PUBLIC IMPACT REPORT

Karratha Airport Solar Project

1 MWp Solar PV System

IMPACT INVESTMENT GROUP

CPS NATIONAL

KARRATHA SOLAR

City of Karratha

Karratha AIRPORT

ARENA

Australian Government
Australian Renewable Energy Agency

REVISIONS

Draft issues of this document shall be identified as Revision A, B, C etc. Upon initial issue (generally approval) this shall be changed to a sequential number commencing at Revision 0. Revision numbers shall commence at Rev. 1, 2 etc.

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AUTHOR

This report was prepared by Russell Harris of Wollemi Consulting Pty Ltd.

Wollemi Consulting is an engineering consultancy specialising in energy systems and with particular expertise in large commercial and utility-scale solar photovoltaic systems. We focus on technical, commercial and risk aspects to optimise returns to our clients.

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1 Executive Summary

This report reviews the operation of the 1 MW Karratha Airport solar project, in particular the performance of the cloud prediction and battery technology that is used to manage the electricity flow to the Karratha Airport and Horizon Power grid.

We have found after 15 months of operation in a real working environment that the plant has performed at or above expectations.

- The CloudCAM™ cloud camera and prediction software does seem to reliably sense and predict interruptions from cloud events, and the system ramps down the PV output ahead of the actual event
- The energy lost due to ramp-down is estimated to be less than 1%, far below the 5% target maximum
- The battery system maximum output capacity is sufficient, with only 92 events requiring maximum output (a total of 42 minutes) during the whole of 2017
- The battery storage capacity may be oversized, which is to be expected in a conservative design with not much practical history of plant performance

Issues with the plant have largely been due to data capture reliability, but these have been solved through alterations to the number of parameters captured.

Lessons from this project should be used to optimise the operation of the plant, and to permit reduced battery bank sizing for future projects thereby saving capital costs. We also suggest that variable or interruptible electricity loads such as chillers, pumping, fans etc should also be considered to manage electricity drawn from the grid.

We report that the technology would have many applications where the network and generation systems are unable to adapt to rapid changes in grid load.

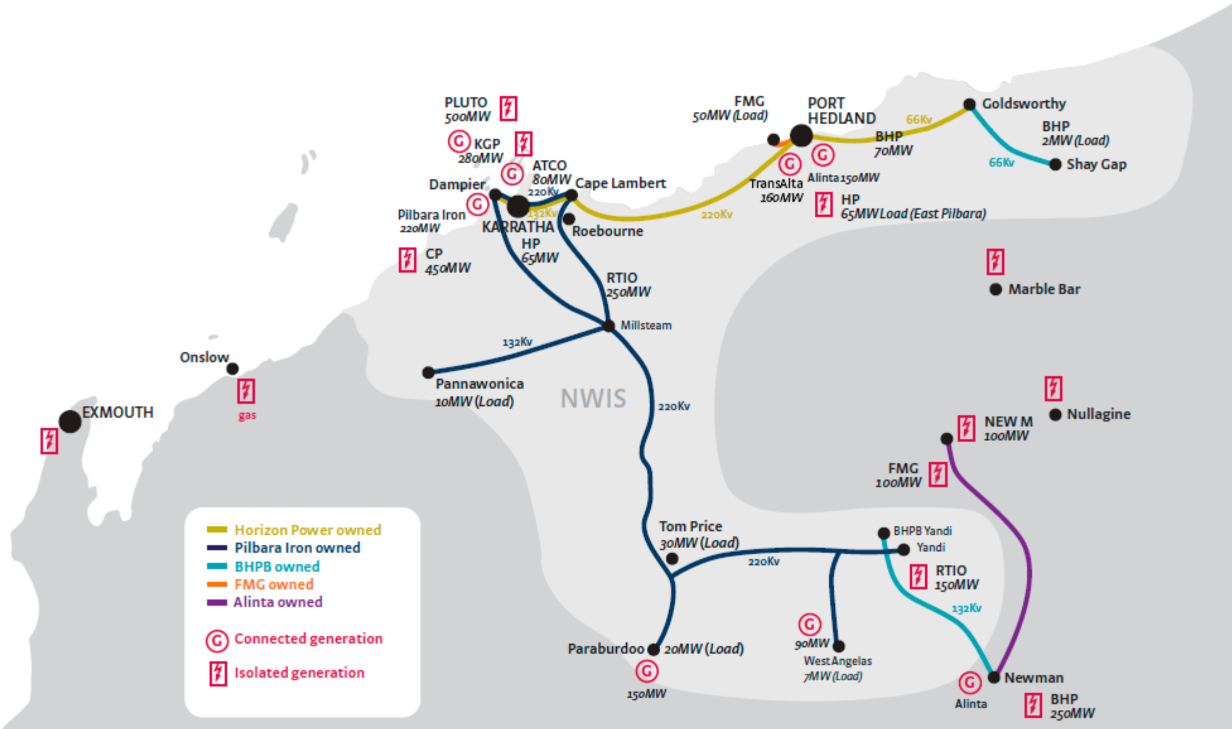
The project participants would also like to thank ARENA for their extensive support during the development and execution of the project.

2 Introduction/project description

2.1 Karratha Airport and the Horizon Power Network

Karratha Airport is located in north-west Australia, around 1400km from Perth and 3300km from Melbourne. Karratha is in a location of climatic extremes, with very hot summers, significant dust and regular cyclone activity.

The township and airport are supplied by the North-West Interconnected System (NWIS) and is a combination of privately-owned network to supply mine-sites as well as Horizon Power's system servicing Karratha and Port Hedland. All of the generation is supplied by natural gas turbines with a small contribution from solar energy.



The isolated nature of the location featuring large loads and long power lines means energy costs are high. Further, Horizon Power have specified tight parameters on generators seeking to connect to the electricity grid.

Karratha Airport, as part of a $35 million major building upgrade, commissioned installation of a 1MW solar and battery array at the airport to complement supply of electricity from the Horizon Power grid, providing up to one-third of the airport's energy requirements.

2.2 ARENA Objectives

This project received $2.3m in funding from ARENA as part of ARENA's Regional Australia's Renewables Program. The objectives of ARENA in supporting this project are to:

- Improve the competitiveness of the NWIS and beyond by demonstrating the role and efficiency of renewable energy systems when integrated with cloud predictive technology and a grid stability system;
- Generate and share knowledge that will assist network operators and decision makers to better understand the economic value and technical viability of connecting distributed renewable energy generation on remote, stretched grids;
- Generate operational data to demonstrate to Horizon Power that its grid management system requirements on the NWIS can be met with lower levels of storage for renewables, comparable to the current HP specification; and
- Improve the business case for renewable energy in remote areas by providing a reference site.

2.3 Solar/Battery PV Project

In brief, the project consists of

- 1055 kWp monocrystalline photovoltaic (PV) solar modules (3104 x SunEdison 340 watt modules)
- 40 x SMA STP25000TL-30 inverters
- 18 x Selectronic SPLC 1202 battery inverters
- 180 x Enersys SBS170F 12 VLRA batteries, arranged in two separate systems (234kW each)
- Schletter FS2V-20 mounting system (fixed 20°)
- Fulcrum CloudCAM™ cloud monitoring and prediction system
- Controls & monitoring subsystems

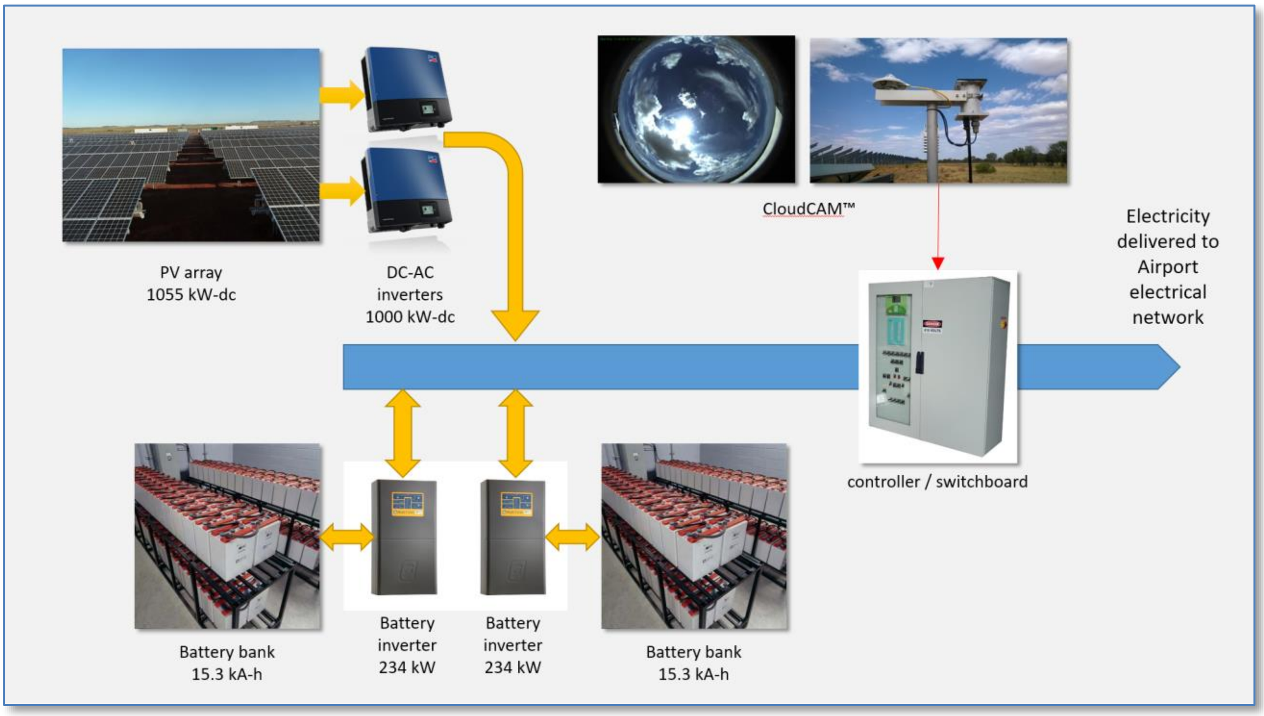
The system is connected to the Karratha Airport high voltage (HV) internal electricity network.

2.4 How it works

For the majority of time, the plant operates as per any other large solar PV plant.

1. Solar energy is captured by the solar panels and converted into DC current.

2. The DC power is sent to the SMA inverters, and converted into grid-quality AC power
3. The AC power is injected into the Karratha HV network, offsetting the requirement to draw power from the main Horizon Power electricity supply



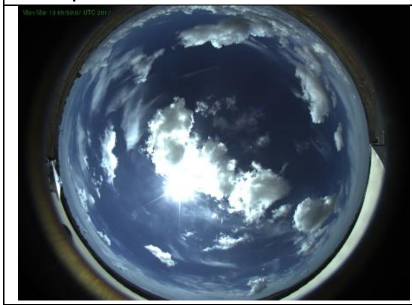
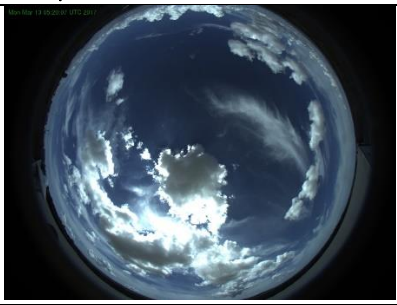
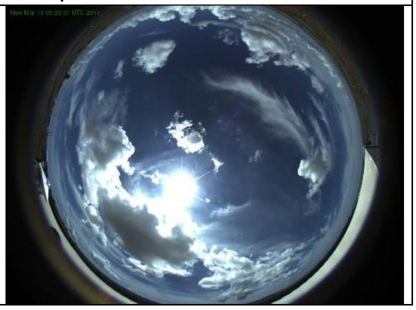
During a clear sunny day, the output of the solar plant is stable and predictable. However, when clouds pass in front of the sun, the output of the plant can fall to around 20% of the peak output. This change in output can be rapid, sometimes occurring over less than 30 seconds.

In most sites with grid connected solar arrays, the local electricity grid increases or decreases supply to make up the balance of electricity consumed by the site. However, the generation units operating on the Karratha electricity network are not fast enough to respond to rapid changes. In order to meet the requirements of Horizon Power, the local supplier of electricity to the Karratha Airport, the rate of change in power output was required to be slowed substantially.

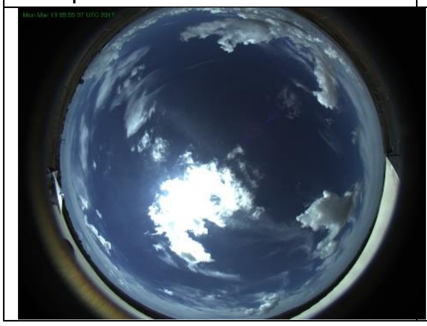
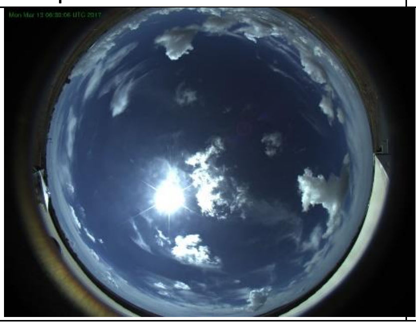
This was achieved by installing a CloudCAM™ cloud recognition camera and analysis software. A camera monitors the sky and sophisticated image recognition software determines if a cloud will impact the solar output from the plant. Upon such a signal, the controls pre-emptively reduce the output of the solar array. If the output of the solar array falls too quickly, the batteries are brought on-line to ensure the ramp-down continues in a smooth and predictable pattern.

The Cloud Predictive Technology (CPT) currently operates in a conservative way to minimise the energy curtailment and related financial impact. The site PV output is only curtailed when overall site PV power is more than 778kW, below this level the grid support (ie battery) system (GSS) provides all the ramp support.

Images at 5-second interval from the CloudCAM™ camera on Monday 13 March 2017 is shown below:

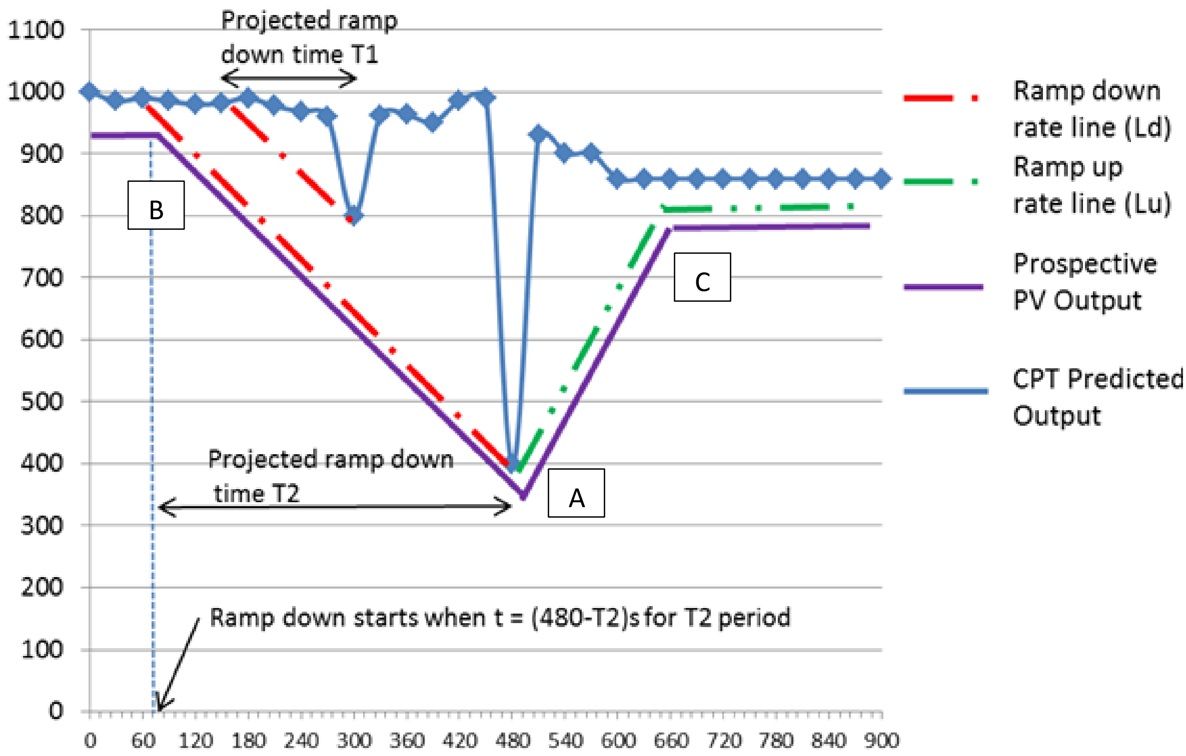
1:05pm	1:20pm	1:25pm
		

1:30pm	1:35pm	1:40pm
		

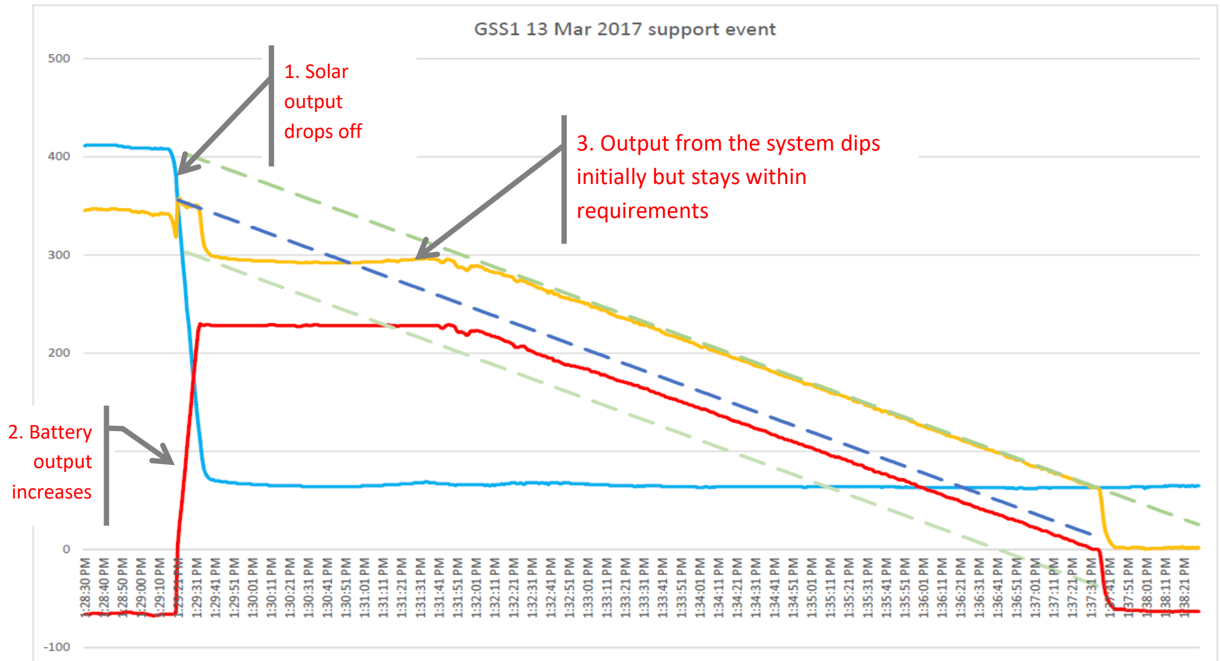
1:55pm	2:00pm	Clear sky with cloud passing
		

Referring to the graphic below, the simplified sequence is

1. The CloudCAM™ system detects that a cloud is approaching, and predicts that the output from the solar plant (blue line) will dip to around 350kW around 480 seconds in the future (‘A’).
2. At (‘B’), the system ramp-down commences, seven minutes before the cloud is due. The output of the plant is smoothly reduced (purple line).
3. When the cloud has passed, the system smoothly ramps up the output back to 100% solar PV output (‘C’).



The chart below shows a ramp-down event where the solar PV output fell by about 300kW in 20 seconds (blue line), and how the battery (red line) was able to switch on quickly to keep the overall power produced by the system (yellow line) within required operating limits (dashed green lines)

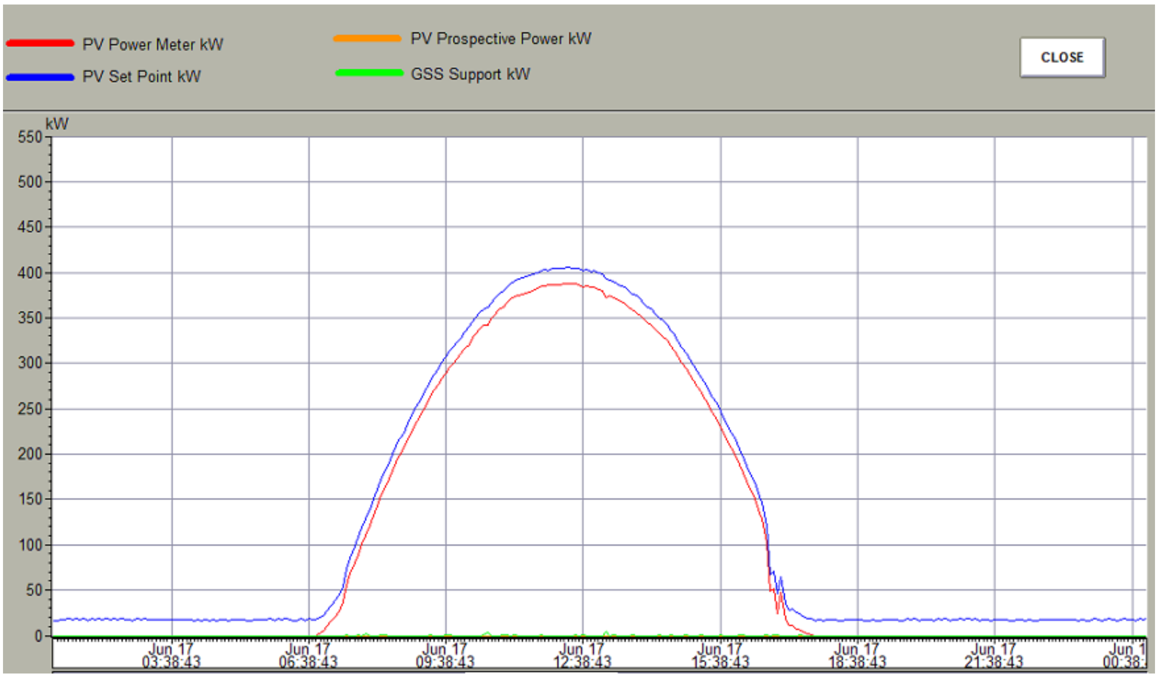


At the end of a cloud event, the batteries are re-charged.

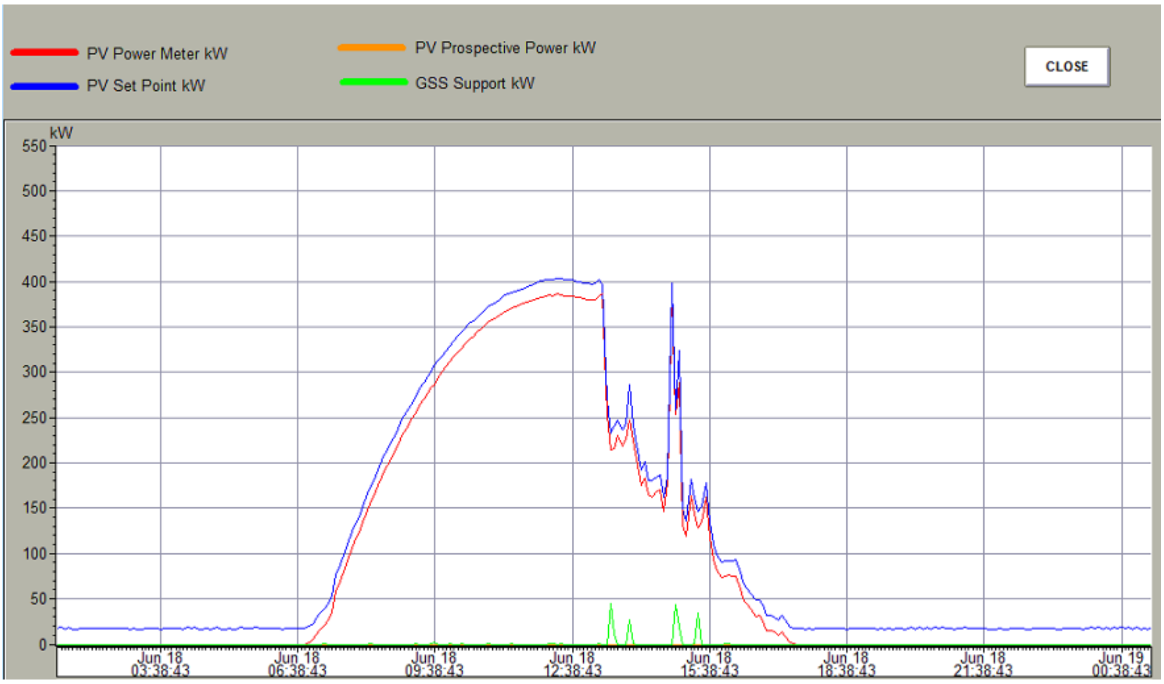
3 Analysis

3.1 Cloud Detection System

The battery and cloud-detection system has performed at-or-above expectations to present a smooth ramp-up and ramp-down generation supply into the Karratha Airport.



17 June 2018, clear day and minimal input from battery or cloud detection system



18 June 2018, clear morning but cloudy afternoon, requiring input from GSS battery system

3.2 Battery System

The performance of the battery system was analysed to determine whether the support was able to inject sufficient energy under extreme conditions to ramp output and keep within the Horizon Power specifications. Note that while this analysis relates to one half of the system ("GSS1"), the second half ("GSS2") is identical and controlled the same way.

In calendar year 2017, there were 92 events requiring full output of the GSS1 battery system (234kW) with a total battery injection time of 42 minutes and 17 seconds.

Time Period (s)	Support Event Qty. (Jan – Dec 2017)	Support Event %
0 - 20	45	49%
21 - 40	26	28%
41 - 60	10	11%
61 - 160	5	5%
81 - 100	5	5%
101 - 120	0	0%
121 – 140	0	0%
141 - 160	1	1%
	92	100%

- Most of the cloud-detection events requiring maximum battery input are very short, with nearly half at 20 seconds or less, and 88% in under a minute
- For days with no requirement for cloud-cover support, parasitic losses were 2-3 kWh or 0.05% of generated PV power
- Typical daily net energy flow showed a consumption loss of around 70kWh while providing 160kWh of supply, a round trip efficiency of 70%, which is typical for this type of battery
- The highest number of 'calls' on the battery for maximum output was nine in one day

4 Results and Conclusions

4.1 Cloud Detection System

The cloud detection and battery system has been successful, in that the output ramp-up and ramp-down has been kept within the limits imposed by Horizon Power, while the draw upon the batteries is low. This has important implications for being able to reduce the number of batteries in subsequent designs (reducing the capital cost).

Without the cloud detection system, the required number of batteries would be doubled, and need to operate at higher rates of discharge to maintain the output within the acceptable ramp-rate. Since the number of batteries has been reduced, and noting the operating cost of the batteries is directly impacted by the frequency and depth of discharge, the investment in the cloud detection system looks to be well warranted.

Over the period of August – December 2017, the calculated curtailment losses from the cloud detection software system was 745 kWh against a total PV generation output of 767,520 kWh – representing a loss of 0.097% - and well within the performance guarantee limit of 5%.

4.2 Settings

The system has been set up with relatively conservative settings. There is an opportunity to tweak the settings to increase the amount of generation and thereby improve the financial returns. However the system is operating in a stable manner with less than 1% of energy lost so it has been decided to leave as is. This process of fine-tuning will continue during the life of the plant.

It would be interesting to perform a cost-benefit analysis to find the optimum point of lost energy versus battery capacity (cost). It may be that a smaller battery (thereby reducing capital cost) would give better project financial returns even if the amount of lost energy rises.

4.3 Dirt and debris

Build-up of dirt on the cloud camera will impact the prediction accuracy. While this was noted in the May 2017 report, heavy rain has cleaned the sensor. The sensor lens is cleaned twice per year as part of the maintenance plan.

This is mirrored in the performance of the solar modules, where heavy rain has periodically cleaned off dust and the output has been maintained at acceptable levels. Given the high dust levels in the town (consistent with the desert-edge location), this is a pleasing result as it avoids physical cleaning of the modules.

4.4 Datalogging

There were initial intermittent data issues with the SMA controller. The root cause was determined to be the large number of data requests to the SMA controller from the datalogger. Reduction of the number of parameters being logged has fixed the issue.

Secondly, collecting the data at 1-second intervals over a large number of sensors produces extremely large datasets, and will exceed the limit of MS Excel to manage effectively. A move to a database solution seems a better approach, and perhaps changing the resolution to 5 or 10 seconds.

At present, the battery system data is collected on one system and the main meters and PV plant on another. Combining the data to get an overall view of the operation is difficult and time-consuming.

The company that installed the original data collection system (SunEdison) has since become defunct, and the new owners of the plant have been forced to install a new data collection system. This highlights the need to make the data available through open protocols.

4.5 Battery Capacity

The battery inverter support capacity is 47% of the nominal PV inverter AC capacity – approximately half of what is required under the current Horizon Power Technical Requirements for generation management systems. This level of support has met the Horizon Power solar smoothing requirements 99.9% of the time, meaning the reliability of the NWIS has not been impacted by the lower levels of battery inverter and battery storage capacity used at Karratha Airport.

It appears that the battery storage size was oversized for the job. There have been no identified cases where the output has been curtailed due to insufficient battery storage size.

Given the lack of industry history of using solar PV, batteries and a cloud prediction camera, such a result is expected as it is better in such cases to oversize rather than undersize. Nonetheless, the economic case should be improved in subsequent projects by reducing the battery bank size. Deep analysis of the 1-second data and system modelling should provide an answer on this issue.

It is also worth noting that the same result could be achieved by reducing load through a controlled shedding schedule, targeting electrical loads that can be interrupted such as refrigeration, pool pumping or electric hot water systems. Holistic management of the grid, by utilising opportunities on both generation and demand sides of the meter and facilitated by high-speed communications, is likely to yield benefits in reducing costs and carbon emissions while improving supply reliability.

5 Applicability for other sites in Australia/internationally

5.1 Geographically isolated networks

Electricity networks in Australia are dominated by the National Electricity Market (NEM), which spans from far north Queensland down to Tasmania and South Australia, the longest in the world. However there are a number of small isolated networks including NWIS (the location of this project), the Darwin-Katherine Interconnected System (DKIS), Alice Springs and arguably the South-West Interconnected System (SWIS) serving Perth and southern Western Australia. In addition, there are several hundred small power stations, typically powered by diesel generators, providing energy to communities and mine-sites and ranging from <100kW to over 100MW.

Many of these are considering and installing solar PV to offset expensive energy costs. All of these networks are experiencing increasing penetration of renewable power.

Nervousness persists in the operators of these networks on the impact of intermittent generation on the overall network and down to the substation level. Substantial investment is often needed to upgrade electrical protection systems if a substation begins to export energy back up the line rather than just supply electricity to consumers. Network operators report that rapid transitions in power output can cause fluctuations in local (street level) voltages, causing excessive wear and early failure of suburban transformers due to increased voltage controller tap movements.

The ability to pre-emptively control the output of a PV system to slow the rate of change of generation, with or without battery for additional support, is likely to be attractive to operators of networks where rapid changes in load are presenting problems. We see the issues faced as being very similar from the NEM to isolated diesel generators despite differences in scale: existing generators being unable to cope with increasingly variable loads.

While one (blunt) solution is to simply limit the amount of variable generation in the network, using technologies such as CloudCAM™ with or without battery support should enable operators to be able to predict intermittencies and act ahead of time to smooth the load on the system.

In this context, we see the opportunity for systems using predictive systems as demonstrated at Karratha to be a valuable and important tool to networks operators at all scales of systems, both in Australia and internationally.

5.2 Brief Review of International Research

There are a number of research efforts and commercial products active in this space.

5.2.1 Commercial Offerings

SteadySun[1] is a French technology company offering up to 30-minute prediction and control of cloud interruption to solar PV using their SteadyEye product. They also offer longer predictions using satellite data and meteorological information.

CloudCAM™ is the technology used in this project, supplied by Fulcrum3D, an Australian company. The capability of their product can be assessed from this report, and examples published on their website.

Sky InSight[2] is a product from Reuniwatt in France, using an infrared camera as the primary detection device. Output from the unit needs to be integrated with a 3rd party controller to manage the output of the PV plant.

TSI-880 Automatic Total Sky Imager[3] appears to be a sky imaging device, but without predictive or control capability

5.2.2 At Commercialisation

The CSIRO[4] has been developing technology in this space. It comprises a low-cost security camera and software capable of measuring wind speed and cloud coverage, as well as predicting cloud movement, shade events, cloud formation, irradiance and power levels.

They are currently seeking commercial partners to develop into a saleable product.

5.2.3 Research

As part of the US Department of Energy SunShot program, the University of California, San Diego has been researching this area. Similarly, there have been many research papers produced (see 5.3 for a brief listing) but the emphasis is related to detection of clouds, rather than the broader application of a cloud camera, battery and ramp-rate control as demonstrated at Karratha.

5.2.4 Demonstration Site Results

At this point we have been unable to find another similar project that demonstrates prediction and control of a PV and battery system at research stage, let alone in an actual production environment. We conclude that this project has been of high quality and advanced in the global context because of these attributes.

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[1] http://steady-sun.com/technology/steadyeye/
[2] http://reuniwatt.com/en/sky-insight-sky-camera-for-intra-hour-solar-forecasts/
[3] http://www.yesinc.com/products/data/tsi880/
[4] https://www.csiro.au/~/media/Do-Business/Files/SME/CSIRO_Solar_Forecasting_Factsheet.pdf?la=en&hash=EBA00A26241B876322A45E17DA28460F1DE9CD00

5.3 Sample of Cloud Prediction Research Papers

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11. Zhen Z, Sun Y, Wang F, Mi Z, Ren H, Su S, et al. A cloud displacement estimation approach for sky images based on phase correlation theory. 2016 IEEE Int. Conf. Power Syst. Technol., IEEE; 2016, p. 1–6. doi:10.1109/POWERCON.2016.7753933.
12. Research on a cloud image forecasting approach for solar power forecasting, Zhao Zhena, Zheng Wang, Fei Wang, Zengqiang Mi, Kangping Li, 9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK