Improvement in PV Plant LCOE from Convection Heat Transfer Changes from Altered Plant Layout

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Abstract

Heat transfer modeling that accounts for how convective cooling changes with PV array layout has been found to improve system LCOE in certain climates conditions. Analysis of fixed tilt systems performed using the System Advisor Model reveals that reducing system ground coverage ratio from 0.46 to 0.35 can lead to as much as a 1.7% increase in module annual energy output in Phoenix. Depending on climate conditions, these energy increases due to changing convective cooling flow can lead to LCOE improvements for systems with increased row spacing despite the increased wiring and land costs associated with increased module row spacing. While the energy gain from decreasing system ground coverage ratio can be largely attributed to increased plane of array irradiance, the convection cooling considerations presented here can have a non-negligible impact on PV power plant energy output and economic viability depending on climate conditions and array spacing parameters.

Introduction

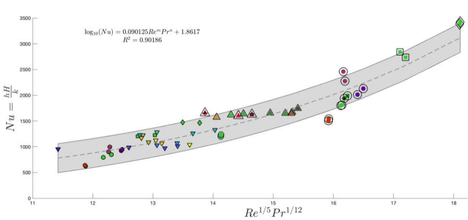
- Accuracy in PV module temperature modeling important to PV performance, economic evaluations
- Current heat transfer models do not account for changing convective cooling flow for changes in PV array layout
- Accounting for array layout in convection heat transfer calculations can module temperature and subsequent efficiency, affect energy output performance and economic metrics such as LCOE

Heat Transfer

- Lacunarity: value representing spatial arrangements
- Lacunarity takes panel height, tilt, GCR, etc. into account in calculation
- Nusselt number curve used to calculate convective heat transfer coefficient *h* based on wind tunnel experiments, flow simulations, plant data [1]:

$$Nu_H = \frac{hL_H}{k_{air}} = aRe^m Pr^n + b$$

- L_H: Lacunarity length scale (m)
- K_air: thermal conductivity of air (W/mK)
- Nu_H: Nusselt number
- Re: Reynolds number
- Pr: Prandtl number
- A = 0.090125, b = 1.8617, m = 1/5, n = 1/12



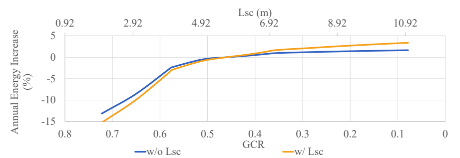
Nusselt number fit from numerical simulations, wind tunnel experiments, field data [1]

Case Study

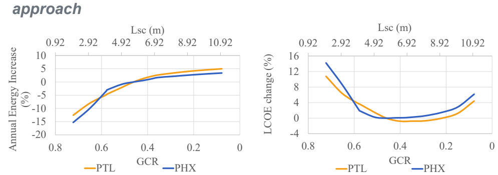
- Simulations of energy and economic performance were performed using the System Advisor Model (SAM)
- SAM: detailed PV calculations with detailed cash flow financial calculations
- Parametric analysis of changing GCR, linked to Lsc (m), costs considerations
- 1 MW system, 0.93 AC:DC Ratio
- Proposed convection heat transfer used in place of conventional flat plate convection assumptions
- Wiring costs linked to GCR based on CAPEX sensitivity studies [2]
- Land area increases based on acreage calculations, fixed $220/acre land lease assumption
- Changing GCR, associated changes in costs, wiring loss assumptions, land lease costs

LCOE Comparisons

- Energy gains increase for greater spacing, cooling flow
- LCOE inflection at point where increased costs outweigh energy gains



Normalized annual energy increase of lacunarity convection heat transfer approach vs. conventional flat-plate convection approach



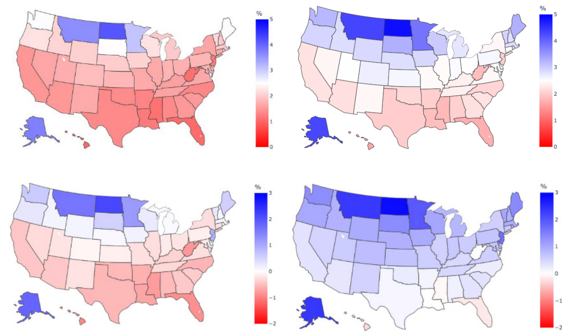
Normalized annual energy (left) and LCOE (right) for Phoenix, AZ and Portland, OR systems

Tabular LCOE and Energy results for changing system GCR

Lsc (m)	GCR	System Costs ($/Wdc)	Land area (acres)	Annual Energy per Module (kWh/yr)	LCOE (cents/kWh)
2.00	0.72	0.16	1.78	527.71	3.30
3.00	0.65	0.17	1.98	560.63	3.13
4.00	0.58	0.19	2.22	601.52	2.95
4.28	0.58	0.20	2.23	604.16	2.94
4.83	0.51	0.21	2.51	617.46	2.89
5.54	0.46	0.22	2.79	622.93	2.89
6.10	0.42	0.23	3.07	626.53	2.89
6.68	0.38	0.24	3.35	630.19	2.89
7.34	0.35	0.25	3.63	633.49	2.89
8.00	0.29	0.26	4.39	636.07	2.90
9.00	0.22	0.28	5.81	639.09	2.93
10.00	0.15	0.30	8.59	641.73	2.97
11.00	0.08	0.32	16.44	644.03	3.06

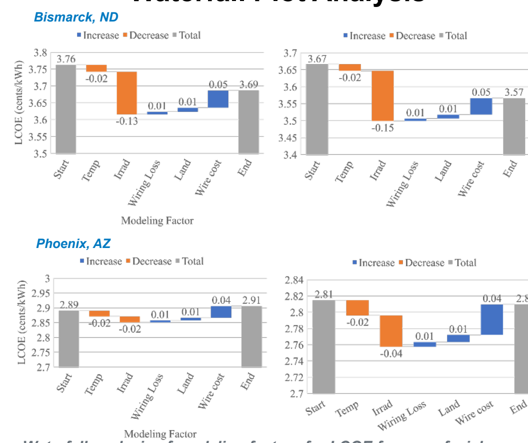
U.S. States Heatmaps

- Analysis of changing system GCR from 0.46 to 0.35 was performed for each U.S. state capitol
- Systems were evaluated with monofacial, bifacial panels (+0.05$/Wdc)
- Cost increases, land lease costs, 0.2% wiring increase
- Phoenix, Portland, etc.



Heatmaps of annual energy gains (top) and LCOE improvement (bottom) for monofacial (left) and bifacial (right) systems

Waterfall Plot Analysis



Waterfall analysis of modeling factors for LCOE for monofacial (left) and bifacial (right) systems

Conclusions

- Accounting for changing convection heat transfer can affect PV plant performance, LCOE
- Degree of LCOE change dependent on climate, array conditions

References

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