Barcaldine Solar Farm

Knowledge Sharing Report

Prepared for ARENA

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Plant Details	
Plant Name	Barcaldine Solar Farm[1]
Location	Barcaldine, Central West Queensland, Australia
Panel Supplier	JA Solar Holdings Co Ltd
Inverter Supplier	Power Electronics S.L.
Engineering, Procurement and Construction	Green Light Contractors Pty Ltd
Operations & Maintenance	ENcome Energy Performance Australia Pty Ltd
Distribution Network Operator	Ergon Energy Queensland Pty Ltd

Project Sponsor Details	
Companies	Barcaldine Remote Community Solar Farm Pty Ltd
Location	Barcaldine, Central West Queensland, Australia
Portfolio Manager	Foresight Group Australia Pty Ltd
Total Commitment	AUS $34.5 million
Portfolio Capacity	25 MW
Portfolio Life	28.5 years from commissioning

Investment Details	
Total Project Construction Cost	AUS $67.6 million
Senior Debt (CEFC)	AUS $20.0 million
ARENA Grant	AUS $22.8 million
Total Investment Amount	AUS $34.5 million

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

Contents

1 Executive Summary

The Barcaldine Solar Farm is a 25 megawatt photovoltaic solar project located approximately five kilometres east of the central western Queensland township of Barcaldine.

The 93 hectare site has approximately 79,000 solar modules. The site generates approximately 53,500 megawatt hours of renewable energy each year. The project has been designed using single-axis tracking technology allowing solar panels to tilt in the direction of the sun as it crosses the sky, maximizing the total energy generated and the effectiveness and efficiency of each of the panels.

Barcaldine Solar Farm was designed to be the first solar generator designed to assist the control of grid voltage in Australia, in this case controlling de 22kV distribution network voltage for Ergon Distribution Network in the Barcaldine area. Requiring output of active and reactive power on a variable basis to meet grid stabilisation requirements.

A key learning from the project is the requirement for a Q-limit which was not set during the commissioning and tuning process, leading to the Solar Farm being unable to meet the Voltage and Reactive Power Control an operation reactive power limits imposed on it. This report explores the difficulties which the project continues to address and develop engineering solutions to address.

This report explores the key learnings arising from:

A. the construction process,
B. operational history from 2017 to present, and
C. proposed future upgrades to perfect the intended functionality grid voltage control in Australia.

3 Lesson 1 - Network Impact Work Plan

Knowledge type: Network connections

Knowledge category: Technical

Technology: Solar photovoltaic

Key learning

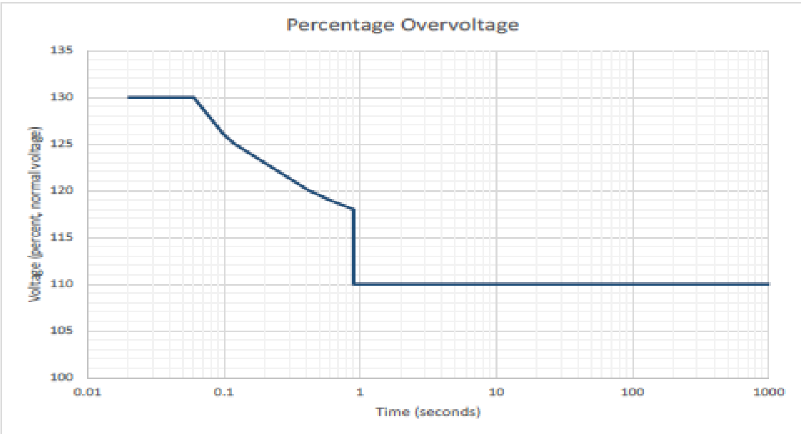
Barcaldine Solar Farm, has been the first solar generator designed to assist the control of grid voltage in Australia, in this case controlling de 22kV distribution network voltage for Ergon Distribution Network in the Barcaldine area.

1) It was discovered that the Barcaldine Solar Farm was unable to meet the Voltage and Reactive Power Control during the commissioning process, Plant was required to rectify this issue through software updates the plant breached the Voltage and Reactive Power Control standards when it tripped completely and unexpected shutdown on the following occasions:
    a) 15:39 on 27 August 2020
    b) 06:59 on 10 September 2020
    c) 16 June 2021
    d) 24 June 2021
2) As a result of these trip events, the plant was directed:
    a) to shut down on 18th Aug 2021 and was not reinstated until 22 Oct 21.
    b) Undertake Rectification works Adjustment of logic and control system settings in the remote telemetry units of the plant by O&M Contractor
3) Contribution to the definition of "Good Industry Practice":
    a) Active power is reduced when a certain amount of reactive power is required by the network, therefore it is important to have a reactive power limit being the upper limit amount of reactive power which the network is entitled to draw.
    b) If this reactive power limit is agreed, it would provide the solar farm an ability to comply with continuous uninterrupted operation as set out in Generator Performance Standards clause S5.2.5.4.
4) It is a requirement under the Barcaldine’s Generator Performance Standards that

    “This generating system and each of its generating units are capable of continuous uninterrupted operation where a power system disturbance causes the voltage at the

connection point to vary within the following ranges: Voltages over 110% for the duration as permitted in the graph below

Figure 1 : s5.1a.4 Power frequency voltage curve



- 90% to 110% of normal voltage continuously;
- 80% to 90% of normal voltage for a period of at least 10 seconds; and
- 70% to 80% of normal voltage for a period of at least 2 seconds.

a) One of the two connection points out of service from 6 June 2020 to 19 January 2021 and operating at 70% output capacity from 19 January 2021.

Controlling the Distribution network voltage is a complicated task, that add a plus of difficulty to the commissioning of the solar farm, due the plant is controlling directly the voltage received by the customers, so the NSP is very sensitive to the plant performance, and very conservative during plant testing.

To address a proper control, is very important to Define a Voltage Control Strategy during the project early stages , defining the Control responsibilities for the generator and for the NSP, as well as covering all scenarios that likely will occur in the grid.

Key items to be addressed for future projects ought to consider:

1. Control Architecture with signals and devices involved.
2. Q limiters to be enabled on the generator and/or on the NSP facilities.
3. Different control scenarios.
4. Transition between the different control scenarios.

The generator Voltage control strategy should be defined, and simulated during the project development, to ensure the proper sizing of the plant.

Is also very important that the NSP keep alive the controls during the generation time to limit the reactive energy that the grid is demanding to the generator; otherwise the generator will be overloaded as the reactive that the grid requires to keep the voltage under control is constantly changing, with big differences between mornings and afternoons.

Implications for future projects

Voltage Control Strategy draft should be provided during project development, and as part of the Connection Agreement, in order to prevent future issues during the commissioning stage, which will delay the project delivery and increase the project cost.

Knowledge gap

Understand well how to integrate the Solar Farm Voltage Control into the existing grid control, which is very an artisanal voltage control on old substations. The swap between the old control and the new control has to be addressed properly to create voltage disturbances.

There is a need for Power Quality data available for the Point of Connection to have a better understanding of the voltage and loads evolution across the day and months.

Background

There were no studies to simulate the voltage control, neither a clear strategy to be followed to integrate the control with the substation one.

The VCS was defined 3 months prior the connection of the plant, which did not allow time for a normal design process to occur.

Objectives or project requirements

Project Sponser and EPC Contractor worked with Ergon to define the requirements for controlling the Barcaldine 132/66/22/11kV substation 22kV bus.

The bus voltage set point , was defined to be 1.03pu (22.66kV).

The generator should control the voltage during sunshine hours and then this control must be transferred to the Barcaldine Substation during non-generating hours.

Process undertaken

EPC Contractor conducted detailed modelling of the grid network using the data provided by Ergon and Powerlink , and the Solar Generator using the final design configurations in order to simulate the different voltage control scenarios, and more specifically the transition between the night and the generator ramping up active power, and at the end of the day when the generator is shutting down.

After several tests on the simulator and on site, it was agreed with Ergon to apply a ramp on the Q that the inverters were producing, so when the inverters arrive at the point of stopping the Q=0, and the substation can take control of the voltage with enough time to make a soft transition.

Supporting information

The figure below how the Solar Farm Voltage control improves the voltage profile in Barcaldine Substation 22kV during the generation, keeping the voltage stable at 22.66kV, and how the voltage fluctuates with the conventional control done by the substation transformers tap changers and reactors.

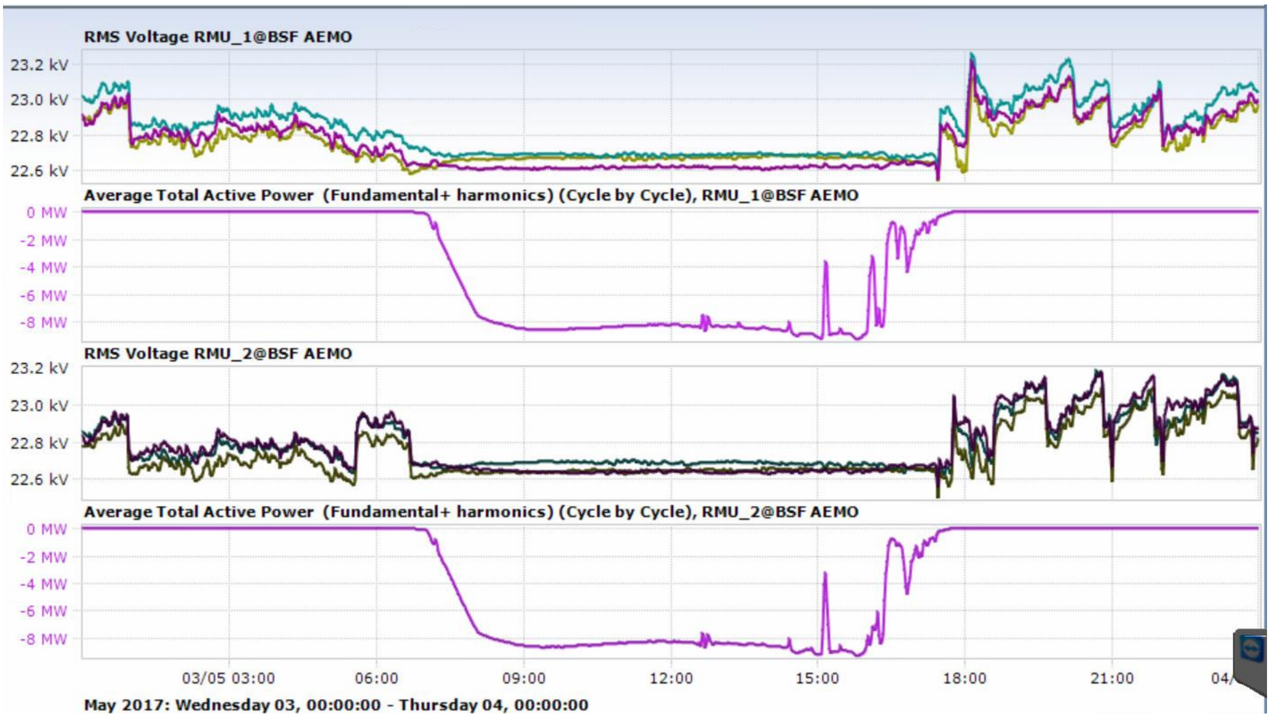


FIGURE 1 EXAMPLE OF HOW THE VOLTAGE CONTROL (CENTRE OF THE PLOT) IMPROVES THE GRID VOLTAGE PROFILE AT PROJECT SPONSER SUBSTATION.

4 Lesson 2 - Flickers emissions in weak grids

Knowledge type: Technology

Knowledge category: Technical

Technology: Solar photovoltaic

Key learning

When a solar farm is connected to a weak grid, like in the case of Barcaldine any single movement of Q will affect grid voltage.

DC voltage controller used in the inverters, that tracks the maximum power point woks manipulating the DC voltage of the solar field, in such way than the maximum energy is obtained for each of the changing conditions (module temperature, irradiance level, etc).

This DC voltage fluctuations is able to create small Q fluctuations, that when applied to a weak grid can cause a high level of flicker emissions.

Those fluctuation on the DC voltage and the flickers , will be higher in periods of maximum activity for the MPPT of the inverters, which is winter and days with poor irradiance.

Implications for future projects

The DC controller should be simulated in the laboratory with the parameters proposed, and probably a by default set of MPPT settings for weak grids to be provided by inverter supplier.

In general the MPPT algorithm should move faster, and with smaller step changes, so the flickers can be mitigated.

5 Lesson 3 - Reactive Capacity

Knowledge type: Technology

Knowledge category: Technical

Technology: Solar photovoltaic

Key learning

The design of the Solar Farm, and more specifically during the sizing and rating of the inverters and the DC solar field, is extremely important take into account the maximum ambient temperature that will limit the Q capacity due to :

a) Inverter current de-rating due to the air cooling temperature.
b) Inverter reactive capacity due to a lower solar field DC voltage related with PV modules temperature.

While point a) is commonly known , the point b) is not the case , and is the factor that will drive the AC voltage of the inverter, and hence the apparent power of the inverter (S) to be installed in the plant.

This is affecting specially the Capacitive zone of the reactive capacity chart.

Implications for future projects

A wide study has to be done, to calculate the PV modules temperatures to ensure that in all conditions the Vmppt of the array is higher than the minimum DC Voltage to deliver the required Reactive Power.

Background

Objectives or project requirements

The generator should deliver at least ±3.95MVAr at full power.

Process undertaken

EPC Contractor performed a detailed environmental conditions study for Barcaldine using the BOM data from the Barcaldine Weather Station (no longer operating), and a subsequent de-rating study to set the envelope to the solar field conditions.

That required to have at least 620DC to deliver the required reactive, which drives the selection of 2150kVA inverters to deliver 2000kW plus the reactive required.

6 Lesson 4 - Grid connection modelling and inverter characteristics

Knowledge type: Network connections

Knowledge category: Technical

Technology: Solar photovoltaic

Key learning

The performance characteristics of the plant inverters are a key input to grid connection modelling conducted for a solar plant. The grid connection model, which forms the basis of the Connection Study and the Connection Agreement, needs to be based on a particular inverter make and model.

On the other hand as important as the inverter, there is the Power Plant Controller, that will be the brain controlling all inverters; therefore is extremely important that in all dynamic modelling the PPC be included with the proper settings, according to the agreed Active and Reactive Power Controls.

When working in Voltage Control Mode, is essential to check the model delays values for the following:

a) Delay in the refresh of the Power Meter data, in order to provide grid parameters to the PPC.
b) Delay in the PPC calculations and set point transfer to the inverters.

Those delays has to be confirmed in the hardware laboratory of the inverter supplier, in order to avoid unexpected behaviours during commissioning.

In voltage control, Q rise times are very restrictive, being requested values under 2 seconds… which in a weak grid , like the ones found generally in the Australian outback, requires a very fast grid parameters acquisition to control properly the plant output, preventing overshoots and to slow responses.

Implications for future projects

Inverter, PPC and metering system, should be tested in a hardware laboratory to confirm PSSE parameters (bench marking of the whole system, not only the inverter), simulating a similar grid impedance that the one observed at the PoC.

Knowledge gap

There are several parameters in the PPC that are not given the importance they have, and sometimes a by default value can be encountered.

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Background

Objectives or project requirements

Original PSSE model provided stated that 20ms was the delay between metering and PPC data acquisition, which was nearly impossible to achieved due to hardware limitations.

Process undertaken

During the hot commissioning of the inverters, the PSSE model was updated with the real delay observed on the laboratory, and a new set of dynamic parameters was tested to obtain the dynamic response required by the GPS.

Supporting information

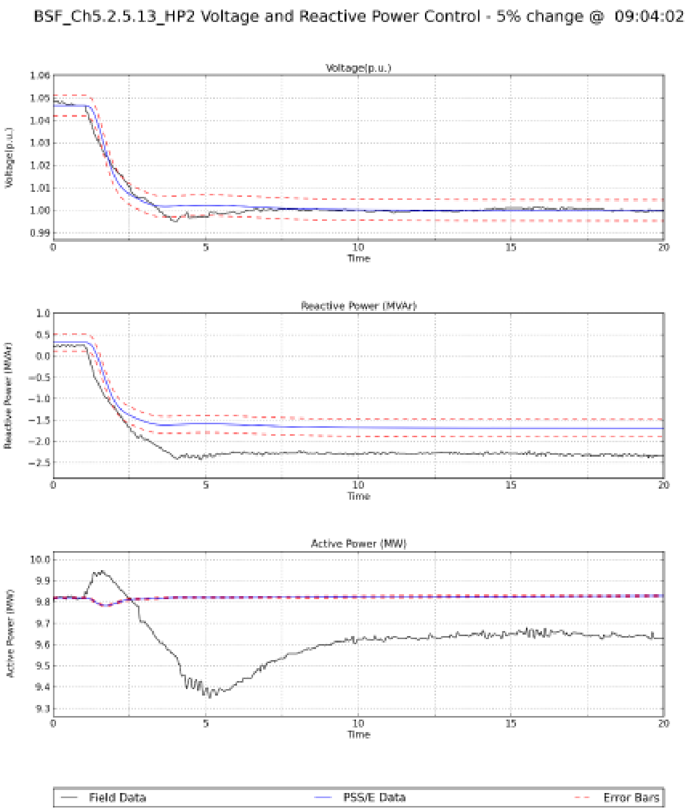

Figure 40: Test 6.1.7 (6): PSS/E Overlay: 5%Step test 4: 1.05pu to 1.00pu at 22kV connection point

FIGURE 2 MODEL SIMULATIONS, IN BLUE, OVERLAPED WITH THE ACTUAL POC BEHAVIOUR

7 Lesson 5 - Interconnection facilities construction – Barcaldine Solar Farm

Knowledge type: Construction

Knowledge category: Technical

Technology: Solar photovoltaic

Key learning

The construction of electrical infrastructure (e.g. substations, switchyards, or overhead lines) assets needs to consider the specific requirements of the Network Service Provider (NSP) as the ultimate owner of these assets. Ergon Energy is the NSP for the Barcaldine Solar Farm.

Power distribution and transmission infrastructure varies across regional Australia, so the impact of connecting a solar plant will have a unique impact on the performance of the local electricity grid. Not every solar plant will require a switchyard, but many may require some other form of local augmentation, and most will require an overhead line.

Unlike other assets constructed at the solar plant, the electrical infrastructure required by the NSP to connect to the solar plant and reinforce the grid, specifically as a consequence of the generator connecting to the grid, are Contestable Works, meaning that either the NSP may construct and operate the asset or that they are built by the generator and gifted to the NSP. This will also include the provision of leases for any associated land. The governance of this is contained within the National Electricity Rules (NER) and associated Regulations.

To mitigate the risk of the project related with the NSP infrastructure, the best option is to involve the NSP in all upgrades and new construction related with their assets (contestable works).

Implications for future projects

Key learnings from the construction of the electrical infrastructure – Ergon Energy’s assets – for the Barcaldine Solar Farm that could be used on future projects:

- Scope of construction – The best option is to include in the Connection Agreement al taks related with Contestable Asset, to prevent delays and ensure a timely delivery of the connection assets.
- NSP / EPC coordination – A weekly coordination meeting between both parties is essential part of the construction process for a timely delivery of the project, from the very early stage of the project.

Knowledge gap

There is no real knowledge gap concerning the construction of assets such as switchyards and substations or installation of electrical infrastructure to augment the grid. However, satisfying the

NSP's requirements is a critical aspect in delivering a solar project and needs to be managed to avoid delay in connecting the solar plant to the grid.

Background

Objectives or project requirements

The Project Sponser generator is connected to the grid via the connection works that included 2 new 22Kv underground feeders owned by Ergon Energy, and also the existing substation protection and control system has been upgraded. All this portion was done by Ergon.

The solar farm should build the 2 feeders till the site boundary, and the switching and metering station.

Process undertaken

Involving Ergon since the project development has been great , as they did the design and the works to build and upgrade the required parts to do the interconnection, delivering a good job in a timely manner.

A weekly coordination meeting between the NSP and the EPC contractor, has been a key for a smooth design and construction process, as both teams were aware of the current status of the project , the issues and the next steps.