System Losses and Derates
Mismatch Losses

- Draft Definitions of System Loss Factors
  Geoff Klise
  Sandia

- Quantifying Mismatch Losses in Small Arrays
  Sara MacAlpine
  University of Colorado, Boulder

- Calculation of Mismatch Losses due to Shading in PVsyst, v6
  André Mermoud
  PVsyst

- Modeling Mismatch Losses in HelioScope
  Paul Gibbs
  Folsom Labs

- Calculating Model Shading Inputs from Design Data
  Tarn Yates
  Borrego Solar

- Discussion – Standardizing Definitions of Mismatch Losses
Derates / Loss Factors

• Is it a derate? Is it a loss factor? Is it both, or neither?

• Sandia has been tasked by DOE to convene an “Industry working group to define PV performance modeling standards (loss definitions, reporting standards and templates, etc.)”

• What do we intend to accomplish with your participation?
Draft Definitions

• We developed a **sample matrix** of the photon to “AC” electron conversion process with our knowledge of PV performance models and with “loss factors” provided by First Solar

• The goal was to show how different models map into each step, *and*

• Compile responses regarding steps/calculations/definitions that were valid, or should be changed
Overview of Working Matrix

• What you’ll see in the next few slides refers to the modeling steps and loss factor definitions on the left side of the matrix
<table>
<thead>
<tr>
<th>Unshaded Irradiance Incident on Plane-of-Array (POA)</th>
<th>Modeling Steps (Calculations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albedo (Snow, no snow)</td>
<td></td>
</tr>
<tr>
<td>POA Orientation Normal Operation</td>
<td></td>
</tr>
<tr>
<td>Suboptimal POA Orientation</td>
<td></td>
</tr>
<tr>
<td>Calculate Spectral Content or Air Mass</td>
<td></td>
</tr>
</tbody>
</table>
## 2 Irradiance Obstructers

<table>
<thead>
<tr>
<th>Irradiance Obstructers</th>
<th>POA Irradiance blocked by distant shading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POA Irradiance blocked by near shading</td>
</tr>
<tr>
<td></td>
<td>POA Irradiance blocked by soil on array</td>
</tr>
<tr>
<td></td>
<td>POA Irradiance blocked by snow on array</td>
</tr>
</tbody>
</table>
## 3 Module Conversion Efficiency

<table>
<thead>
<tr>
<th>Module Conversion Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident Angle Correction</td>
</tr>
<tr>
<td>Spectral/Air Mass Correction</td>
</tr>
<tr>
<td>Calculate Cell Temperature</td>
</tr>
<tr>
<td>Module Efficiency vs. Temperature</td>
</tr>
<tr>
<td>Module Efficiency vs. Irradiance</td>
</tr>
<tr>
<td>Module Rating Correction</td>
</tr>
<tr>
<td>Light-induced Degradation</td>
</tr>
<tr>
<td>Module Degradation</td>
</tr>
<tr>
<td>Seasonal Annealing</td>
</tr>
</tbody>
</table>
## 4 Losses in DC System

<table>
<thead>
<tr>
<th>Losses in DC System</th>
<th>Losses in Diodes, Connectors, Fuses...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Losses in DC Wiring</td>
</tr>
</tbody>
</table>
## 5 Array Utilization

<table>
<thead>
<tr>
<th>Array Utilization</th>
<th>Current Mismatch in String &amp; Voltage Mismatch in Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma_{\text{Mod DC Out}}$</td>
<td>Not at Array MPP</td>
</tr>
</tbody>
</table>
• Mismatch

Results in energy loss due to:

– Module manufacturing variability
– Temperature gradient
– Partial shading
System Losses and Derates

Panel Discussion: System Losses and Derates

- **Jeff Roche**, SunPower
- **Rob Andrews**, Queens U
- **Paul Gibbs**, Folsom Labs
- **Alex Panchula**, First Solar

- Discussion – Standardizing System Loss Factor Definitions

Performance Degradation

- **Modeling Module Power Degradation**
  - **Thomas Roessler**, Yingli Green Energy Europe

- **Fleet-Wide Study of System Degradation**
  - **Mike Anderson**, SunPower

- **Standardizing Definitions: Survey Results and Inputs to the Working Group**
  - **Geoff Klise**, Sandia
Overview of Working Matrix

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<table>
<thead>
<tr>
<th>Modeling Steps (Calculations)</th>
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</thead>
<tbody>
<tr>
<td>DC to DC Efficiency</td>
</tr>
<tr>
<td>DC to AC Efficiency</td>
</tr>
<tr>
<td>Inverter Efficiency Adjustment</td>
</tr>
<tr>
<td>Inverter Loads, Fans, Controls...</td>
</tr>
</tbody>
</table>
8 Transformers

- MV Transformer at Inverter Output
- HV Transformer
<table>
<thead>
<tr>
<th>Other AC Loads</th>
<th>Tracker Motors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Acquisition &amp; Aux</td>
</tr>
</tbody>
</table>
## 10 Losses in AC System

<table>
<thead>
<tr>
<th>Losses in AC System</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant AC Wiring Losses</td>
<td></td>
</tr>
<tr>
<td>AC Wiring Losses to Interconnection (Meter)</td>
<td></td>
</tr>
</tbody>
</table>
## 11 Utility Interactions

<table>
<thead>
<tr>
<th>Utility Interactions</th>
<th>AC Interconnection Capacity Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Utility Line Loss</td>
</tr>
</tbody>
</table>
12 System Output

<table>
<thead>
<tr>
<th>System Output</th>
<th>System Availability: component outages, loss of grid...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System-Wide Degradation</td>
</tr>
</tbody>
</table>
Standardizing Definitions:
Survey Results & Inputs to the Working Group
Model Matrix

• Survey Response:
  – 16 respondents
  – Ranged between ‘big-picture’ comments, changing modeling steps, definition changes, and the use of specific values for specific models
  – Models added to matrix include:
    • PV*Sol Expert,
    • PVSim v2.4 (SunPower),
    • PR-FACT, and
    • SRCL ‘Tester’ model
• Consensus on **definitions of the terms** would be helpful

• Are **derate** and **loss factors** the same? Are they used to **describe an input** to the model, or are they a **modeling result**?

• Re-defining conventional language? Some nominal “**losses**” are actually **efficiency gains** (albedo, positive quality loss factor due to plus tolerance, etc.)

• …using these current naming conventions, “**loss**” and “**derate**” factors, in a standard may lead to some confusion. I don’t have any ideas to get around this besides re-defining the conventional language as something like “**loss/gain**” or “**scale**” factors…
• Should losses be grouped according to how they are measured in the field?

• Performance models should be validated through measurement of derate factors

• Certain derate factors should be modeled stochastically given their intrinsic variability and uncertainty

• Should there be ways to translate derate/loss factors to compare one model to another?
Specific ‘Step’ Comments

• Regarding initial steps with POA irradiance
  – Provide more clarity on what *blocks* irradiance and factors that *reduce* irradiance
  – Move the *spectral content* or *air mass* calculation below where sunlight is converted to DC energy
  – More granularity on what constitutes *sub-optimal* POA orientation
Specific ‘Step’ Comments

- Regarding conversion of light to DC energy
  - Change definition to reflect conversion step
  - More granularity in the module efficiency vs. irradiance and temperature step
  - The module rating correction step was discussed with regards to PV syst
  - Addition of a seasonal annealing factor
Specific ‘Step’ Comments

• Regarding Array Utilization
  – Change definition
  – On module mismatch, requests for better defined and consistent modeling approach
  – In **not at array MPP**, more granularity for separating **MPPT error and clipping losses**
  – Should some of these descriptions be moved in inverter conversion steps (DC to DC, or DC to AC)
Specific ‘Step’ Comments

• Regarding DC to DC / DC to AC / Transformers
  – DC to DC efficiency is **not a relevant loss/metric**
  – Role of DC Optimizers and proper modeling techniques
  – What is **inverter efficiency adjustment**?
  – Should transformer losses be post-processed?
Specific ‘Step’ Comments

• Regarding Other AC / Losses in AC / Utility Interactions / System Output
  – Should the **AC Interconnection Capacity Limitation** take place at the inverter instead?
  
  – There should be more granularity to include factors such as **ramp rate control, operating at non-ideal power factors, curtailment issues, etc.**
  
  – Is a single **degradation factor** appropriate to model out to however many year, or should this change due to higher array to inverter ratios?
Working Group

• These definitions and matrix are not ‘set in stone’

• Friday working group will be ‘industry-driven’ to help us better understand what is important and necessary if standardized definitions are eventually agreed upon

• This work will be summarized in a report along with definitions published on the PVPMC website

• We will rely on the working group to recommend next steps for continuing work in this area