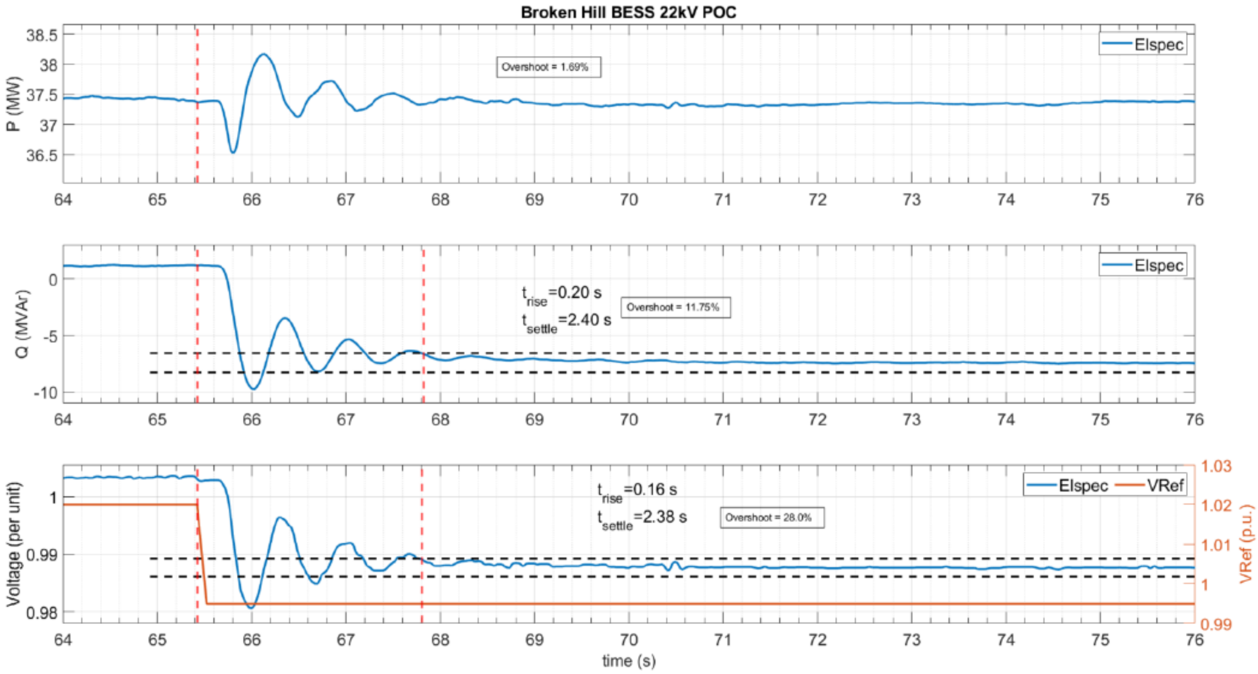


Figure 5.3.2.2: Voltage step test (Vref: 0.995 à 1.02 pu), high SoC, high output (charging), result at POC

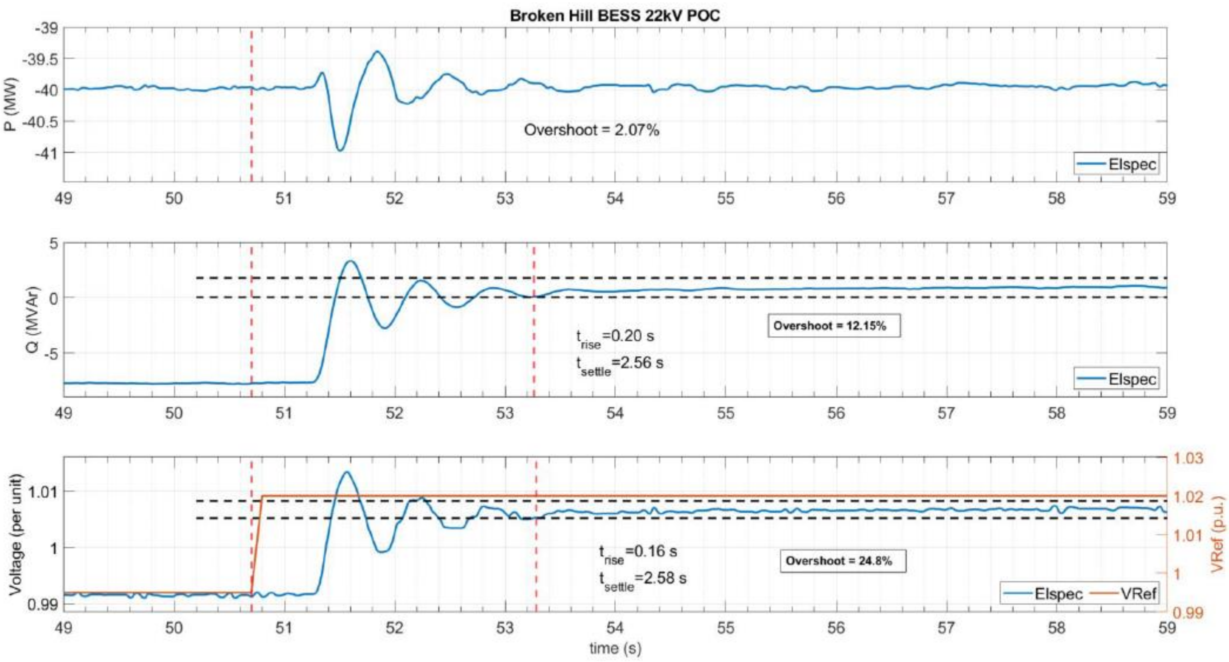
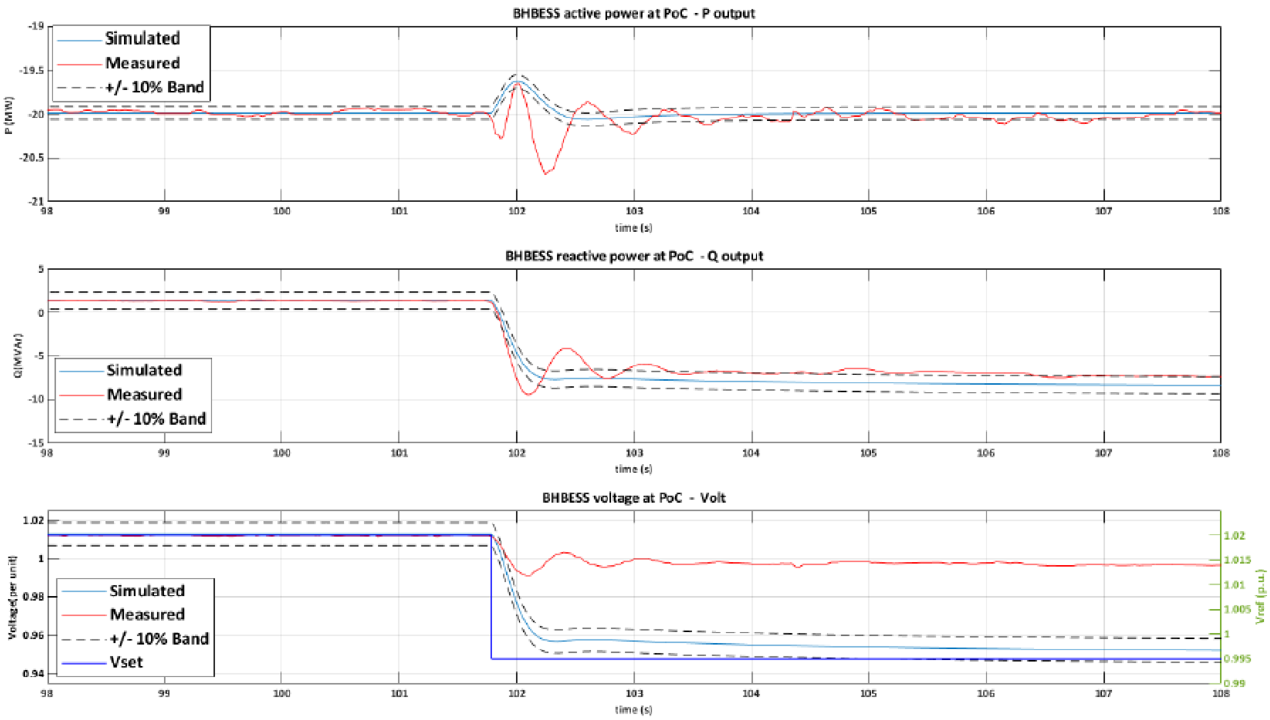


Figure 5.3.2.3 shows an overlay of the model, comparing simulated responses with site measurements. Although some damped oscillations are present in both active and reactive power response measurements, these responses fall within the ±10% error band as specified by AEMO guidelines.

Figure 5.3.2.3: Model overlay simulation, voltage step test (Vref: 1.02 à 0.995 pu), low SoC, low output, result at POC



Additionally, misalignment between measurement and simulation of voltage after step applied is observed and is due to the missed elements in the simulated model as it did not represent 100% SMIB environment[5].

[5] Static var compensator (SVC) was actively controlled the reactive power on the grid side (22kV circuit), that opposed the voltage increase.

6. Key Lessons Learnt

Lessons Learnt during Milestone 3 of the Broken Hill Battery Energy Storage Project has been provided as a separate document.

7. Project Applicability and Next Steps

BHBESS project has successfully completed HP2 stage and has received approval from AEMO and Transgrid for the commercial operation with the full 50 MW capacity. AGL also completed the reliability test over a two-week period and the plant demonstrated continuous uninterrupted operation following the AEMO dispatch target. As a next stage of the project, the plan is to follow the 5.3.9 process to accommodate the new firmware which can demonstrate grid-forming capability at all times including the transient events such as contingencies, faults etc.

Because the BESS is a grid-forming system, there is a possibility for it to participate in future system restart or local islanding contingencies, to provide benefits to the local region. However, at the current moment the facility has built in anti-islanding protection as a requirement of the Transgrid connection process. If future islanding services are offered to Transgrid, the anti-islanding protection will need to be re-negotiated and removed with Transgrid. AGL is preparing to test this functionality internally behind the meter to demonstrate that the BESS can energize the 22kV Bus bar and function as a voltage source without reliance on the main grid. Due to site limitations, the test will be conducted on a single core. The behind the meter islanding test is focused on confirming the reliability, stability, and safety of the BESS during isolated operation, to prepare for future islanding services offer discussions with Transgrid.

8. Associated Parties and Project Contact Details

	Proudly Australian for more than 185 years, AGL operates Australia's largest private electricity generation portfolio within the National Electricity Market, comprising coal and gas-fired generation, renewable energy sources such as wind, hydro and solar, batteries and other firming technology, and gas production and storage assets. We are building on our history as one of Australia's leading private investors in renewable energy to now lead the business of transition to a low emission, affordable and smart energy future in line with the goals of our Climate Transition Action Plan. AGL owns and maintains the 50MW / 50MWh battery, which provides both regulated network services and competitive market services.
	ARENA is the Australian Renewable Energy Agency and supports improvements in the competitiveness of renewable energy and enabling technologies, increase the supply of renewable energy in Australia, and to facilitate the achievement of Australia's greenhouse gas emissions targets by providing financial assistance and sharing knowledge to accelerate innovation that benefits all Australians. ARENA is partially funding this project as part of ARENA's Advancing Renewables Program.
	Aurecon Group Pty. Ltd. is an engineering, management, design, planning, project management, consulting and advisory company based in Australia. Aurecon is undertaking the power system network modelling for this Project.
	The University of New South Wales (UNSW) is a public research university based in Sydney, New South Wales, Australia. UNSW, in conjunction with AGL is undertaking the power system studies and the simulations for this Project.

FLUENCE A Siemens and AES Company	Fluence Energy brings proven energy storage products and services, and digital applications for renewables and storage to support the modernization of our energy networks. Fluence Energy is the Engineering, Procurement and Construction (EPC) Contractor for this project.
worley consulting	Worley Consulting Pty. Ltd. is the advisory and specialist consulting arm of Worley Pty. Ltd. Worley Consulting is the Knowledge Sharing Partner for the Project.

For more information on the Project, please log into the Broken Hill BESS Project Portal located at the following address: https://www.agl.com.au/about-agl/how-we-source-energy/broken-hill-battery-energy-storage-system?zcf97o=vlx3ap

The portal contains the ability to ask questions of the project team. It also contains relevant information including:

- Construction update of the Broken Hill BESS
- Planning and environmental approvals

All publicly published Knowledge Sharing material, including key reports, operational updates, presentations and access to live and historical data from the operational BESS will be uploaded progressively as they are made available.