

Effect of Torque-Tube Parameters on Rear-Irradiance and Rear-Shading Loss for Bifacial PV Performance on 1-Axis Tracking Systems

Silvana Ayala Peláez, Chris Deline, Joshua S. Stein (*Sandia National Labs*), Bill Marion, Kevin Anderson (Cypress Creek Renewables), and Matthew Muller

The south

46th IEEE PVSC, June 16-21, 2019, Chicago, Illinois

NREL/PR-5K00-74236

### Bifacial modules boost energy yield by 4% to 15%



Ayala Pelaez, Silvana, et al. "Model and Validation of Single-Axis Tracking With Bifacial PV." IEEE Journal of Photovoltaics(2019).



# Effect of torque tube on rear-irradiance

Repercussions on energy loss

Ideal location of sensors?

## Tracking and Torque tube

# Hourly annual simulations

O 0.4 20 0.3 200 250 50 100150 300 350 Grear/Gfron 0 1 tk Main Control 0.1 nput Variables Fi Search READ SAVE bifacial\_radiance program (raytrace) TestFolder: C:\Users\sayala\Docun Search WeatherFile Input: GetEPW C ReadEPW / TM 0.0 Get EPW (Lat/Lon): -110 FDW / TMV File EPWs\\USA\_VA\_Richm Search Simulation Name Demo Simulation Control Cairo, Egypt. 20 modules per row, 7 rows. Fixed, Cumulative Sky Yearly Module Parameters Prism Solar Bi60 Fixed, Cumulative Sky with Start/End times Number of Panels Fixed, Hourly by Timestamps Cell Level Module Fals True Fixed, Hourly for the Whole Year numcells x numcells v: Size Xcell: Size Vcell: Tracking, Cumulative Sky Yearly Xcell gap: Tracking, Hourly for a Day Module size x: 0.98 1.98 Tracking, Hourly with Start/End times Xgap | Ygap | Zgap 0.05 0.15 0.10 200 points per hour modeled across center Bifacial Factor (i.e. 0.9): 0.9 VIEW Tracking, Hourly for the Whole Yea Module Name StartDate (MMIDDIHH) Prism Solar Bi60 Enddate (MM | DD | HH ): **Rewrite Module** G True C Fals module's collector width Timestamp Start: 4020 4024 Timestamp End: Scene Parameters Row spacing by: G GCR C Ditch **Tracking Parameters** GCR: 0.35 @ True Backtrack C False Albedo 0.62 Limit Angle (deg): 60 # Mods 20 # Rouse Angle delta (deg): Azimuth Angle (i.e. 180 for South): 180

Albedo of 0.28, GCR of 0.25

### Hub height: 0.9 VIEW **Torque Tube Parameters** Analysis Parameters TorqueTube True False # Sensors: Diamete Mod Wanted: 10 Row Wanted: 3 Tube type: C Square CLEAR DEFAULT RUN TorqueTube Material: @ Metal\_Grey C Black

Clearance height: 0.8

Axis Azimuth (i.e. 180 for EW HSATtrackers):

https://github.com/NREL/bifacial\_radiance/ Open Source! (a.k.a. free!)

Axis of Rotation: @ Torque Tube @ Panels

190

Comparing to a case with no torquetube, This base case has a 5.7% Shading Factor



CW = 2 m



NREL | 6

### Compared to various scenarios



### Varying torquetube reflectivity



$$G_{rear} \text{ Shading Factor} = 1 - \frac{\sum_{t=0}^{8760} G_{rear average} \text{ (with tube)}}{\sum_{t=0}^{8760} G_{rear average} \text{ (no tube)}}$$



### Varying torquetube reflectivity





## Torque tube reflections

### al 🤗 : 0 Other bookmarks



What are bifacial solar modules and how ... solarpowerworldonline.com



**S** Bifacial PV module











bifacial modules add to solar tracker solarbuildermag.com

What are bifacial solar modules and how . solarpowerworldonline.com

Trend to Watch: Bifacial Modules .... civicsolar.com

Bifacial solar panels: Breaki... solarpowerworldonline.com

bifacial PERC solar module advances ... solarbuildermag.com

Bifacial + NX Horizon = A Winnin... nextracker.com





1000 × 662 - Images may be subject to copyright. Learn More

Bifacial Gains: How much will bifacial modules add to so...

🕲 Visit	🗍 Add to	Collections	< Share	

### Related images





https://solarbuildermag.com/featured/bifacial-gains-how-much-will-bifacial-modules-add-tosolar-tracker-value-we-are-about-to-find-out/





# Shading plus Electrical Mismatch





NREL | 13

1.1

**DC %** 

1.2

0.5

0.6

### PVSYST V6.78 15/01/19 Page 4/4 Grid-Connected System: Loss diagram Project : Richmond Tracking Mismatch Loss Exploration Simulation variant : New simulation variant Loss<sub>DC</sub> to parameters in PVSyst? Main system parameters System type Unlimited Trackers with backtracking PV Field Orientation tilt PV modules Model LR6-60 HBD 305 M Bifacial Pnom 305 Wp PV Array Nb. of modules 12 Pnom total 3660 Wp Model 4.2 kWac inverter Pnom 4200 W ac Inverter User's needs Unlimited load (grid) Loss diagram over the whole year • Structure shading factor, a.k.a. Rear shading 1610 kWh/m<sup>3</sup> Horizontal global irradiation +28.3% Global incident in coll. plane factor gets put directly into the loss diagram +0.0% Global incident below threshold -2.4% Near Shadings: irradiance loss as "Shading loss on rear side". 9-1.5% IAM factor on global +0.7% Ground reflection on front side **Bi-facia** Mismatch loss factor a.k.a. rear mismatch Global incident on ground 1295 kWh/m<sup>2</sup> on 50 m<sup>2</sup> loss, affects the Mismatch for back Ground reflection loss (albedo) 65.8% View Factor for rear side irradiance in the loss diagram +9.8% Sky diffuse on the rear side -5.0% Shadings loss on rear side 14.6% Global Irradiance on rear side (292 kWh/m2) 2000 kWh/m<sup>2</sup> \* 20 m<sup>2</sup> coll Effective irradiation on collectors efficiency at STC = 18.07% PV conversion, Bifaciality factor = 0.75 8.14 MWh Array nominal energy (at STC effic.) -0.1% PV loss due to irradiance level -7.7% PV loss due to temperature +0.5% Module quality loss ⇒-1.1% Mismatch loss, modules and strings -1.3% Mismatch for back irradiance -1.2% Ohmic wiring loss 7.27 MWh Array virtual energy at MPP -3.4% Inverter Loss during operation (efficiency) ₩0.0% Inverter Loss over nominal inv. power >0.0% Inverter Loss due to max, input current >0.0% Inverter Loss over nominal inv. voltage >0.0% Inverter Loss due to power threshold ÷0.0% Inverter Loss due to voltage threshold 7.02 MWh Available Energy at Inverter Output 7.02 MWh Energy injected into grid

Bi-facial system definition	n				- 🗆	×
eneral Simulation Parameters						
		General param	eters for all models			
Bifacial Model						
• Don't use in the s	imulation	i –				
© Use unlimited she	ds 2D-n	nodel				
© Use unlimited trad	kers 2D-	model ?				
(2D models	with pedag	logic tool)				
Other models are currer - General scene define - Bifacial vertical wall o	itly under co ed in the 3D or rows	editor				
Incident irradiance on th	e ground					
Beam ground factor	From sur	n's position, 2D model				
Diffuse ground factor	0.0	% No model defined				
Shed transparent fraction	0.0	% not sensitive				
Ground albedo	30.0	% 🥅 Monthly values				
Reflected irradiance on b	ackside					
Reemission form factor	0.0	% No model defined				
Structure shading factor	5.0	% (0 = no shadings)				
PV array behavior						
Mismatch loss factor	10.0	%	Please choose a	bi-facial model for th	e simulation !	
	1					

PVSYST V6.78			15/01/19 Page 1/4	
(	Grid-Connected System	n: Simulation parameter	rs	
Project :	Richmond Tracking Misma	tch Loss Exploration		
Geographical Site	Richmond	Country United States		
Situation Time defined as	Latitude Legal Time Albedo	37.70° N Longitu Time zone UT-5 Altitu 0.20	ude -77.43°W ude 60 m	
Meteo data:	Richmond	NREL NSRDB Typ. Met. Year P	SMv3_1998 to 2016 - TMY	
Simulation variant :	New simulation variant			
	Simulation date	15/01/19 15h35		
Simulation parameters	System type	Unlimited Trackers with back	tracking	
Tracking horizontal axis Rotation Limitations	Simplified model, unlimited Phi min.	10tracker rows Axis Azime -45° Phi ma	uth 0° ax. 45°	
Backtracking strategy	Nb. of trackers Tracker Spacing Left	10 Unlimited tracket 5.00 m Collector wite 0.02 m Riv	ers dth 2.00 m aht 0.02 m	
Backtracking limit angle	Phi limits	+/- 65.8° Ground cov. Ratio (GC	R) 40.0 %	
Models used	Transposition	Perez Diffu	use Imported	
Horizon	Free Horizon			
Near Shadings	No Shadings			
Bifacial system	Model Tracker Spacing Tracking limit angle Average albedo Module bifaciality factor Module transparency	Unlimited trackers, 2D calculation   5.00 m Tracker with   45° Go   27.9 % Axis height above grou   75 % Rear shading factor   5.0 % Rear mismatch lo	on dth 2.04 m CR 40.8 % Ind 2.10 m stor 80.0 %	
Monthly albedo	Jan.     Feb.     Mar.     Apr.     Ma       40%     30%     30%     30%     30%     30%	y June July Aug. Sep. 6 10% 10% 30% 30%	Oct. Nov. Dec. 30% 30% 35% 7.9%	
User's needs :	Unlimited load (grid)			
PV Array Characteristics PV module Original PVsyst databas	Si-mono Model e Manufacturer	LR6-60 HBD 305 M Bifacial Longi Solar		
Total number of PV module Array global power Array operating characteris Total area	es Nb. modules Nominal (STC) stics (50°C) U mpp Module area	12     Unit Nom. Pow       12     Unit Nom. Pow       3660 Wp     At operating cor       364 V     Im       20.3 m²     Cell ar	ver 305 Wp nd. 3326 Wp (50°C) pp 9.1 A ea 17.6 m²	
Inverter Original PVsyst databas	Model se Manufacturer Operating Voltage	4.2 kWac inverter Generic 125-500 V Unit Nom. Pov	ver 4.20 kWac	
Characteristics	Nb. of inverters	1 units Total Pow	ver 4.2 kWac tio 0.87	
Inverter pack	2/21	Filonita		
Inverter pack	<u> </u>	FIGHTS		

### Shading Factor and Rear Electrical Mismatch Factors



$$P_0 = \left(G_{F_0} + G_{R_0} \cdot \varphi\right) \cdot \eta_0$$

$$P_1 = \left(G_{F_0} + G_{R_0} \cdot \varphi\right) \cdot \eta_0 \cdot (1 - L_{DC}) \qquad 1%$$

$$P_1 = \left(G_{F_0} + (1 - \mathbf{X})G_{R_0} \cdot \boldsymbol{\varphi}\right) \cdot \eta_0$$

 $X = L_{Inherent Mismatch} + L_{Structural Shading}$ 

$$11\% \quad X = \frac{L_{DC}}{BG} + L_{DC}$$
$$10\%$$



G<sub>rear</sub> Shading Factor: -0.1 to 8.1 % metallic 7.8 – 8.5 % black

# Sensor Position Study

### **Rear-Irradiance Modeling at different locations in the tracker**



- Single row of HSAT, N-S oriented on Jackson, Michigan
- Data collected for 4 months, Dec. 2018 to April 2019.
- 45.9% DHI to DNI ratio for location
- Albedo measured on location.



# MBE and RMSE of Sensor location modeled value vs. average modeled value of north-part of the array for 1 day



## MBE and RMSE of Sensor location modeled value vs. average modeled value of north-part of the array for 1 day



## Conclusions

- Shading optical loss for modeled systems is between 2-8%
- Gap + torquetube reflections equal potential energy gains
- System mismatch loss (Dc losses) are around 1%, but must be propagated backwards to reflect the losses at the Grear irradiance level for implementation in current softwares.
- Grear irradiance measurements must account for non-uniformities and equipment shading. Avoid ends and middles of the modules for sensor placements.

# Thank you

www.nrel.gov

Silvana.Ayala@nrel.gov

A portion of this research was performed using computational resources sponsored by the Department of Energy's Office of Energy Efficiency and Renewable Energy and located at the National Renewable Energy Laboratory.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 30286, 34910, and Award Number DE-EE0008564. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.



# Measured vs. modeled Rear Irradiances, overall modeling accuracy at any position













### In-plane torque-tube causes a different shading profile



# Measured vs. modeled Rear Irradiances, overall modeling accuracy at any position



