Bifacial Considerations from an Engineering, Procurement & Construction (EPC) Perspective

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September 2019

res
power for good

Presentation Today

RES would like to thank the Conference Committee for the opportunity to present today.

Special Thanks to:

- Chris Deline at NREL for supporting RES with modifications to existing Capacity Test procedures.
- Our Industry Partners
- Owners who have allowed use of photos from job sites.

Today's presentation is based on RES' US market bifacial experience working with industry partners.

Agenda

RES Overview

RES Team: Bifacial Project Experience

Bifacial Impacts to Utility Scale Projects:

- Design
- Construction
- Commissioning & Testing

Next Steps

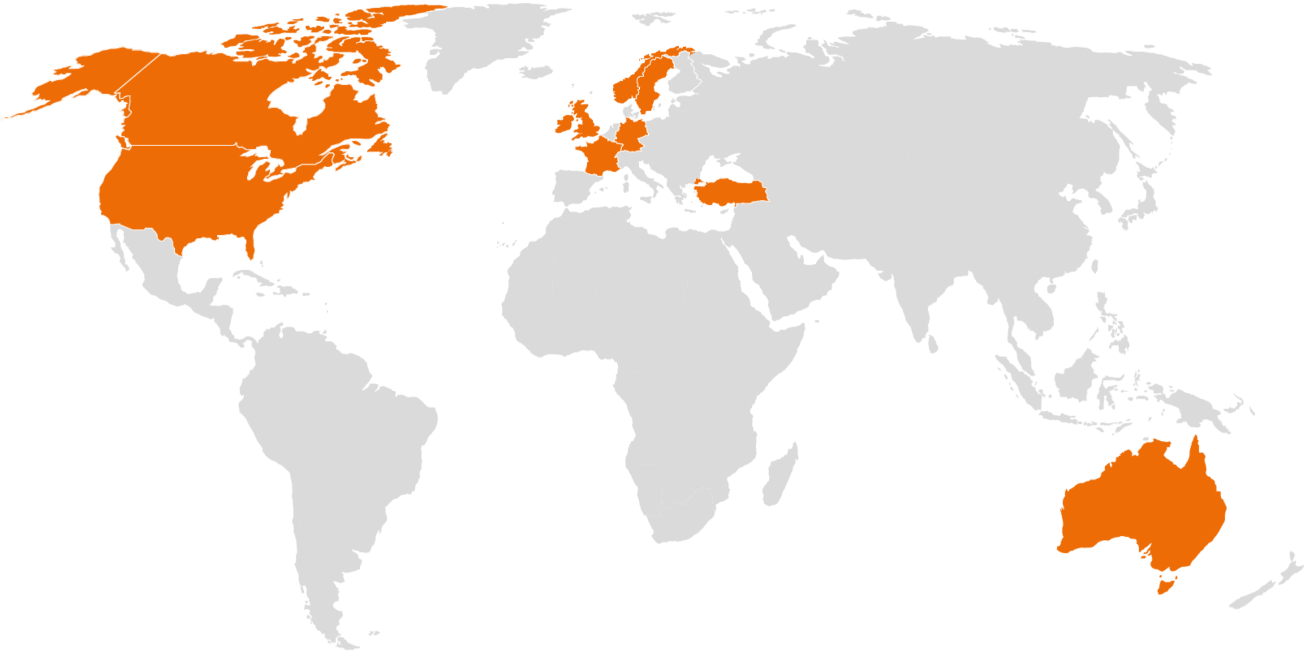
RES Overview

16 GW
PROJECT PORTFOLIO

37
YEARS OF EXPERIENCE

5 GW
OF OPERATIONAL ASSETS SUPPORTED

2,000
EMPLOYEES



ACTIVITIES

DEVELOP

CONSTRUCT

OPERATE

TECHNOLOGIES

WIND

SOLAR

STORAGE

T&D

Our Vision


To create a future where
everyone has access to
affordable zero carbon energy

RES Americas Project Experience

RES Development

- Globally RES Develops Solar Projects
- 226MW DC Bifacial Project in Australia

RES Development, US

- RES Develops Greenfield Solar Projects – 300 MW's in Operation
- Mid-Stage Development Sales - (2GW per yr. Pipeline Globally)
- ~800 MW DC in the US pipeline for COD 2021

RES Construction, US

- Engineering, Construction & Procurement, (EPC)
- Bifacial Engineering and Construction Experience
- Construct RES Developed projects, Projects for 3rd Party Developers, IPP's and Utilities
- Self - Perform or Internal Turn-Key construction execution teams
- Design Engineering Phase ~ 550 MW DC (Bifacial)
- Construction Phase ~ 250 MWDC (Includes largest Bifacial Project under construction in US to date)
- Locations: Texas and Midwest, Southeast US

Bifacial Project Impacts

Standard Industry Practices for utility scale design, construction and testing are impacted by the integration of bifacial technology in utility scale solar plants.

Engineering Impacts:

- Decreased System Size
- Decreased DC/AC Ratio
- Decreased GCR
- Improved Yield / Area
- DC Architecture: Cable and Protection Device Sizing and Aggregation

Construction Impacts:

- DC Wire Management
- Installation Rates: wire management & module weight changes

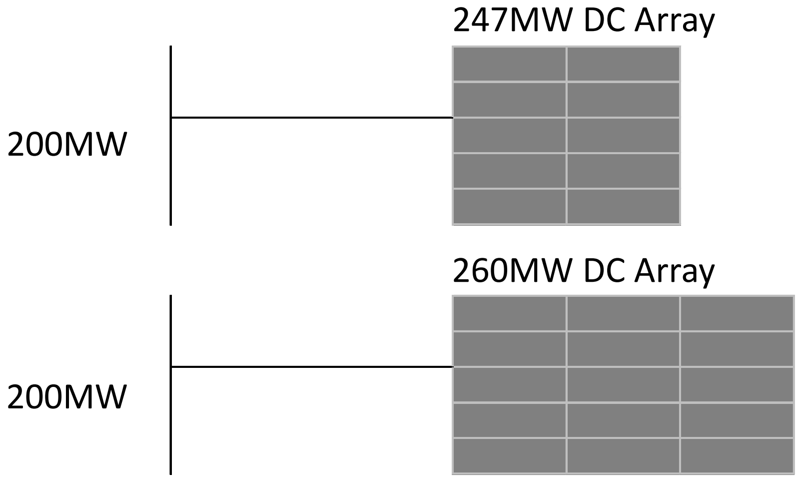
Performance Testing

- Imp & IV Curve Testing
- Performance Testing:
  - Capacity Testing Protocol
  - Meteorological Station Equipment Selection & Station Locations

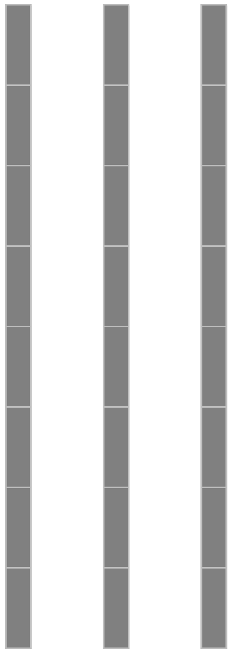
Engineering: Bifacial Design Assumption Levers

Overall DC Size & DC/AC ratio

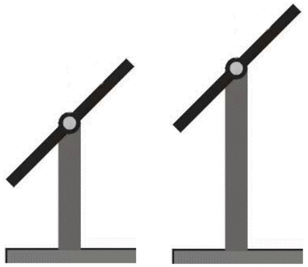
AC Grid Connection **DC Array Size**



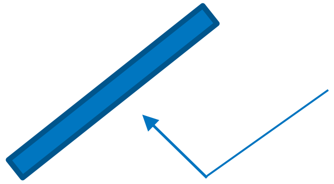
Ground Cover Ratio (GCR)



Height above ground



Energy Yield Assumptions - Bifacial Gain



- Albedo
- Module Transparency
- Rear Side Shading
- Rear Side Mismatch
- Bifacial Factor

Question: Which of these is RES implementing in collaboration with Industry Partners today?

Design Impacts Today

Implementing on US Projects: Single Axis Tracking (1P), albedo in 0.18- 0.2 range (US Regions Without Snow), height 1.4m, Bifaciality Factor 0.7 – 0.75.

- ✓ Albedo + Bifacial specific Modeling Assumptions ~3.0-5.0% Bifacial Gain
- ✓ Decrease in Overall System Size DC ~3-5% for the same AC System
- ✓ Decreased GCR, Depends on Land Constraints in ~ the Range of 0.28 – 0.33
- ✗ Current Pile Foundation Material and Install $ = cost prohibitive to increase Pile Heights to Increase Bifacial Gain
- ✗ Currently cost prohibitive to change or alter the utility scale Site Ground Cover

Bifacial Decreased BOS but Increased EPC Risk

↓	Decrease in Overall System Size DC	=	↓	Overall Decrease in Balance of System (BOS) cost due to module reduction
+	recent Bifacial Solar Module tariff exemption in a market	=	↑	Evaluation of Bifacial technology across projects

Given the limited industry experience and standardization around utility scale bifacial projects,
There is increased EPC risk around:

- BOS cost (without industry standards or consensus, what are your competitors assuming?
- BOS Installation (Schedule Risk on already tight project schedules)
  Delay Liquidated Damages (LDs) Range $15,000 to $200,000 USD per day.
- Commissioning and Performance Testing
  Performance LDs

Increased internal planning & contingency is required to mitigate.

DC Cable and Fuse Sizing - & Increased DC terminations

- Bifacial Gain Assumptions and Irradiance Gain Safety Factor Currently Open to Interpretation for Engineer of Record & Owner.

US National Electric Code

Current = Isc * 1.25 (Safety Factor) For Irradaince > STC(1250W/m^2)

or

Model historical irradiance data to determine Irradiance Gain Safety Factor Isc * 1.XX

- Bifacial: Size wire for "peak" front -side + "peak" rear side gain to determine overall "worst case" current.

↑ Module Efficiency & Isc * Irradiance Gain Safety Factor Assumption Uncertainty =

↑ Cost & quantity of wires, if less in parallel with 32A Fuse

DC Wire Management

Utility Scale DC Wiring Already Labor Intensive:

Goal is to properly Secure & protect wires for life of project

Due to accelerated project schedules,
Must capture all wiring challenges before Golden Row is constructed.

Additional Considerations required for each new module & structural system combination:

- Where and how long are the module leads?
- Can the wire travel across racking system without shading
- the rear side of Modules?
- How will the wire be secured?
- Can the proper bend cable radius be maintained?
- New training / Learning Curve for Crews
- QA/QC measures

Solutions must be as fast and cost effective as other module technologies.

DC Wire Management Example

Example from a very small scale project where crews inexperienced with bifacial wired initial rows without considering rear side shading rear impacts.

Wire Harness and Homerun Wire Management

Bifacial:
Added complexity and time spent to avoid "rear side shading".

Shortened Module leads in center of Module work well for wire management & minimize rear – side shading

Project Commissioning & Testing Impacts

Imp & IV Curve Testing - Standard Contractual Obligation

Existing challenges to IV Curve testing in the field **not specific** to bifacial include:

- Limited Stable Irradiance Conditions when testing 6,000 to 30,000 strings per project
- Given schedules sometimes have to manually position trackers
- Large amounts of re-testing due to combination of low/Instable Irradiance conditions & test crews attempting to move rapidly (measurement error)

Additional Challenges when Bifacial IV Curve Tracing Large Scale projects with limited time

Commercial IV Curve Testers currently on the market:

- No way to measure & incorporate rear-side irradiance gain.
- Therefore, only utilize front-side irradiance for trace and translation to STC.

Limited, preliminary results, so far:

- Preliminary Results suggest Increased Imp Standard Deviation across traces as compared with mono-facial technologies.
- Increased Variation in bifacial Imp and performance metrics makes Comparative analysis more challenging for identifying underperforming strings.

Variation in Site conditions during Commissioning & Performance Testing

- Vegetation variation during commissioning (Imp, IV Curve) and Capacity testing
- Seasonal rear side variations that depend on time of year test is being performed
- Increased time and costs to manage vegetation and ground cover during construction for Commissioning and Performance Testing



Project Commissioning & Testing Impacts

Performance Tests for Achieving Substantial Completion:

- Capacity Test and Availability or Operational/Functional Tests

Capacity Test

IEC 61724-2

ASTM 2848

Front Side POA
Module Cell Temperature
Temperature Corrected Power

Typically these test protocols or modified versions.

Front Side POA
Ambient Temperature
Wind Speed
Measured Power MWac

Both regression tests compare Target Capacity versus Measured Capacity = Guaranteed Capacity Ratio

- Typical Guaranteed Capacity Ratio Ranges: 97% to 98%, (Minimum 5 day test)
- Performance LDs range, can be as high as $300,000 to 4 million per 1% below Guaranteed Ratio
- Bifacial adds additional Uncertainty for establishing Target Capacity and Measured Capacity values
- Test modifications underway, however, Contractual Tests RES encounters are not yet adapted to bifacial modules.

Capacity Test: Target Capacity Considerations

Consensus is Bifacial Gain should be accounted for in Target Capacity Values

- Need to agree to Contractual energy Model Assumptions and Methodology for Generating Target Capacity
- Bifacial Gain Assumptions in Energy Model that generate Target Capacity can be additional risk for EPC

Albedo
Bi-faciality Factor
Module Transparency
Rear-side Shading
Rear-side Irradiance Mismatch

- Currently, RES collaborating with industry partners to ensure tests meet Owner and financier expectations, but do not pass undue risk onto the EPC

Albedo

Albedo in RES' Experience: Large Lever for Rear Side Gain Assumptions

- On-site measurement prior to design phase not typical
- Largely using albedo tables with pre-generated ranges or NREL PSMv3 datasets for modeling.

RES using proposed modifications to existing tests from "Suggested Modifications for Bifacial Capacity Testing", Martin Waters, Chris Deline, Jeffery Webber, Johan Kemnitz, PVSC 46 2019-6-3.

For the Target Capacity:

Substituting E_{Total} = for E_{POA} in contractual energy model and measured test results

$$E_{Total} = E_{POA} + E_{Rear} * \varphi$$

where E_{POA} *is equal to front-side POA,*

E_{REAR} *is equal to rear-side POA,*

φ *is equal to the bifaciality factor*

For Measured Capacity:

Incorporating measurement devices (reference cell or pyranometer) that measure rear-side irradiance into the project Met Station Specification to mitigate against:

- Annual Energy Model Albedo and rear side irradiance assumptions versus rear side irradiance during construction testing phase
- Rear-side shading and mismatch due to installed racking system and DC wiring

Measured Capacity Considerations

- Incorporating measurement devices (reference cell or pyranometer) that measure rear-side irradiance into the Met Station Specification

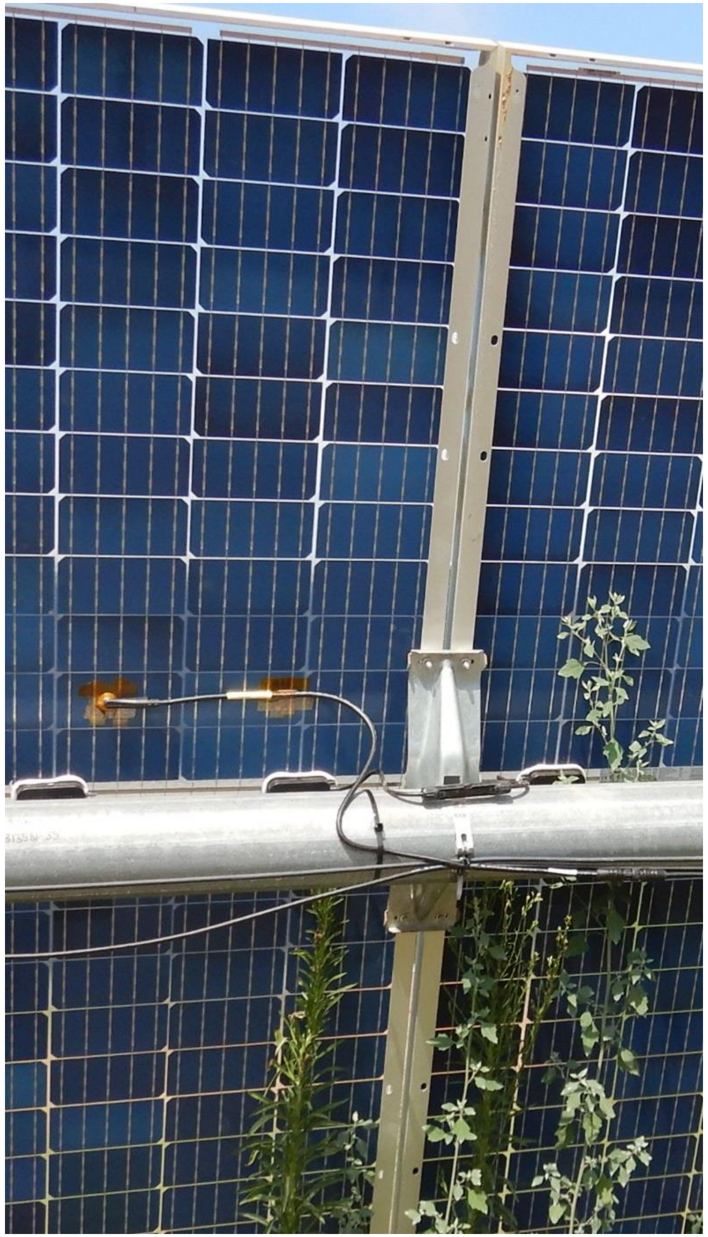
- Typically (1-2) Front side POA and (1) Rear side POA per 20 – 30 MWac

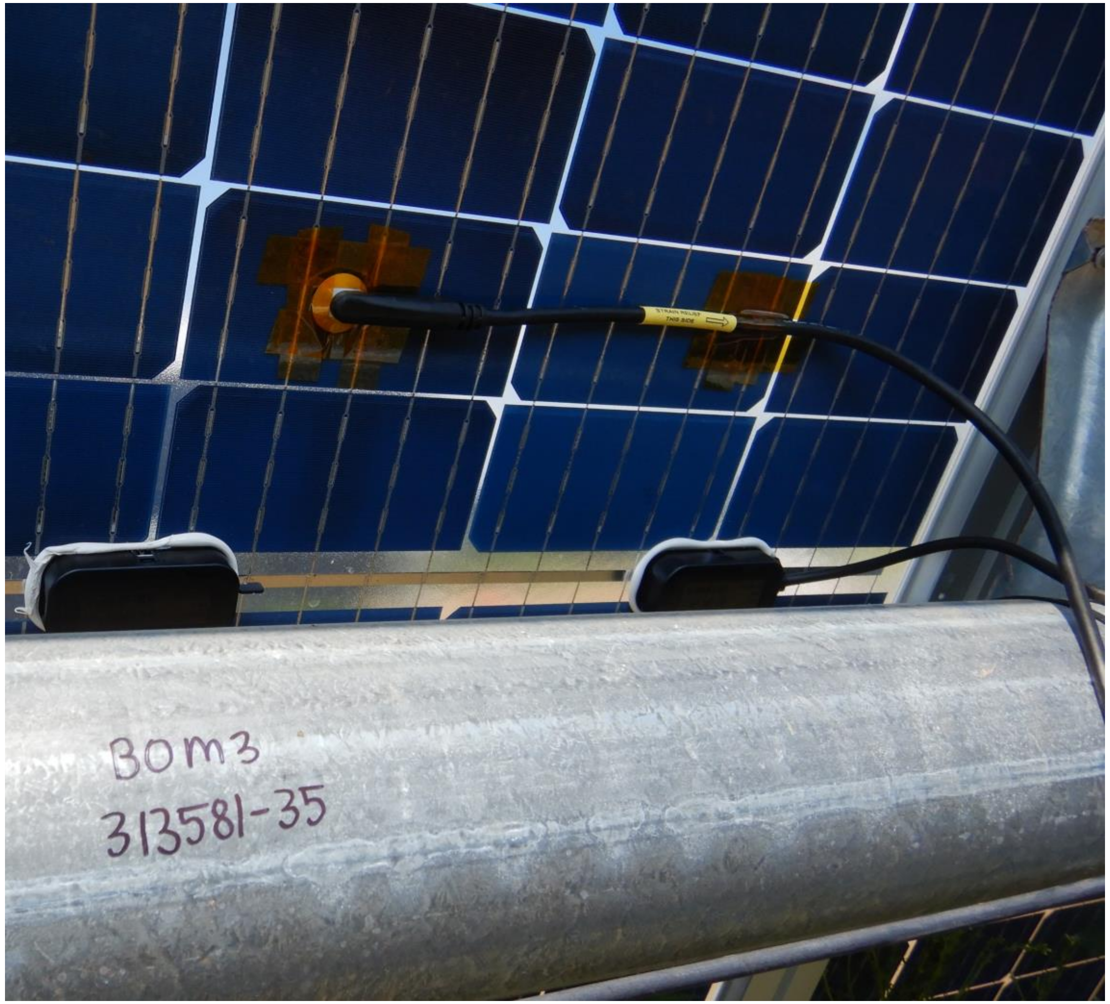
- Currently RES is using Class A, Secondary Standard Pyranometers that match the front-side pyranometers in device model number and quantity

- Given scale of projects, 1000 to 1500 acres, ensure that Met Station placement is representative of the overall site rear side irradiance contribution.

  - Sensor placement needs to take into account rear side shading and irradiance uniformity to ensure limited number of sensors reflects rear side irradiance typical for the majority of arrays.
  - Met Stations located close to certain inverter area cut-outs, which are areas close to roads with high staging and site traffic, may not be representative of project site.
  - Sensor mounting needs to consider shading and placement on rear side, so far, limited, non-standardized options.

Sensors Mounting to Rear Side of Bifacial Modules – Module Cell Temperature Examples



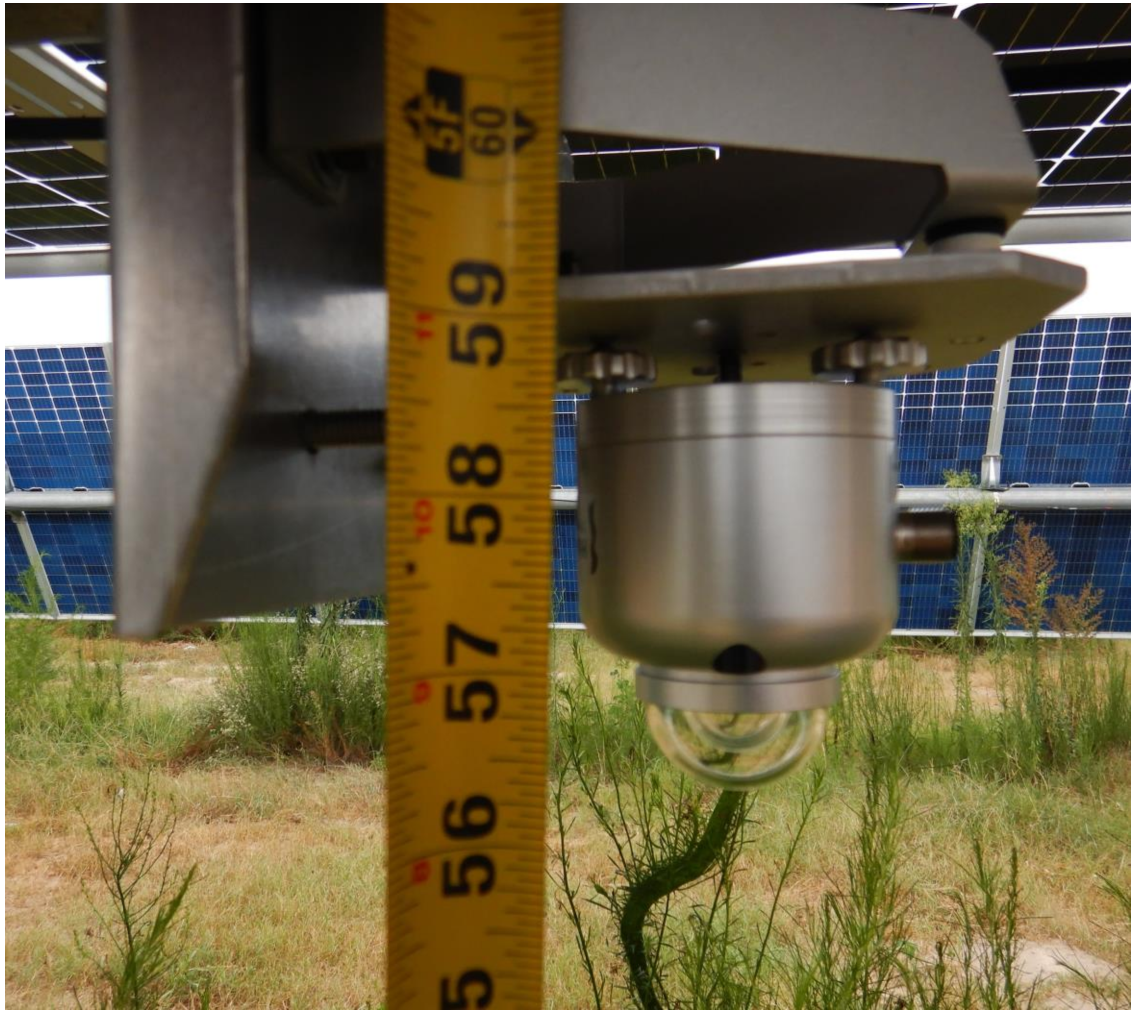


Sensors Mounting – Rear Side Irradiance Sensors

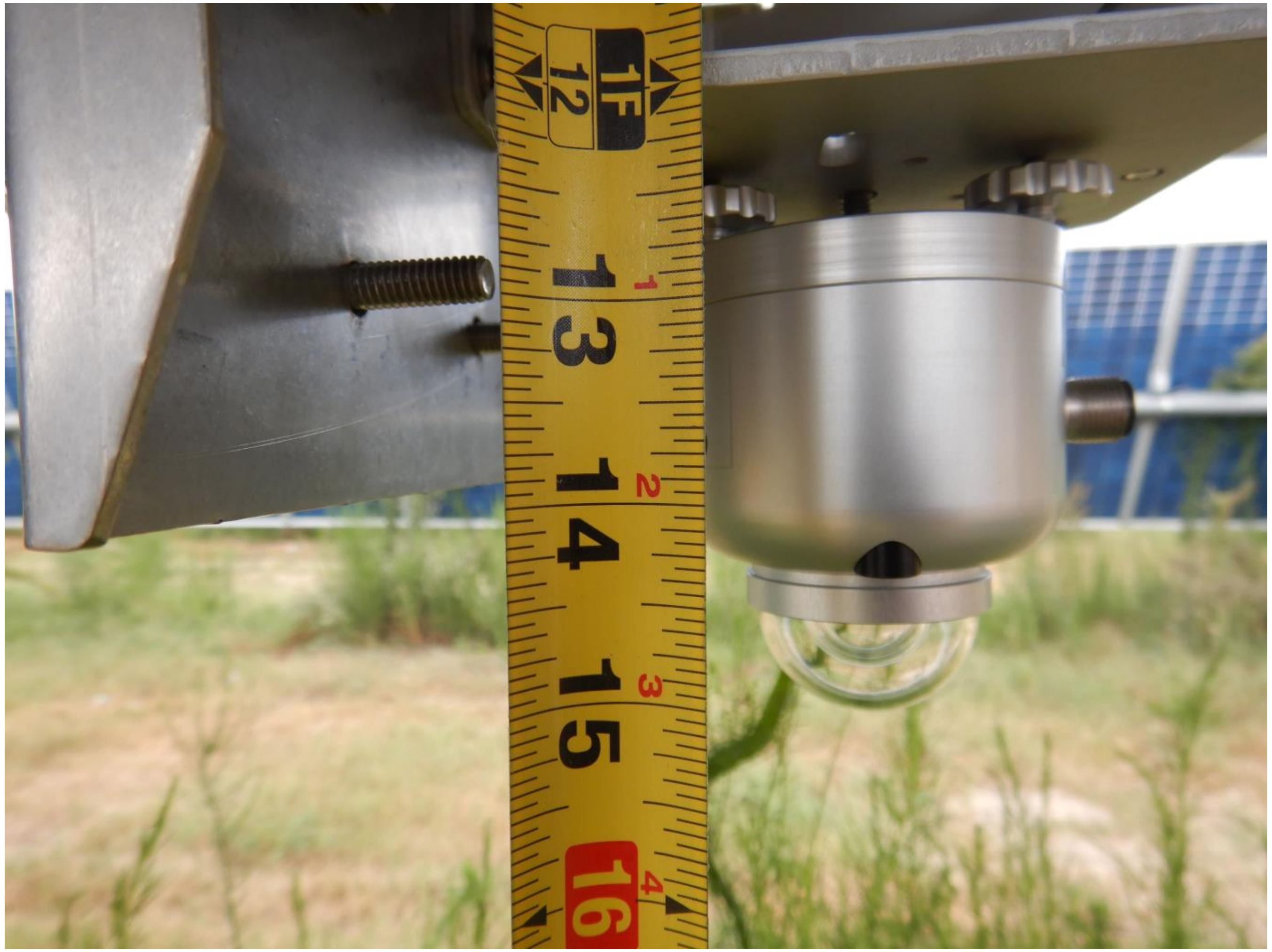
Pyranometer mounted to rear side of torque tube.

Sensors Mounting – Rear Side Irradiance

Distance from Grade (Inches)



Distance from rear side of the module (Inches)



Varying ground cover conditions during Construction Phase

Met Stations located close to inverter cut-outs which are high traffic, trenching and staging areas and impacts ground cover during construction and testing phases.

Rear Side Sensor located in row where DC is trenched to the inverter.

Sensors Mounting – Rear Side Irradiance Sensors

One test consideration is acceptable variability between rear side sensors during given data interval.

Next Steps

- Continuing to Collaborate with industry partners to better understand performance and installation of bifacial modules.
- Continuing to evaluate BOS equipment selection and installation best practices to ensure optimized design and installation of bifacial technology.
- Evaluate Capacity Test protocol modifications incorporated at time of Contract versus actual test practices and actual test results
- Continue to evaluate Meteorological Station Test Equipment, Locations, acceptable variation across sensor placement and data output.
- As already stated by others, a whole systems approach and System Integration is key to Bifacial implementation for PV projects.

Questions?
Thank you!

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