UNCERTAINTY ANALYSIS OF SOLAR PHOTOVOLTAIC ENERGY YIELD PREDICTION

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Abstract

Developers of photo-voltaic (PV) systems need better information about the uncertainties in energy yield predictions, since the uncertainty in the return on investment is a financial risk which the financier will deflect back to the developer in higher cost of finance, thereby adding to the project lifecycle costs. Therefore better understanding of PV modelling uncertainty is needed to inform development of more accurate measurement and modelling. This paper reviews the uncertainty of all input parameters used for the CREST PV energy yield model. More detailed tolerance data in PV module datasheets is proposed, in addition to a more accurate ohmic and fault loss analysis of the AC (alternating current) sub-system using a simple classification of utility connection type.

Introduction

The uncertainty of commercially available PV system performance models is not published with the models, so the onus is currently on the system developer to try to quantify this uncertainty, albeit with limited information available. Indeed many developers may be unaware of the magnitude of uncertainty. Therefore it is imperative for the PV industry to

- Accurately quantify the uncertainty in performance predictions
- Identify the major sources of uncertainty & develop more accurate models
- Clearly publish performance uncertainty with software tools.

Comparison between PV performance models and outdoor measurements identified bias uncertainties of 5% or more for certain technologies[1]. In real terms in the case of the 5MW Lanhydrock solar farm in Cornwall, with a predicted capital cost of £10-12M; this would represent a £0.5M difference in project profit yield[1]. A 5% variation in performance presents a significant risk for investors, which would be passed back to the developer in higher interest payments or penalty clauses, thereby increasing the cost of capital. Previous research identified that incorrect identification and selection of project parameters can be a significant contribution to energy yield (E_{YIELD}) uncertainty[1].

To make further improvements in the accuracy of E_{YIELD} models, a greater understanding of the uncertainties in individual parameters is needed. This paper reports on a comprehensive survey of model parameter tolerance data. This data will inform a better understanding of the uncertainty in PV performance prediction and identify how the accuracy of performance prediction can be improved.

The uncertainty analysis by CanMet (Canada Centre for Mineral and Energy Technology) reported a 7.9% combined uncertainty for modelled average E_{YIELD} over the PV system lifetime based on Monte-Carlo simulations (breakdown of components shown in Figure 1)[2]. However the uncertainty in the measurements themselves has been reported by CREST at 4.5%[3].

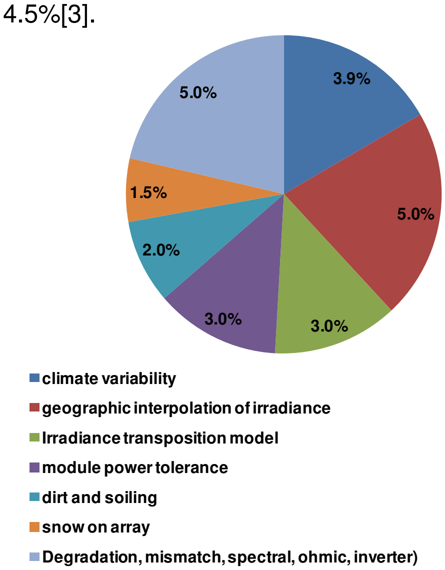

Figure 1: Chart showing breakdown of PV model uncertainties, based on data from [2].

Uncertainty in Irradiance data

Table 1 details the typical uncertainties identified for the meteorological datasets most commonly used for solar energy performance prediction.
Recent research at CREST compared data from MeteoNorm and PV GIS with measured data from the UK Met offices Sutton Bonington site and from CREST's Loughborough monitoring station [4].

[1] based on 900kWh/kWp & 8.5p FiT

Database & availability	RMSE	MBE (%)	Period	Time resolution
PVGIS Europe [5]	4.7	-0.5	1981-1990	Monthly average
Meteonorm 6.1 [6]	6.2	0	1981-2000	Monthly average
ESRA [7]	~7.5	-	1981-1990	Monthly average
NASA SSE 6 [8]	8.7	0.3	1983-2005	3-hourly
Satel-Light [9]	21	-0.6	1996-2000	30-minute
HelioClim-2 [9]	25.3	2.2	2004-2007	15-min

Table 1: Uncertainties in commonly available Met datasets, courtesy of [10].

In the CREST analysis, Classic PVGIS had a lower average percentage difference in comparison to measured data in average daily irradiation throughout the year (7.64%) than Meteonorm (9.84%). However for annual total irradiation, Meteonorm varied from measure data by only 0.45%, compared with 7.7% for classic PV GIS [4]. MeteoNorm data is usually averaged from 10 or 20 year datasets, longer datasets will not increase accuracy due to the long term trend for increasing global irradiance, as shown in Figure 2.

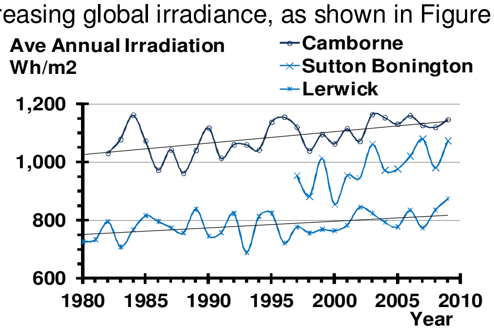

Figure 2 Long term trends for Global Irradiance in the UK from measured data

The diffuse component of irradiance is reducing; therefore the direct portion must be increasing (Figure 3).

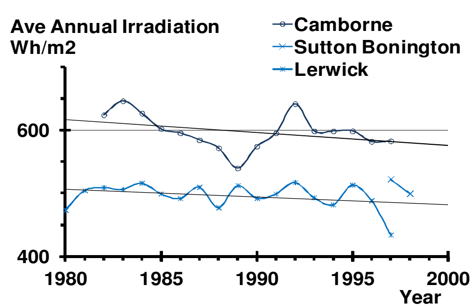

Figure 3 Long term trends for Diffuse Irradiance in the UK from measured data

Uncertainty in module power

PV module datasheets typically only give tolerances for the maximum power at STC (P_{MPP}) and not for the other parameters. However IV translation using the single diode model also requires the current and voltage at maximum power point (I_{MPP} and V_{MPP}) and the short circuit current (I_{SC}). Analysis of flash test data for 4800 PV modules from 6 different manufacturers was analysed to identify any relationships between the deviation in the different parameters. Figure 4 shows the frequency distribution of the % deviation of the flash test results away from the datasheet P_{MPP}

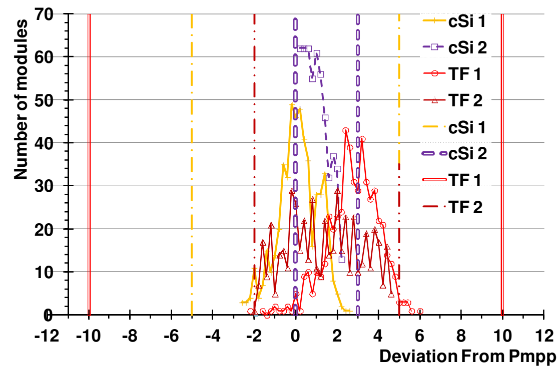

Figure 4 Distribution of the % deviation from datasheet power rating (PMPP).

The vertical bars in Figure 4 indicate the P_{MPP} tolerance specified by the manufacturer in the datasheet.

From the manufacturer's flash data in Figure 4, the P_{MPP} for most modules was evenly spread over the tolerance range. However spot checks of small samples of modules from PV installers by Ipsol Energy have indicated that most production modules are within 1% of the lower end of the tolerance range (When the manufacturer would not have been aware of any study).

Figure 5 from the same dataset shows there is close correlation between the deviation in I_{SC} and P_{MPP}

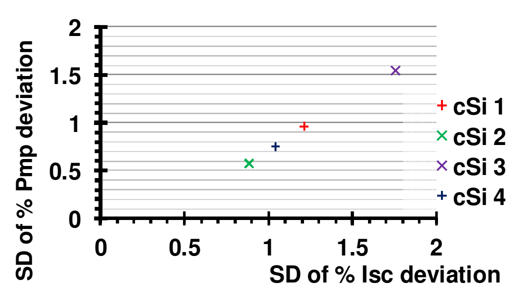

Figure 5: Chart showing correlation between deviation in maximum power (PMPP) and deviation in maximum current (ISC).

However there is little correlation between the deviation in P_{MPP} and V_{MPP} or I_{MPP} (Figure 6 and Figure 7), likewise between I_{MPP} and I_{SC}). Therefore distinct tolerance bands for I_{MPP} , V_{MPP}

and I_{SC} are needed to assess their impact on E_{YIELD} uncertainty.

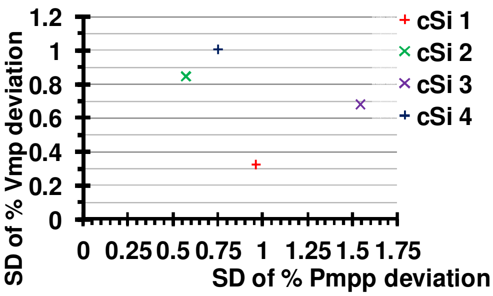

Figure 6: Correlation between deviation in voltage at maximum power (VMPP) and deviation in maximum power (PMPP)

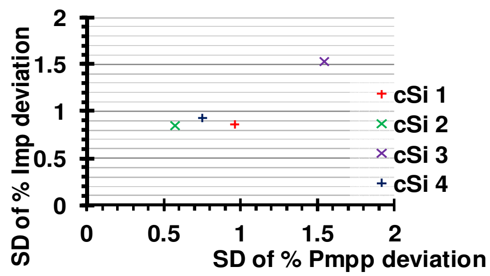

Figure 7: Correlation between deviation in current at maximum power (I_{MPP}) and deviation in maximum power (P_{MPP})

Variation in module ageing

Recent research at CREST has analysed 570 results from 86 distinct projects which reported results for PV ageing[11]. The results of this study enable the CREST E_{YIELD} model to predict module ageing based on the users cell technology selection.

Uncertainty in AC voltage

Solar PV inverters stop generating if the AC voltage is outside the proscribed range (207-264V in the UK for <50kW PV) to prevent damage to appliances [12]. The AC cabling in a PV system must be sized to prevent this inverter disconnection due to excessive voltage drop and to minimise ohmic energy loss from the system. The impact of the cable size will depend on the voltage supplied by the network operator.

The nominal AC supply voltage in the UK is 230V +10%-6% (formerly 240V+/-6%). Data on the actual voltage range experienced at point of use in the UK is not readily available so voltage data from 8 properties with solar PV systems was analysed.

The results for individual sites are shown in Figure 8and the UK average results are shown in Figure 9. The sites can be divided into 2 classes, those averaging around 238V and those averaging around 245 volts.

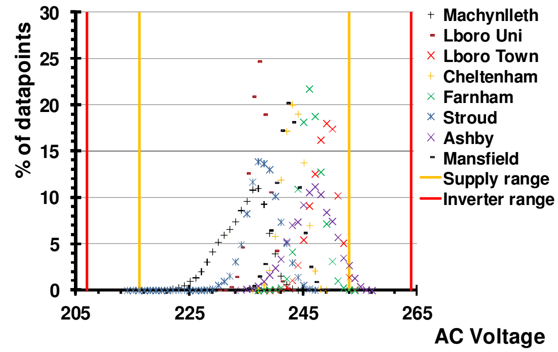

Figure 8: Distribution of AC Voltage for 8 locations in England and Wales2.

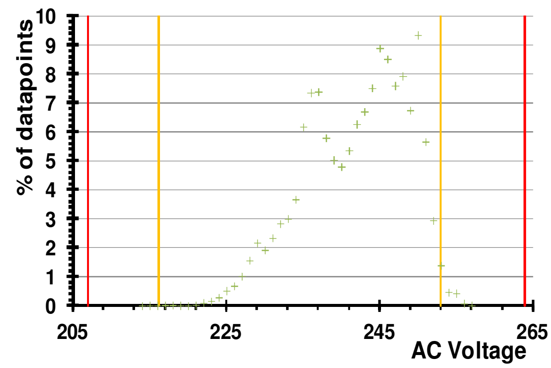

Figure 9: Average distribution of AC Voltage for monitored locations in England and Wales.

Location	**Geography**	**RMSD%**	**MBD%**
Machynlleth	Rural (C)	2.47	-2.17
Loughborough	Suburban (C)	1.28	-1.08
Stroud	Rural (R)	1.49	-0.88
Private network summary		**2.43**	**-1.81**
Loughborough	Suburban (R)	3.88	3.76
Toddington	Rural (R)	1.42	1.04
Lipscombe	Rural (R)	2.77	2.66
Ashby	Rural Town (R)	3.27	2.89
Mansfield	Rural village (R)	1.32	0.99
Small connections summary		**3.09**	**2.80**

Table 2: Analysis of UK AC voltage distribution.

(C) Commercial / large property; (R) Residential property

The sites averaging 245 volts are all small residential properties connected directly to the LV utility network. Whereas those averaging 238V are special cases, either large sites with private networks or other non-standard installations.

[2] Data courtesy of Nick Mills (Dulas Ltd); Jaise Kuriakose (Centre for Alternative Technology); Carl Benfield (Prescient Power Ltd); Shiva Beharrysingh and Murray Thompson (CREST)

Better information about the supply voltage would enable improved value engineering of cable costs by designers rather than following a one size fits all specification, in this case the maximum 1% voltage drop [13].

Recommendations & conclusions

Developers of PV systems need better information about the uncertainties in E_{YIELD} predictions in order to reduce the cost of financing systems. More information about PV module tolerance is required for accurate modelling; therefore PV module datasheets need to show tolerance values for I_{MPP}, V_{MPP} and I_{SC} in addition to the tolerance given for P_{MPP}. At present this information can only be deduced from flash test data of large batches of PV modules.

Analysis of AC voltage data, suggests there are 2 distinct classes of AC connection type, A) small properties with direct connection to the utility network B) Special cases (large sites with private networks or other non-standard installations). This classification would allow the user of PV modelling software to select connection type, and enable more accurate E_{YIELD} modelling and better inform cable sizing decisions. Models currently use the nominal AC voltage (230V) for modelling.

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