ASIA-PACIFIC SOLAR RESEARCH CONFERENCE

Peer Reviewed
2017 Solar Research Conference

Nick Morley

Fleet Performance of Large Scale PV in Australia

Nick Morley[1], Nicole Ghiotto[1], Sravanthi Boppana[2], James Frederick[2], Adam Reynolds[2]

[1]*First Solar Australia Pty Ltd, Sydney NSW Australia*

[2]*First Solar Inc, Tempe AZ United States*

E-mail: nicole.ghiotto@firstsolar.com; nick.morley@firstsolar.com

Abstract

With over 165 MW AC operating under FS management and total installed capacity to exceed 400MW in 2018, First Solar's fleet of Australian large-scale photovoltaic plants is a reliable source of credible long-term solar energy performance data in the country. Located across Australia in a range of environments, including Broken Hill and Nyngan in New South Wales and Geraldton in Western Australia, the operational data from these plants highlights the nuances of prediction models against design and actual plant parameters, and provide local validation of the reliability and performance advantages of thin-film PV technology in Australia. An analysis of the operational data from three large-scale solar farms has been performed using First Solar's PlantPredict energy modeling software, demonstrating measured performance within ±1% of modeled.

1. Introduction

This paper shares the predictive modeling approach optimised by First Solar and third parties, and compares these with actual performance data of the fleet of Australian plants to date. The accuracy of First Solar's PlantPredict prediction tool has been verified by independent engineers (https://plantpredict.com/), and will be used in this analysis to compare prediction with actual performance data. The comparison will take into account the progress of technology and system parameters over two series of First Solar module technology products, including Series 3, Series 3 Black Plus, Series 4 and Series 4V2.

Understanding spectral shift has had a significant impact on the analysis of module performance for different environments in recent years. Spectral shift helps explain the seasonal variation in energy output that cannot be explained by irradiance and temperature data alone (Lee & Panchula, 2016). PlantPredict includes native functionality to calculate spectral shift effects.

2. Australian Fleet

First Solar's installed, operated and maintained fleet of large-scale solar PV plants in Australia has grown to 165 MW AC since 2012 covering a range of locations and climates across the continent (see Table 1).

Plant	Location	MW (AC)	MW (DC)	Comm'd	Climate	Module
Greenough River	Geraldton, WA	10	13.0	Sept 2012	Hot summer Mediterranean	Series 3
Nyngan	Nyngan, NSW	102	132.4	Sept 2015	Hot semi-arid	Series 3 Black +
Broken Hill	Broken Hill, NSW	53	69.5	Dec 2015	Hot desert	Series 4/4A/4V2

Table 1 - Australian fleet of First Solar large-scale PV plants

The 10 MW (AC) Greenough River Solar Farm, located in Geraldton, WA and commissioned in September 2012, was Australia's first commissioned and operational large-scale power plant. Australia's largest operational PV plant, the 102 MW (AC) Nyngan Solar Plant, is located in Nyngan, NSW and was commissioned in September 2015. The 53 MW (AC) Broken Hill Solar Plant, located in Broken Hill, NSW, is the sister plant to the Nyngan Solar Plant and was commissioned in December 2015.

These plants are constructed using a range of First Solar module technologies and follow the advancement of Cadmium Telluride (CdTe) technology improvements in efficiency and reliability over recent years. First Solar's Series 3 modules, released to market in 2010, improved on Series 2 modules by enhancing current/voltage characteristics for use in large-scale solar plants. Series 3 Black Plus modules introduced in 2013 brought an increase in reliability, demonstrated by third party Long-term Sequential and Thresher testing, as well as continued improvement in efficiency and a reduction of long term degradation guidance. In 2015 First Solar started production of Series 4 modules, continuing efficiency improvements as well as introducing compatibility for 1500V systems. Series 4V2 modules, in production by mid-2015, exhibit an improved quantum efficiency curve resulting in efficiency improvements.

2.1. Performance Prediction Accuracy

Through the design, construction, and ongoing operation of over 5 GW of PV power plants and with total module sales exceeding 13.5 GW globally, First Solar has developed energy prediction methodologies that accurately reflect the unique field performance of their CdTe thin-film modules. Historically, First Solar has used a combination of the PVsyst software and in-house post-processing tools to create energy models for its PV plants. In order to integrate the capabilities of PVsyst and post-processing software into a single modeling tool and improve the transparency of the energy modeling approach, First Solar developed our own software called PlantPredict – this tool has been validated across our operating fleet as illustrated in Figure 1.

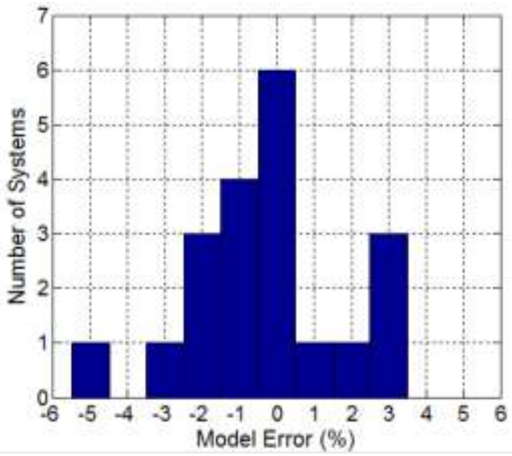

Figure 1 - PlantPredict average model error (Passow, et. al. 2015)

PlantPredict has recently been further developed into a cloud-based web application designed to simplify the creation of large-scale PV power plant energy models. The tool also allows users to easily factor in conditions that influence solar system performance, such as spectral adjustments, that are notably absent from other commonly used modelling software. In previous work, PlantPredict has been validated against both measured performance and PVsyst simulations (Passow, 2015), and is available for free public use. First Solar also provides specific guidance documentation and tools for use with PVsyst, which enable users to achieve modelling results that are consistent with PlantPredict.

3. Expected vs. actual performance

3.1. Methodology and Tools

PlantPredict is used in this analysis to compare predicted results with actual performance data. In the analysis of PV plant performance, actual performance can be compared to expected energy referencing either the contractual or the as-built design. While First Solar's ongoing performance monitoring is typically assessed against contractually agreed performance, the purpose of this analysis is to assess the accuracy of performance models. Therefore, actual performance as measured at the facility connection point, excluding HV transformer losses and HV transmission losses, is compared against the expected energy based on the as-built design and measured weather data. Weather data is recorded using equipment complying with accuracy requirements as detailed in **Table 2**.

Measurement	Instrument Type	Quantity	Test Function	Range	Accuracy
Irradiance	Pyranometer (Global Horizontal Irradiance)	Minimum 2 meteorological stations	Primary for both Capacity Test and Energy Performance Test	0 to 1600 W/m^2 285 to 2800 nm	±2.0% daily
	Pyranometer (Plane of Array)		Primary for Capacity Test		
Ambient Air Temperature	Temperature Probe		Primary for both Capacity Test and Energy Performance	-52°C to +60°C	±1°C

			Test		
Wind Speed	Sonic Wind Sensor		Not used in Capacity Test or the Energy Performance Test	0 – 60 m/s	±5%
Barometric Pressure	Barometer			600 – 1100 hPA	±1hPa
Rain Fall	Raincap Sensor		Primary for the Energy Performance Test	None specified	±5.0%
Relative Humidity	Temperature/ Humidity Sensor		Primary for both Capacity Test and Energy Performance Test (Spectral Shift)	0% to 100%	±5%
Power Plant Power, Amperage, Power Factor and Voltage	Plant Power Meters (Permanent ANSI C-12.20)	Refer to Schedule B (Scope of Work of the Agreement)	Primary for both Capacity Test and Energy Performance Test	0 to Power Plant size +20%	ANSI C-12.20
Module Surface Temperature	RTD (Platinum wire)	Minimum 2 Quad Clusters per Power Plant	Primary for Capacity Test	-50°C to 85°C	±0.5°C
Inverter Power, Volts and Amperage	Inverter Power Metering	1 per inverter	Primary for Effective Availability	Determined from inverter data sheet	Determined from inverter data sheet
Soiling	Soiling Monitoring System	Minimum 2 per Power Plant	Primary for both Capacity Test and Energy Performance Test	0 to 100%	±0.2%

Table 2 - First Solar standards for Primary Measurement Devices

3.2. Loss Assumptions

Energy modelling software requires the user to enter input assumptions for the various losses that occur within the system. The following losses were assumed:

Loss	**Value**	**Source of input assumption**
Horizon Shading	n/a	Observed by onsite measurement stations
Near Shading	Calculated (%)	Calculated by PVsyst and PlantPredict based on actual plant layout
Incidence Angle Modifier (IAM)	Tabular (%)	Series 3 modules: ASHRAE model B_0=0.05 Series 4 modules: Measured tabular values supplied by First Solar, and determined by a third party laboratory, according to module series.
Soiling	Measured (%)	Measured on First Solar reference module soiling stations and input as a monthly irradiance-weighted % loss, calculated from daily comparisons of measured output.
Temperature Coefficient	S3: -0.25%/°C S3 Black+: -0.29%/°C	PV module temperature coefficient supplied by First Solar and determined by a third party

	S4: -0.29%/°C S4V2: -0.34%/°C	laboratory, according to module series.
Thermal Loss Factor (Uc)	30.7 W/m^{2}K	Thermal loss coefficient determined by First Solar (Hayes, W. et. al., 2012), with Uv = 0.
Module Quality	0.0 %	First Solar module performance guidance
DC Health	1.0 %	Standard First Solar input
Spectral Adjustment	Calculated (%)	Calculated based on measured temperature and humidity according to First Solar's 2-parameter spectral model
Module Mismatch	1.0 %	First Solar module performance guidance
DC Ohmic Loss	1.5 %	Standard First Solar assumption
Auxiliaries	0.2 %	Standard First Solar assumption
AC Ohmic Loss	1.0 %	Standard First Solar assumption
Transformer Loss (resistive/inductive)	0.9 %	According to MV transformer manufacturer data
Transformer Loss (iron loss)	0.1 %	According to MV transformer manufacturer data
Degradation	Series 3: 0.7% p.a. Series 3 Black+ onwards: 0.5% p.a.	Applied linearly to total plant output each month after year 1

Table 3 - Summary of loss factor inputs

3.2.1. *Transposition*

A significant factor of uncertainty in energy predictions comes from the transposition of the Global Horizontal Irradiance to the Plane of Array Irradiance. This is typically achieved in energy predictions via the use of either the Hay model or the Perez model, which can commonly lead to a difference in the amount of expected available solar energy compared to actual available of 1% or more – First Solar has previously published on this topic (M. Lave and W. Hayes, 2014). This analysis avoids this potential source of bias using PlantPredict's POA input feature, where the software bypasses the transposition model and instead accepts measured POA data from the plant POA pyranometers for the analysis

3.2.2. *Module Quality*

All PV modules have a tolerance associated with their nameplate output. First Solar Series 3, Series 3 Black Plus, Series 4, and Series 4V2 PV modules are binned in steps of 2.5W$_{DC}$. A key point of difference of First Solar's CdTe modules is that they are de-rated to account for the initial stabilisation that occurs with CdTe thin-film PV modules. First Solar applies an Engineered Performance Margin (EPM) to the measured output on the production line, designed to account for this initial efficiency loss and ensure that the output at the end of year one is equal to or exceeds the nameplate power. This is the basis for First Solar's guidance of a 0.0% loss for module quality.

3.2.3. *DC Health*

The DC Health Factor Loss is a steady-state loss which accounts for faults such as under-performing strings due to module connection issues, blown fuses, defective modules, as well as array in-homogeneities due to temperature gradients and the impact of hourly averaging, and MPPT tracking efficiency on system performance. A portion of this loss is attributed to the time delay between the onset of small distributed failures and their detection and repair. PV plants with string-level monitoring may achieve an improvement in DC Health, but at some increased capital cost. First Solar has assumed a DC Health loss of 1% in these studies, matching the original energy predictions that were done for the project financing.

*3.2.4. **Soiling***

Dust from various sources will accumulate over time, and reduce the amount of irradiance reaching the active material in the PV module. The soiling losses incurred are primarily a function of the frequency of rainfall, as well as the ground and soil conditions and associated dust levels at the site.

Soiling monitoring stations are installed at First Solar's large-scale sites to compare actual soiling data with that used in predictions. The stations consist of two side-by-side calibrated reference modules, one of which is cleaned weekly.

Table 4 and Figure 2 illustrate measured soiling losses at each site of First Solar's Australian large-scale fleet. For Nyngan and Broken Hill, the monthly losses have been applied as an input to PlantPredict to determine the expected performance. As the graphs below indicate, measured soiling has been relatively low at all sites. Nevertheless, there are many examples of sites where soiling levels are much more significant, even exceeding 10% in some months - local site conditions must always be factored in for a detailed energy performance analysis.

Site	Average actual measured soiling
Greenough River Solar Farm	0.31%
Nyngan Solar Plant	0.34%
Broken Hill Solar Plant	0.16%

Table 4 - Average measured soiling Greenough River, Nyngan and Broken Hill Solar Plants

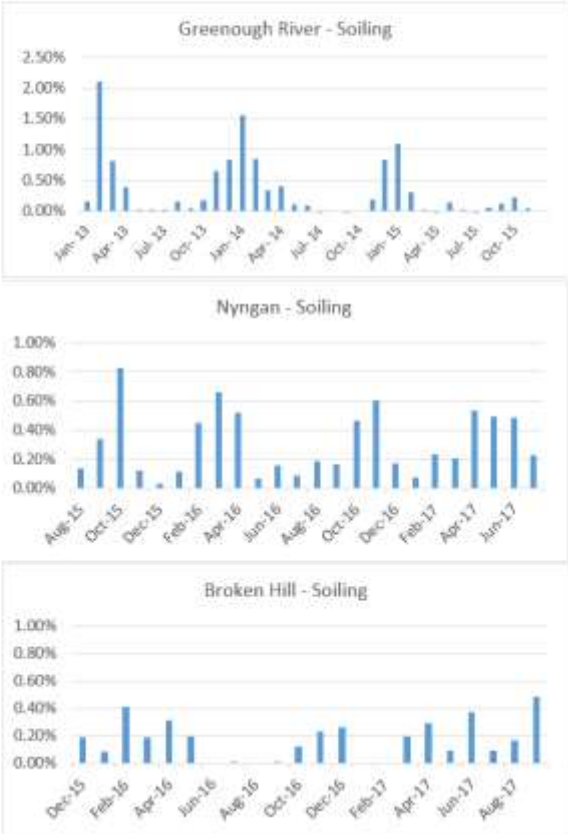

Figure 2 - Actual measured soiling at Greenough River, Nyngan and Broken Hill Solar Plants

3.2.5. *Spectral Adjustment*

Typical PV system modelling assumes a constant solar spectrum based on the ASTM G173 standard with an air mass (AM) of 1.5 and a precipitable water (Pwat) value of 1.42 cm. However, both seasonal and time of day changes in the solar spectrum compared with standard test conditions (STC) are known to induce shifts in the performance of PV modules. Due to the distinct quantum efficiency (QE) curves of their respective cell technologies, CdTe and c-Si (as well as other PV devices) exhibit different sensitivities to changes in the solar spectrum relative to observed solar energy measured by broadband pyranometers. To manage the increased sensitivity to short wavelengths of CdTe devices, First Solar has done extensive research to quantify the impact of changes in the solar spectrum on expected performance and is developing increasingly accurate models for calculating spectral shift (M). The first model was a function of Pwat only, after identifying that atmospheric water vapour was the primary driver of spectral shift in CdTe devices (Lee & Panchula, 2016). First Solar has recently developed and published a 2-parameter spectral model which considers both Pwat and AM, suitable for use with both CdTe and c-Si devices. This model results in improved accuracy for expected versus measured spectral shift for both technologies (Lee & Panchula, 2016).

The model and field results indicate that First Solar modules will experience positive spectral shift (increased performance) under conditions of high Pwat and low AM, when field conditions are hot and humid. This usually occurs seasonally during the summer and in the middle of the day, when irradiance is high and the majority of energy is generated.

Conversely, negative spectral shift (decreased performance) is experienced by First Solar modules under conditions of low Pwat and high AM under cool, dry conditions, which typically take place during early morning and late afternoon and seasonally during the winter, when irradiance and production are lower.

Unfortunately, most commercial energy modelling tools such as PVsyst do not yet offer the capability to apply a spectral adjustment. First Solar has produced an application note to allow PVSyst users to calculate spectral shift for entry into the PVSyst model, however one significant advantage of PlantPredict is that none of this post-processing is required. The user simply selects the spectral model he or she wishes to apply (the 2-parameter model is now the default), and the software will apply an hourly spectral shift to the Plane of Array (POA) irradiance.

3.2.6. *Models of the PV Plants*

Both Nyngan and Broken Hill solar plants utilise a combination of different module bin classes, and in the case of the Broken Hill Solar Plant, modules of different series. In PlantPredict this is managed through a nested hierarchy of blocks and arrays, which allows the user to define separate DC and AC architectures for sections within a PV Plant. The software then aggregates the output from each sub-component to obtain a final result. PVsyst provides a similar function through the use of sub-arrays; however, because the soiling losses are defined globally for the whole system within PVsyst, it is not possible to apply independent spectral shift values to each sub-array using First Solar's post-processing spectral adjustment tool. Since the Broken Hill Solar Plant contains array types using both Series 4 and Series 4V2 modules which have different spectral responses due to the advancement of a graded semiconductor band gap, the native inclusion of spectral shift in the software was particularly valuable since the calculation is automatically run at the DC array level.

3.2.7. *Determination of Adjusted Expected Performance*

The output of the PlantPredict models provide the 'expected performance' of the PV Plants based on actual weather. The expected performance then requires an adjustment to account for degradation, monthly recorded availability losses, and other lost energy to determine the 'adjusted expected performance,' against which we can compare the actual measured output.

In accordance with First Solar guidance, degradation is not applied to the expected performance in the first year of operation. After the first year, a degradation loss has been applied to the DC output on a linear-hourly basis through a built-in PlantPredict function. For example in the case of the Nyngan Solar Plant, which has now been operational for more than two years, degradation was applied on an hourly basis at a rate of 0.5% per year (0.000057% per hour) after July 2016.

For availability and other lost energy, the operations and maintenance contractor (in this case First Solar) logs forced outages, planned outages, maintenance outages, out of management control events, and curtailments. This analysis accounts for availability and other lost energy through a combination of data filtering and calculation of lost energy. Lost energy due to derating of inverters or inverter outages was calculated using a methodology developed by Hunt et. al. (2015) during each outage period, and subtracted from the expected performance – the amount of lost energy can be accurately determined by comparing the output of identical operating inverters, and the overall impact on energy is fairly small. Outages periods that occurred at the combiner switchgear level or higher and plant curtailment periods where the PV plant is directed to reduce its output by the grid authority were excluded from the analysis by manually reviewing O&M logs and plant setpoint data, then deleting both actual and expected generation from those periods.

3.3. Results

Figure 3 and Figure 4 show the PlantPredict models compared to actual metered data for the Nyngan and Broken Hill solar plants in the post-commissioning operational phase.

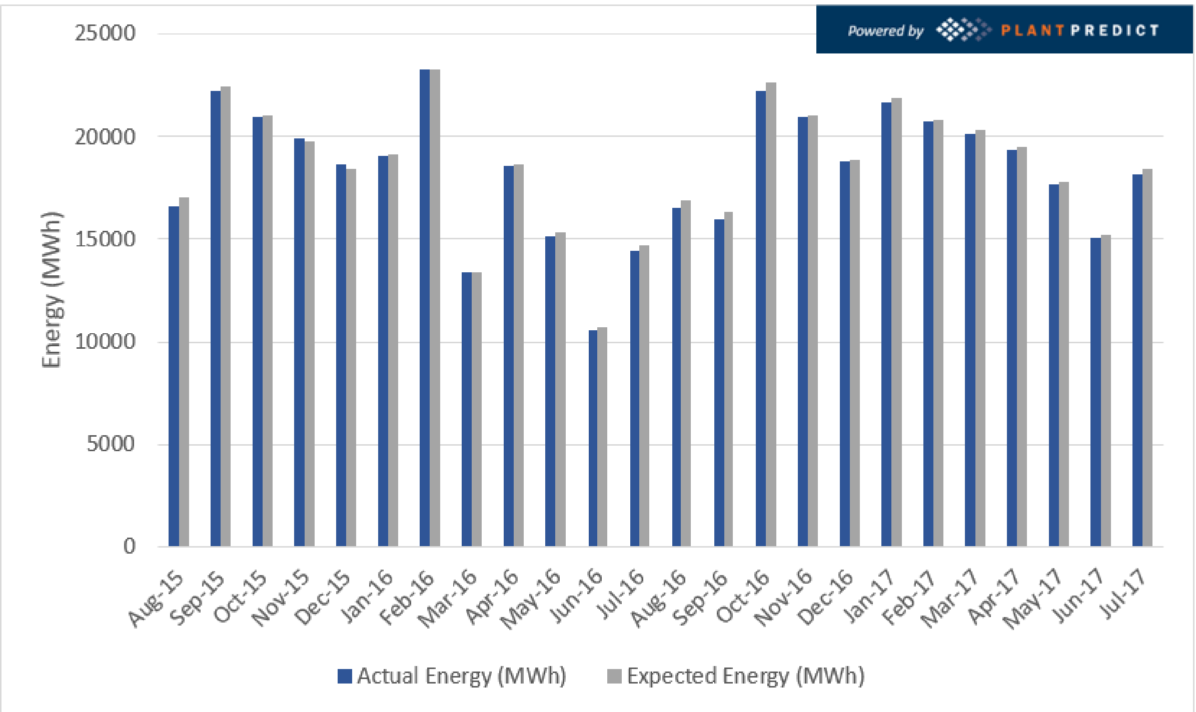

Figure 3 - Nyngan Solar Plant actual vs. expected performance modelled in PlantPredict (NYSP 2017)

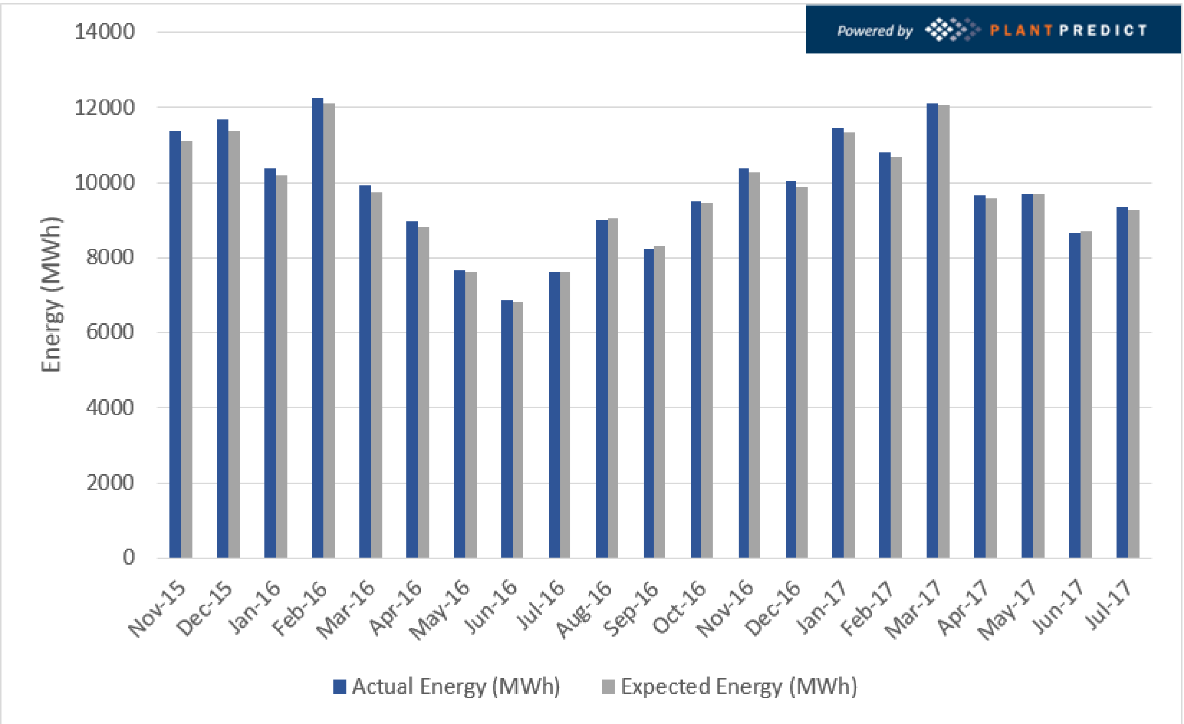

Figure 4 - Broken Hill Solar Plant actual vs. expected performance modelled in PlantPredict (BHSP 2017)

Figure 5**Error! Reference source not found.** shows benchmarking results for Greenough River between October 2012 and June 2017. Expected monthly energy using PVsyst and an irradiance-scaling methodology described in the original study (Ghiotto, N. et al., 2016) is compared with metered generation data at Greenough River Solar Farm, with degradation applied at 0.7%p.a. in accordance with the historical guidance for Series 3 modules. PlantPredict was not used for this analysis as the previous methodology and code was already in place. A comparison of PlantPredict results and this methodology could be the subject of future work.

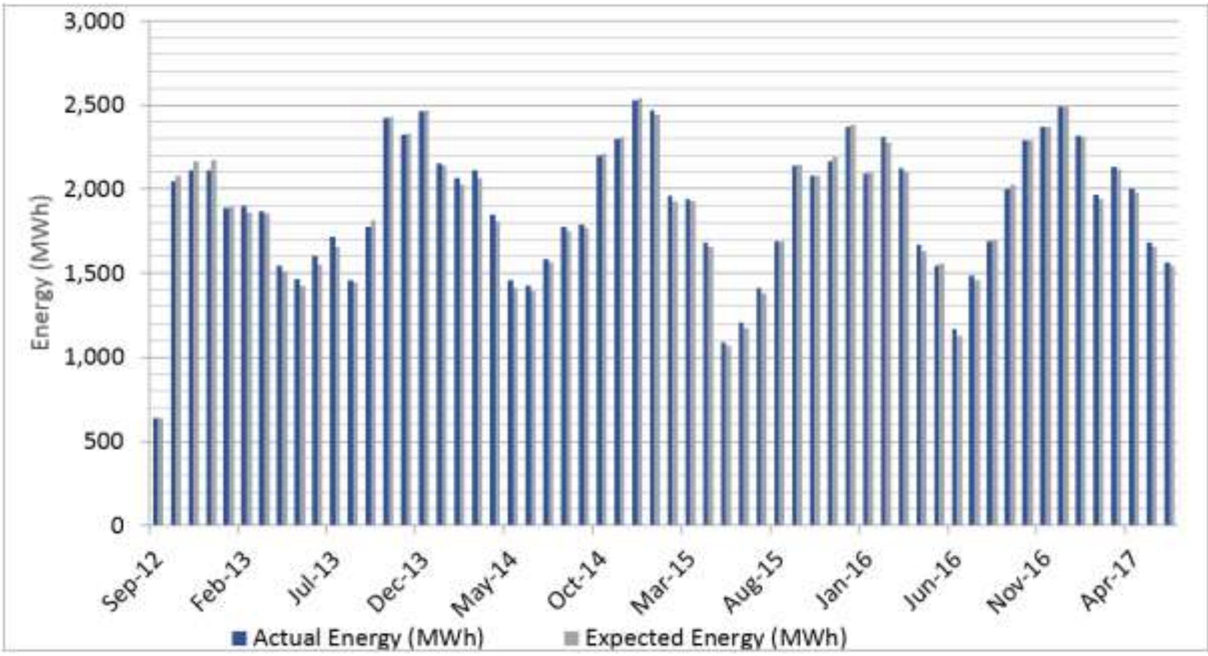

Figure 5 - Greenough River Solar Farm actual vs expected site performance using irradiance-scaling methodology and including lost energy adjustment (GRSF 2017)

The existing fleet of large-scale solar plants in Australia using First Solar modules is performing within ±1% of predicted, further validating the accuracy of First Solar's modelling guidance. A breakdown of the results is shown in Table 5 - **Summary of results** (positive values indicate actual performance exceeded expected performance):

Site	Validation period	Actual vs PlantPredict adjusted expected performance
Greenough River Solar Farm	4 years 9 months	+0.78%
Nyngan Solar Plant	2 years	-0.80%
Broken Hill Solar Plant	1year, 9 months	+0.95%

Table 5 - Summary of results

These results indicate that First Solar's large-scale fleet in Australia is on average, performing to within ±1% of expected output. Particularly considering that energy modelling uncertainty is generally considered to be approximately 3%, the results are a firm indication that the energy prediction guidance and assumptions are accurate, without being overly conservative. The results are also a strong validation of PlantPredict's effectiveness as energy modeling software, providing further evidence that PlantPredict delivers results comparable with other industry-standard tools such as PVsyst.

4. Discussion

Results from all plants being within 1% of modeled is certainly a strong outcome. Nevertheless given their closeness in proximity and commissioning date, the spread of performance results between Nyngan and Broken Hill warrants some discussion and investigation. Aside from general model uncertainty there were three primary contributing factors identified which reduced Nyngan's result compared to Broken Hill's.

4.1. AC Cable Losses

In this analysis, Nyngan Solar Plant suffers from additional 33kV cable losses compared to Broken Hill – two of the four 25MW blocks at Nyngan are separated by a large environmental offset areas which half of the generation must traverse to reach the connection point, compared to Broken Hill where the two blocks are adjacent to their combiner switchgears where they are metered for this analysis. Comparing total generation at the combiner switchgear level (edge of each block) with the integrator switchgear where meter data was taken for the analysis, 0.2% energy losses were measured. Since both simulations use a standard assumption of 1% AC cable losses, this is likely to be a contributing factor.

4.2. Module technology

Nyngan Solar Plant utilizes First Solar Series 3 Black Plus modules, whereas Broken Hill utilizes Series 4 and Series 4V2 modules. It's possible that the newer module technology is performing better than older Series, and it's also possible that the average module deviation from nominal output of the modules at Broken Hill out of the factory (sometimes referred to as bin distribution or positive tolerance) is slightly higher for Broken Hill than for Nyngan.

4.3. Sub-hourly Clipping

As part of the analysis, each hour of the actual and expected data was graphed for review in order to identify periods of underperformance and analyse potential causes. Figure 6 shows the actual vs expected output profile of a typical clear day at Nyngan from April 2017 where actual output exceeded expected by 5.3MWh (0.67%), and the actual vs expected output profile of a typical cloudy at Nyngan from April 2017 where actual output exceeded expected by 15.5MWh or 8.9%.

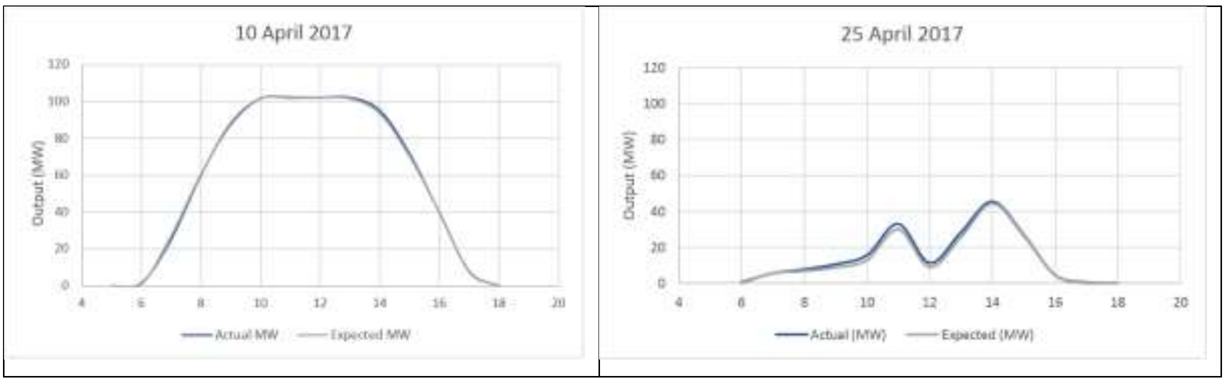

Figure 6 – Generation profile for typical sunny and cloudy days at Nyngan

This behaviour indicates modules performing slightly above expectation during clear conditions, and well above expectation during cloudy conditions. Under what conditions, then, does the model over-predict the performance of the solar farm? Figure 7 shows an example of a partly clear, partly cloudy day at Nyngan from February 2016, where actual energy slightly exceeds expected all morning until 12pm where it suddenly drops for just over an hour, on the whole falling short of expected by 9.7MWh or 1.2% for the day, and from the period from 12-1pm underperforms by over 12%. The right-side image is taken from a one-second trend from the plant SCADA system and shows the actual generation compared to the irradiance – here the reason for the underperformance becomes clear. Nyngan, as is common to most utility-scale solar farms, has a DC:AC ratio greater than 1 and as such the output from the inverters will “clip” at a certain irradiance level, meaning there is capability to produce more power on the DC side but the inverters have reached their maximum output and cannot produce more. Normally, the modeling software accounts for this clipping loss, however the simulation has been performed using hourly-averaged data. When the conditions change from clear to cloudy, we can see rapid changes in irradiance – each time the irradiance exceeds the clipping level, energy is lost by the plant. However when the average irradiance value for the hour is calculated, it is now low enough that the modeling software determines that there should not have been any clipping, seeing instead that there should have been only just enough solar irradiance for the plant to achieve its maximum output. A manual review of the actual vs expected output curves for the entire period of analysis at both Nyngan and Broken Hill showed that almost every period of significant underperformance could be directly tied to this effect.

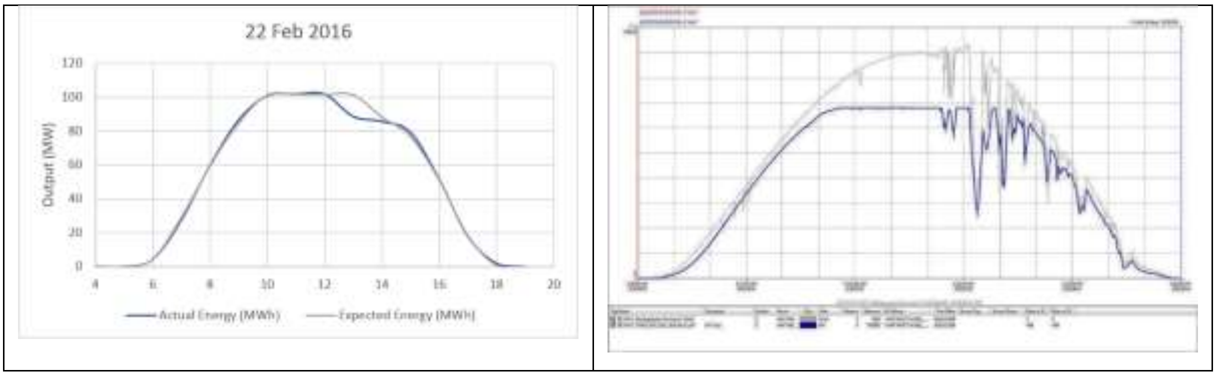

Figure 7 – Generation profile (left) and 1-second generation vs irradiance (right) for a partly clear, partly cloudy day at Nyngan

This modeling error due to sub-hourly clipping losses is a topic First Solar have published on previously (Hayes, et. al, 2013), where it was determined this effect was expected to impact annual energy by 0.2-0.3%. The previous research was validated at a site in the North American High Desert, and the results at Nyngan provide an interesting addition to these conclusions. Ideally, a 1-minute analysis (PlantPredict accepts averaging periods up to this level) would be performed to redo the analysis so that the modeling software could more accurately account for clipping losses during brief periods of high irradiance, however unfortunately there was not sufficient time available in this study. Instead, a simple data filter was used to estimate the impact on total energy by filtering out periods when expected energy was simultaneously greater than 80% of the nominal output (if average output is much below this the likelihood of any clipping is diminished), and actual energy was greater than 5% below expected (designed to ensure underperformance from other minor factors is not also filtered out, but so that periods like that on the 22nd February 2016 are excluded from the analysis). The clipping filter does not exclude all periods with sub-hourly clipping and may also filter out some periods with underperformance caused by other factors, however it appears to give a reasonable approximation of a 1-minute analysis. Applying this filter improved the result at Nyngan by 0.85% such that actual measured energy exceeded expected by 0.05% over the two year period, shown in detail in Figure 8. Applying the same filter at Broken Hill provided less of a benefit, only improving the result by 0.23% to +1.18% above expected. Part of the reason for this is expected to be because Broken Hill experienced far more curtailments from the grid authority over the test period, and many periods where sub-hourly clipping would have occurred were already excluded from the analysis because the solar farm had a set-point below 100%.

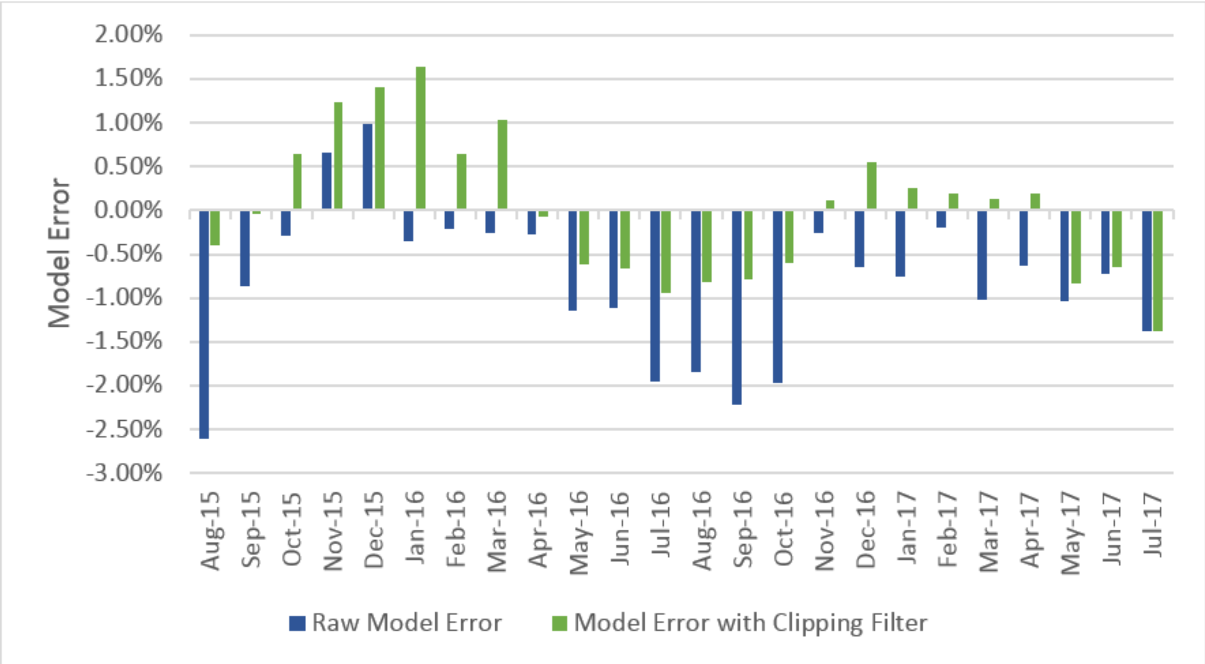

Figure 8 – Reduction in model error when the clipping filter is applied

These results suggest hourly averaging may result in more significant modeling errors than previously estimated, with the primary drivers being high DC:AC ratio (which increases the total clipping periods and therefore the likelihood of sub-hourly clipping) and climates with high irradiance and large amounts of cumulous clouds which cause rapid changes in irradiance. It may be the case that the climate in Western NSW contains a higher frequency of these weather conditions than the North American desert, and that we see model error as a result of this effect as high as 0.85% compared to previous maximum estimates of 0.3%. This is something that warrants further investigation and may potentially be a topic of future research.

4.1. Spectral Shift

The impact of the spectral shift model on the error between actual and expected results was reviewed by subtracting the monthly spectral shift factor from the monthly model error after the clipping filter had been applied. The spectral model is shown to either improve or not impact the accuracy of the prediction 73% of the time, demonstrated in Figure 9 via a generally higher model error when the spectral shift factor M is removed from the calculation. Although for these locations the magnitude of the cumulative spectral shift factors calculated for the overall analysis (+0.03% for Nyngan and -0.36% for Broken Hill) is very small compared to the overall uncertainty and other factors affecting performance, there is a clear demonstration that on average the spectral model has resulted in a meaningful improvement in simulation accuracy on a monthly basis. If only months where the calculated spectral shift was greater than ±0.5% are considered, the spectral model reduces the simulation error approximately 86% of the time – this helps to filter out noise from other sources of uncertainty and strengthens the indication that the spectral shift model improves simulation accuracy. In both cases, the spectral model improves the simulation accuracy and is therefore not expected to be a contributing factor behind the difference in results between Nyngan and Broken Hill.

Figure 9 – Reduction in model error from inclusion of spectral model

5. Conclusion

The accuracy of prediction models is a critical requirement for reducing the contractual performance risk of PV projects. These results indicate a strong correlation between expected and actual energy when the energy model is designed according to First Solar's modelling guidance and thereby should act to improve the viability of future PV projects in Australia.

Furthermore, the close correlation between actual performance and results obtained using PlantPredict validate the accuracy of First Solar's energy prediction software in the Australian climate, with results closely matching previous studies performed in the USA. The demonstrated performance of First Solar's Australian fleet also highlights the importance of modelling guidance that takes into consideration spectral shift and accurately models parameters beyond the standard functionality and default settings of pre-existing modelling software.

Finally, in validating input parameters to the model which include temperature coefficients, spectral shift, degradation, and first-year output, the analysis demonstrates the performance and reliability advantages inherent to First Solar's CdTe PV modules in a range of Australian environments.

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GRSF performance data courtesy of Synergy and GE Energy Financial Services

NYSP and BHSP performance data courtesy of PARF