FORTESCUE ALINTA SOLAR GAS HYBRID PROJECT

LESSONS LEARNT: COMMISSIONING AND TESTING PHASE

Date: August 2022

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

This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

1. Introduction

Alinta has completed the construction of its Chichester Solar Gas Hybrid Project (the **Project**) in the Pilbara region of Western Australia (WA). On behalf of the Australian Government, the Australian Renewable Energy Agency (**ARENA**) has provided funding support of $24.2 million for the Project as part of its Advancing Renewables Program. The Northern Australia Infrastructure Facility (**NAIF**) has also provided a loan of approximately $90 million for the Project. A condition of the funding support from ARENA is that Alinta provides a series of reports summarising the lessons learnt from each stage of the project lifecycle.

This report has been prepared in accordance with Alinta's knowledge sharing obligations under the Funding Agreement reached with ARENA. The Report describes the challenges, issues and lessons learnt for the Project from the completion of construction through to the commencement of operations.

2. Other Lessons Learned Reports

This is the third of a series of four lessons learned reports to be issued, each focussed sequentially on a specific lifecycle phase of the Project.

Lessons Learned Report 1: Inception to Financial Close

This report has been issued and accepted by ARENA. It covers the period from project inception to financial close, which occurred on 27 November 2019.

Lessons Learned Report 2: Financial Close to Completion of Construction

This report has been issued and accepted by ARENA. It covers the period from financial close to commencement of commissioning. The report was issued in January 2022.

Lessons Learned Report 3: Energisation, Commissioning and Testing

This report, to be issued in mid 2022, covers the energisation, commissioning and testing phase which occurred for each separable portion of the project prior to the commencement of operations.

Lessons Learned Report 4: Operations and Maintenance

This report will be issued approximately 12 months after the commencement of operations and maintenance of the Solar Farm. It is expected to be issued in the fourth quarter of 2022.

3. The Project

Alinta has constructed a 60MW AC Solar Photovoltaic (**PV**) power station with interconnecting infrastructure in the Pilbara to supply electricity to Fortescue Metal Group's (**Fortescue**) Chichester Hub mining operations. Fortescue is Alinta's second customer on its Pilbara inland power system, the first being Roy Hill's Iron Ore mine. The Project is the first example of large-scale renewables in both low inertia grids and remote mining operations in Australia. Alinta's Pilbara inland power system now includes six sources of generation:

- Alinta's Newman gas turbines;
- Alinta's Newman Battery Energy Storage System (**BESS**);
- Alinta's Roy Hill diesel generators;
- Fortescue's Christmas Creek diesel generators;
- Fortescue's Cloud break diesel generators;
- Alinta's Solar PV facility;

and 4 load centres:

- Alinta's Newman Battery Energy Storage System;
- Roy Hill Iron Ore's mine;
- Fortescue's Cloudbreak mine; and
- Fortescue's Christmas Creek mine.

The complete power system will integrate PV cells, battery energy storage , diesel fired reciprocating engines and gas turbine technologies across five physically distributed locations.

The project is located in the Pilbara region of Western Australia, near the Chichester Ranges approximately 150km North of Newman.

The graphics below illustrate the location of the existing infrastructure (highlighted in green in figure 2) and new infrastructure (highlighted in purple in figure 2).

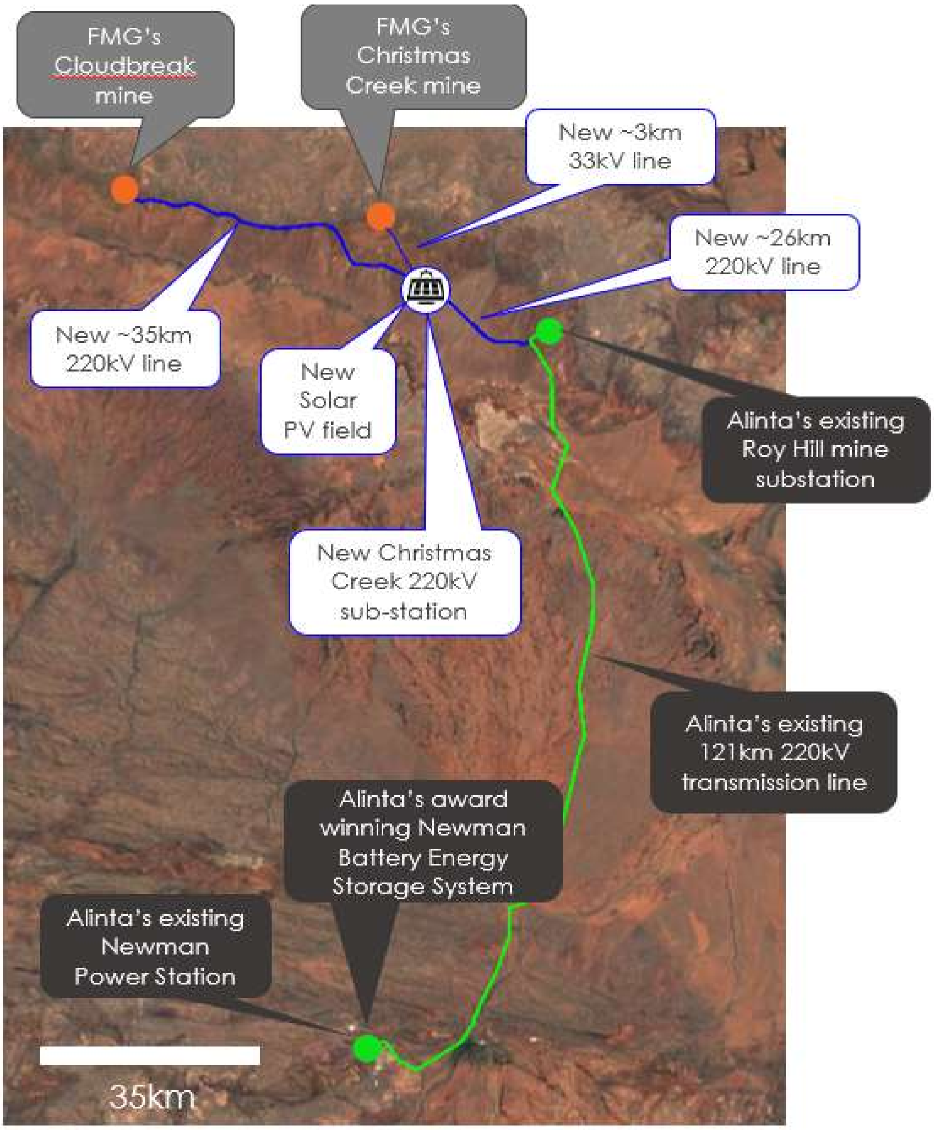

Figure 1: Detailed Project Location

Refer to Figure 1 above for an overview of the location of the infrastructure. The distance from Alinta's Newman Power Station to the Roy Hill substation is 121km. The new 220kV transmission lines which will feed power to the Christmas Creek and Cloudbreak mines are 26km and 35km respectively. The total line distance across the network is therefore spans approximately 182km.

3.1. Contract Arrangements

The Project was delivered under two Engineering, Procurement, Construction (**EPC**) Contracts, one for the Solar Farm and one for the electrical distribution infrastructure, including transmission lines, substations and customer interface works. Both EPC Contracts were awarded to the same contractor. Alinta also entered into separate contract arrangements with an electrical equipment manufacturer to supply a number of long lead items, including three primary transformers and 220kV switchgear.

A Development Agreement (**DA**) was executed between Fortescue and Alinta to set out the term, conditions and requirements for engagement between the parties during the delivery phase of the project. Once each separable portion achieved Practical Completion under the DA, the DA fell away in all material respects and the Power Purchase Agreement (**PPA**) came into force. Practical Completion under the EPC and DA occurred as follows:

	EPC Contract	DA
Separable Portion 1 (Supply to Christmas Creek mine)	June 2021	July 2021
Separable Portion 2 (Supply to Cloudbreak mine)	August 2021	October 2021
Solar Farm	November 2021	November 2021

3.2. Project Scope

The scope of the Project comprises:

1. construction of a new, single circuit 220kV overhead transmission line between the existing Roy Hill 220kV substation and the new Christmas Creek 220/33kV Substation located adjacent to the Chichester Solar Farm;

2. augmentation of the existing Roy Hill 220kV substation to accommodate the new transmission line;

3. construction of a new Christmas Creek 220/33kV substation;

4. construction of a 33kV transmission line to a new 33kV/11kV transformer at the Christmas Creek Mine Power Station and a 11kV underground cable

connection to the Christmas Creek Mine Power Station 11kV distribution board;

5. detailed design, engineering, procuring, constructing, installing, testing and commissioning and performance trials of the infrastructure, systems and equipment required to provide a fully operational 60MW AC Solar Farm connected to the Christmas Creek 220/33kV substation;

6. construction of a new single circuit 220kV interconnecting overhead transmission line between the Cloudbreak 220kV substation and the Christmas Creek 220kV substation, and the interfacing with Fortescue Cloudbreak mine facility; and

7. construction of a new 220 / 11kV Cloudbreak Substation. and a 11kV overhead / underground cable connection to the Cloudbreak Mine Power Station 11kV distribution board.

3.3. Key Project Objectives

Key objectives of the Project are to demonstrate:

- significant penetration of an intermittent renewable energy source for mining operations;

- the ability of solar to meet 100% of the load (as forecast on execution of the DA) for Fortescue's mining operations during favourable irradiance conditions; and

- no reduction in system security and reliability in a low inertia grid with significant intermittent renewable generation.

The Project will also aim to demonstrate that:

- a mining operation can run solely on solar power with battery storage during the day;

- miners can operate in a "business as usual" manner when being supplied by an intermittent renewable generation source along with battery storage; and

- integration of renewables into an existing generation portfolio can facilitate further electrification of diesel-powered auxiliaries.

The Project is estimated to displace around 100ML of diesel every year. Once the project is operational, Fortescue's diesel generators will be utilised for security of supply, network support (including during outage events) and during maintenance periods.

The Project will optimally dispatch solar, gas, diesel and battery storage to meet the continuously varied load demands of both key users while maintaining network stability and maximising the renewable generation.

Figure 1: New Christmas Creek Substation

4. Transmission Lines & Substations – Energisation, Testing and Commissioning

4.1. Energisation

Alinta Energy utilises an Authority to Energise (**ATE**) process for the energisation of new equipment with voltage ratings of 1kV or above. The ATE application incorporates a team-based Risk Assessment to identify, manage and mitigate risks to personnel, property and the reliable operation of the network.

The Senior High Voltage Operator (**SHVO**) with authority to sign the ATE is required to undertake their own due diligence to satisfy themselves of the readiness for the asset to be energised. This may include a walkdown of the assets and a review of the quality documentation supporting the ATE.

In addition to Alinta's ATE process, the Development Agreement with Fortescue required separate approval by Fortescue under their Notice of Energisation (**NOE**) process prior to the energisation of any newly constructed assets. The key objective of this approval requirement was to ensure that Fortescue was aware of the energisation sequence and was provided with ample opportunity to issue a Site Notice of the change in state of electrical equipment. The NOE process is discussed in further detail in Section 5.

Energisation of the new infrastructure was undertaken in the following sequence:

1. new 220kV bay within the Roy Hill Substation;
2. 220kV transmission line from the Roy Hill Substation, including the 220/33kV 48MVA transformer, up to the 33kV breaker in the Christmas Creek Substation;
3. 33kV line from the Christmas Creek Substation, including the 33/11kV 48MVA Transformer up to the 11kV Delivery Point in Fortescue's Christmas Creek Switchroom; and
4. 220kV transmission line from the Christmas Creek Substation, including the 220/11kV 48MVA transformer, up to the 11 kV Delivery Point in Fortescue's Cloudbreak Switchroom.

4.2. Control of Assets

The trigger point for a change in control of high voltage electrical assets was clearly defined and understood by all parties. With regard to the Chichester Project, the control of any high voltage electrical asset was transferred from the Contractor to Alinta Operations as soon as there was a potential for energisation to occur. Should a physical air-gap exist (e.g. linking cables removed) to create electrical isolation of electrical infrastructure, the infrastructure remained under Contractor control. Immediately upon removal of the air-gap, the electrical infrastructure would fall under the control and operation of Alinta Operations. The presence of a disconnector or breaker does not qualify as an 'air gap'. Air gaps were therefore closed as late as possible to ensure that the Contractor was able to work under their own health and safety systems to complete outstanding physical works. Once the air-gap was closed, all works fell under Alinta's permit arrangements. Clarity and alignment across all stakeholders on this principle is paramount for the safe integration of new assets to an existing electrical network.

4.3. Testing and Commissioning

This section outlines the testing and commissioning of the new transmission line and substation infrastructure under the EPC Contract.

Practical Completion, commissioning and performance requirements are documented within the Principal Project Requirements section of the EPC Contract.

Commissioning Plan

The Contractor was required to prepare a Commissioning Plan for each separable portion (Christmas Creek and Cloudbreak) which set out all tests demonstrating that the transmission line had been completed and commissioned in accordance with the requirements of the EPC Contract and good industry practice. The commissioning plan included testing of all new equipment and successful integration with existing equipment and systems, including:

- all synchronisation, metering and protection equipment;
- Newman Power Station monitoring equipment and the connection to the Fortescue and Alinta's remote monitoring equipment; and

- power quality.

Switching Procedure

The Contractor was responsible for developing the switching procedures and switching sheets to support the detailed switching sequencing required to carry out the commissioning tests.

Commissioning Tests

The Contractor was required to carry out the following commissioning tests for the transmission lines:

- high potential testing of the phase conductors;
- visual inspection of the line to confirm all jumpers are in place, earthing connections removed and insulators are in sound condition;
- phasing checks;
- insulation resistance testing of HV cables;
- ductor testing of bolted connections;
- Optical Time-Domain Reflectometer (**ODTR**) testing for the Optical Ground Wire (**OPGW**); and
- line impedance testing.

The Contractor was required to carry out the following commissioning tests for the substations:

- circuit breaker pre-energisation checks;
- circuit breaker functionality tests;
- transformer pre-energisation checks; and

- transformer functionality checks (including tap changer, cooling, winding temp indicators, oil temp indicators, pressure relief devices, gas surge devices and conservator).

The Contractor was required to carry out the following Protection Scheme Functional testing:

- 220kV line protection functionality verification through primary injection tests;
- 220kV line communications aided functionality;
- 220kV line scheme checks through to breaker operating coils; and
- Supervisory Control and Data Acquisition (**SCADA**) equipment functional testing to demonstrate satisfactory communication and data exchange with the relevant Remote Terminal Units (**RTUs**).

The Contractor was required to carry out the following additional activities as listed in the EPC Contract:

- complete and sign off all ITPs;
- issue Training Plan and conduct training sessions;
- develop and issue Operation and Maintenance Manuals;
- issue of all 'For Construction' drawings with red line mark-ups; and
- deliver agreed spare parts and special tools.

4.4. Testing

The Contractor was required to prepare a Performance Test Plan for each transmission line separable portion (Christmas Creek and Cloudbreak) which set out all tests required to show that the transmission line complies with the requirements of the EPC Contract and good industry practice.

Furthermore, the EPC Contract specifically required the Contractor conduct a 3-day reliability test for each separable portion, during which the following applied:

- the Transmission Line needed to supply power to the delivery points at Christmas Creek and Cloudbreak mines as required by the Customer’s mine operations;
- the Transmission Line was to be operated as per manufacturer's instructions;
- the Transmission Line was to be operated with a normal complement of operating personnel;
- the Transmission Line was to remain within normal operating limits, as defined in the Transmission Line Manuals, for all parameters normally measured by the control system;
- the Transmission Line was to remain within the limits of the North West Interconnected System (**NWIS**) Technical Rules;
- the Transmission Line controls was to be placed in “automatic mode” to an extent consistent with normal operating practice;
- manual control of the Transmission Line equipment and systems was to be minimised; and
- trips, shutdowns or downtime due to reasons not attributable to the Transmission Line provided by the Contractor, or due to correct operation of protection systems caused by external influences, were to be evaluated as successful operation time during the reliability test.

Additional transmission line testing required under the EPC Contract included:

- line insulation, continuity, phasing and support footing resistance tests;
- ductor testing of all electrical connections;
- line impedance tests; and
- thermographic survey of the transmission lines under load within 9 months of Practical Completion.

4.5. Transmission Line Testing and Commissioning Lessons Learned

Key lessons learned from the transmission line energisation, testing and commissioning were:

1. Ensure there is early clarity by all parties for the trigger that causes change on control of the asset.
2. Clear list of commissioning and testing requirements for each asset.
3. Ensure contractor design and commissioning personnel are available to promptly review operational data and address emerging issues in a timely manner

5. Integration of Alinta's Network with Fortescue's Systems

A significant challenge presented to the commissioning engineers centred around connection and integration of Fortescue's power systems into the Alinta network, while maintaining safe, continuous and reliable power to both Fortescue mines and Alinta's existing customer. The ramifications to any unplanned loss of power supply to an iron ore mine are significant. Production must be maintained at the mines, 24 hours per day with the only exception being planned outages for maintenance.

5.1. Notice of Energisation Procedure

As noted in section 4.1, prior to any connection to Fortescue assets, Alinta was required to submit a NOE in accordance with Fortescue's notice of energisation procedure. The NOE process gives Fortescue assurance that the electrical equipment to be energised has been designed, constructed and commissioned in accordance with standards, regulatory requirements and good engineering and operating practices. It also provides Fortescue with an opportunity to issue Site Notices in advance of any connection or energisation to ensure all stakeholders within the mine site are aware of the change of state of the infrastructure.

Each NOE incorporated a significant volume of quality documentation and certifications. The provision of this array of documentation was undertaken in stages to ensure the earliest possible commencement of the review process. Following this process, approval was issued promptly after the release of the final batch of quality documents.

5.2. Functional Control Testing

Prior to commissioning the new supply to Christmas Creek and Cloudbreak mines, both mines were self-sufficient for power by utilising local diesel generation. These diesel units were controlled using a standalone ComAp control system. Integration of the Alinta network involved a significant change to the way these diesel generation units would be utilised. In essence, once connected to the network, the diesels would lay dormant in stand-by mode unless there is a fundamental reason for them to operate. The possible reasons that a run command might be issued to the diesel generators includes:

- a planned or unplanned supply constraint within the Alinta network;
- a power quality issue on the network presented (e.g. power factor outside acceptable band);
- gas constraints at Newman Power Station; or
- during a high-risk period such as lightening which increases the probability of a transmission line outage.

Both Fortescue and Alinta were very concerned about the potential for an interruption to mine supply due to the integration of the control systems. As a result, Alinta and Fortescue worked together to create an eleven step Functional Control Test Plan for each mine.

This joint commissioning between Alinta and Fortescue's control systems comprised testing of primary and secondary systems connected to the Alinta-Fortescue interface points. Further, it incorporated functional testing and proving of the control and SCADA requirements to ensure operation and function as per the agreed operating concepts. The functional testing was performed for the following functions between the Alinta's control system and the Fortescue Christmas Creek mine and Cloudbreak mine control systems:

- primary protection and control equipment;
- secondary protection and control equipment;
- Operational Protocols:
  - SCADA
  - power station controls / interfacing
  - dispatch control
  - proactive load shedding ;
  - under frequency load shedding; and
  - integrated control system functional and performance testing.

The table below outlines the individual test instructions that were created.

Functional Test Name	Functional Test Description
01_StartSignal	Verification of critical signal transfer between the two control systems and failure response.
02_ConnectToGrid	Verification of the sequence steps and mode changes leading to the synchronisation steps.
03_SynchronisingTuning	Tuning of the auto-synchronisation system to provide near bumpless connection of the two power systems
04_FirstSynchronisation	First electrical connection of the Alinta and Fortescue power systems – validation that the two power systems switch to parallel operation, operate stably and transducer directionality is correct.
05_ExportImportControlProtection	Validation that the Fortescue generation does not export power to the network in both steady state and dynamic conditions, a scenario that could lead to disconnection of the Newman Power Station and automatically limits the import of both active and reactive power in accordance with PPA and real-time power system constraints
07_ProActiveLoadShed	Validation of the load shedding function that disconnects load based upon shortfall in generation, rather than waiting for system

	frequency to drop below defined thresholds
08_DisconnectbyFMG	Validation of the process for disconnecting from the Alinta Network if there was an integrated control system or communications system fault.
09_DynamicStabilityTests	Assessment of the Fortescue generation dynamic response when operating in parallel with the Alinta Network.
10_DispatchBySupplier	Assessment of the Fortescue generation to operate in response to commands received by the Alinta control system.
11_ConnectDisconnectFullSequence	Validation of the semi-automated process for connecting a mine site to the Alinta network and transferring the load to the Alinta generation and likewise the transfer of load to the Fortescue generation and disconnecting from the Alinta Network
12_SupplementaryDispatch	Validation of the automated the operation of the Fortescue generation in response to PPA limits, Security of Supply, Supplementary Generation etc

The integration of the two separate control systems (Alinta and Fortescue) to achieve overall integrated operation proved to be very challenging. Several interruptions to the testing program occurred during the functional tests due to unexpected results in the integrated control system response. The technical challenges required a holistic engineering review of the integrated control system, development of detailed bench testing and fine calibration to achieve the desired performance for the integrated operation of the two control systems.

A key lesson learned is that the integration of two distinct control systems require a significant program of pre-commissioning tests and bench testing for the specific operation scenarios. This program of control system tests should be developed early in the project to ensure a deep understanding of the way the control systems will respond to various circumstances and under stress-test scenarios. This testing may result in the identification of 'tuning' of the control system(s) which can be further validated using control system modelling.

5.3. Performance Tests

The Development Agreement between Alinta and Fortescue stipulated certain Performance Tests required to be completed by Alinta in order to achieve Practical Completion.

In relation to the Christmas Creek and Cloudbreak mines, satisfaction of the following performance Tests was required:

<u>Part A – 3 Days Full Mine Operation</u>

a) Synchronise to the Alinta Network.

b) Power Station switchboard 11kV voltage is maintained within NWIS specifications.

c) System frequency is maintained within NWIS specification.

d) No diesel generation on line (unless otherwise agreed with FMG).

<u>Part B – Power System Control Integration & Functional Testing</u>

a) Demonstrate generator dispatch, active and reactive power control.

b) Virtual demonstration of System Black Start following network failure (Note: Black System Start is a condition where all generation is ceased and generation needs to be started from a zero power state).

c) Virtual demonstration of new load management system.

The 3 Days Full Mine Operation tests described above required that supply of the full load requirements be maintained for 72 hours to the respective mine without fault, error or manual intervention. During this period, the power supply on the network needed to remain within NWIS specifications and automated dispatch and control needed to be demonstrated.

For both Christmas Creek and Cloudbreak mines, the tests were passed within the 72-hour window.

Performance Tests in respect of the Solar Farm are described in Section 7.

5.4. Lessons Learned

The following are lessons learned from the integration of the Fortescue power systems into Alinta's network:

1. Engage a dedicated Commissioning Manager as early as possible to manage the interactions between stakeholders. Keep the Commissioning Engineers focussed on the technical aspects of the process as far as practicable.
2. Approval processes for energisation requires significant volumes of quality documentation to be reviewed. Commence this review process at the earliest by 'drip feed' issue as documents become available.
3. Develop a series of pre-commission bench tests to develop a deep understanding of the control systems which are to be integrated. Use this bench testing to fine tune the control systems prior to integration and to minimise the risk of delays caused by unexpected results during functional control system testing.

6. Solar Farm – EPC Contract Energisation, Testing and Commissioning

6.1. Energisation

Energisation of the Solar Farm occurred subsequent to the commencement of supply to Christmas Creek and Cloudbreak mines. Both Alinta ATE and Fortescue's NOE processes were satisfied.

6.2. Commissioning and Testing

A series of tests, described as 'Hold Point' testing, was performed to test the Solar Farm in a staged and controlled manner. The allowable maximum power output for each hold point was as defined in the EPC Contract. The objective of the hold point testing was to ensure and validate the Solar Farm performance at lower power outputs before proceeding in a stepwise manner to a higher power output. The hold point testing phase was used to validate that the Solar Farm met the minimum Generator Performance Requirements (**GPR**) and that the power system model of the Solar Farm satisfactorily represents the actual performance of the Solar Farm. A hold point commissioning plan was used to demonstrate compliance of the Solar Farm to the requirements at each Hold Point active / reactive power levels as indicated in the table below.

Where applicable, the data obtained during the testing (for Hold Point reports) were also used for the purposes of R2 model validation. R2 testing is terminology commonly used in the power industry to describe a series of tests which demonstrate the generator (in this case the Solar Farm) behaviour is as predicted by the **PSSE** (Power System Simulator) modelling.

The table below provides a summary of the Hold Point testing.

Hold Point Test (Maximum MW)	Inverters Connected	Active Power, Pmax (MW)	Reactive Power, Qmin /Qmax (MVAr)	HP Testing Duration (Days)
HP-0 (5 MW)	PCS403 (3 x inverters)	5	+/-2.42	8
HP-1 (15 MW) Feeder 4	PCS401 - PCS403 (12 x inverters)	15	+/- 7.26	7

HP-2 (30MW) Feeder 3, 4	PCS301 - PCS403 (24 x inverters)	30	+/- 14.52	7
HP-3 (60 MW) Feeder 1, 2, 3, 4	PCS101 – 403 (48 x inverters)	60	+/-29.04	7

6.3. Low Voltage Ride Through Card Issues

During commissioning of the Solar Farm inverters, regular tripping of the inverters was observed due to the failure of so-called Low Voltage Ride Through (**LVRT**) cards. The investigation into the LVRT card failures and a detailed root cause analysis was completed collaboratively with the Contractor and the equipment supplier.

It was found that, under certain circumstances, the voltage of the board reacted to high frequency common mode perturbations resulting in the hardware sending a false fault signal. The root cause of the issues experienced with the LVRT cards was the level of noise in some hardware circuits.

The equipment supplier replaced the LVRT cards with modified LVRT cards on all the Inverters to rectify the issue of noise signals and frequent tripping.

6.4 Solar Farm Communications Issues

The communication between the Solar Farm inverters, power quality meters and the plant control system was a major challenge. Delays in communication signals (albeit only fractions of a second) caused nuisance tripping of the Solar Farm. A detailed technical investigation was completed jointly by Alinta, the contractor and equipment supplier engineering teams. As a result, an upgraded communication circuit was implemented to overcome this issue. The issue caused a delay of several weeks to the completion of the Solar Farm Hold Point testing.

6.5 Network Reliability Strategy

Network security and reliability was a key consideration during the Solar Farm commissioning and testing phase. Alinta's network engineers understood that unexpected trips could occur at any time during the Solar Farm hold point testing. 'Spinning reserve' is a term given to the difference in the output of a generation unit to the generation capacity of the generator. For example, a 40MW gas turbine generating at 30MW is said to have 10MW of spinning reserve. As a risk management strategy, a minimum level of spinning reserve was maintained at the Newman Power Station to ensure that a sudden loss of active power generation at the Solar Farm could be managed within the gas turbine fleet. While this strategy was effective, it did result in inefficient gas use at the Newman Power Station for the testing period. The higher the Solar Farm output, the greater level of spinning reserve required and the greater the gas use inefficiency. The spinning reserve strategy often meant that more gas turbines were operating at a low output than would otherwise be the case.

6.6 Capacity Test

The Solar Farm capacity test is to confirm that the tested capacity of the Solar Farm is equal to or greater than the guaranteed capacity. The capacity test was performed after completion of the hold point testing. The test was completed over 7 days.

The capacity test was performed in accordance with both the EPC Contract and the approved Performance Test Plan. The steps for the capacity test are set out below:

1. **Measure and record the data:** The test was to be performed within seven (7) consecutive days and made up of instantaneous measurements of one-minute intervals. It included the following measurements:
    - AC power output for the plant measured at the connection point;
    - back of module temperature(s); and
    - irradiance levels.
2. **Primary Measurement Device Verification:** Data was to be filtered so that the data set was free of nuisance data points, including data recorded during any disturbances and bad data (that exhibit a degree of error), until there is a minimum of 500 data line entries without error or corruption.
3. **Prepare and Compile Data:** The two sets of Met Station signals from all like instruments were averaged for the same timestamps (e.g.: pyranometers, back of module temperatures, air temperatures and soiling).

4. **Filter Test Data Set:** The measured and modelled data sets were filtered for any data that was not indicative of the capacity regression. Details of this data exclusion is described below and was included in the Capacity Test Procedures. Data associated with or arising from the following was removed:

    - measurements taken when the average plane of array irradiance is below 200 W/m2 or above 1200 W/m2;
    - measurements taken when one or more inverters are offline or otherwise producing minimal power relative to the other inverters;
    - measurements taken when one or more inverters indicate a grid failure fault state, or when the utility grid voltage is more than five percent (5%) different from the design voltage.
    - measurements taken when the utility grid voltage is less than 0.98 p;
    - measurements taken when the Solar Farm's Tariff Meter records a net negative power output (power is flowing to the Solar Farm);
    - measurements taken when at least one inverter is Clipping;
    - measurements taken when direct beam row-to-row shading occurs;
    - measurements taken when there are fewer than two (2) plane of array irradiance sensors reading correctly;
    - measurements taken when any inverter AC power measurement is erroneous;
    - measurements taken when there is a system-wide failure to collect critical data, including
    - irradiance, module surface temperature, inverter AC power and power meter AC power; or
    - measurements taken when more than three percent (3%) of trackers fail to properly track.

5. **Apply Temperature Correction to Measured Power:** Each power measurement to the "Reference Condition" was corrected and the module power temperature coefficient to determine the equivalent power value at STC. An average daily soiling adjustment was then applied to each 1-minute "Measured Active Power" that was corrected to the Reference Condition, for each test day.

6. **Plot Data Sets Using MS Excel software of:** Temperature-corrected measured AC power versus measured plane of array irradiance.

7. **Generate Linear Regression**: MS Excel was used to generate linear regressions for the scatter plot established in accordance with the previous step and the respective regression coefficient obtained.

8. **Determine the Tested Capacity**: The Reference Condition irradiance of 1000 W/m2 in the linear regression line formula to determine the Tested Capacity was used.

9. **Determine Test Results**: The Tested Capacity to the Guaranteed Capacity was compared.

The Capacity Test was conducted in November 2021 and the results satisfactorily demonstrated that the Solar Farm capacity exceeded the guaranteed capacity of 60MW AC after adjustment for non-standard temperature, irradiance and soiling.

6.6 Solar Farm Testing and Commissioning Challenges and Lessons Learned

1. A specific issue was identified with the low voltage ride through (LVRT) e-cards, which caused multiple nuisance tripping in the early stages of commissioning. The issue was resolved through a minor modification to the cards.

2. Solar Farm transitioning into the ‘Q at Night’ (Reactive Power Support at night-time) mode was not seamless initially. Some inverters would not transition to Q at night mode at sunset and back to day mode operation at sunrise. The issues were rectified over time by Solar Farm inverter control tuning.

3. Solar Farm nuisance tripping due to communication malfunction amongst the inverters, power quality meters and the central plant control systems. The issue was rectified through an upgrade to the communication network architecture to improve the communication signal processing time.

7. Solar Farm – Development Agreement Performance Test Requirements

The Development Agreement between Alinta and Fortescue stipulated certain Performance Tests required to be completed by Alinta to achieve Practical Completion.

In relation to the Solar Farm, satisfaction of the following performance Tests was required:

<u>Part A – Solar Performance Acceptance (per 30MW bank) – 24 hours</u>

a) Demonstration of nominal performance test against MVA, MW & MVAR design specifications.

b) Demonstration of MW & MVAR control.

<u>Part B – Capacity Test</u>

a) Demonstration of the Solar Farm capacity of 60MW AC at standard temperature and conditions.

The Solar Farm achieved the full capacity during hold point 3 testing on 23 Nov 2021. The maximum generation recorded at point of connection on 23 Nov 2021 for the Solar Farm was recoded well above 60 MW. The Solar Farm combined power output of more than 60 MW AC above the guaranteed capacity was achieved at the connection point.

The screen shot below was taken during the capacity test and indicates an active power output of 62MW, exceeding the 60MW threshold.

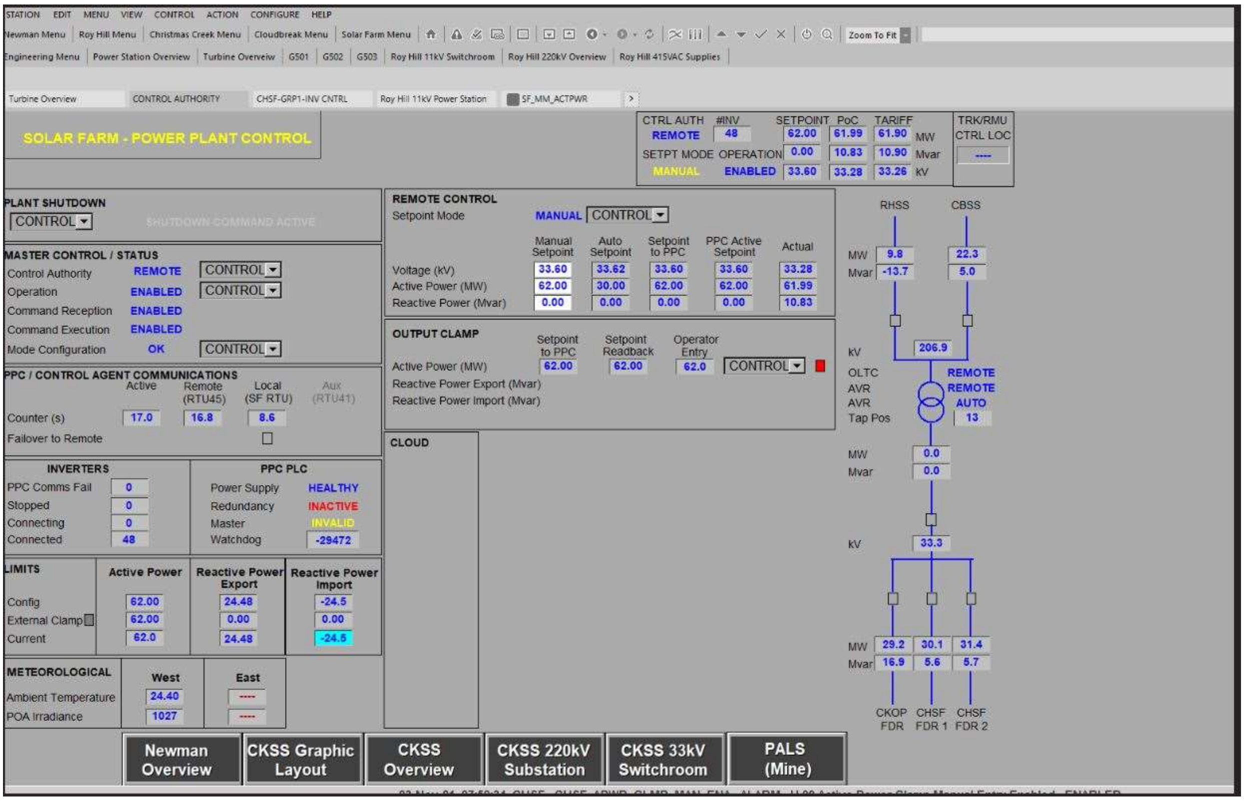

Figure 2: Screenshot during Capacity Test

8. Solar Farm – Post Practical Completion Energy Yield Test

Once Practical Completion of the Solar Farm was achieved, the Contractor was required to commence a 12-month energy yield test which must be completed during the 24-month defects liability period.

8.1. EPC Contract Requirements

Satisfaction of the Energy Performance Test requires that the Actual Plant Generation is equal to or greater than the Energy Yield Guarantee over a twelve-month period commencing on a date after Practical Completion. The Energy Yield Guarantee is 98% of the Adjusted Expected Energy in MWh over the same period. Definitions of Actual Plant Generation and Adjusted Expected Energy are as follows:

Actual Plant Generation means the sum of all energy exported for each non-zero data line entry for the number of days for the Energy Yield Test.

Adjusted Expected Energy means the output of the Energy Model adjusted for the hourly Availability, monthly soiling loss figures and PF adjustment when PF < 0.9.

Requirements of the Energy Yield Test are stipulated in the EPC Contract as follows:

- The Contractor is responsible for carrying out the test.
- The test must be carried out over 365 contiguous days.
- The test may be completed within the Defects Liability Period.
- Actual Plant Generation readings are taken from the tariff meter at the connection point in MWh (AC).
- The contractor shall record all relevant data required to perform the Energy Model evaluation.
- The evaluation for the energy yielded during the Energy Yield Test shall use data line entries of one minute duration each.
- Each one minute data line shall be zeroed should the following occur:
    - irradiance less than 100 W/m2;

  - o any grid contingency event such that the grid is operating outside the normal operating range of the NWIS;
  - o anytime the grid is operating below the voltage p.u. of the Energy Model;
  - o export constraint outside the responsibility of the contractor;
  - o an event that is the result of a direction by the principal; and
  - o an event that was the result of an action or event outside the contractor's responsibility.
- If the data line entry has one of the above events occurring, then that data line shall be zeroed for all results.
- Data line entries are input into the Energy Model to determine the Adjusted Expected Energy.
- The Adjusted Expected Energy results for each one-minute data lines are summed to determine hourly, daily and monthly results.

8.2. Testing and Commissioning Results to date

The Solar Farm monthly energy yield assessment for the Dec 2021 and January 2022 have been performed based on the PVSyst model energy yield prediction and actual plant generation data. The monthly results show the Solar Farm meeting the guaranteed expected energy yield for the month (98% +).

1/ Adjusted Expected Energy Summary	
Period	24Nov - 31 Dec 2021
Adjusted Expected Energy (yield at Tariff Meter minus Solar Facility Consumption) (MWh)	**21,285**
2/ Actual Plant Generation	
Daily Active Power Sum (MWh)	21,022
Solar Farm Facilities Consumption (MWh)	3.675
Actual Plant Generation (MWh)	**21,018**
3/ Energy Yield Test Results	
AEE/APG Ratio	**98.7%**

Figure 3 : Energy Yield Test results for December 2021

1/ Adjusted Expected Energy Summary	
Period	01Jan - 31 Jan2022
Adjusted Expected Energy (yield at Tariff Meter minus Solar Facility Consumption) (MWh)	**14,187**
2/ Actual Plant Generation	
Daily Active Power Sum (MWh)	13,988
Solar Farm Facilities Consumption (MWh)	3.265
Actual Plant Generation (MWh)	**13,985**
3/ Energy Yield Test Results	
AEE/APG Ratio	**98.6%**

Figure 4 : Energy Yield test results for January 2022

8.3. Solar Farm Energy Yield Test Lessons Learned

The following lesson is learned from the Solar Farm Energy Yield Test:

- Energy Yield Test should clearly articulate risk allocation between the Contractor and Principal for planned and unplanned outages

9. Cloud Forecasting

9.1. Introduction

The Fulcrum3D CloudCAM system is a turn-key cloud detection and solar forecasting system, targeted at optimal management of solar power output fluctuations due to cloud impacts. It can be used for general monitoring / alarm applications or integrated directly into the power plant control systems

The main advantages of CloudCAM are short-term forecasting, stability via pre-emptive ramping of solar and in island grid applications, fuel savings via spinning reserve management.

CloudCAM consists of an on-site all-sky camera and processing unit. High-resolution all-sky images are captured every few seconds and processed on-site using Fulcrum3D's proprietary algorithms to detect and track clouds.

Site specific models of the solar power station allow for accurate power forecasts. Real-time data is presented via modbus and all high-resolution all-sky images can be archived onsite for post analysis. CloudCAM can perform high-volume synchronous logging of local SCADA parameters for system monitoring and performance analysis.

The accurate energy forecasting model will need collection of the Chichester data over a period of time, likely to be several months to fine tune the forecasting model for accurate Solar Farm generation forecasts.

The below picture shows the location of the CloudCAM for Chichester Solar Farm.

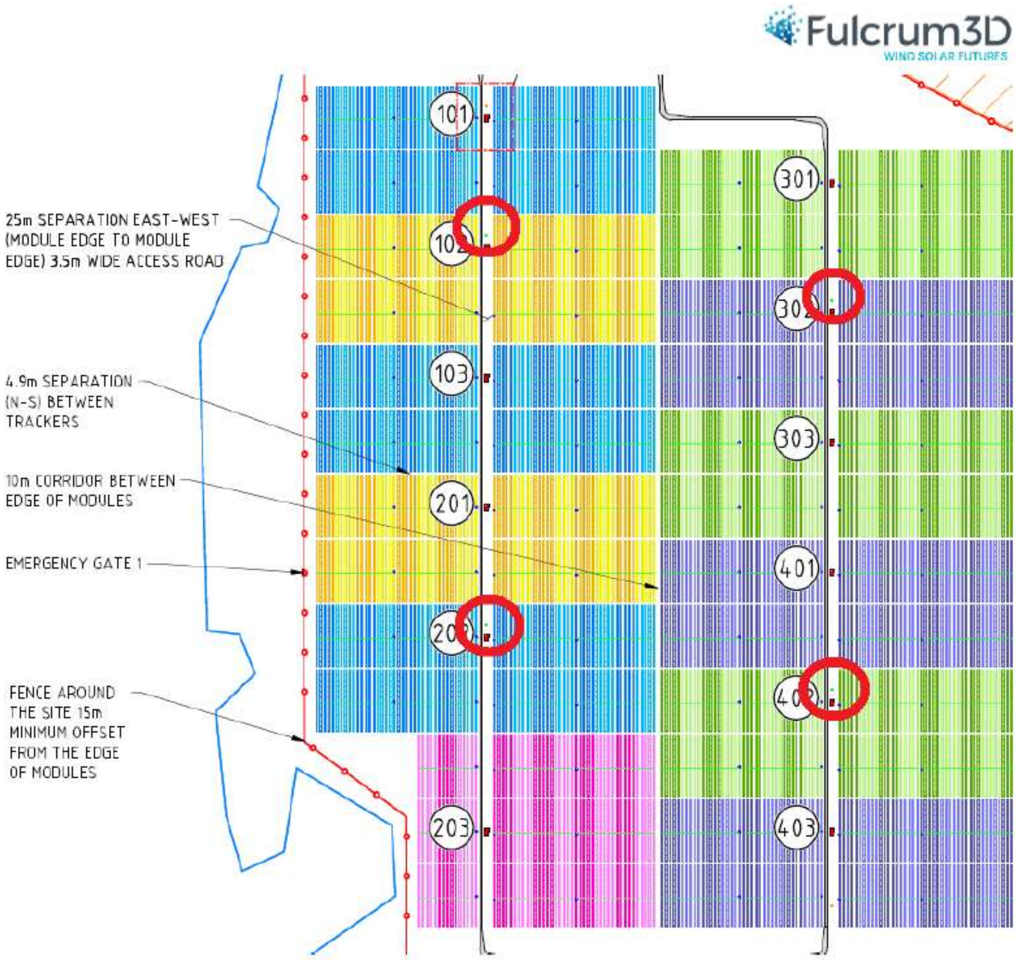

Figure 5:Plan of Solar Farm showing CloudCAM locations

9.2. Performance to Date

The performance of the forecasting system was initially unusable, primarily due to the insufficient time provided to commission and observe the cloud cover events prior to Solar Farm operation. The system continues to improve but is yet to achieve the accuracy required for optimal dispatch of the Newman Power Station.

9.3. Fulcrum Cloud Forecasting System Lessons Learned

1. There was a lack of appreciation for the effort and time required to configure/tune the forecasting system. It is recommended that the system is made operational as soon as physically practicable, with temporary power

supplies and communications if required to allow for data collection and tuning.

2. The asset owner should have the ability to engage directly with cloud forecasting equipment suppliers during design, installation and commissioning, in parallel with the Contractor. Optimally, the Contractor should be required to install and make the system operational at least 3 months prior to grid connection.

10.Disclaimer

The purpose of this document is to provide a summary of the Project, challenges and lessons learnt from project inception to the financial close of the project, for the purposes of fulfilling Alinta's knowledge sharing obligations to ARENA as part of the Project Funding Agreement.

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This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

Figure 6: Completed Solar Farm

Appendix 1 - Definitions and Abbreviations

AC	Alternating Current
ARENA	Australian Renewable Energy Agency
ATE	Authority to Energise
BESS	Battery Storage Energy System
DA	Development Agreement
EPC	Engineering, Procurement, Construction
Fortescue	Fortescue Metal Group
GPR	Generator Performance Requirements
HV	High Voltage
JV	Joint Venture
kV	kilo Volt
LV	Low Voltage
LVRT	Low Voltage Ride Through
NAIF	Northern Australia Infrastructure Facility
NOE	Notice of Energisation
NWIS	North West Interconnected System
ODTR	Optical Time-Domain Reflectometer
OPGW	Optical Ground Wire
PPA	Power Purchase Agreement
Project	Chichester Solar Gas Hybrid Project
PSSE	Power System Simulator
PV	Photovoltaic
RTUs	Remote Terminal Units
SHVO	Senior High Voltage Operator