Technoeconomic Analysis of changing PV System Layout and Convection Heat Transfer

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Abstract

This work includes analysis of potential economic improvements for PV systems for changing system parameters such as ground cover and incident incident irradiance on PV modules through a newly proposed convective heat transfer model. The changing heat transfer considerations can be shown to improve system LCOE along with improved performance for increased incident irradiance from conventional heat transfer model and increased system LCOE. State-level analyses show that the impact of changing system LCOE is greater for climates with high annual ambient temperatures and moderate to high average annual wind speeds. Further water analysis of changing system parameters reveals that the changing heat transfer dynamics have a non-negligible impact on system LCOE when compared to the changes in incident irradiance that serve as the primary driver of annual energy performance changes.

Introduction

- PV module heat transfer models do not account for changing convective cooling flow for changes in PV array layout
- Accounting for array layout in convection heat transfer calculations can affect module temperature and subsequent conversion efficiency
- Convection flow is affected by array spacing, tilt, clearance height, etc.

Heat Transfer

- Lacunarity: value representing spatial arrangements of modules
- Lacunarity takes panel height, tilt, GCR, etc. into account in calculation
- Nusselt number correlation used to calculate convective heat transfer coefficient $h$:
  
  \[ h = \frac{\Delta T_s}{L_s} = \frac{a h_m P M}{l^{1/5}} + b \]

  - $L_s$: array canopy height (m)
  - $h_m$: thermal conductivity of air (W/mK)
  - $l$: lacunarity length scale (m)
  - $a = 0.090125, b = 1.8617, m = 1/5, r = 1/12$

Case Study

- Technoeconomic analysis was performed using the System Advisor Model (SAM)
- SAM: detailed PV system calculations with detailed cash flow financial calculations
- Parametric analysis of changing GCR and tilt, linked to $L_H$ (m) values, system costs
- 1 MW system, 0.93 AC/DC Ratio
- Proposed convection heat transfer correlation used in place of conventional flat plate convection assumptions
- Wiring costs linked to GCR based on CAPEX sensitivity study

Changing GCR requires changes in costs, DC wiring, and lease and lease for different fixed tilt angles.

Takeaways

- LCOE improves for decreasing GCR despite cost increases for several states
- Moving away from latitude tilt can have performance improvements due to improved convection heat transfer
- Waterfall analysis of changing heat transfer effects are non-negligible for LCOE improvements

LCOE Comparisons

<table>
<thead>
<tr>
<th>GCR</th>
<th>System Costs ($/Wdc)</th>
<th>Land area (acres)</th>
<th>Annual Energy per Module (kWh)</th>
<th>LCOE (cents/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.72</td>
<td>1.78</td>
<td>527.71</td>
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Changing LCOE with decreased GCR

- LCOE improvement from GCR = 0.46 to GCR = 0.35 (Monofacial Tilt 26°)

Energy Increases with decreased GCR

- Annual energy improvement from GCR = 0.46 to GCR = 0.35 (Monofacial Tilt 26°)

U.S. States Heatmaps

- Analysis of changing system GCR from 0.46 to 0.35 was performed for each U.S. state capital at tilt angles of 26, 30, 41 degrees
- Systems were evaluated with monofacial panels with fixed tilt angles
- Cost increases, land lease costs, 0.2% DC wiring loss increase for decreased GCR

Waterfall Plot Analysis

Waterfall analysis of modeling factors for LCOE for monofacial (left) and bifacial (right) systems at 30° fixed tilt angle

References