CHARACTERISING PV MODULES UNDER OUTDOOR CONDITIONS: WHAT’S MOST IMPORTANT FOR ENERGY YIELD

J. Sutterlueti1, S. Ransome2, R. Kravets1, L. Schreier1,
1 Oerlikon Solar, PV Systems Group, Hauptstrasse 1a, 9477 Truebbach, Switzerland
2 SRCL, Steve Ransome Consulting Ltd, UK

INTRODUCTION & OBJECTIVE

- The Standard PV parameters Final Energy Yield (YF) and Performance Ratio (PR) in IEC 61724 are sums or averages over time and do not allow detailed correlations with irradiance & temperature.
- Previous studies have only done limited analysis of IV curves.
- This work analyses IV curves in more detail to give a better understanding of the PV performance limiting effects of parameters such as RSC (~RSHUNT).

A NEW “LOSS FACTORS” MODEL (LFM)

The “loss factors” model (LFM) fits measured outdoor IV curves to find 5 independent normalised loss factors: ISC, RSC, FF, ROC, VOC plus 2 corrections: spectral and temperature.

Performance Factor:

\[ PF = \frac{nISC \cdot nRSC \cdot nFFR \cdot nROC \cdot nVOC_{T}}{nISC_{G} \cdot nRSC_{G} \cdot nFFR_{G} \cdot nROC_{G} \cdot nVOC_{T}} \]

\[ n_{ISC} \] High from low dirt and good AR coating
\[ n_{RSC} \] High RSHUNT minimise losses at low light levels, RSC>90%
\[ n_{FFR} \] Good FF >110% (c-Si), >120% (TF)
\[ n_{ROC} \] Low RSERIES minimise losses at high light levels ROC>85%
\[ n_{VOC_{T}} \] Good β coefficient, low TMODULE

BENEFITS OF THE LOSS FACTORS MODEL

1. Monitors relative changes in efficiency and finds the reasons.
2. Normalises parameters by reference values (e.g. STC or flash test).
3. Identifies differences of nominally identical mass produced modules.
4. Quantifies benefits to PMAX and energy yield from improvements (e.g. low light, temperature, spectrum).
5. Compares module measurements from different climates without correcting to STC.
6. Distinguishes seasonal changes (e.g. annealing) from degradation.
7. Can predict energy yield drop due to RSC and ROC losses.
8. Will allow more reliable energy yield & Performance prediction.

OPTIMISE PARAMETERS FOR HIGH kWh

After site selection, optimum orientation, minimal shading, ventilation, cleaning: Optimise the product of the loss factors (LFM).

<table>
<thead>
<tr>
<th>Loss factor</th>
<th>Optimal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISC</td>
<td>High from low dirt and good AR coating</td>
</tr>
<tr>
<td>RSC (~RSHUNT)</td>
<td>High RSHUNT minimise losses at low light levels, RSC&gt;90%</td>
</tr>
<tr>
<td>FF</td>
<td>Good FF &gt;110% (c-Si), &gt;120% (TF)</td>
</tr>
<tr>
<td>ROC (~RSERIES)</td>
<td>Low RSERIES minimise losses at high light levels ROC&gt;85%</td>
</tr>
<tr>
<td>VOC</td>
<td>Good β coefficient, low TMODULE</td>
</tr>
<tr>
<td>Spectral correction</td>
<td>Max. absorption of each junction, matched for best site yield</td>
</tr>
</tbody>
</table>

IMPORTANCE FOR ENERGY YIELD

- Energy Yields (in kWh/kWp) are important for:
  - design and validation of a PV system
  - its levelised cost of electricity (LCOE)
- Optimized LFM parameters within mass production leads to:
  - higher confidence about production quality
  - realistic lifetime expectations
  - confidence for energy yield harvest and performance prediction

VALIDATION OF THE LOSS FACTORS MODEL

- Oerlikon Solar measure outdoor performance of their own, customers’ and competitors’ modules at several sites around the world.
- Data is shown from central Europe (OTF1-CH) and South West USA (OTF4-AZ).
- Analysis is based on 4 different “weather types” at 2 different sites – Switzerland and Arizona.
- Results of LFM fitting to data points vs. Irradiance.
- micromorph Modules: similar modules at both locations.

A NEW “LOSS FACTORS” MODEL (LFM)

LOSS FACTORS – MEASURED vs. MODELLLED

<table>
<thead>
<tr>
<th>Weather types</th>
<th>Clear Morning</th>
<th>Clear Noon</th>
<th>Clear Evening</th>
<th>Diffuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance (W/m²)</td>
<td>800 to 1200</td>
<td>800 to 1200</td>
<td>800 to 1200</td>
<td>200 to 400</td>
</tr>
<tr>
<td>Irradiance (W/m²)</td>
<td>1000 to 1400</td>
<td>1000 to 1400</td>
<td>1000 to 1400</td>
<td>200 to 400</td>
</tr>
<tr>
<td>Irradiance (W/m²)</td>
<td>1200 to 1600</td>
<td>1200 to 1600</td>
<td>1200 to 1600</td>
<td>200 to 400</td>
</tr>
</tbody>
</table>

Left: Fitted loss factor coefficients from 6 different technologies at OTF4-AZ at (800W/m², coloured bars) and (200W/m², black bars) spectrally and thermally corrected.
Right: Typical fitted (coloured) vs. measured (black) loss factor parameters and weather data for a thin film module measured at OTF4-AZ showing good agreement for a diffuse and a clear day.

For further information see
Oral Presentation 4DO.6.4
“Improving and Understanding kWh/kWp Simulations” by S. Ransome and J. Sutterlueti, Thursday @ 17:45

Visit our booth in Hall A4 / A11