UPDATED STATUS ON DISCREPANCIES BETWEEN MEASURED AND MODELLED OUTDOOR PV PERFORMANCE

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Introduction

Discrepancies have been found by SRCL between the 1-diode model as used in most PV performance simulation programs (PVSP) and real world outdoor measurements [1].

These have been confirmed by third party comparative kWh/kWp measurements in the US, Europe and Asia. Errors dominate the values of energy yield predicted by these programs giving systematic biases of 5% or more (that do not exist in real kWh/kWp comparisons) to certain technologies and manufacturers [2].

PVSPs tend to use different temperature coefficients (particularly P_{MAX} γ <1>) and "Low Light Efficiency Change" (LLEC) values <2> than is published in manufacturers' datasheets (measured according to IEC standard EN50380).

$$\text{Gamma } \gamma = \frac{1}{P_{MAX}} * \frac{\partial P_{MAX}}{\partial T_{MODULE}} \qquad \text{<1>}$$

$$\text{LLEC} = \frac{(\text{Eff@200W/m}^2 - \text{Eff@1000W/m}^2)}{\text{Eff@1000 W/m}^2}. \qquad \text{<2>}$$

1-Diode model

Most PVSPs studied use a 1-diode model which is fitted (as in figure 1) to IV parameters from data sheets at STC or a tested module but with no allowance for module performance variability.

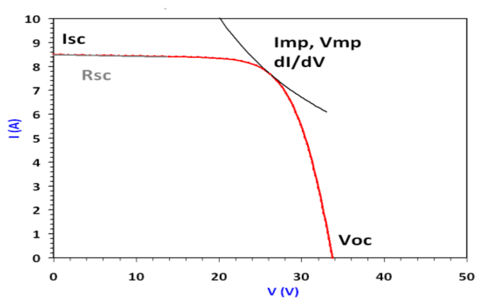

Figure 1: A 1-diode fit to 4 known values and estimated R_{SC} (Resistance at I_{SC}).

Figure 2 illustrates a matrix of efficiency vs. module temperature and irradiance (as used by many PVSPs) and as measured for by standards such as IEC 61853[3] - annotated with P_{MAX} temperature and LLEC coefficients appearing as orthogonal slopes. Equations used in the 1-diode model also predict a value for P_{MAX} temperature dependence (which is often used in the PVSPs instead of the measured IEC 61215/61646 value) and LLEC (again used by PVSPs not that measured to EN 50380).

The value of R_{SC} is guessed as it is not on datasheet and can vary for each module with processing variabilities. It may also depend on voltage dependent collection (if current rises in reverse bias due to better collection from a wider depletion width) and if cells are mismatched a stepwise fall in current with V near I_{SC}. R_{SC} is known to rise as irradiance falls [2] but it isn't yet known how best to model it when the manufacturers don't generate R_{SC} vs. irradiance values on datasheets.

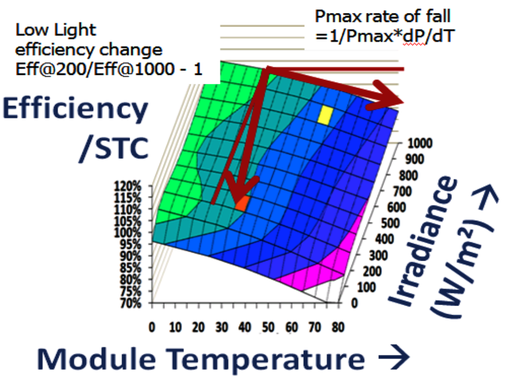

Figure 2: Relative PV efficiency vs. module temperature and irradiance as predicted in a typical PVSP.

Gamma and LLEC discrepancies

The values of γ and LLEC as calculated by 5 PVSPs have been compared with 13 commercially available PV modules of various technologies in figure 3. PVSP authors have been told of this study and have recently been changing their calculations and databases in response to these findings but some large discrepancies are evident on the graphs calculated at the end of 2010. These are in the process of being updated in time for the presentation in April 2011.

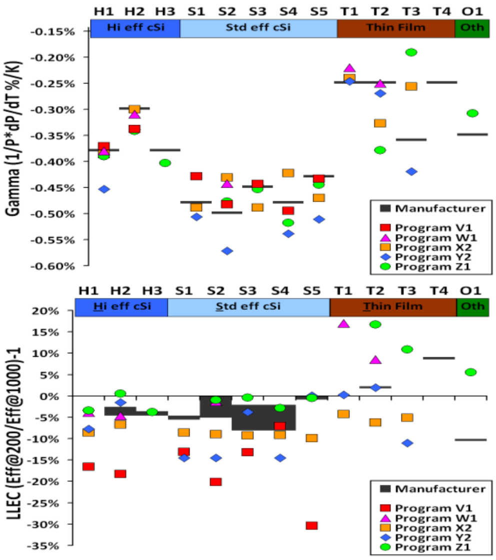

Figure 3: Measured and modelled gamma (top) and LLEC (bottom) for 13 modules from 5 PVSPs vs. Manufacturer datasheet as at Sept 2010 – (will update at talk).

Modelled IV curve differences at high and low light levels

These discrepancies are further illustrated with IV curves predicted by 4 out of 5 PVSPs (not all programs have the same modules) for a c-Si module and a thin film module (figure 4) at both STC (1000W/m², AM1.5, 25C) and low light conditions (200W/m², AM1.5, 25C).

Even though the PVSPs should be constrained to fit the I_{SC}, I_{MPP}, V_{MPP} and V_{OC} defined by the manufacturers (grey lines) and P_{MAX} (black curves) they can predict different values at 1000W/m² and larger variations at 200W/m² for VOC.

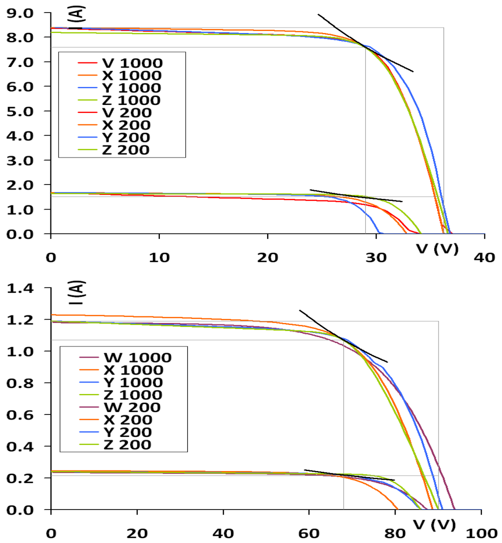

Figure 4: IV curves from 4 PVSPs for a c-Si module (top) and a thin film module (bottom) at 1000W/m² and 200W/m².

Figure 5 looks at how the modelled efficiency/nominal STC varies for a given thin film device with irradiance and temperature. The green spots indicate the normalised efficiency at 200W/m² and is the LLEC value which should correspond with this manufacturer's measured value of 102% - only PVSP W and Z are close, Y is 85% meaning a much worse predicted than measured value.

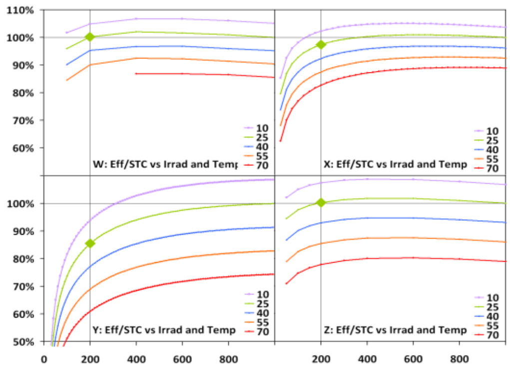

Figure 5: Efficiency/nominal STC vs. irradiance (x axis) and temperature (lines).

R_{SC} variation with irradiance

R_{SC} is assumed to behave in given ways by the PVSP authors as illustrated by the black lines in figure 6 (c-Si top and thin film bottom) being either constant or variable with irradiance and/or temperature – and this assumption will determine how the predicted energy yield will be.

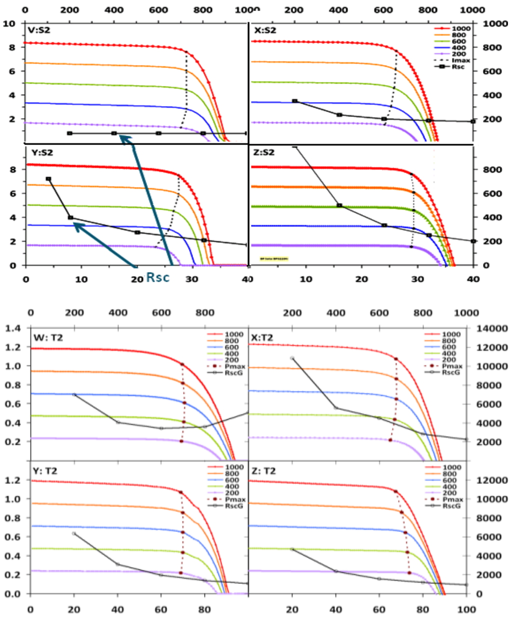

Figure 6: IV curves from 4 PVSPs for c-Si and a thin film module at 200-1000W/m² with R_{SC} vs. irradiance (right and top axes)

IV variation with temperature

Figure 7 draws how 4 different PVSPs predict the IV curves vs. module temperature for a thin film module, again large differences can be seen.

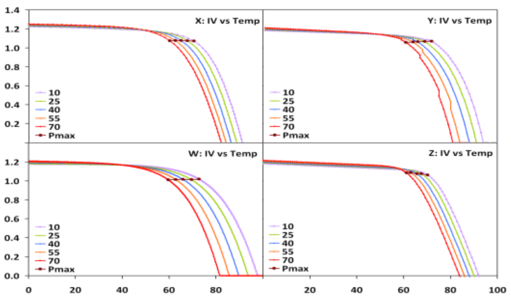

Figure 7: IV curves from 4 PVSPs for a thin film module at 10-70C.

Module Pmax bin variability

“Identically produced” modules on a production line will also vary somewhat. Manufacturers don’t quote these variabilities off their datasheets but the minimum variability of PV parameters per power bin can be ascertained by studying the values of parameters for each P_{MAX} bin from an example thin film module from its manufacturers’ datasheet as plotted in figure 8. The change in P_{MAX} from bin to bin will depend on how the other values change in equations <3> and <4>.

$$\Delta P_{MAX} = \Delta V_{MPP} + \Delta I_{MPP} \quad \text{<3>}$$

$$\Delta P_{MAX} = \Delta V_{OC} + \Delta FF + \Delta I_{SC} \quad \text{<4>}$$

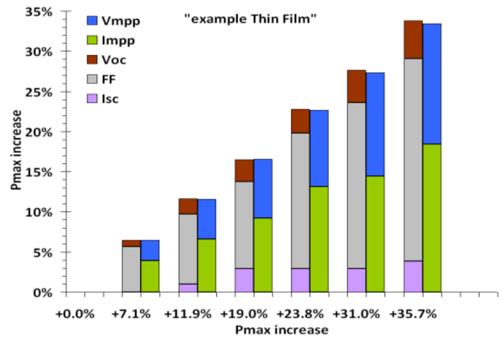

Figure 8: How the changes in I_{SC}, V_{OC}, FF, I_{MPP} and V_{MPP} determine P_{MAX}.

Figure 8 allows the minimum parameter variation within a range of modules to be estimated, in reality it will be higher e.g. this thin film has ~6% P_{MAX} bins and will be >3% Imp and >3% V_{MPP} variation for each P_{MAX} bin. It can also be seen that more improvement is realised from a better fill factor than I_{SC} and V_{OC} gains.

Figure 9 illustrates the IV curves at STC in a PVSP database for a given thin film module and its R_{SC} vs. irradiance, note the improvement in I_{SC}, V_{OC} and FF as the P_{MAX} rises but not linearly.

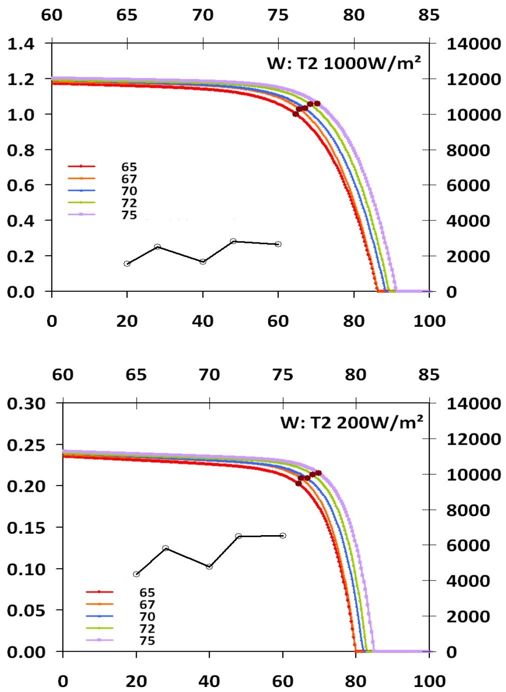

Figure 9: IV curves and R_{SC} vs. P_{MAX} (right and top axes) modelled by a manufacturers’ datasheet values at 1000 and 200W/m².

The PVSPs ought to allow for variability of modules performance but this rarely seems to be done as they are based on one datasheet or one characterised module output.

Sandia PV modelling workshop

SRCL was invited to present some of these findings at a workshop in SANDIA in Sept 2010 along with representatives from PVSPs (PVSYST, PVSOL, PVWatts, PVSIM, CECPV etc.), research establishments such as Sandia, NREL, Universities of Wisconsin and Colorado, PV manufacturers (First Solar, Sunpower, BP Solar, Abound), installers and US government departments.

“Participants at the workshop [4] were sent design descriptions of three systems along with recorded solar resource and weather data and were asked to model system performance using models of their choice and return the results to Sandia for analysis before the meeting. Since recorded performance data was available for the same time period, this exercise provided a basis for discussion of model accuracy and intercomparison.” Input Uncertainties caused large differences in predicted kWh/kWp.

There was also discussion on a Standardized Process for Model Validation [5]: *“A key step is to understand which algorithms and model inputs are most critical to model accuracy, so that efforts to improve and validate models may be prioritized and focused.”* Stein et al have developed an approach based in part on residual analysis.

It was agreed at the workshop to make a concerted effort to improve the measured vs. modelled performance by exchanging datasets of measurements and involve other institutes and manufacturers around the world.

Some of the results from papers presented at the Sandia workshop will be discussed and examples shown.

Conclusions

- PVSPs still use different values for LLEC and γ than on manufacturers' data sheets (measured to IEC 61215/61646 and EN 50380) and these determine modelled kWh/kWp.
- R_{SC} as a function of irradiance seems very important in determining the LLEC behaviour of the PV – it’s not on the datasheets.
- There is a concerted effort with Sandia, modellers and some production companies to understand and improve the accuracy and uncertainty of modelling kWh/kWp.

References

SRCL www.steveransome.com

Sandia PV modelling workshop photovoltaics.sandia.gov/r_e.html#PVperformance

(1) Ransome "Recent Studies of PV Performance Models" Sandia PV modelling workshop, Sept 2010

(2) Ransome "The present status of kWh/kWp measurements and modelling" 5th World PVSEC Valencia 2010

(3) IEC 61853-1

(4) Cameron et al “Evaluation of PV Performance Models and Their Impact on Project Risk” PV Rollout, Boston 2011

(5) Stein Sandia Workshop