Bifacial PV System Performance: Investigation of Shading Conditions

Amir Asgharzadeh Shishavan, Fatima Toor
Electrical and Computer Engineering Department
University of Iowa

Chris Deline
National Renewable Energy Laboratory

Joshua S. Stein
Sandia National Laboratories

May 2, 2018
Team Acknowledgements

This work is a collaborative project among three institutions funded by the US DOE SuNLaMP funding

- Sandia National Laboratories
  - Joshua Stein - PI
  - Cliff Hansen
  - Dan Riley
  - Matthew Lave

- National Renewable Energy Laboratory
  - Chris Deline – Co-PI
  - Bill Marion

- University of Iowa
  - Prof. Fatima Toor
  - Amir Asgharzadeh (graduate student)
Agenda

- Photovoltaic (PV) Performance Modeling
  - RADIANCE Modeling
  - Cumulative Sky Approach
- Performance Comparison of Bifacial PV Systems with Different Orientations
  - Optimally tilted Facing South/North vs Vertically Installed Facing East/West
  - No Shading
  - Under Shading Conditions
- Conclusions and next steps
RADIANCE Modeling

- RADIANCE, a simulation software that utilizes the backward ray-tracing method

Forward Ray Tracing

Backward Ray Tracing
Agenda

- Photovoltaic (PV) Performance Modeling
  - RADIANCE Modeling
  - Cumulative Sky Approach

- Performance Comparison of Bifacial PV Systems with Different Orientations
  - Optimally tilted Facing South/North vs Vertically Installed Facing East/West
  - No Shading
  - Under Shading Conditions

- Conclusions and next steps
Cumulative Sky Approach

- Producing annual results by running hourly simulations is computationally expensive
- To perform annual simulations, we use Cumulative Sky Approach

Agenda

- Photovoltaic (PV) Performance Modeling
  - RADIANCE Modeling
  - Cumulative Sky Approach

- Performance Comparison of Bifacial PV Systems with Different Orientations
  - Optimally tilted Facing South/North vs Vertically Installed Facing East/West
  - No Shading
  - Under Shading Conditions

- Conclusions and next steps
Among different possible orientations for bifacial modules, the two most popular options are:

- Optimally tilted south/north-facing module ($\text{Bi}_{S/N}$)
- Vertical east/west-facing module ($\text{Bi}_{E/W}$)

Optimum tilt angle for south-facing bifacial module is latitude of the location [1]

Simulation Setup

- Multiple locations were chosen for the simulation purpose.
Agenda

- Photovoltaic (PV) Performance Modeling
  - RADIANCE Modeling
  - Cumulative Sky Approach
- Performance Comparison of Bifacial PV Systems with Different Orientations
  - Optimally tilted Facing South/North vs Vertically Installed Facing East/West
    - No Shading
    - Under Shading Conditions
- Conclusions and next steps
Observed that for all locations, except Singapore, the Bi_{S/N} has more annual energy yield than Bi_{E/W} (up to 120 kWh/year)

Performance of the PV system installed in Singapore, installed at low tilt, is affected adversely by self-shading and therefore the yield of Bi_{S/N} is slightly lower than Bi_{E/W}
Agenda

- Photovoltaic (PV) Performance Modeling
  - RADIANCE Modeling
  - Cumulative Sky Approach
- Performance Comparison of Bifacial PV Systems with Different Orientations
  - Optimally tilted Facing South/North vs Vertically Installed Facing East/West
  - No Shading
  - Under Shading Conditions
- Conclusions and next steps
Under Shading Conditions

- Horizon obstructions can decrease the diffuse and direct light received by photovoltaic (PV) modules.
- We ran simulations sweeping parameters shown below for both $\text{Bi}_{S/N}$ and $\text{Bi}_{E/W}$.

$$5 \text{ m} \leq r < 100 \text{ m} \quad 5 \text{ m} \leq W \leq 50 \text{ m}$$

$$0^\circ \leq \theta < 360^\circ \quad 5 \text{ m} \leq h \leq 50 \text{ m}$$

Concrete Obstruction Reflectivity $\sim 28\%$
The goal is to determine under which shading conditions Bi\textsubscript{E/W} system performs better than Bi\textsubscript{S/N}.

We analyzed two locations: (i) Albuquerque, NM and (ii) Anchorage, AK.

Of the 6000 simulations for each of the two locations and for each of Bi\textsubscript{S/N} and Bi\textsubscript{E/W} systems, the cases where the performance of Bi\textsubscript{E/W} was higher than Bi\textsubscript{S/N} were identified.
Effect of Obstruction’s Orientation

- Obstructions around south (azimuth angle of 180°) can cause $B_{E/W}$ perform better than $B_{S/N}$
  - Closer shadow to the module and therefore decrease in the diffuse ground reflected irradiance
  - Occasional direct shading
  - No reflection from the obstruction due to its shaded surface

![Graph showing number of cases where $B_{E/W}$ performed better than $B_{S/N}$ for different azimuth angles]

- Number of the cases $B_{E/W}$ performed better than $B_{S/N}$
  - Various locations:
    - Albuquerque, NM
    - Anchorage, AK

Azimuth (°)
- Larger obstructions result in greater diffuse and direct irradiance loss on modules.

![Graph showing the number of cases where Bi_E/W performed better than Bi_S/N vs. height and width of obstructions.](image-url)
Effect of Obstruction’s Distance to the Module

- From the view of the module, closer obstructions seem larger

- Number of the cases $B_{E/W}$ performed better than $B_{S/N}$

- Diagram showing distribution of better performance cases with distance (m) for Albuquerque, NM in black and Anchorage, AK in red.
In order to identify the obstruction which resulted in better performance for $\text{Bi}_{E/W}$ than $\text{Bi}_{S/N}$, J48 decision trees were developed for both locations using Weka [1].

Class Labels:
N: $\text{Bi}_{E/W} < \text{Bi}_{S/N}$
Y: $\text{Bi}_{E/W} > \text{Bi}_{S/N}$

Accuracy: 99.3%

Characteristics of obstruction which resulted in having better performance for $\text{Bi}_{E/W}$ than $\text{Bi}_{S/N}$ in Albuquerque, NM:

- $r \leq 5$ m
- $120^\circ < \theta < 180^\circ$
- $W = 5$ m
- $10$ m $\leq h$

- $r \leq 5$ m
- $120^\circ < \theta < 210^\circ$
- $5$ m $< W$
- $10$ m $\leq h$

- $5$ m $\leq r \leq 15$ m
- $120^\circ < \theta < 210^\circ$
- $15$ m $\leq W$
- $25$ m $\leq h$

These conditions are basically the large obstructions in south which are also very close to the module resulting in heavy direct shading.
Decision Tree: Anchorage, AK

Class Labels:
N: Bi_{E/W} < Bi_{S/N}
Y: Bi_{E/W} > Bi_{S/N}

Accuracy: 97.8%
Cont. Decision Tree: Anchorage, AK

- Characteristics of obstruction which resulted in having better performance for $\text{Bi}_{E/W}$ than $\text{Bi}_{S/N}$ in Anchorage, AK

<table>
<thead>
<tr>
<th>Condition</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r \leq 5,\text{m}$</td>
<td>$210^\circ &lt; \theta \leq 240^\circ$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Large obstructions which are also very close to the module

<table>
<thead>
<tr>
<th>Condition</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r \leq 35,\text{m}$</td>
<td>$120^\circ &lt; \theta \leq 210^\circ$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Can result in having up to 75 kwh/year more energy yield for $\text{Bi}_{E/W}$ than $\text{Bi}_{S/N}$
Conclusions and Next Steps

- RADIANCE utilized to model a bifacial PV module with two orientations: optimally tilted facing south/north (Bi_{S/N}) and vertically installed facing east/west (Bi_{E/W})

- Compared annual energy yield of the two systems for different locations and observed that Bi_{S/N} module had higher energy yield than Bi_{E/W} for all locations except for Singapore (latitude of 1.2°) for which Bi_{E/W} outperformed Bi_{S/N}

- Investigated performance of two PV systems installed at two locations under shading conditions caused by horizon obstructions
  - For a high latitude location such as Anchorage (~61°), the presence of certain obstructions can result in having up to 75 kwh/year more energy yield for Bi_{E/W} than Bi_{S/N}

- Next steps include (i) studying the impact of other parameters such as reflectivity of the obstruction and (ii) studying the performance of PV systems installed in practical scenarios by integrating building data into our bifacial model
Thanks for your attention

Any Questions?