HOW WELL DO PV MODELLING ALGORITHMS REALLY PREDICT PERFORMANCE?

S. J. Ransome, BP Solar UK
**Performance Ratio definition**

PR = (Measured)/(Theoretical Lossless) ac output

PR = (kWh\textsubscript{AC}/kWp) / (POA Insolation)

0.78 = 780 (kWh/kWp) / 1000 (kWh/m\textsuperscript{2}) e.g.

PR from Sizing Program predictions and measurements are often ~75-80%

But

Do programs model everything correctly? Are there sufficient unknowns and user defined inputs to enable predictions to coincide with measurements?
General Sizing program methodology

Inputs

- Site Location
- Array Orientation, mounting
- Select PV modules
- User Losses e.g. Shade, dirt, snow
- Select BOS components

Databases

- Monthly Average Weather
- PV Model vs Irradiance, Temp. etc
- BOS Models Inverter, Wiring etc

Calculations

- Horizontal plane Irradiance /hour
- Tilted plane Irradiance /hour
- Module Temperature C
- DC Power
- AC Power
- Sum year $\Sigma$=Energy yield

discussed in this talk proceedings
Calculating Tilted plane irradiance from horizontal plane measurements

How do we calculate the Diffuse:Beam ratio if it’s not measured?
Calculating kT (Clearness index) to find the beam:diffuse ratio

Cloudy kT = 0.1-0.3, Clear kT = 0.6-0.8
Calculating Beam:Diffuse fraction from Clearness Index (i)

Models use a curve fit for Beam Fraction from Clearness Index
Calculating Beam:Diffuse fraction from Clearness Index (ii)

Models use a curve fit for Beam Fraction from Clearness Index

ISET data looks quite different

Large scatter but doesn’t follow the model well
Calculating tilted plane irradiance from monthly horizontal average insolation

- Horizontal Global /Month
- Horizontal Global /Hour
- Horizontal Global /Minute
- Horiz. Global and Diffuse /Minute
- Tilted Global /Minute

- Cloudy day
- Sunny day
- Variable day

- from database
- transition matrices for clearness index
- diffuse fraction from clearness index
- realistic tilted plane
Measured vs Simulated Insolation vs Irradiance and frequency of measurement

Measured data
- Averaging overpredicts low light levels, loses high light

Modelled data
- also shows “averaging effect”
- has the wrong overall shape
Module Temperature vs time and irradiance under variable weather

Variable weather:
brightness will be higher and temperatures cooler than averaging would suggest
• Models predict most insolation at low irradiance

• Measurements show most insolation at high irradiance (except for poor year 2000)

• Yearly insolations have a stdev of ~ ± 4%

• Model has wrong shape
Models for module efficiency vs irradiance and temperature

- **Lookup table**
  (EN 50380  200-1000W/m² @25C, AM1.5)

- **Pmax at “high” and “low” irradiances**
  Then interpolate a curve between two points
  (mathematically > 3 points are required for a curve)

- **Equivalent circuit 1-diode model (nf, Jo, Rs, Rsh, Jsc)**
  A 1-diode model does not fit IV curve near Pmax.
  Some parameters are temperature dependent

- **Spec sheet Data**
  Temperature dependency from α β γ coefficients.

- **Characterisations usually on one module, but there is a spread in module parameters**
Outdoor Measured Efficiency
sc-Si, mc-Si, CIS, a-Si, ISET, Germany (i)

vs Irradiance

- Similar relative efficiencies at low light level
- This looks very different to some models
Outdoor Measured Efficiency
sc-Si, mc-Si, CIS, a-Si, ISET, Germany (ii)

- Similar relative efficiencies at low light level
- This looks very different to some models

vs Irradiance

vs Diffuse:Beam
- Similar relative efficiencies at Diffuse
- This looks very different to some claims
Outdoor Measured Efficiency
sc-Si, mc-Si, CIS, a-Si, ISET, Germany (iii)

Efficiency / nominal

Measured

Sizing program

Irradiance (kW/m²)
All weather related parameters are correlated with irradiance

<table>
<thead>
<tr>
<th>Weather Parameter</th>
<th>&quot;Poor weather&quot;</th>
<th>&quot;Good Weather&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance (kW/m²)</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Ambient Temp. (C)</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Module Temp. (C)</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Angle of incidence</td>
<td>~Parallel</td>
<td>~Normal</td>
</tr>
<tr>
<td>Solar height</td>
<td>Low (redder)</td>
<td>High (bluer)</td>
</tr>
<tr>
<td>Beam Fraction</td>
<td>~Diffuse</td>
<td>~Direct</td>
</tr>
</tbody>
</table>

Hotter module (y axis) with higher irradiance (x axis) →

Difficult to extract dependencies from outdoor measurements
Inverter Modelling

How well are inverters modelled?

Their efficiencies can depend on:

• Input voltage (Baumgartner et al)
• Ambient temperature (ISET)
• Transient weather conditions
• Turn on
• Clipping
• Are all these considered?
• High and low limits for loss in a typical PV System
• Final performance depends on the product of each of these
• A typical system is shown in black
• Just these losses result in a PR of ~75%
PR vs loss stage showing ±1 and ±2σ spreads with uncertainties

- Estimate 3sigma distribution from previous graph for loss in a PV System
- Final performance depends on the product of each of these
- Just the spread in these losses result in a PR of ~75±3% for 1stdev
CONCLUSIONS

• Met Data programs can overestimate low light insolation
• There is a spread in performance of real modules not modelled in databases
• PV efficiency at low light/high diffuse is often better than Sizing databases
• Performance ratios ~75-80% can be obtained from both measurements and Sizing programs
• Unknown inputs can result in PR ± ~5% for a system
• Outdoor data gives better understanding of performance
• Sizing programs help minimise avoidable losses
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This paper will soon join more than  
70 of BP Solar’s other technical papers at  
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Thank you for your attention!