WEBINAR
Understanding bifacial’s true potential: technology innovation and technical bankability of bifacial PV projects
MONDAY, 7TH OCTOBER 2019
Bifacial PV Technology: Ready for Mass Deployment

PV Magazine Webinar on Bifacial PV

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VP Global Technical Services
PI Photovoltaik-Institut Berlin AG
Overview

- History of Bifacial PV
- Bifacial PV Technologies
  - Solar Cells
  - Solar Modules
- Impact of the System Design to the Achievable Energy Gain
- Yield Prediction Softwares
- Examples of Real Installations
History of Bifacial PV

- 1954: the world´s first solar cell design was bifacial

- late 1990ties: the world´s No.1 solar cell was a bifacial cell (Siemens PowerMax)
History of Bifacial PV

- 2003 – 2010: 1st phase of commercialization with some early commercial products (Sanyo HIT; SolarWind) and a R&D programs of serious players (Hitachi; Sunpower)

- 2011 – 2016: 2nd phase of commercialization with some early bifacial power plants (PVG; Sunpreme) and first companies building specific bifacial technology platforms and production lines (MegaCell; CIE; Linyang; ..)

- Since 2017: 3rd phase of commercialization; started with some large fields in correlation with Chinese „FrontRunner“ program. Now bifacial PV is one of the most attractive options for reducing LCOE

- Outlook: ITRPV says the majority of solar modules will be bifacial in 10 years
### Bifacial PV Technologies

#### Table 2.1 Bifacial solar cells and their main parameters

<table>
<thead>
<tr>
<th>Cell concept</th>
<th>Bifaciality factor (on cell level)</th>
<th>Si base material</th>
<th>Junction and BSF doping method</th>
<th>Contacts</th>
<th>(Front) Efficiency potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.1 Heterojunction</td>
<td>&gt;92%</td>
<td>n mono</td>
<td>a-Si:H p- and n-type doped</td>
<td>TCO/Ag printed TCO/Cu plated</td>
<td>22%–25%</td>
</tr>
<tr>
<td>2.5.2 n-PERT</td>
<td>&gt;90%</td>
<td>n mono</td>
<td>Boron and Phosphorous diffusion</td>
<td>Ag and Ag/Al printed</td>
<td>21%–22%</td>
</tr>
<tr>
<td>2.5.3 p-PERT</td>
<td>&gt;90%</td>
<td>p mono</td>
<td>Phosphorous and Boron diffusion</td>
<td>Ag and Ag/Al printed</td>
<td>21%–22%</td>
</tr>
<tr>
<td>2.5.4 PERC+</td>
<td>&gt;80%</td>
<td>p-mono</td>
<td>Phosphorous diffusion and local Al BSF</td>
<td>Ag and Al printed</td>
<td>21%–22%</td>
</tr>
<tr>
<td>2.5.5 IBC</td>
<td>&gt;70%</td>
<td>n-mono</td>
<td>Boron and Phosphorous diffusion</td>
<td>Ag and Ag/Al printed</td>
<td>22%–23%</td>
</tr>
</tbody>
</table>
Bifacial PV Technologies

1. p-PERC

Source: SOLARWORLD White Paper: “Calculating the Additional Energy Yield of Bifacial Modules”
Bifacial PV Technologies

1. p-PERC

- p-PERC manufacturing process can easily be modified for a bifacial solar cell version
n-PERT is the technology-of-choice for many bifacial solar cells because of better bifaciality
3 Hetero-junction technology

- HJT has the highest efficiency and best bifacial coefficient
- Very different manufacturing process requires higher investment in equipment

Source for graphics: MeyerBurger
Bifacial PV Modules

Standard module technology is double glass (p-PERC based)

Source: www.solitek.eu
Bifacial PV Modules

Advanced module technology designs

White patterned glass improves front side STC power

Half-cut bifacial back-contact solar cells

Bifacial shingled solar cells
Bifacial PV Modules

Substitution of rear glass by a clear backsheet

JinkoSolar Swan Bifacial Module
Bifacial PV Modules

- Today glass-glass is still the predominant technology for bifacial PV modules
- Glass-backsheet is becoming more relevant because it has the advantage of lower weight plus some former disadvantages got resolved
- Our position: there is not a clear better or worse module concept
Impact of the System Design to the Achievable Energy Gain

Bifacial PV: simple concept but many additional factors for energy gain

- Albedo (which is not constant over the day and also seasonally)
- Level above ground
- Row spacing
- Uniformity of backside irradiance
- Tilt angle
- Light spectrum onto rear side
- Backside IAM
- Obstructions from racking structure
- Modules portrait or landscape
- Tracking algorithm

Source: SOLARWORLD White Paper: “Calculating the Additional Energy Yield of Bifacial Modules”
Impact of the System Design to the Achievable Energy Gain

Influence of ground albedo

Source: R. Kopeczek (ISC Konstanz): Presentation at the “HERCULES” workshop 2018
Impact of the System Design to the Achievable Energy Gain

Influence of level above ground

Source: SOLARWORLD White Paper: “Calculating the Additional Energy Yield of Bifacial Modules”
Impact of the System Design to the Achievable Energy Gain

- Larger row spacing is beneficial for bifacial gain
- Important factor for overall project optimization (technical and financial aspect)

Source: I. Shoukry et al.: 6th International Conference on Silicon Photovoltaics, SiliconPV 2016
Yield Prediction Softwares

„Well accepted methodology for energy modeling is the biggest hurdle with bifacial systems.“

Jenya Meydbray, Cypress Creek Renewables

(now with PVEL)

Source: presentation on the workshop on bifacial PV 2018
Yield prediction softwares

1. PVSYST
   ▪ has a bifacial option since 2017

2. SAM
   ▪ Free software developed by NREL

3. MOBIDIG
   ▪ Special software for bifacial PV from ISC Konstanz; user version under development

4. BIGEYE
   ▪ Software from ECN TCO

5. SolarFarmer
   ▪ By DNV

6. Name =?
   ▪ Software by IMEC and EnergyVille (Belgium)

7. PlantPredict
   ▪ Software tool from First Solar

... plus several others
Yield prediction softwares

A lot of activities to verify accuracy of software tools

1. PVEL, supported by DoE grant

Deploy bifacial systems with monofacial reference in the field to validate energy modeling practices
- Bifacial Test Stations: single module IV curves, 2-apartment single axis trackers
- 4 manufacturers side by side with 1500V Strings on 2 albedos
- Impact of spectral albedo and temporal change in albedo

Partner with Energy Modeling community for field validation on reduced order models
- PVsyst, TNO, SAM, Solar Farmer, Plant Predict

Source: workshop on bifacial PV 2019
Yield prediction softwares

First publications about comparison of test sites with simulation tools

Conclusions from the comparison [1]

- The three simulation tools give similar results
- are in agreement with the experiment
- bifacial yield modeling is reaching a stage of maturity.

Source: A. Burgers (workshop on bifacial PV 2019)
Examples of Real Installations

System data:
Capacity: 38 MWp DC
Installation: HSAT
Location: Arizona

Source: www.soltec.com
Examples of Real Installations

System data:
Capacity: 15 MWp DC
Installation: fixt-tilt
Location: New Jersey

Source: www.sunpreme.com
Examples of Real Installations

System data:
Capacity: 6 MWp DC
Installation: fixt-tilt agro-PV
Location: Jiangsu (China)

Source: own photo
Examples of Real Installations

System data:
Capacity: 1 MWp DC
Installation: vertical east-west agro-PV
Location: Germany

Source: www.next2sun.de
Examples of Real Installations

System data:
Capacity: 3 MWp DC
Installation: carport
Location: Qidong (China)

Source: own photo
Examples of Real Installations

System data:
Capacity: 30 MWp DC
Installation: rooftop
Location: China

Source: LINYANG company brochure
Examples of Real Installations

<table>
<thead>
<tr>
<th></th>
<th>Mono-facial</th>
<th>Bifacial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-tilt</td>
<td>100% (ref.)</td>
<td>105 – 115%</td>
</tr>
<tr>
<td>(rooftop)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed-tilt</td>
<td>100% (ref.)</td>
<td>107 – 130%</td>
</tr>
<tr>
<td>(ground)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSAT</td>
<td>110 – 122%</td>
<td>117 – 145%</td>
</tr>
</tbody>
</table>

- With no system design changes you can simply achieve 5-7% more energy.
- More than 10% energy is achievable for almost every system but it requires design modifications (ground albedo; row spacing; higher inclination; ...)

PI Photovoltaik-Institut Berlin AG
1. Bifacial PV is not a new thing – it is just new to many people in the PV industry

2. There are two drivers of bifacial PV becoming mainstream
   - p-PERC solar cells can easily be made bifacial
   - Cost reduction of n-type wafers

3. Bifacial PV system design has to consider many more parameters and variables than conventional systems
   - Can be combined with HSAT

4. Yield prediction software tools for bifacial systems have significantly improved
   - PVSYST is known to finance partners
   - Results can be verified with several other tools from institutes (SAM; MOBIDIG; ...)

5. Bifacial PV offers a large potential for lower LCOE with very limited risk
   - Requires thoughtful system design

Recommendations:
- Free download of white paper on bifacial PV at www.pi-berlin.com
- All publications from every „Workshop on Bifacial PV“ are available for free download at www.bifipv-workshop.com
Your independent solar advisors!

Contact us:

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Bankability improvement for bifacial technology

The other side of the coin

7 Oct 2019
BIFACIAL TECHNOLOGY

1. Introduction
2. Design variables
3. Testing and certification
4. Bankability and modeling
5. Main mitigations
6. Bifacial main challenges
7. Conclusions / Questions
Introduction

- For Lenders, bifacial technology is considered as a “new technology”

- Lender’s points of attention regarding bankability study to grant the “non recourse loans” are:
  - The resource
  - The specific technological risks
  - The supplier’s track record
  - Specific O&M risks
  - Additional risks
BIFACIAL TECHNOLOGY

Design variables

Front- and rear-side performance to be optimized to maximize bifacial gain without an offsetting reduction in front-side performance

- **Albedo**: bright is better (but rare)
- **Ground clearance**: 0.5 m (NREL recommendation)
- **Structure**:
  - **Height**: higher is better (but expensive)
  - **Spacing**: wider is better (but unpopular)
  - **Tilt angle**: Higher than what might be optimal for monofacial
- **DC/AC ratio**:
  - Less than 1.15 may be optimal depending on the site and design
  - Clipping
BIFACIAL TECHNOLOGY

Testing & Certification

- **Specific adaptation of existing standards needed**: higher currents
  - because of the power contribution from the rear side requires

- **Standard for bifacility factor**: IEC TS 60904-1-2.
  - Important also for labelling. To be issued by the beginning of 2019

- **Re-testing guidelines** for differences in BOM for bifacial modules
  - not available yet for bifacial modules

- **Quality and reliability testing**
The **bankability** of a project depends on the confidence of the energy output predictions which are generally modeled.

**Validation of bifacial energy modeling** has not been generally accepted in the industry yet.

IE community is actively seeking **sufficient field validation data** to support bankable energy forecasts.
Main Mitigation Measures / Initiatives

- Mixing technologies Mono/bi
- Reducing leverage of debt
- Increased warranty levels
- Manufacturer Bankability reports
- Collaboration with manufacturers
- The importance of BOM
- Maintenance Reserve Account
- Presentations to Banks

U.S. Department of Energy awards study of bifacial PV technology, which could prove a 10% increase in energy output

Research study by DNV GL will be the most comprehensive energy yield analysis for bifacial PV modules to date
# PV Module Technology Bankability

## Main Challenges / Risks – PERC / Bifacial

<table>
<thead>
<tr>
<th>Manufacturing</th>
<th>Technical</th>
<th>Design</th>
<th>Testing</th>
<th>Modelling</th>
<th>O&amp;M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional steps</td>
<td>New product reliability and durability</td>
<td>Site Selection</td>
<td>Not fully developed</td>
<td>Lack of validation</td>
<td>Limited field experience</td>
</tr>
<tr>
<td>New Materials</td>
<td>LID / LeTID</td>
<td>Measurements</td>
<td>IEC 60904-1-2</td>
<td>Stability and actual value of Bifaciality factor</td>
<td>Higher OPEX</td>
</tr>
<tr>
<td>Quality Assurance System</td>
<td>Long term degradation</td>
<td>Supporting Structure</td>
<td>Warranties</td>
<td>Albedos Variability</td>
<td>Clipping, actual vs predicted</td>
</tr>
<tr>
<td>Weight</td>
<td>Weight</td>
<td>Lower GCR</td>
<td></td>
<td>Tracking System</td>
<td></td>
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<tr>
<td>Mismatching</td>
<td></td>
<td>Backside shading</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Overtightening bolts. Frameless</td>
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PV MODULE TECHNOLOGY BANKABILITY

Conclusions

- Bifacial Technology is a really promising technology

- DNV GL notes that gains of even 5% may require significant attention to design and siting detail

- However, standards and technology are subject to future improvements for a better bankability
Thank you.

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SAFER, SMARTER, GREENER
Swan Bifacial Module
Short Introduction of JKS

- **Shipments #1**
- **Delivered 40GW**
- **Market Share 12.8%**
- **Cell Efficiency Record 24.58%**
- **Bankability #1**

Data source: By the end of 2018
## JKS Product Portfolio 2019

<table>
<thead>
<tr>
<th>Model</th>
<th>Power (Wp)</th>
<th>Efficiency</th>
<th>Warranty</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cheetah FC</strong></td>
<td>400</td>
<td>20.17%</td>
<td>25 Year Linear</td>
</tr>
<tr>
<td><strong>Cheetah HC</strong></td>
<td>410</td>
<td>20.38%</td>
<td>25 Year Linear</td>
</tr>
<tr>
<td><strong>Cheetah Dual</strong></td>
<td>395</td>
<td>19.69%</td>
<td>30 Year Linear</td>
</tr>
<tr>
<td><strong>Swan Bifacial DG</strong></td>
<td>400</td>
<td>19.54%</td>
<td>30 Year Linear</td>
</tr>
<tr>
<td><strong>Swan Bifacial TB</strong></td>
<td>400</td>
<td>19.54%</td>
<td>Lower weight</td>
</tr>
</tbody>
</table>

- **Cheetah FC**:
  - 400Wp
  - Efficiency 20.17%
  - 25 Year Linear Power Warranty

- **Cheetah HC**:
  - 410Wp
  - Efficiency 20.38%
  - 25 Year Linear Power Warranty

- **Cheetah Dual**:
  - 395Wp
  - Efficiency 19.69%
  - 30 Year Linear Power Warranty

- **Swan Bifacial DG**:
  - 400Wp (front only)
  - Efficiency 19.54%
  - 30 Year Linear Power Warranty

- **Swan Bifacial TB**:
  - 400Wp (front only)
  - Efficiency 19.54%
  - 30 Year Linear Power Warranty
  - Lower weight
JKS Swan Bifacial Features

- Cheetah Cell efficiency up to 22.3%
- Bifacial Energy Yield Up to 500+ Watt in Total
- Front side max power 415 Wp
- Rear side: plus 5-25% additional power
- 30 Years Linear Power Warranty
- Reduce BOS Cost by 3%
- Reduce O&M Cost by 5%

158.75mm cell dimension
## Over 25% less Module Weight

<table>
<thead>
<tr>
<th>weight</th>
<th>↓ 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swan Bifacial TB module: 22~23kg</td>
<td></td>
</tr>
<tr>
<td>Framed Bifacial module: 31~32kg</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>labor cost</th>
<th>↓ 20%</th>
</tr>
</thead>
</table>

- JKS Swan bifacial with transparent backsheet reduces the module weight over 25% compared to bifacial dual glass.
- Effectively reducing the transportation and installation costs.
- Saving labor cost related to module installation by over 20% using bifacial modules with transparent backsheet.
Installation System Design

Bifacial with transparent backsheet

- **Fewer** supporting structures
- **Compatible with the system of monofacial modules**
- **↓ 15%** mounting construction cost

Bifacial with dual glass

- **More** supporting structures
- **Incompatible with the system of monofacial**

Modules Stronger load-bearing structure is requested
Reliability of Backsheet

PVF film in transparent backsheet shows excellent transmission and mechanical property after 360 kWh/m² UV exposure, which equals a more than 30-year usage in desert area climate.
Case Studies – Reliability of Backsheet

Amsterdam BAPV Project

Location
Amsterdam, Netherlands

Completion Time
2000 – (18 years Service Life)

System information
Size: 6.228 kWp 51 full size panels

Module type
Bifacial with transparent backsheet

Inspection result in 2018
✓ No signs of degradation of Tedlar in the front or back
✓ No yellowing

California Rooftop Project

Location
Presidio National Park, Building 1016, San Francisco, CA

Completion Time
May 1996 – (23 years Service Life)

System information
Size: 1.25 kWp  Projected System Output: 716.4 kWh/yr

Module type
Bifacial with transparent backsheet

Source: DuPont.
Real Energy Generation Gain

**Location:**
Jinko factory, Haining, 30.3° N/ 120.4° E

**Fixed Tilt angle:**
30°, close to the latitude

**Mounting height:**
distance from lower edge to ground is 1.2m

**Capacity:**
1.5kW/array

**Energy gain:**
Compared with mono-facial module in same condition

*Note: The PR of sand is higher than cement, because the yellow light reflected by sand is better for the energy gain. Bifacial modules with transparent backsheet have almost the same bifacial factor as bifacial with dual glass.*
Case Study 1: White paint Fixed installation

Swan bifacial reached average 16% bifacial gain compared with monofacial modules, and in summer energy gain was up to 20%.
Case Study 2: Sand Fixed Mounting System

- Swan bifacial with transparent backsheet
- Energy gain for bifacial modules between 10%-12.5% compared with monofacial modules

Location: Haining, Zhejiang Province
Tilt Angle: 30°
Installation Height: 1.2m above from the ground
Ground Type: Sand
Testing Date: 2019.2.17~2019.5.27
Case Study 3: Grass Fixed Mounting System

- Gain of bifacial modules is **9.05%** compared with monofacial modules
- Bifacial modules gain is proportionally higher in low-irradiance environments
- Energy gain reached **15.07%** in January with many overcast days

**Location:** Lv Liang, ShanXi Province
**Tilt Angle:** 30°
**Installation Height:** 0.3m-1.2m above the ground
**Ground Type:** Grass/Soil
**Testing Date:** 2019.1~2019.6
Case Study 4: Grass Tracker Mounting System

- Energy gain from Swan bifacial modules is **12.6%** compared with monofacial modules.
- Grass turns yellow in autumn, leading to increasing energy gain.

**Graph Details:**
- **Location:** Haining, Zhejiang Province
- **Tilt Angle:** +/-60°
- **Installation Height:** 1.2m above from the ground
- **Ground Type:** Grass
- **Testing Date:** 2019.2.17~2019.5.27
Case Study 5: Sand Tracker Mounting System

- Total energy generation monitoring from February to May
- Energy gain from bifacial modules is 11%-12.7% compared with monofacial modules

Location: Haining, Zhejiang Province
Tilt Angle: +/-60°
Installation Height: 1.2m above from the ground
Ground Type: Sand
Testing Date: 2019.2.17~2019.5.27
Business case study

Project Size

100MW

TOTEX

72,000,000 $

CAPEX

70,000,000$

OPEX

2,000,000$
during 25 years

Energy yield
during 25 years

2,850,000 MWh

1,500 kWh/m²

Annual Irradiance

PR 85%
Assumption: Rest of the costs (loan interest, development costs, installation costs, etc.) remains the same in two different options.

**Option 1:** Monofacial 400Wp modules
- **TOTEX** 72m$
- **LCOE** 72m$/2,850,000MWh = 25.3$/MWh

**Option 2:** Swan 400Wp modules
- +10% energy yield
- Lower annual degradation
- **TOTEX** 75m$
- **LCOE** 75m$/3,157,000MWh = 23.8$/MWh
- 1.5$/MWh lower or 6% reduction of the LCOE by using the SWAN modules (compared with Cheetah modules)
- Additional benefit: with Swan modules the lifetime of the PV park increases to 30 years

---

**Assumption:** Rest of the costs (loan interest, development costs, installation costs, etc.) remains the same in two different options.
Bifacial gain 25%
Lighter ↓ 25%
Module Installation Labor Cost ↓ 20%
LCOE reduction ↓ 6%*
*(based on case study presented)
Thanks