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Photovoltaic Module R&D Considerations for Soiling Mitigation

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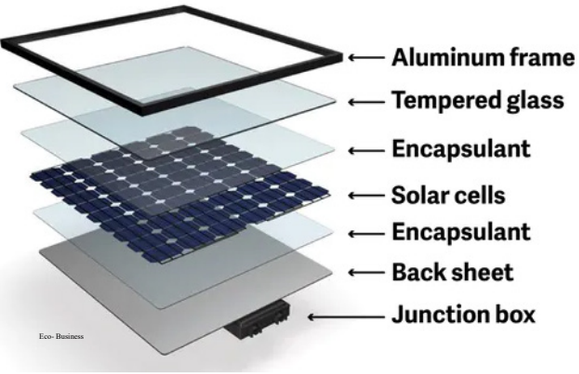
I. Introduction

Background and Motivation

Natural soiling reduces PV energy output and increases levelized cost of electricity.

- *Material deposits on PV component surfaces decreases light throughput and energy production in a variety of ways*
- *Annually, billions of dollars lost and/or spent on cleaning*
- *Not doing anything or implementing some mitigations (e.g., dry brush cleaning)[i] can lead to lost energy output and increased degradation.*



Research Goals

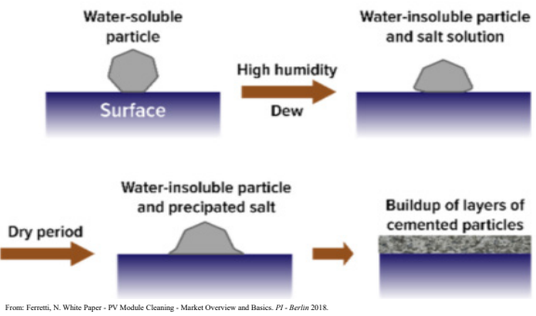
HELP WANTED *to develop component & maintenance recommendations to minimize PV soiling losses*

- *Start to a R&D roadmap*
- *Lead to a comprehensive "best practices" standard [ii]*

II. Example Soiling Modes

Blowing Dust, Sand, Dirt, Soot

- *Very site specific: Lots of work done and needed*
  - *Cause surface abrasion, particularly for large, sharp particles*
  - *Fine particles harder to remove, cause light scattering*
  - *Electrostatic attraction strong with dry air and high voltage*
  - *Climate trends leading to longer, more intense pollen blooms*
  - *Cementation with humidity and dew [iv]*



From: Ferretti, N. White Paper - PV Module Cleaning - Market Overview and Basics. *PI - Berlin* 2018.

Birds, leaves, debris

- *Induces partial shading/hot spots*
  - *Lose 1/3 panel production with just one*
- *Can be strongly adhesive and dependent on season and tilt angle*

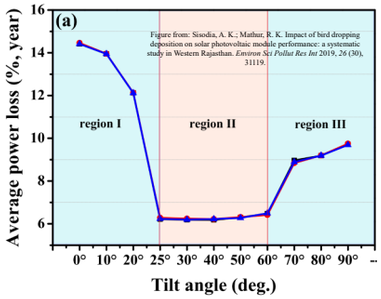


Figure from: Sisodia, A. K.; Mathur, R. K. Impact of bird dropping deposition on solar photovoltaic module performance: a systematic study in Western Rajasthan. *Environ Sci Pollut Res Int* 2019, *26* (30), 31119.

Microbes

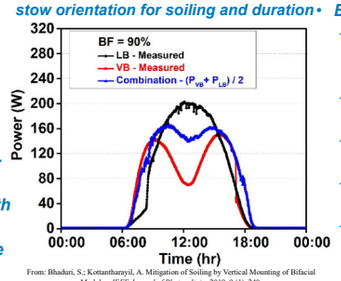
- *Showing up even when rain should clean*
  - *Less growth on frameless, steep, coated, sunny modules*
  - *Can pit glass, produce exopolymers that increase dust soiling*

III. Proposed Example Investigations / Recommendations

Components

- *Frame: Remove or mount glass on top of frame unless lightning or high winds are common*
  - *R&D: new frame mounting methods and costs*
    - *Impact on ground faults and potential induced degradation*
- *Glass coatings: Anti-reflective, -soiling and -microbial*
  - *R&D: hydrophobic, hydrophilic, durability, self-clean …*
  - *Night heating, adjustable emissivity – night sky cooling, …*
- *Glass: Surface morphology and chemical composition*
  - *R&D: smooth or sharp-features, low-alkali glass doped with Bi^{3+} and Gd^{3+}, Cu, corrosion based on environment*
- *Encapsulants: Use ionomer-based, not ethylene vinyl acetate*
  - *R&D: design and material impact on ion transport*
- *Cells: Use cells with low reverse bias breakdown*
  - *R&D: decrease impact of hail and non-uniform soiling*
- *Use hard backsheet[iii] material with aluminum layer embedded*
  - *R&D: Impact of more soiling; vertical and inverted mount*
- *Electric Connections: Lower cost components*
  - *R&D: Soiling-induced ground faults/shorts*
  - *R&D: more built-in, less labor intensive where wind vibration, corrosion, and animal interactions are less of a problem especially when panels inverted at night*

Optimize tilt/tracking range, azimuth, and stow orientation for soiling and duration



From: Bhaduri, S.; Kottantharayil, A. Mitigation of Soiling by Vertical Mounting of Bifacial Modules. *IEEE Journal of Photovoltaics* 2019, 9 (1), 240.

Maintenance

- *Enhance[ii] with science-based best practices*
  - *Module cleaning schedule; in low- or no-light conditions*
    - *R&D: More cost vs. efficacy trades*
    - *Identify site conditions that enable microbes*
  - *Use soft, thin bristle brushes if contact cleaning is necessary*
    - *R&D: Site-specific method, frequency and efficacy trade*
  - *Use deionized water near the module temperature for washing*
    - *R&D: Site-specific environmentally friendly additives*
  - *Keep away from wind-pollinated trees*
    - *R&D: Rapid identification of pollen-based soiling*
  - *Combine vertically and latitude-mounted bifacial modules*
    - *R&D: Stow vertical or inverted capability vs. cleaning/storm trade*

Table 1. Impact of soiling and potential mitigation issues on different module components

Module Component	Front surface anti-reflection coating	Front surface glass	Cell encapsulant	Solar cells	Backsheet	Frame	Junction box/wires
Mechanical: Abrasion	From sand and cleaning	From sand and cleaning					
Mechanical: Cyclic load stress (look at Hacke's everything test)				Cracking, robotic cleaning		Important for robotic cleaning	Wires abraded by repeated cleaning
Mechanical: Acute load stress	Scratches from walking	Cracking form walking		Cracking from walking	Unknown	Important	Wires ripped loose from cleaning
Mechanical: Thermal shock	Delamination			Cracking	Delamination	Debonding	
Chemical: Corrosion	Soil type dependent, fungi	Soil type dependent, fungi			Soil type dependent		Seals and connectors
Chemical: Ion migration	Alter reflection properties	Alter transmission properties (e.g., Fe)	Potential induced degradation from salts	Potential induced degradation from salts	Potential induced degradation from salts		
Electrical: Ground faults			May be issue				Trips inverter protections
Electrical: Shorting					Cracks in sheet lead to shorting with cleaning		Water overspray cleaning

IV. Conclusions and Future Pursuits

Conclusion

- *Effectively reducing soiling will increase production and decrease cleaning costs, helping PV grow*
- *Proposed recommendations may be broadly applicable, but site-specific adjustments must be considered*
- *Soiling mitigation measures must include cost trades and durability issues*
- *Environmental parameters still play a key role in material selection and site design and should be tested if possible*
- *Need design of an artificial soiling apparatus able to simulate different environmental and site conditions to test various types of cleaning systems for efficacy and damage to the modules*

Future Plans

- *Perform more literature reviews and customer discovery interviews to identify comprehensive set of soiling induced issues*
- *Work with PV soiling community and PV manufacturers to develop roadmap for science-based R&D needed*
- *Coordinate with community to gather results as more work is performed to fill out needed knowledge base*
- *Publish best practices guide: report, literature publication, and/or standard*

Please provide your input on needed R&D efforts

References

i. IEC 62788-7-3 abrasion standard. IEEE Journal of Photovoltaics 10, 1, 173 (2020), The Abrasion of Photovoltaic Glass: A Comparison of the Effects of Natural and Artificial Aging. Review of Artificial Abrasion Test Methods for PV Module Technology, NREL Technical Report NREL/TP-5J00-66334, 2016.

ii. IEC 62446-2 - PV Systems - Requirements for Testing, Documentation and Maintenance.

iii. IEC 62788-2-series (PV backsheets) standards

iv. Nayshevsky, I.; Xu, Q. F.; Barahman, G.; Lyons, A. M. "Fluoropolymer coatings for solar cover glass: Anti-soiling mechanisms in the presence of dew." Solar Energy Materials and Solar Cells, 2020, 206.

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