TASK 13: PERFORMANCE AND RELIABILITY OF PV SYSTEMS

Quality assessment of PV systems by analysis of system performance

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IEA-PVPS-Task 13 parallel event WCPEC6

“Challenges and Promises to Large Scale PV Development”
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Content

• Motivation

• Work from IEA-PVPS-Task 13
  – Monitoring guidelines
  – Example: performance Italy
  – Example: data from web scraping

• Dutch examples
  – Specific yield determination in the Netherlands
  – “Counting the Sun” campaign (8TuO.11.3)

• Conclusion
Motivation

• PV is becoming a mainstream energy harvesting option
  135 GWp power, end 2013

• **Optimal** performance is required

• But, do we know

  “How well is PV serving the world?”

- Do good promises lead to good performance (= quality)?
Motivation

Shade is one reason for lower performance (inverter MPP)

Pannebakker, 2014
Monitoring Data: What to Measure?

- **PV array**
  - $V_{DC}$
  - $I_{DC}$
  - $P_{DC}$

- **Inverter**
  - $V_{AC}$
  - $I_{AC}$
  - $P_{AC}$

- **Grid**

- **$G_t$**

- **$T_{amb}$, $T_{mod}$, $S_W$**

- **$y_r$** Reference yield
- **$y_A$** Array yield
- **$y_f$** System yield

- **$I_c$** Array capture losses
- **$I_S$** System losses

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Definitions: Yields & Losses

Yields
Reference yield $Y_r = \text{in-plane irradiation} / 1 \text{ kW/m}^2$
Array yield $Y_A = \text{DC energy} / \text{PV peak power}$
Final yield $Y_f = \text{AC energy} / \text{PV peak power}$

Losses
Capture losses $L_C = Y_r - Y_A$
System losses $L_S = Y_A - Y_f$

Performance Ratio $PR$
$PR_A = Y_A / Y_r$
$PR = Y_f / Y_r$

[Woyte, 2014]
Data Plots – A Visual Tool

AC power (W/kWp)

Irradiation (POA) W/m²

Courtesy of Christian Reise, Fraunhofer ISE
Systematic Approach

- Use data for identifying the system and component parameters
- Identify simplified physical relationships
- Derive **linear model** parameters from regression
- Update periodically (day, week, month) and compare the results
- Deviations indicate irregular operation → may be a malfunction that should be solved
Physical Relationships of Quantities

**System Level Performance**
- System performance \( y_f \ vs \ y_r \)
- Influence of module temperature \( PR \ vs \ T_{Mod} \)

**Module Temperature**
- Module temp. \( T_{Mod} – T_{Amb} \ vs \ y_r \)

**Array Level Performance**
- Array performance \( y_A \ vs \ y_r \)
- Influence of module temperature \( PR_A \ vs \ T_{Mod} \)

**Grid Connection**
- Resilience of grid voltage on active power \( v_{AC} \ vs \ y_f \)

**Temp. – Secondary Effects**
- Influence of wind speed on module heat transfer \( k_{th} \ vs \ S_W \)

**Array Level – Specific Effects**
- Array voltage \( V_A \ vs \ T_{Mod} \)
Final vs. Reference Yield

8 weeks in summer 2012

No shadow, June

Deviation caused by growing vegetation, May

Installation in Belgium, monitored by 3E
Irradiance, PR and Module Temp.

March 2012: smooth operation

Final vs reference yield

Temperature influence

Installation in Sweden, monitored by ABB
Irradiance, $PR$ and Module Temp.

May 2012: inverter failure (1 out of 3)

**Final vs reference yield**

**Temperature influence**

Installation in Sweden, monitored by ABB
Motivation

• Performance has been increasing in the past decades

• Still, reasons for lower performance than expected (or promised) are difficult to detect
  – due to insufficient monitoring in particular 1-5 kWp residential systems
Performance ratio is going up

IEA – PVPS Task 2
[Nordmann, 2007]

PR from ~60% to >80% [Reich, 2012]
90% max?!
Performance data

To answer the question “How well is PV serving the world?” we need at least the following DATA:

- **Annual Yield** (AC)
  kWh/y/installed kWp as a function of location, climate zone

- Annual average **performance ratio** PR
  Use measured irradiance from local sensor or satellite data

- **Degradation rate**
  For plants in the field for a 5-year period (if possible)

All data per system size bins (<1 kWp -- >10 MWp)
Focus on annual data is what the **customer** needs to know
Example: Statistical analysis Italy

- Example size bin: 10-100 kWp, installed in 2007, full year measurements for 2008-2012 (5 years)
- Courtesy: Francesca Tilli (GSE) [T13 participant]
Italy

All years averaged

Larger systems somewhat better performing

# systems
North: 58
Central: 48
South: 48
Example: Data mining

- Market is introducing web tools for system owners to share monitor data, e.g., SolarLog

- Objective is to analyze PV performance data obtained by web scraping techniques that collect and organize these data automatically in databases

- “What you see, is what you can extract”

- Developed Python scripts
## Results

<table>
<thead>
<tr>
<th>Country</th>
<th>Samples</th>
<th>System Size kWp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>728</td>
<td>11.1</td>
</tr>
<tr>
<td>Germany</td>
<td>764</td>
<td>15.6</td>
</tr>
<tr>
<td>Italy</td>
<td>532</td>
<td>13.1</td>
</tr>
<tr>
<td>France</td>
<td>325</td>
<td>15.1</td>
</tr>
<tr>
<td>Belgium</td>
<td>565</td>
<td>6.5</td>
</tr>
</tbody>
</table>

### Breakdown by Country:

- **Germany**
  - Polycrystalline: 60%
  - Monocrystalline: 40%
- **Italy**
  - Polycrystalline: 50%
  - Monocrystalline: 50%
- **Netherlands**
  - Polycrystalline: 50%
  - Monocrystalline: 30%
  - Amorphous: 20%
- **France**
  - Polycrystalline: 40%
  - Monocrystalline: 60%
- **Belgium**
  - Polycrystalline: 50%
  - Monocrystalline: 50%
Results

- Yearly variation between 2011-2013 from 2-11%
## Annual yield (kWh/kWp) ±(stdev)

<table>
<thead>
<tr>
<th>Country</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>979±153</td>
<td>937±126</td>
<td>882±109</td>
</tr>
<tr>
<td>South</td>
<td>1081±154</td>
<td>1044±121</td>
<td>992±125</td>
</tr>
<tr>
<td>France</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>1030±362</td>
<td>993±201</td>
<td>959±154</td>
</tr>
<tr>
<td>South</td>
<td>1099±96</td>
<td>1092±224</td>
<td>1103±166</td>
</tr>
<tr>
<td>Italy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>1219±170</td>
<td>1177±157</td>
<td>1094±148</td>
</tr>
<tr>
<td>South</td>
<td>1352±113</td>
<td>1337±199</td>
<td>1288±203</td>
</tr>
</tbody>
</table>

South: +6-18%
### Results: NL Geographical Variation

<table>
<thead>
<tr>
<th>Region</th>
<th>PR</th>
<th>Annual Yield kWh/kWp</th>
<th>Irradiation kWh/kWp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast</td>
<td>79.3+/-2%</td>
<td>895+/-21</td>
<td>1165</td>
</tr>
<tr>
<td>Mainland</td>
<td>77.1+/-2%</td>
<td>833+/-19</td>
<td>1021</td>
</tr>
</tbody>
</table>

Temperature, wind ?
Task 13 aims for mapping

AIM:
Energy Yield-GIS or PR-GIS?
Dutch performance data specific yield for statistical purposes

Advice: 875 kWh/kWp (25% increase!), starting from 2011

Presently, PV contributes ~0.5% annually to electricity supply in the Netherlands (and increasing)
“Counting the Sun”

- Dutch Solar Days 2014 (May 12 – May 18)
- Awareness campaign “How well is my system doing”
- Social media, national television show “Kassa”
  → >5000 systems spread over the country
  → “citizen science”

weekly yield average 33.4 kWh/kWp
“Counting the Sun”

- Most systems are performing well
- Average performance ratio $0.74 \pm 0.10$
- No geographical variation in performance ratio
- Some 10% of participants indicated some form of shade, performance ratio: $0.70 \pm 0.10$. 

[Maps showing irradiation, yield, and performance ratio]
Conclusions

- Obviously, without DATA one cannot say anything about PERFORMANCE (=quality)
  Reliability? = continuously high PR

- IEA PVPS Task 13
  - Collecting and analyzing data
  - From participants
  - Statistical analysis, web scraping

- Dutch examples
  - standard specific yield, awareness campaign

Please join!
Reports by IEA PVPS Task 13

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Thank you for listening!

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