How accurate can PV energy yield simulations be?

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Introduction to Sizing programs

- Sizing programs
  - contain component databases
  - have many user defined inputs
  - use complicated algorithms
  - estimate AC energy yield $Y_F \text{ (kWh/kWp)}$

- Performance Ratio $PR = \frac{\text{measured}}{\text{expected}} \text{ energy yield}$
- Measured $PR$ can be $\sim$ predicted values of 75-80%

- Do the programs model everything correctly?
- Are there so many unknowns that the predictions and output happen by chance to coincide to within a few %?
Weather and electrical measurements

- Irradiance (preferably plane of irradiance kW/m²)
  - pyranometers (flatter spectrally than cells and different angle of incidence)
  - reference cells (usually c-Si filtered for Thin Films response)

- Temperatures
  - shaded thermocouples (Tambient)
  - fixed to the back of the module (Tmodule)

- Wind speed

- MPP tracking – useful to monitor dc voltage

- AC power
  - instantaneous power
  - cumulative energy value

- Other – diffuse fraction, horizontal irradiance, precipitation
Common calculation steps in sizing programs

- Site information, orientation etc.
- Horiz. Irradiance series (hourly)
- Diffuse/direct fraction
- Tilted Plane Irradiance
- Module Temperature
- DC losses (e.g. Dirt, $I^2R$, shade)
- DC Power from IV = $f(Irr, T_{mod})$
- AC losses (e.g. Inverter)
- Sum over year for kWh
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Complicated algorithms

Accuracy of inputs?

Accuracy of models?

Weather d’base

Module d’base

BOS d’base

SRCL
Sizing programs predict one value for kWh/kWp

How does this compare with real outdoor measurements?
Typical 3rd party data - 7 years daily Thin Film array in USA

- Repeatable Tambient and Insolation each year
- Slight decline in PR 1st year then becomes more seasonal
- Lowest PR in summer
Typical 3\textsuperscript{rd} party data - 7 years
daily Thin Film array in USA

- Repeatable Tambient and Insolation each year
- Slight decline in PR 1\textsuperscript{st} year then becomes more seasonal
- Lowest PR in summer
- Some clumps of too high or low PR

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Performance of the thin film array yearly sum 2001-2007

Note variability in PR each year >5%

2001 PR system downtime?

2002 PR low Irradiance measurements?
Typical 3rd party data
3+ years daily c-Si array in USA

- Repeatable Tambient and Insolation each year
- Slightly lower PR in summer
- Some PR data too low in winter

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- Note variability in PR each year (>2%) full years
- 2004 start up, not full year
Summary of both typical sites

Even though the Temperature and Insolation appeared steady each year there were still changes in the PR values, some due to measurement error, other may have been due to changes in the modules and/or bos components
Estimating variabilities in kWh/kWp produced

\[ PR = \frac{YF}{YR} = \frac{AC \text{ yield}}{POA \text{ insolation}} = \frac{\text{(kWh/kWp)}}{\text{(kWh/m}^2\text{)}} \]

Rearrange to find kWh

\[ \text{kWh} = PR \times (YR) \times (\text{kWp}) \]

Performance Ratio

Insolation kWh/m²

Pmax Wp array
## Estimating variabilities in kWh - at different test sites

<table>
<thead>
<tr>
<th></th>
<th>Different sites</th>
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<tbody>
<tr>
<td><strong>PR</strong>&lt;br&gt;Downtime&lt;br&gt;Vmax tracking&lt;br&gt;Inverter loss&lt;br&gt;Rshunt eff at low light&lt;br&gt;Dirt etc.</td>
<td>?&lt;br&gt;?&lt;br&gt;?&lt;br&gt;?&lt;br&gt;± 1%</td>
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<tr>
<td><strong>YR</strong>&lt;br&gt;Pyranometer calibration&lt;br&gt;Yearly Insolation</td>
<td>± 2%&lt;br&gt;± 4%</td>
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<tr>
<td><strong>kWp</strong>&lt;br&gt;Reference Module&lt;br&gt;Module in Band&lt;br&gt;degradation&lt;br&gt;seasonal/annealing</td>
<td>± 2%&lt;br&gt;± 2.5%&lt;br&gt;&lt;-1%/y&lt;br&gt;?</td>
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<tr>
<td><strong>Sum</strong></td>
<td>± 6-12%</td>
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## Estimating variabilities in kWh - side by side comparisons

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<tr>
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<th>Different sites</th>
<th>Side by Side</th>
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<tbody>
<tr>
<td>PR</td>
<td>Downtime</td>
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<tr>
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<td>☐0 to -1%/y ?</td>
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<tr>
<td></td>
<td>Sum</td>
<td>☐± 6-12%</td>
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<td>☐± 6%</td>
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Conclusions

- Several large unknowns explain some variabilities in array performance (different sites and side by side comparisons).
- ac logged data shows random variations year by year
- Sizing programs can never be better more accurate than the unknown input variables.
- Sizing programs should be used mostly to design and check monitored systems to not have large avoidable losses.
- Comparisons shouldn’t just show kWh/kWp sums but attempt to find reasons for any variations such as low light, high temperature, downtime or module rating.
Thank you for your attention

The presentation paper and slides will soon be available at

http://www.steveransome.com