AN ASSESSMENT OF PHOTOVOLTAIC MODELLING SOFTWARE USING REAL WORLD PERFORMANCE DATA

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ABSTRACT: The Desert Knowledge Australia Solar Centre (DKASC) is a solar technology demonstration facility located in Alice Springs, Central Australia, with over 30 installed Photovoltaic (PV) systems. Data from the DKASC PV systems, as well as site meteorological data, is publicly available over the internet. PV modelling software is widely used in the design of PV systems to determine expected energy yield. To date, few independent studies have been conducted to assess the accuracy of commonly used PV modelling software against real world performance data. Using the available data collected by the DKASC, six existing PV systems were modelled using four different modelling tools and the model outputs were assessed against actual system performance. The modelling tools assessed were PVsyst, HOMER, RETScreen and SMA Sunny Design. In the context of the DKASC, and accounting for the uncertainties present in the models and testing, the modelling tools were found to be relatively accurate.
Keywords: Desert Knowledge Australia Solar Centre, DKA, Modelling, Monitoring, Photovoltaic, Qualification and Testing, Simulation, Small Grid-connected PV Systems, System Performance, PVsyst, HOMER, RETScreen, SMA Sunny Design

1 INTRODUCTION

The Desert Knowledge Australia Solar Centre (DKASC) is a solar technology demonstration facility located in Alice Springs in Central Australia [1]. It provides a facility for commercialised solar technologies to be installed, operated and monitored under the same conditions by an independent organisation. All metered data from these technologies, along with operational and meteorological data, is made publicly available over the internet in real time. Since it began operation in October 2008, over 30 solar technologies have been installed at the DKASC. The majority of these installations have been multi-string arrays of 5-6 kW in size and the total capacity of the facility has reached 201 kW.

Photovoltaic (PV) modelling software is widely used in the design of PV systems to calculate expected energy yield. To date, few independent studies have been conducted to assess the accuracy of commonly used PV modelling software against actual measured field data [2]. Using the available measured data collected by the DKASC, four PV modelling software tools have been assessed and their performance compared. The modelling tools assessed were PVsyst, HOMER, RETScreen and SMA Sunny Design.

2 METHODS

2.1 DKASC Measurements

The DKASC measures a number of meteorological parameters using an on-site automatic weather station: global horizontal solar radiation, diffuse horizontal solar radiation, ambient temperature, humidity, rainfall, wind speed and wind direction. Each solar PV system at the DKASC is metered using IEC 60044-1 Class 0.5 power and energy meters. All data from the weather station and metering is collected at a resolution of 5 minute intervals.

2.2 DKSAC PV systems

Six different PV systems at the DKASC were selected for assessment. The systems selected were ground mounted on frames apart from the roof-mounted polycrystalline array. The systems selected were:

- 5.1 kW monocrystalline (medium efficiency) array.
- 5.8 kW monocrystalline (high efficiency) array.
- 5.4 kW polycrystalline array.
- 5 kW polycrystalline roof-mounted array.
- 6 kW amorphous silicon array.
- 7 kW cadmium telluride (CdTe) thin-film array.

The systems each use suitably sized SMA SMC transformer-based, single phase inverters, are oriented towards true north and tilted 20º. The systems were all installed within 2 months of each other.

2.3 PV modelling software

Four commonly used PV modelling software tools were assessed. The details of these modelling tools are listed in Table I.

Table I: Details of PV modelling software assessed

	PVsyst	HOMER	RETScreen	Sunny Design
Version assessed	5.51	2.68 beta	4	2.01.0R
Commercial licensed software	Y	N	N	N
Meteo. data input	1 year of hourly data	1 year of hourly data	1 year of monthly average data	Not possible
Irradiance Model [3]	Hays and Davis model	Hays and Davis model	Isotropic Sky model	private
Array perf. Model [3]	one-diode equiv. circuit model (mod. for thin film)	linear irradiance model with temp. correction	Evan's average efficiency model	private

Each modelling tool applies its irradiance and performance model algorithms before a number of derating factors are applied to determine the final system output. PVsyst provides extensive options for calculating derating (i.e. inverter profile and efficiency curve, field thermal loss, standard NOCT factor, Ohmic losses, module quality, mismatch, soiling [annual or monthly], and IAM losses). HOMER and RETScreen both provide a single derating factor for inverter efficiency and calculate temperature derating. However, all other deratings in HOMER and RETScreen are simply specified by a single, user-input percentage derating factor. Sunny Design calculates derating for inverter efficiency, temperature and line losses but does not allow the user to input any other separate derating factors.

2.4 Modelling

The system and meteorological dataset collected at the DKASC was analysed and data anomalies such as grid disturbances and initial system installation issues were identified. An optimal 1 year period of validated continuous data was then selected accounting for the expected output degradation of the six PV systems. In particular, the initial drop in efficiency of the amorphous silicon array to its nameplate rating, as a result of the Staebler–Wronski effect, was accounted for by selecting a period after this initial efficiency drop [4]. Concurrently, the unwanted gradual output degradation experienced by the other non-amorphous PV systems was minimised by selecting a period as close to their installation dates as possible. The resulting 1 year period of data selected for modelling the systems was April 2009 to March 2010. The DKASC had no downtime or data anomalies in the daylight hours during this period.

The selected 1 year period of DKASC meteorology data was compared with the Australian Government Bureau of Meteorology (BOM) 20 year average climate data for Alice Springs. As shown in Fig. 1, it was found that the DKASC average daily global horizontal solar radiation for the year compared well with the average climate data for Alice Springs, with a closely matching annual average and some deviation around the summer months.

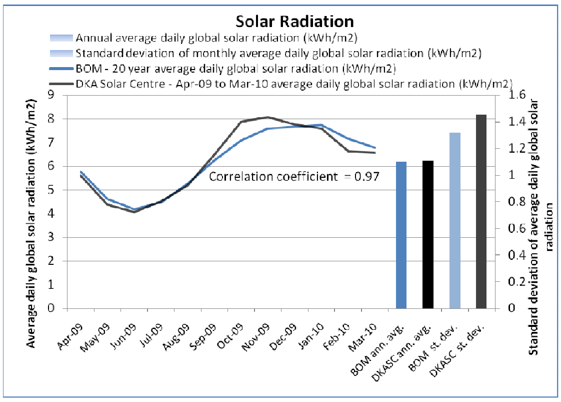

Figure 1: Comparison of the selected 1 year period of DKASC solar radiation with the BOM 20 year average

To create the models for each PV system, the DKASC 5 minute interval meteorological data was converted into formats that could be accepted by each modelling tool. Meteorological data could not be input into Sunny Portal and its private, default meteorological data for Alice Springs was used instead. The details for each PV system were then input into each modelling tool, e.g. modules, inverters, tilt, azimuth, location, array layout, cable dimensions and mounting. For consistency, the same assumptions and derating factors were applied across each modelling tool where possible. In cases where a modelling tool did not have the facility to calculate a particular derating factor, or there was uncertainty about an input into a modelling tool, the tool's recommended or default value was used. For instance, HOMER does not provide the facility to calculate many derating factors and the user must specify a single non-temperature array derating factor. HOMER support provides advice that the typical non-temperature array derating factor should be around 90% [5]. As such, the non-temperature array derating factor in the HOMER models of the PV systems was set to 90% and the same non-temperature array derating factor was subsequently used in RETScreen.

3 RESULTS AND ANALYSIS

3.1 Individual PV system results

The energy yield (kWh) results from each modelling tool and their comparison with the actual energy yield of the DKASC systems are provided in Figures 2 to 7 below.

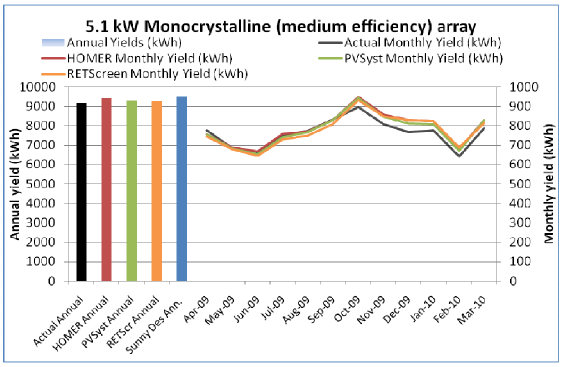

Figure 2: 5.1 kW monocrystalline (medium efficiency) array results

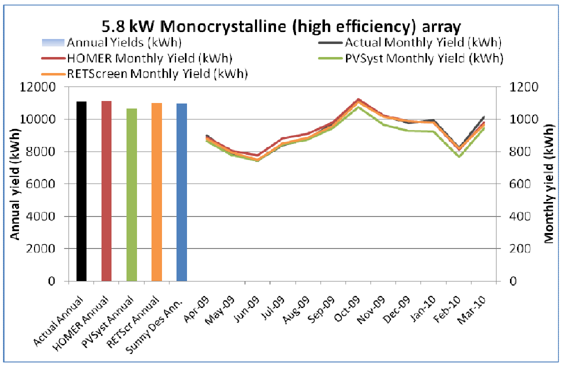

Figure 3: 5.8 kW monocrystalline (high efficiency) array results

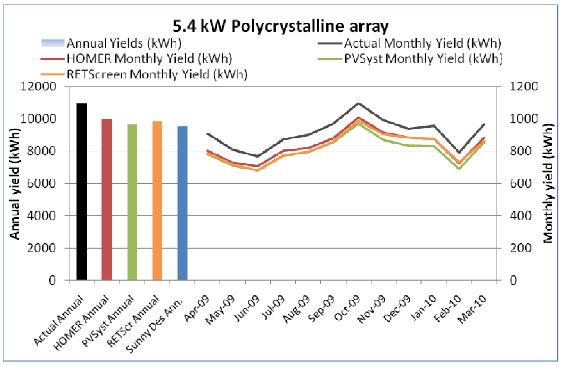

Figure 4: 5.4 kW polycrystalline array results

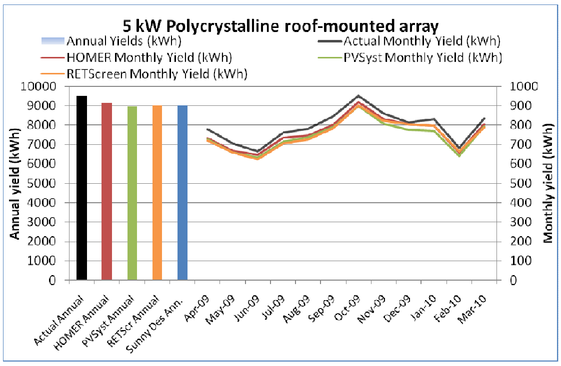

Figure 5: 5 kW polycrystalline roof-mounted array results

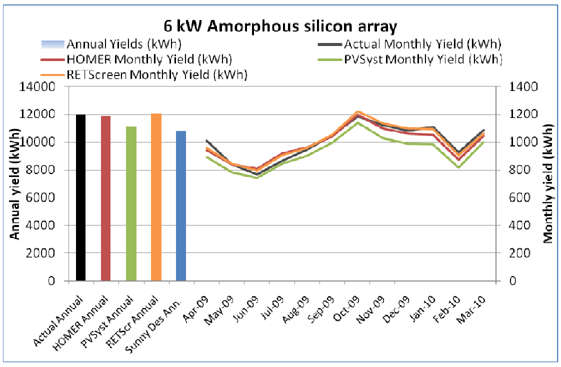

Figure 6: 6 kW amorphous silicon array results

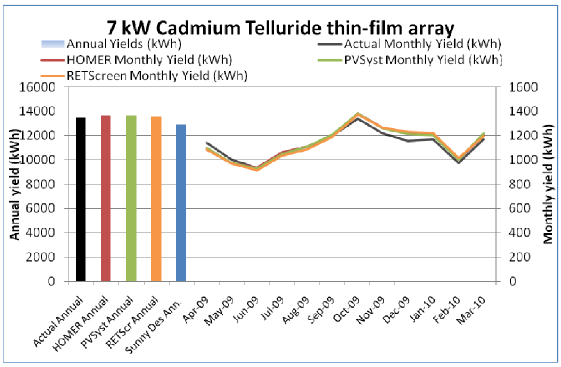

Figure 7: 7 kW CdTe thin-film array results

The accuracy of the results for each system modelled ranged from monthly overestimations of up to 8.2% to underestimations of up to -14%. In general, the most accurate results from the modelling tools were observed for the monocrystalline and CdTe arrays. Less accurate modelling results and a general underestimation of energy yield is evident for the polycrystalline and amorphous silicon arrays. It is unclear as to the specific reasons why the models produced more accurate results for certain technologies. However, monocrystalline silicon PV technology, in particular, is generally more well understood in comparison to other PV technologies and the algorithms behind the models may reflect this.

The actual monthly energy yields matched well with the monthly modelling results from all modelling tools (except Sunny Portal, which does not provide monthly results). The greatest difference between the monthly modelling results and the actual yields was observed in the warmer months of the year (November to April). This was particularly evident for the amorphous silicon array modelling results and for the PVSyst results. From November 2009 to February 2010, the average maximum ambient temperature recorded at the DKASC was 35°C, with ambient temperatures reaching up to 44°C. This suggests that temperature derating is not modelled as accurately when temperatures are relatively high, such as in desert environments.

3.1 Combined PV system results

The combined modelling results of all PV systems for each modelling tool are presented in Table II.

Table II: Combined modelling results

	PVsyst	**HOMER**	**RETScreen**	**Sunny Design**
Total average percentage difference from actual yield	-4.33%	-1.44%	-2.31%	-4.93%
Standard deviation of monthly percentage differences from actual yield	5.48%	4.75%	5.11%	6.04% (annual standard dev.)

The combined results show that the PV modelling software tools tend to slightly underestimate the performance of the PV systems at the DKASC. This result confirms results from other studies comparing PV modelling software [3] [6]. This implies that the mathematical calculations used in modelling tools may tend to be conservative.

HOMER most accurately modelled the PV systems at the DKASC, with the least variation, followed by RETScreen, PVsyst and Sunny Design respectively. This confirms the results from PHOTON magazine, which found the accuracy of HOMER, RETScreen and PVsyst to be in this same order [6]. Given the number of derating factor calculations involved with PVsyst, this would suggest that PVsyst is geared to produce conservative results rather than overestimations. This finding also confirms the results from SOLARPRO magazine, which found PVsyst to be the most conservative of the modelling tools tested [3]. RETScreen and Sunny Design use the simplest mathematical models of all the modelling tools for calculating PV performance so their relative accuracy in comparison to PVsyst is somewhat unexpected.

3.2 Uncertainties

The average percentage difference of the modelling results to actual energy yield for each software tool was less than 5%, which would generally be considered acceptable for feasibility and simulation studies. A number of uncertainties are present that contribute to this deviation of the results from actual energy yield. The initial uncertainties are those that are present in the underlying mathematical algorithms used in the modelling tools. These include calculations of radiation on the plane of array extrapolated from global horizontal radiation, self shading and horizon shading calculations, and low light levels calculations, amongst others. In particular, low light levels, as well as short term high radiation peaks, have in other studies been shown to not be handled well by model algorithms [7]. There are also a number of other contributing uncertainties to consider [7], which are detailed as follows.

The estimates and assumptions that must be made as inputs into the modelling tools are especially critical to the accuracy of the models. These estimates are handled with varying levels of complexity by each of the different modelling tools. For example, each of the various derating factors considered by PVsyst are calculated based on a number of user inputs, whereas a single non-temperature derating factor value is input into HOMER and RETScreen to encapsulate many possible derating factors (such as array mismatch, line resistive losses, panel soiling, shading, degradation, etc.). Sunny Design, in contrast, does not provide this single derating factor as a possible input. The estimates and assumptions input into the modelling tools are highly dependent on the user and their experience.

There is a level of uncertainty in the metorological data as a result of the accuracy of the individual measuring equipment devices used. Although these devices were selected for their accuracy and have been calibrated, there is still some level of remaining uncertainty. For instance, the specifications of the Delta-T Sunshine Pyranometer type SPN1 used state that individual 10 second sample readings have an overall accuracy of ±8% ±10 $W.m^{-2}$ within 95% confidence limits. Averaged over 5 minute intervals, the overall accuracy increases, however the combination of the uncertainties from each measuring device used is a factor that must be taken into consideration.

The rated/nominal power of the PV modules was used in modelling the systems. Manufacturers are unable to manufacture all PV modules to the same rating due to material and process variability. PV modules, particularly crystalline, also experience an initial rapid light-induced degradation in the order of 1% or more after exposure of about 40 kWh/m² [4]. As such, manufacturers list a nominal power for PV modules along with a certain tolerance range. As the I-V characteristics of the PV modules are not completely identical, connecting them in an array will also result in module mismatch losses.

In using the rated power of the PV modules for modelling the systems, the results are reliant on how the manufacturer specifies their nominal power. This was particularly the case in examining the manufacturer provided flash test results provided for the 5.4 kW polycrystalline array. Although the modules of this array were rated 135W ±5%, their manufacturer flash test results showed that all modules flash tested above 135W and in fact averaged 140W. This largely explains why the 5.4 kW polycrystalline array was underestimated by the models by a disproportionate margin, with an average difference of -11%.

The use of manufacturer flash test data, however, is still reliant on a non-independent party – the manufacturer and the flash tester used. In order to account for the various issues associated with the power ratings of PV modules, each PV module in each system would need to be independently flash tested using the same flash tester after their initial rapid light-induced degradation. The modules could then be sorted into arrays that minimise module mismatch losses.

Similarly to manufacturer provided nominal power, there are also uncertainties associated with the temperature coefficients and low light efficiency change values specified by manufacturers [7].

4 CONCLUSIONS

Six existing PV systems located at the DKASC, in the desert environment of Alice Springs, Australia, were modelled with four different PV modelling software tools. The results of the modelling were compared with the actual real world performance data from the systems. All modelling tools had an average accuracy of within 5% of actual performance. The use of certain PV technologies and high temperature periods generally increased the inaccuracy of the modelling tools. In particular, modelling polycrystalline and amorphous silicon arrays resulted in greater variation relative to their actual performance.

There are a large number of uncertainties that influence the energy yield resulting from PV modelling software tools. As such, the modelling tools are not able to provide a very precise prediction of future output. However, if the models are created by experienced users with available high quality input data, and uncertainties can be minimised, energy yield projections can be obtained that are comparable to actual yield. In this context, all of the modelling tools used in this study were found to be relatively accurate, both over one year and at a monthly resolution. HOMER and RETScreen in particular provided the most accurate results, while PVsyst generally provided conservative results. Sunny Portal was the simplest of the models and provided the least accurate results. These results agreed with other available studies comparing PV modelling software tools.

A number of further studies can be conducted to build on the results of this study, such as:

- Incorporating other PV technologies.
- Incorporating a larger sample of technologies.
- Modelling the same technologies in other locations, particularly tropical and cold climates.
- Modelling the systems with other PV modelling software tools.

- Investigating differences in hourly, daily or multiple year modelling results versus actual output.
- Investigating the sensitivity of the models to different input parameters and conditions.
- Attempting to minimise all possible uncertainties, for instance flash testing all modules to determine their actual rated power and re-configuring arrays accordingly.
- Determining a standard process for validating software models.

5 REFERENCES

[1] Desert Knowledge Australia. (2011, Aug 30). *Solar Centre: Desert Knowledge Australia* [Online]. Available: http:// www.dkasolarcentre.com.au

Little done to validate –

[2] C. Cameron, J. Stein, and C. Hansen, " Evaluation of PV Performance Models and Their Impact on Project Risk," Presented at PV Rollout Conference, Boston, MA, 2011.

[3] T. Yates and B. Hibberd, "Production Modelling for Grid-Tied PV Systems," SOLARPRO, vol. April/May 2010, pp. 30-56, May. 2010.

[4] D. Chianese, A. Realini, E. Burà, N. Ballarini and N. Cereghetti, "News on PV Module Testing at LEEE-TISO," presented at EU PVSEC, Dresden, Germany, 2006.

[5] M. Browne. (2011, Aug 10). *10256 - PV derating factor in HOMER* [Online]. Available: http://support.homerenergy.com/index.php?/Knowledgebase/Article/View/183/71/10256---pv-derating-factor-in-homer

[6] A. Fichtner and M. Hirsch, "Simulation Programs," Photon, vol. April 2010, pp. 30-51, Apr. 2010.

[7] S. Ransome, J. Sutterlueti and R. Kravets, "How kWh/kWp Modelling and Measurement Comparisons Depend on Uncertainty and Variability," presented at the 37th PVSC, Seatle, WA, 2011.