Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Construction
	Operating Protocol with Network Service Provider (NSP)

KEY LEARNING

The Operating Protocol is an agreement between the generator and the NSP that outlines the procedures to be followed for safe and efficient operation. It typically covers:

- Operational boundaries
- Operational responsibilities
- Notification processes
- Communication processes
- Switching for planned works
- Switching for emergency conditions
- Special conditions

Both Nyngan and Broken Hill had special operational conditions (unrelated to solar) that needed to be understood by both parties.

While the Operating Protocol may be anticipated in the Connection Agreement it is a stand-alone document.

IMPLICATIONS FOR FUTURE PROJECTS

The Operating Protocols need to be finalised prior to the commencement of operations. For both Nyngan and Broken Hill the Operating Protocols were finalised more than 3 months before any generation.

Discuss the process for developing the Operating Protocol with the NSP and their timing expectations well in advance of generator completion, allowing one month for preparation of the protocol.

KNOWLEDGE GAP

None. The Operating Protocol is based on pro-forma documents provided by the NSP. There is little difference in the Operating Protocols applied to solar compared to other types of generating assets.

SUPPORTING INFORMATION

Essential Energy has a library of documents related to HV connections:
http://www.essentialenergy.com.au/content/hv-connections-documents

The document CEOP8079 - Connection Process includes a section on the HV Operating Protocol:
http://www.essentialenergy.com.au/asset/cms/pdf/contestableWorks/CEOP8079.pdf

Essential Energy also provides a Sample Operating Protocol:
https://www.essentialenergy.com.au/asset/cms/pdf/hv/SampleOperatingProtocol.pdf

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	SCADA and communications

KEY LEARNING

The PV Plant SCADA system provides supervisory control and data collecting capabilities. This data mainly consists of the status of equipment (on/off etc) and analogue quantities such as volts, amps and watts etc. This data is collected from key points in the field that will support the observation, operation and control of the plant. The entire list of data points is generally termed the I/O list as it records the inputs (I) and outputs (O) for the plant. The SCADA system then arranges this data into sets that can then be used by different Stakeholders. These sets constitute the data that each SCADA Stakeholder will be given for their required purposes. For example AGL will require all of the operational control inputs and outputs, and analogue outputs to effectively operate the plant. The NSP may only want to view the analogue outputs as it does not operate any portion of the plant. Hence different sets of data are created and sent to each Stakeholder as required.

The data collected includes:

- Generation data (P, Q, V, I) for the site
- Generation data for individual inverters
- Meteorological Data (solar insolation, temperature etc.)
- Statuses and alarms
- Power data from the NSP

As Nyngan and Broken Hill were the first large-scale solar projects to be connected to the AEMO grid, coordination and early planning with all stakeholders has been identified as critical to the smooth commissioning of the plant. In particular, the I/O list should be agreed among all parties as early as possible. This would allow time for all of the necessary iterations to occur.

First Solar commissioned the SCADA system and engaged a local firm specialised in automation and controls to assist in the commissioning field work for the hardware. This proved to be an excellent combination that added the necessary manpower and experience required during this phase of the project.

With data being shared between a large number of stakeholders, strong coordination and early preparation is required to get everything tested in a short time frame. By using the same contractor at both Nyngan and Broken Hill, these staff were already familiar with the design and procedures. This significantly reduced First Solar's internal costs as less commissioning staff from the USA were required.

IMPLICATIONS FOR FUTURE PROJECTS
In order to take advantage of key learnings, it is important to maintain consistency in SCADA system design. This leads to efficiency not only in commissioning, but also in operation.

Further efficiencies could be gained by developing a standard I/O list for solar plants that is agreed by AEMO and the various NSP's.

While there are unique aspects for every site depending on the connection arrangement, there are core requirements for meteorological data (average solar insolation, average ambient temperature) and plant output at the point of connection (phase & average active power, reactive power, voltage, current, power factor, set points, operating modes, main breaker statuses) the could easily be standardised. Alternately, a guideline similar to the existing AEMO guidelines for semi-scheduled generators could be put in place specifically for solar power plants.

KNOWLEDGE GAP
Apart from solar-specific meteorological data, there is little difference in SCADA systems applied to solar compared to other types of generating assets.

SUPPORTING INFORMATION
None.

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	Commissioning of Inverters

KEY LEARNING

In partnership with the Power Plant Controller (PPC), the inverters provide the performance that the solar plant requires for National Electricity Rules (NER) registration and compliance. The inverters are one of the most complex parts of the solar plant, and require a large amount of analysis prior to commissioning and operation. This analysis was performed by using specialised software (eg. Siemen's Power System Simulation for Engineering (PSS/E)) modelling to determine the theoretical performance and response of the inverters (selection of settings) and PPC prior to operation. This established the performance criteria for NER registration and compliance. The knowledge of the settings gained by this analysis was then transferred into the actual inverters firmware (via the inverter model settings list) prior to commissioning, to ensure that the actual inverters performed in accordance with the NER requirements. The theoretical performance of the inverters was reviewed by the NSP to confirm stable network operation. Hence the commissioning of the inverters allowed the validation of the inverter settings (hence NER requirements) to occur.

The commissioning of the inverters was greatly assisted by selecting a partner (inverter supplier/manufacturer) with a strong local field servicing team, and ensuring that some key spare components were available on site or readily obtainable.

It was found that it is essential to provide a full list of inverter settings to the NSP at an early stage, since all settings may not be captured in the PSS/E model.

It was found at Nyngan that a clear map between inverter model settings and the firmware settings did not exist (i.e. it was unclear from the inverter PSS/E model documentation how to choose equivalent firmware settings that would ensure the inverters provided matching performance to the simulations when operating in the field. To remedy this, a settings map was developed in cooperation with the inverter manufacturer as part of the Broken Hill commissioning.

IMPLICATIONS FOR FUTURE PROJECTS

In future projects, the inverter's complete firmware parameter list should be submitted as an attachment to the R1 data, along with a map to corresponding model settings. This will help to ensure consistency between the simulation and actual plant performance, and reduce the risk of needing to make adjustments to the inverter settings later in the commissioning.

KNOWLEDGE GAP

A number of different inverter manufacturers have been found to have limited knowledge of the AEMO registration process and the model accuracy requirements. Compared with other energy markets overseas, Australia's modelling and validation process appears to be significantly more rigorous.

Generally speaking, First Solar has not seen clear documentation from inverter manufacturers that provides a detailed settings map between firmware and their PSS/E model. This is a significant front-end project risk that may be relevant for all inverter manufacturers, since very few have experience in the Australian market.

However, First Solar has subsequently noticed that some networks in the USA are adopting a similar regulatory approach to that used by AEMO, which should reduce the knowledge gap for Australian developers.

SUPPORTING INFORMATION
None.

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	Commissioning of PVCS and PVIS

KEY LEARNING

The Photovoltaic Combiner Switchgear (PVCS) and Photovoltaic Integrator Switchgear (PVIS):

- Collect the energy produced by the inverters and converges it at the Point of Connection,
- Provide protection for the HV AC cables via circuit breakers and protection relays,
- Provide input into the metering and control of the power production via Current Transformers (CTs) and Voltage Transformers (VTs), and
- House SCADA equipment, fire detection systems, and auxiliary power from an auxiliary transformer.

A PVCS contains circuit breakers for a number of "Way Feeders" (3 per block at Nyngan and 4 per block at Broken Hill) that collect high voltage power from the "Ways". Each Way Feeder is made up of several Power Conversion Stations (PCS) connected in series. Each PCS contains a Ring Main Unit (RMU), step-up transformer, a pair of inverters. The PVCS has an incomer circuit breaker that connects the PVCS to one of the "Block Feeders" circuit breaker at the PVIS. At Broken Hill, the PVCS is used to connect the solar plant to the Point of Connection at the Broken Hill Substation via a 22kV OHL.

At Nyngan the PVIS connects the solar plant to the Point of Connection via the 132/33kV transformer.

The PVCS and PVIS are similar to switchgear arrangements used by other modular generators, such as wind farms. At Nyngan and Broken Hill, the PVCS's were designed by different local 3rd parties. A key lesson learned was that changes to the Generator Performance Standards (GPS) that impact the inverter protection will also impact the PVCS protection schemes, and that this can have a significant project impact through the need to coordinate with third parties to revise and test relay protection settings.

It was also found that the access door designs at Broken Hill (single-person hinged door, sealed with a locking handle compared to a simple roller door design at Nyngan) provided significantly better protection against dust ingress and provided an all-weather environment for personnel during the operating phase of the plant.

Some of the advantages of having a PVIS in addition to PVCSs at a site such as Nyngan are:

- Improved protection of AC cables,
- Provides a level of redundancy when equipment fails,
- Reduces availability losses during maintenance, for example, to perform work on an RMU, it can be isolated at the PVCS feeder, isolating a way feeder, rather than de-energising the entire block at the PVIS.

However, the solar industry is moving to designs that contain less intermediate switchgear, as the availability gains from redundant equipment have not proven to justify the additional capital (including materials, engineering, installation, and commissioning) and maintenance costs that come with increased complexity of the plant design.

Due to the large number of different technical elements involved in delivery and commissioning the PVCS and PVIS (including civil, mechanical, AC and DC electrical, fire detection and suppression, and SCADA) a key challenge was coordinating between the various 3rd parties and ensuring that the complete scope was implemented in full without any gaps in responsibility. This experience will drive additional attention and detail in the subcontractor scope of the PVIS and PVCS on future projects.

IMPLICATIONS FOR FUTURE PROJECTS

Whilst the PVCS design at BH delivers some improvements over Nyngan, they are not directly comparable as the BH PVCS's included several features of the Nyngan PVIS and enjoyed a larger budget allocation due to the site not having a PVIS. In future, we would recommend to avoid roller-door designs since the door design at Broken Hill delivers improved dust protection at negligible additional cost.

KNOWLEDGE GAP

None.

SUPPORTING INFORMATION

None.

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	Coordination with NSP during Commissioning Generation

KEY LEARNING

Key aspects of the commissioning process that required interface with the Network Service Provider (NSP) were:

- Connection Agreement and agreed performance standards in place.
- Preparation of the Commissioning Plan.
- Demonstration that the site was ready to energise – this was achieved through:
    - Submission of Generator Performance Standards (GPS) and associated technical studies
    - Connection Agreement between AGL and the NSP
    - Commissioning Plan and GPS Test Plan
    - Operating Protocol between AGL and the NSP)
    - NSP notices (e.g notices to the NSP for testing and commissioning)
    - Submission of design documentation
    - Certificates of Installation Compliance to AS3000
    - Certificates of Design Compliance to AS2067,
    - Protection test reports
    - Calibration certificates associated with testing equipment
    - Installation inspection by an NSP representative prior to energization.
- Inspection of the HV equipment to be energised by a representative of the NSP.
- Coordination with the NSP Control Centre.
- AC back-feed from the PVIS incomer to the PVCSs and inverter AC circuit breaker.
- First export (inverter AC commissioning) to the grid in accordance with the Commissioning Plan.
- Satisfactory completion of all commissioning tests (SCADA, GPS, etc.) involving generation that might impact the network.
- Permanent connection and ongoing generation.
- Day-to-day operation of the solar farm.

For each of these items, minimum notice-periods apply, which need to be considered in order to avoid the notice period adversely impacting the project schedule. However, it can be difficult during commissioning to adhere strictly to the schedule, but this ensures the best chance of guaranteeing NSP availability.

Introductions between commissioning staff and the NSP early-on, contact sheet (details of key personnel), and communication protocols all assisted with coordination and ensured information was shared efficiently.

It was found that additional time needs to be allowed for any works involving NSP assets due to limited availability of NSP personnel, particularly in regional areas where a small number of staff service a very large network area. Furthermore, time needs to be allowed to become familiar with the specific requirements of each NSP for each specific project - as the requirements, engagement and relationship with Essential Energy for Nyngan and TransGrid for Broken Hill differed in several key ways, including:

- TransGrid took a more active role in determining the inverter and plant controller settings, and made requests for changes to the Connection Studies at a late stage in the project.
- Nyngan was required to implement an Emergency Runback Scheme, which needed to be designed and commissioned in cooperation with Essential Energy.
- In the case of Broken Hill, getting access to the Connection Point at the TransGrid substation for installation of a continuous high-speed meter required a First Solar staff member to undergo several days of training. Arranging for TransGrid to have staff at the substation for implementing line current differential settings was also a task that had significant lead time (~3 months).
- AEMO and Essential Energy disagreed over several aspects of the GPS Compliance Test Plan, and reaching an agreement took over 1 month, with the desire to completely asses GPS Compliance in conflict with the stability of the network. A low-load period during commissioning also required the project to wait several weeks before performing some tests.

IMPLICATIONS FOR FUTURE PROJECTS

With the advantage of hindsight, many of the above challenges could have been managed or mitigated through earlier, more active engagement with the NSP. Based on experience it seems likely that future projects would encounter similar difficulties, all of which are manageable provided that sufficient time is allowed and that this aspect of the commissioning process is prioritised accordingly.

The commissioning plan and test procedures should be:

- Developed in cooperation with the NSP at least 3 months prior to commissioning,
- Need to identify all activities that involve the NSP, and
- Should aim to schedule dates for these activities at least 1 month in advance

Make allowance in the schedule for the unpredictable nature of commissioning impacting on fixed dates agreed with the NSP.

KNOWLEDGE GAP

A general lack of experience commissioning large-scale solar farms in Australia on all sides contributed to the time frames that were necessary for the coordination around commissioning activities.

In future, as NSP's become more familiar with the modular nature of the commissioning process (export coming on block by block) and the nature of control requirements for a generator whose output is highly variable, the process for agreeing settings and commissioning procedures will become more efficient.

SUPPORTING INFORMATION

None.

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	Commissioning of Generating System to AEMO Requirements

KEY LEARNING

Both solar plants are located in remote areas of the network where the grid was very sensitive to the solar plant's performance. As a result, it was found that First Solar's standard commissioning tests and the Generator Performance Standards (GPS) compliance tests for the solar plant occasionally conflicted due to network stability requirements, for example testing the full reactive capability of the plant would have pushed the local network voltage out of range. In some cases it was not possible to perform the tests or the tests needed to be done across a much narrower performance range. To address this, it was necessary to coordinate with both AEMO and the NSP to either reduce the testing scope, or arrange a time to perform the test when the network was more robust, or provide alternative data to satisfy the requirements.

It was found that with less data available on remote areas of the network, it was very important to take pre-generation quality of electricity measurements so that the impact of the solar plant could be accurately assessed.

After experience at Nyngan where there was less engagement with the NSP with regards to the AEMO commissioning program, development of this plan in close cooperation with TransGrid ensured that the testing went more smoothly, and reporting could be completed more quickly.

First Solar planned its commissioning activities based on its experience in the USA and other markets. AEMO commissioning requirements require accurate validation of a user-written Power System Simulation for Engineers (PSS/E) model through overlays of high-speed test and simulation data. First Solar contracted the services of a local consultant to assist in managing compliance AEMO requirements, however the scope was not fully understood in the early stages which led to gaps later on.

The requirement for PSS/E model overlays during the GPS testing (and later R2 validation to 10% accuracy) also highlighted a failure to consider the impact of the power plant controller on the PV plant response. In combination with this, numerous deficiencies were identified with the accuracy of the inverter model, which only came to light once the commissioning process had begun. This led to extensive delays in completing GPS and R2 testing as multiple iterations of the inverter model and firmware were needed in order to improve their accuracy and meet the requirements.

It was also found that whilst the meters in the original design were suitable for ongoing compliance monitoring, they lacked several features that are preferred for validation of the AEMO requirements, such as continuous monitoring at 1ms intervals.

As a consequence of the solar plant being built in stages with a large number of small generators (inverters), it was found that the original version of the GPS Commissioning Plan misinterpreted inverter availability at the various hold points. For example, the plan expected the plant to generate full Reactive Power at 50% Active Power, except that with only half of the inverters online this effectively halves the reactive capability of the plant.

IMPLICATIONS FOR FUTURE PROJECTS

A thorough understanding of the AEMO requirements is required prior to any work (including the GPS) being submitted to AEMO. Time needs to be allowed for development of commissioning and GPS compliance test plans in cooperation with the NSP – the current requirement is 3 months prior to commissioning, but we would recommend presenting a draft several months prior to this to ensure there is time for multiple iterations.

This phase of the project can have significant impact on project timelines and should receive appropriate attention from the outset. This would include holding detailed design review meetings with the NSP and AEMO during the modelling stage of the project, to ensure consistency between the Generator Performance Standards and the intended design of the plant.

KNOWLEDGE GAP

The lessons learned show that knowledge gaps existed among all parties, largely as a consequence of these projects being the first utility-scale solar farms to connect to the NEM, and several of the players involved going through the process for the first time.

The main residual knowledge gap exists around the inverter, which has several unique characteristics for solar power. It was found that the details of the inverter fault-ride-through behaviour were not well understood, or sufficiently represented by the PSS/E model and corresponding documentation (provided by the inverter manufacturer). Failure to identify modelling inadequacies in the Connection Study combined with unfamiliarity of the AEMO commissioning requirements created significant challenges for the project. It is likely that other project developers and inverter manufacturers who lack experience in the Australian utility-scale market will face similar challenges unless they invest in early and sustained engagement with local, suitably-experienced, consulting firms and directly with AEMO.

SUPPORTING INFORMATION

AEMO Completion Requirements
http://www.aemo.com.au/Electricity/Network-Connections/NEM_Generator_Distribution_New-Connection/Stage-6

AEMO National Electricity Rules
http://www.aemo.com.au/About-the-Industry/Legislation/National-Electricity-Rules

AEMO Generating System model Guidelines
http://www.bing.com/search?q=aemo+generating+system+model+guidelines&src=IE-TopResult&FORM=IETR02&conversationid=

AEMO Reliability Standards Implementation Guidelines
http://www.aemo.com.au/Consultations/National-Electricity-Market/Reliability-standard-implementation-guidelines

AEMO Technical Information Requirements for Generators
http://aemo.com.au/Reports-and-Documents/network-connections/Technical-Information-Requirements-for-Generator-Transmission-Connections-in-Victoria

AEMO R2 Testing Guidelines
http://www.aemo.com.au/Electricity/Policies-and-Procedures/R2-Testing-Guideline

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	Minimum Capacity Test

KEY LEARNING

The Capacity Test is performed for each Block in the Solar Plant once it has been brought up to full power and any initial DC Health issues (disconnected leads, etc.) have been rectified. The purpose of the Capacity Test is to confirm that the plant will generate its contracted AC output capacity. This is measured at the Connection Point, with agreed corrections made for temperature and irradiance variations. This is to allow for differences in the DC output of the actual PV modules versus Standard Test Conditions on which the contracted amount is based.

Whilst the Capacity Test is not a direct measure of the energy that a PV plant is likely to produce over its lifetime, the fast and simple test is used to demonstrate to the Principal that the plant is capable of delivering its nameplate AC capacity at the Connection Point. This was agreed as an acceptable starting point from which Practical Completion was granted and the year-long performance tests could commence.

The test procedures followed at Nyngan and Broken Hill were standardised procedures developed by First Solar. Given their ubiquity within First Solar there were no further learning opportunities or improvements to the procedure.

IMPLICATIONS FOR FUTURE PROJECTS

The test procedure used for determining the minimum capacity of the plant should be agreed between the owner/ developer and the Principal Contractor and appended to the contract.

KNOWLEDGE GAP

Procedures for confirming the installed capacity of solar plants vary somewhat across the industry, as there are a number of different methods for assessing that a plant will perform in accordance with its design (Laboratory module tests, Capacity Test, Performance Ratio, Energy Guarantee, etc.).

In order to assure consistency in the quality of design and performance of PV plants that receive funding from ARENA and to ensure that funding is distributed to projects in a fair and equitable manner, it would be advisable to have a standard procedure, such as an industry wide "Standard Capacity Test". This would ensure that plants are built to deliver their intended AC capacity at the Connection Point under normal operating conditions, rather than just the inverter nominal power at 25°C and unity power factor.

SUPPORTING INFORMATION

IEC 61646 - Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval

IEC 60904 - Photovoltaic devices - ALL PARTS

Knowledge Sharing Report

Feedback and areas for improvement – Nyngan and Broken Hill Solar PV

Project Name:	*AGL Energy Solar Project (Nyngan and Broken Hill Solar Plants)*

Knowledge Category:	Technical
Knowledge Type:	Other (please specify): Commissioning
	Demobilisation

KEY LEARNING

Demobilisation planning commenced some months prior to the end of construction and commissioning and included:

- Preparing a layout of the facility during the operational phase
- Identifying any hardstands or laydown areas that did not need to be rehabilitated
- Identifying structures, materials and equipment that needed to be moved or demobilised
- Planning when each activity could take place
- Identifying who would be responsible for each activity

The timing of demobilisation activities depended on punch list items being closed out.

The IT infrastructure at Nyngan and Broken Hill was embedded in the commissioning building, which prevented demobilisation of the building until alternate IT connections could be constructed. If the operational phase needs and temporary nature of the construction-phase buildings had been considered at the outset then the IT infrastructure could have been installed once and had no impact on demobilisation.

Considering the location of hardstands at the outset – placing them where they could be used during the operational phase of the plant – could have reduced the area that needed to be regenerated.

At Broken Hill material excavated for cabling was used to fill in the temporary dam.

IMPLICATIONS FOR FUTURE PROJECTS

Demobilisation for a solar project is identical to other construction projects.

There are opportunities at the outset to leverage off operational-phase infrastructure during the construction phase.

KNOWLEDGE GAP

None.

SUPPORTING INFORMATION

None.