BIFOROT –

Experimental data for LCOE appraisal of bifacial systems

BIFOROT: Bifacial Outdoor Rotor Tester

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Konstanz, bifi PV 2017
BIFOROT set-up

- Array instead of single stand-alone module
- Real world conditions as in actual bifacial PV system
- Continuously varying tilt angle (automated, 1-minute cycle 0°-90°, 12 steps)
- Variable parameters (albedo, height, distance, width - manually)
- Focus on central module(s) => Expansion of 3x3 to 3x4 array
BIFOROT - LCOE appraisal

- LCOE of bifacial systems (…yield, kWh/kWp…)
  - Crucial, but prediction not feasible with sufficient accuracy today
    ⇒ Need for reliable yield prediction

⇒ Systematic compilation of data
  - Generation of data at system level (demo, comparison)
  - Reveal optimized installation conditions
  - Verify simulation tools and improve calculations

- Analyze specific properties of bifacial modules / systems
  - Angular sensitivity, intensity distribution at rear, …
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BIFOROT- Annual yield for varied tilt

Annual yield of the center module

⇒ Prediction of PV system output for similar systems

⇒ Optimized installation conditions for given, specific installation situation

<table>
<thead>
<tr>
<th>Tilt [°]</th>
<th>0</th>
<th>10</th>
<th>15</th>
<th>18</th>
<th>21</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>60</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield [kWh]</td>
<td>323.8</td>
<td>340.3</td>
<td>345.6</td>
<td>348.0</td>
<td>349.6</td>
<td>350.6</td>
<td>350.0</td>
<td>347.9</td>
<td>344.6</td>
<td>340.4</td>
<td>325.6</td>
<td>268.3</td>
</tr>
</tbody>
</table>


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BIFOROT - Annual yield for varied tilt

Max.: 1292 kWh/kWp @ 25° tilt angle
(Here: net data without correction for downtime)
⇒ underestimation of actual kWh/kWp value
Unfavorable shading situation since 27th of March
(see next slide)

Specifications
- Azimuth angle: 0° (south orientation)
- Axis height: 0.75 m (axis center)
- Module height: Axis height ⇒ “lower edge” dependent on tilt angle!
- Axial spacing: 2.86 m (axis center to axis center)
- Ground albedo: 0.51 (measured at axis height on “dirty” foil)
- Location: Winterthur, Switzerland
- Module (STC): Pmpp front: 271.4 W; Pmpp rear: 188.5 W; B: 0694 (J-Box)
- Module type: Megacell MBF-GG60-270
Challenges

Downtime: white spaces in sun-path diagram
Site specific limitation / shading
⇒ azimuth angle range: 93.4° to 265.1°

Since 27th of March 2017 😕
Building crane in front of BIFOROT
Winter (Oct. – March) unaffected

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BIFOROT - LCOE appraisal

- Data collection and testing of algorithms
- Project with ISC Constance / Djaber Berian just started
  
  \[ \uparrow \]

  - Verify simulation tools and improve calculations

- Analyze specific properties of bifacial modules / systems
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  \[ \downarrow \]

- Some examples for more general analysis at the next slides
Rear and front contribution

- Module 3 (M3): Rearside covered for $I_{SC,\text{front}}$ measurement
- Module 2 (M2): IV-curve measurement ($I_{SC,\text{bifacial}}$)
- Module 1 (M1): Frontside covered for $I_{SC,\text{back}}$ measurement

- Bifacial gain & rear side power contribution directly if $P_{\text{mpp}}$ measurement for M1, M3 realized
- Analysis of Irradiance/ $I_{SC}$
Rear and front contribution

- M3: $I_{sc}$ front; M2: $I_{sc}$ bifacial; M1: $I_{sc}$ back
- October – March (winter season)
- Bc: Backside contribution
- Bc relative to front: 0.15 (45°) to 0.35 (0°)

- $\Sigma I_{sc}$ in kAh
- $\Sigma$ front + back
good but not perfect correspondence to bifacial
- $\Sigma I_{sc}$ back (absolute) surprisingly constant
Illumination intensity and homogeneity

- Small irradiance sensors - crystalline silicon cells
- Sensors enable mapping of illumination intensity at front and rear side
Illumination intensity and homogeneity

- Compare M1–M3 results to small sensors
- October – March (winter season)
- Local output (rear) normalized to ISE (front)
- Compare to M1–M3 results (backside contr.)

Lowest rear side illumination intensity determines backside contribution

See also talk of Mr. Eisenberg/Solaround yesterday
Illumination intensity and homogeneity

- Sensors at short side

- Normalized to ISE reference cell turning with module front

- Short-term data for test of simulation

- Here: Integrated data from Oct 2016 to March 2017

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Miniaturized test rig
Miniaturized test rig / basic idea

BIFOROT: Long term measurements

- Reveal yield; Compile data for simulation
- Manual adjustment (height, dist., albedo) slow

Miniaturized rig - more flexible solution?

- Param. varied quickly → nearly identical conditions
- Multiple cheap rigs → vary at identical conditions !!!
- Multiple cheap rigs → directly compare locations !!!
Miniaturized Test Rig / Correspondence
Miniaturized Test Rig / Correspondence
Correlation of small and large rig

- Example 05/09/2017
- Miniaturized device: Surprising correspondence
- Determine scaling factors for each tilt angle
- Several possibilities
Correlation of small and large rig

- Example 05/09/2017
- Scaling factor for each cycle (1-minute)
- Ongoing work
Planned: Mobile test platform

Miniaturized rig - more flexible solution

Parameters varied quickly → nearly identical conditions

- Multiple cheap rigs → vary at identical conditions !!!
- Multiple cheap rigs → directly compare locations !!!

Current plan: Improved version with two systems as mobile test platform
Summary and Outlook

- **BIFOROT**
  - Suitable tool to analyze bifacial installations
  - For investors → test / demo system; Reveal optimized installation conditions
  - Data generation to verify simulation algorithms
  - Systematic analysis of general properties (e.g. intensity distribution at rear)
    - Suboptimal location at ZHAW roof
    - Long-term measurement

- **Miniaturized test rig**
  - Data shows good correspondence to BIFOROT results
  - More flexible than large array
  - Parallel use of devices will reveal effects by direct comparison!