Bifacial Commercial Installations with Improved Bifacial Gains

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Outline

- Who is Prism Solar Technologies?
- Quick optimization method
- What is the issue facing the optimization of bifacial systems?
- Bifacial Commercial White Roofs
- Bifacial Carport Systems
- Conclusions

Prism Solar Technologies Inc.

- **Prism Solar Technologies was founded in 2005.**
- **Researching bifacial and holographic/bifacial technology and applications since 2006 (Hitachi cells); six awarded patents in bifacial technology and applications.**
- **Commercially selling bifacial modules since 2012.**

Design Optimization With Model

BGE'(%) = (0.317/deg*(θ)+12.145/m*(h) +0.1414/%*(α)) * (BR'[%]/95%) *(Azimuth Correction Factor(%)) * (Inter-row Correction Factor(%)) * (1-η(%))

θ = Module Tilt Angle (deg)
h = Module Minimum Height/Elevation (m)
α = Ground Albedo/Reflectance
BR' = Bifacial Ratio, or Bifaciality of the Module
η = Rear Obstruction Factor (%)

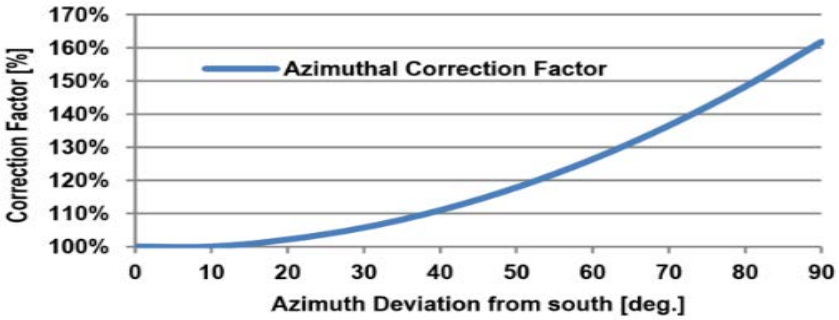
Total Bifacial System Energy Yield [%] = Monofacial*(BGE'(%) + 100%)

A good match has been found between the Prism Solar annual best-fit model and the annual results with PVSyst 6.70 for the high bifacial gains regions of interest of this presentation.

****Use your preferred model to estimate bifacial gains for your design****

Azimuth Correction Factor = **0.0000822*(ϕ^2) - 0.0005129*(ϕ) + 0.9988**

ϕ = Azimuth deviation from south in northern latitude (deg.)



Inter-row Correction Factor = **(-0.0467*(t) + 1.42)*100% ; max=100%, min=86%**

t = Time used for Dec 21st Shadow Length Calculations for inter-row spacing determination; between 9am and 12pm.

Prism Solar Model Reference: J. E. Castillo-Aguilella and P. S. Hauser, "Bifacial photovoltaic module best-fit annual energy yield model with azimuthal correction," 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), Portland, OR, 2016, pp. 3109-3112. doi: 10.1109/PVSC.2016.7750238

Optimizing the Bifacial Gain: Issue

Maximizing the bifacial gain beyond certain values can significantly increase the cost of the bifacial system

Bifacial gains reach saturation points at certain heights and tilts. This is especially true in area constrained installation sites.

Maximum bifacial gains lead to cost increases that are not compensated by the peak achievable bifacial gain. Law of diminishing returns

Examples of Bifacial Installations in Literature

Location (Type)	Elevation / Module Height (m)	Albedo / Bifaciality	Tilt Angle / Facing	Reported Bifacial Gain (%)	Calculated Bifacial Gain (%)	Difference (%)
Cairo (Sim.) [11]	1 / 0.93	0.2 / 0.8	26° / South	11.0	11.1	-0.1
Cairo (Sim.) [11]	1 / 0.93	0.5 / 0.8	22° / South	24.8	25	-0.2
Oslo (Sim.) [11]	0.5 / 0.93	0.2 / 0.8	51° / South	10.4	13.6	-3.2
Oslo (Sim.) [11]	0.5 / 0.93	0.2 / 0.8	47° / South	16.4	22.8	-6.4
Hokkaido* (Exp.) [46]	0.5 / 1.66	0.2 / 0.95	35° / South	23.3	25.7	-2.4
Hokkaido* (Exp.) [46]	0.5 / 1.66	0.5 / 0.95	35° / South	8.6	13	-4.4
Albuquerque (Exp.) [16]	1.08 / 0.984	0.55 / 0.9	15° / South	32.5**	30.2	2.3
Albuquerque (Exp.) [16]	1.08 / 0.984	0.55 / 0.9	15° / West	39**	36.7	2.3
Albuquerque (Exp.) [16]	1.03 / 0.984	0.25 / 0.9	30° / South	19**	14.6	4.4
Albuquerque*** (Exp.) [16]	0.89 / 0.984	0.25 / 0. 9	90° / South	30.5**	32.2	-1.6
Golden (Exp.) ****	1.02 / 1.02	0.2 / 0.6	30° / South	8.3	8.6	-0.3

* Only data from May to August were used to eliminate snowing effects.
** Average bifacial gain of multiple test modules was used.
*** The east-west-facing vertical modules measurement in [16] shows great discrepancy between two modules; therefor, it is not included here.
**** Bifacial measurement (12/2016 to 08/2017) performed by the National Renewable Energy Laboratory.

Table Source: Sun, Xingshu, Khan, Mohammad Ryyan, Deline, Chris, and Alam, Muhammad Ashraful. *Optimization and performance of bifacial solar modules: A global perspective*. United States: N. p., 2018. Web. doi:10.1016/j.apenergy.2017.12.041.

Bifacial Commercial White Roof

Commercial Rooftop And Bifacial Modules:

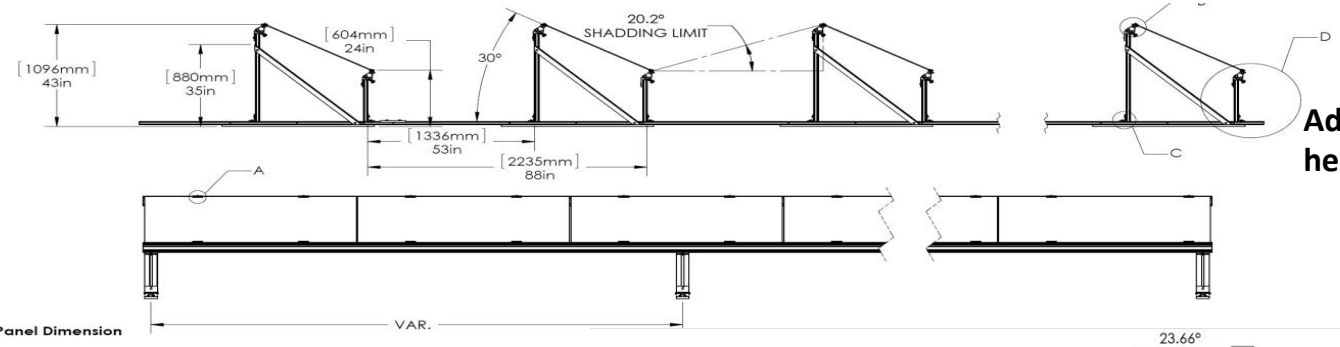
- **Higher albedo**
- **Higher tilt acceptable**
- **Increased module height (advantage in snowy regions)**
- **Optimizers/Microinverter[*] (Other building code benefits)**

Detrimental System Consequences:

- **Area constrained, lower system GCR due to higher tilt**
- **Lack of wind deflector & at the higher module tilt and heights, racking costs can become prohibitive.**
- **Optimizing the bifacial gain leads to less modules installed**

[*]: Riley, D. et al. 2018 Performance of Bifacial PV Modules with MLPE vs. String Inverters, WCPEC-7, Waikoloa, HI.

Bifacial Optimized Racking Examples

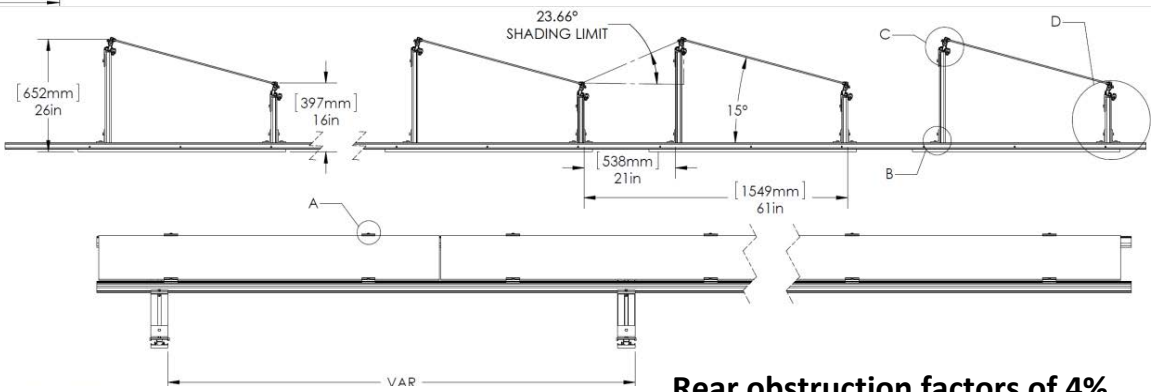


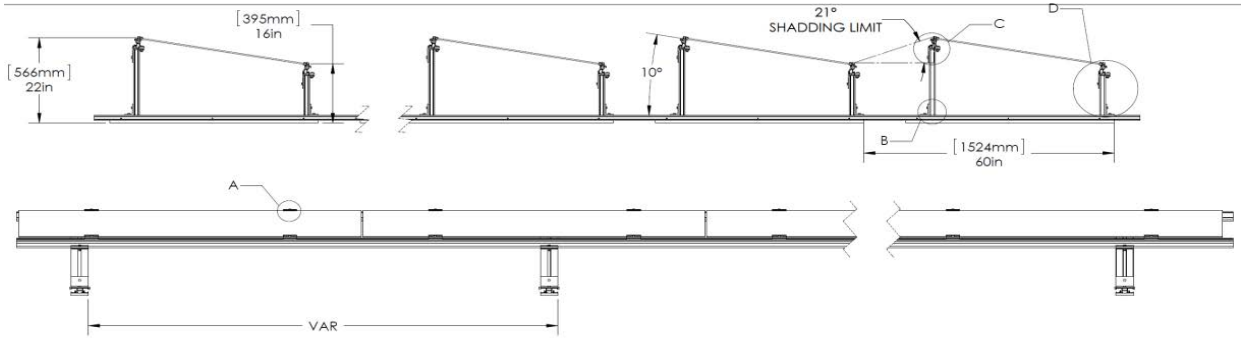
PV Panel Dimension

Additional bracing for extra height and snow loads

Upright racking elements can be reduced in quantity, reducing the system costs, increasing the Rear Obstruction Factor for the bifacial module.

Alternative, the cross-rails can be strengthened to reduce the number of uprights, but this also increases the system cost.





Rear obstruction factors of 4% to 5% are relatively easy to obtain with careful upright placement, but trying to achieve 0% to 2.5% might be cost prohibitive from a racking perspective.

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White Roofs Bifacial Recommendations

- Min. Tilt Angle = 10 degrees; Max. Tilt Angle = 30 degrees
- Min. Module Elevation = 0.3m; Max. Module Elevation = 0.5m, or 0.6m for snow regions
- Min. Initial Roof Albedo = 75% (Albedo decreases with time)
- Min. Inter-row spacing = 11am
- Min. recommended rear Obstruction Factor = 3%
- Max. recommended rear Obstruction Factor = 8%

Using all these values at the worst condition, and using the Prism Solar bifacial model, this still yields a ~14% Bifacial Gain with a 90% Bifaciality module.

The bifacial gain would be directly reduced if the module bifaciality is reduced.

154.3 kW Bifacial Upstate NY Installation

Prism Solar

154.3 kW Bifacial Upstate NY Installation

Component	Model	Rating (W)	QTY	Specifications/Manufacturer's Website:
Module	Bi60-368BSTC	290 W DC	532	http://www.prismsolar.com/pdf/bi60specs.pdf
Optimizer	P730	730 W DC	266	http://www.solaredge.com/sites/default/files/se-P5-series-commercial-add-on-power-optimizer-datasheet-na.pdf
Inverter	SE33.3KUS	33,300 W AC	5	http://www.solaredge.com/sites/default/files/se-three-phase-us-inverter-datasheet.pdf
Racking	Sunrail Bifacial	-	-	http://opsun.com/mounting-solutions/flat-roof/bifacial-pv-racking/

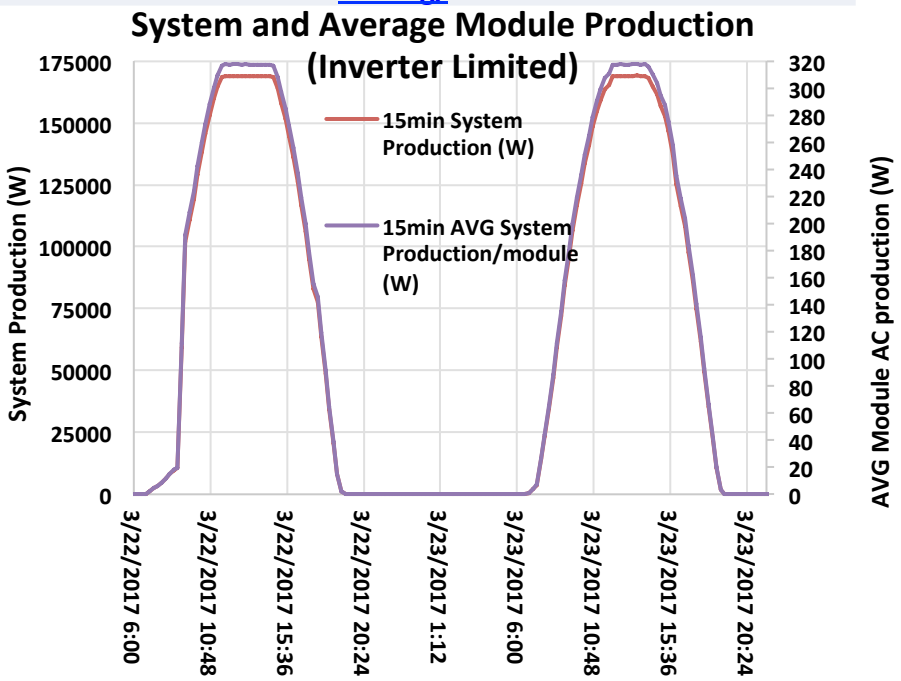
Client supplied data system:

Based on the modules and inverters, the system has a DC/AC ratio of 0.927

Inter-row spacing 11am, Albedo of +75%, system tilt of 30 degrees, Azimuth = 10 degrees from south, and Rear Obstruction Factor of ~5%.

Once the optimizers capped, the modules were producing 12.7% to 21.45% over STC.

Using the Prism Solar Model + PVSyst for the front yields a yearly output of 1633.5 kWh_{ac}/kW_{dc}. The PVSyst bifacial model V6.70 yields 1657 kWh_{ac}/kW_{dc}.



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154.3 kW Bifacial Upstate NY Installation

PVSYST V6.70	Prism Solar Technologies, Inc. (United States)	31/07/18	Page 3/4

Grid-Connected System: Main results

Project : **Ulster Ave Kingston NY**

Simulation variant : **Bifacial PVSyst Model 290WSTC** **5x33kW - July 2018**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	30°	azimuth	10°
PV modules	Model	Bi60-368BSTC Bi	Pnom	290 Wp
PV Array	Nb. of modules	533	Pnom total	**155 kWp**
Inverter	Model	SE33.3K	Pnom	33.3 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**167 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**255.3 MWh/year**	Specific prod.	1651 kWh/kWp/year
	Performance Ratio PR	99.90 %		

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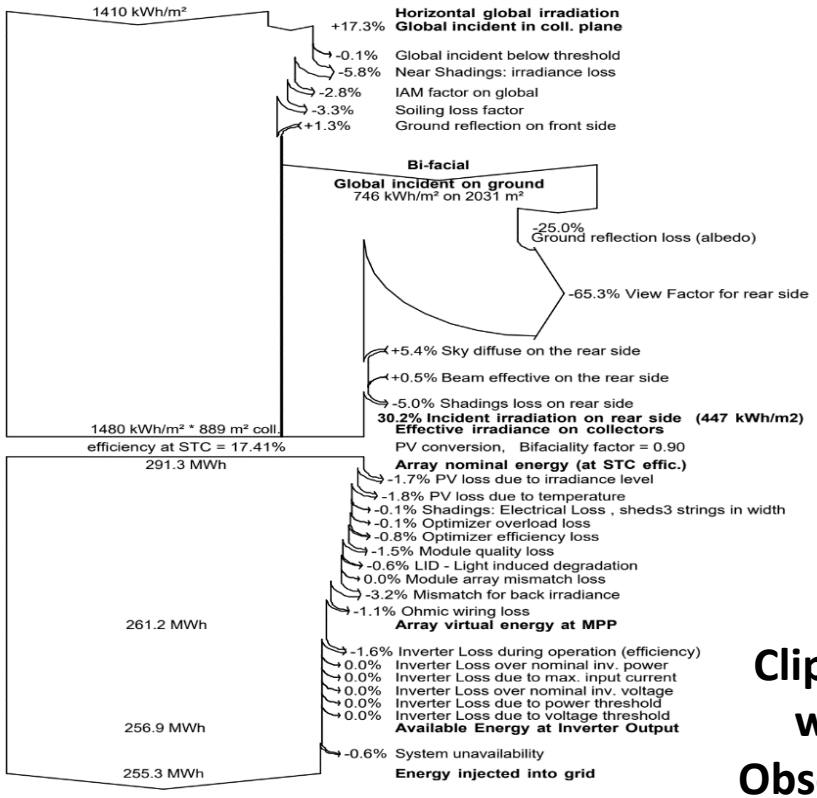
Loss diagram over the whole year



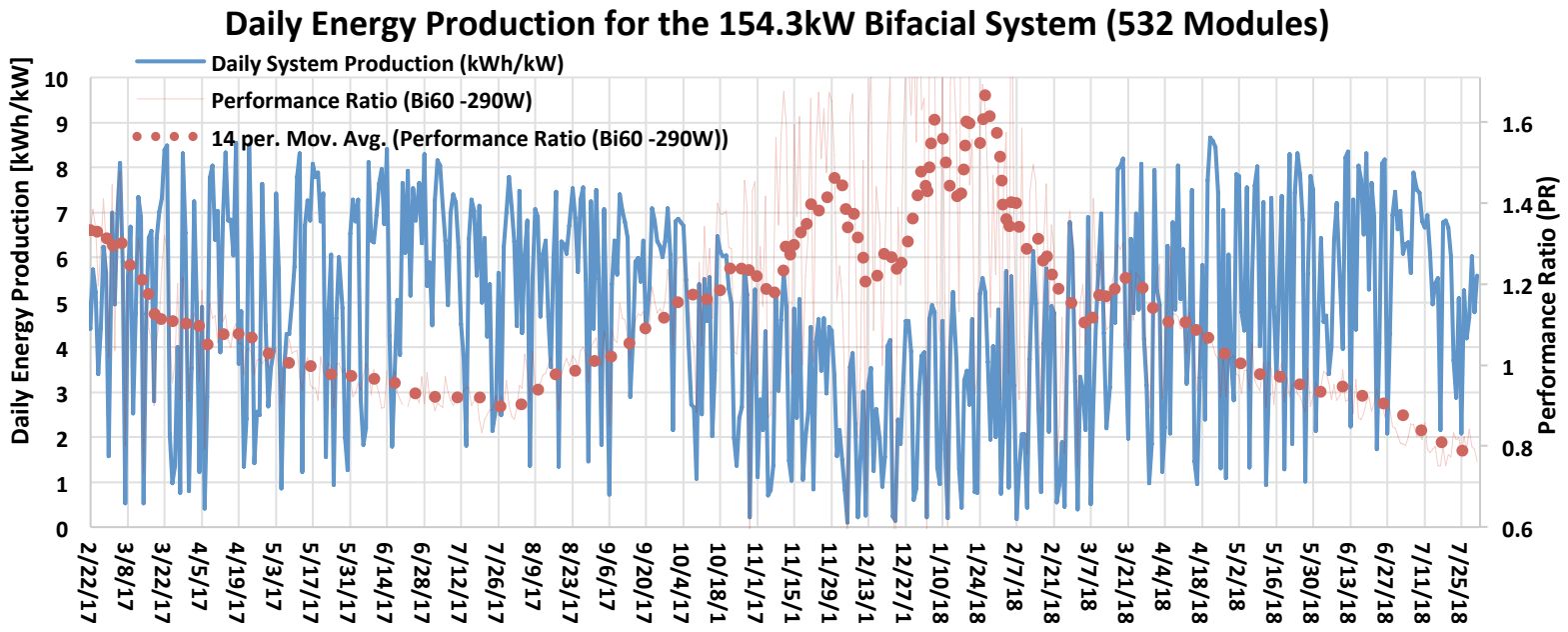
Clipping was Observed

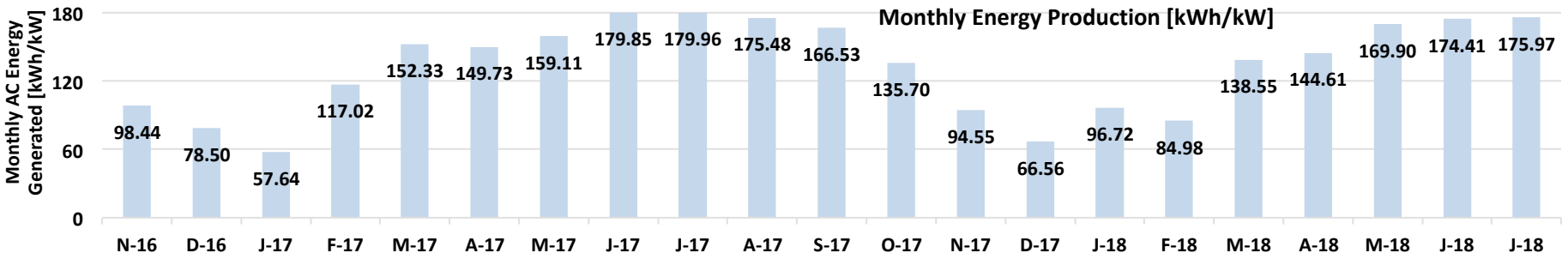
PVsyst Licensed to Prism Solar Technologies, Inc. (United States)

154.3 kW Bifacial Upstate NY Installation

The system was turned on a few months before the irradiance system/ PR system was put in place.

The highest Performance Ratio (PR) coincides with lowest daily kWh/ kW, and vice-versa.





The median annual production, using a 12-month averaging window is 1633.9 kWh_{ac}/kW_{dc}. Median PR=1.025

Commercial Rooftop

- Bifacial rooftop and carport system in Quebec, Canada.
- 30 Degree module tilt
- Elevation = 0.42m
- Estimated Bifacial Gain = +20%
- Owner data since July 2018

Bifacial Carports

Carport And Bifacial Modules:

- Higher carport module/system height
- East/West Configurations
- Usually not GCR constrained
- Aligning the modules long edges with the structure purlins, reduces the Rear Obstruction Factor.

Detrimental System Consequences :

- Racking costs increase with carport height and tilt angles over +10 degrees
- Ground Reflectance/Albedo in most cases between 8% (Fresh Asphalt) -20%, rarely exceeds 40%.
- Increasing the height or tilt angle excessively, can reduce the carport shading effect for the vehicles under the structure.

Bifacial Carports Recommendations

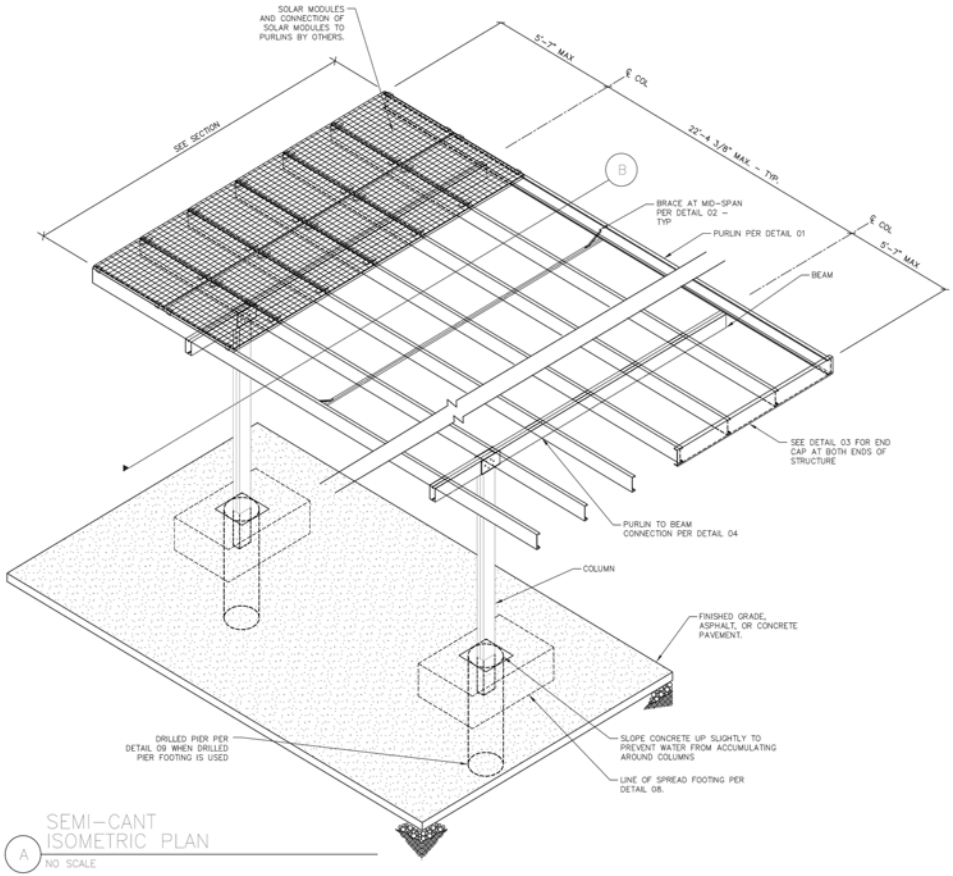
- Min. Tilt Angle = 7 degrees; Max. Tilt Angle = 20 degrees
- Min. Module Elevation Ratio = 0.3
- Max. Module Elevation Ratio = 0.6
- Max. recommended rear Obstruction Factor = 10%

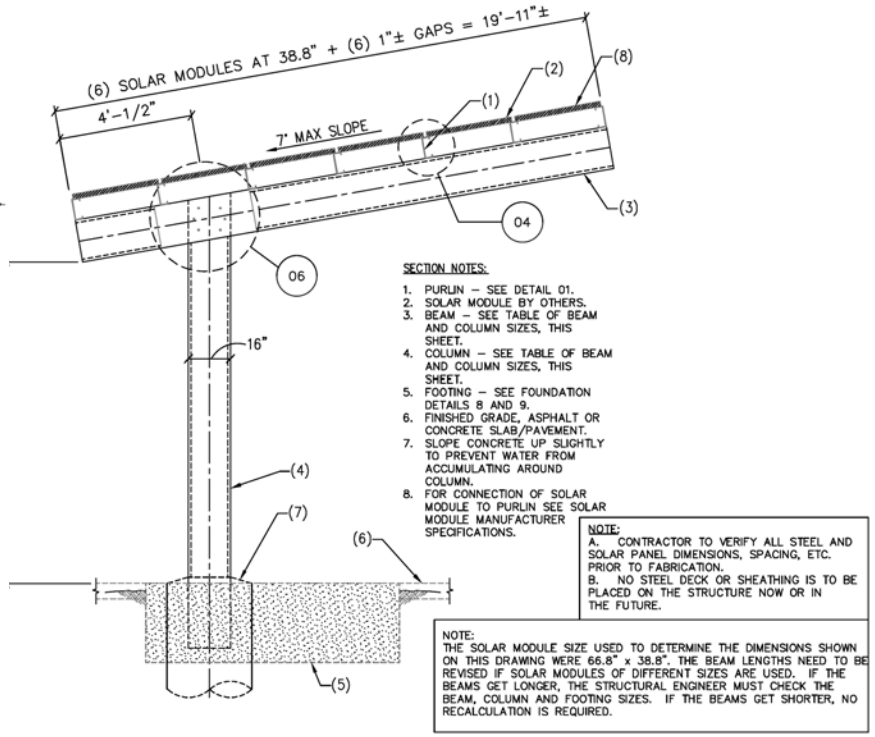
Using all these values at the minimum/worst condition, Albedo=10%, and using the Prism Solar bifacial model, this still yields an ~6% Bifacial Gain with a 90% Bifaciality module.

This increases to ~10% for an East/West installation .

The bifacial gain would be directly reduced if the module bifaciality is reduced.

Bifacial Carport Example





Carport system designed in such a manner to minimize the rear obstruction factor, module aligned with purlins, and the major structure elements are placed in the places where modules meet.

Bifacial Carport Example

- Elevation Ratio= ~0.5
- +600kW Bifacial carport system in Quebec, Canada.
- Mostly E/W aligned
- Data since July 2018

Bifacial Carport–Tucson AZ (2 Year data)

9.72kW (36 modules)
DC/AC ratio = 1.28 (caps May-Aug)
Bifacial Ratio = 90%
Azimuth = East Facing
Height Ratio = 0.5
Tilt = 7 degrees
Albedo/SR = 40%
Estimated Bifacial Gain : 21.4%
Owner provided data

The average measured annual energy production for the 2 year period was 1817.9 kWh_{ac}/kW_{dc}

The averaged Gain measured for the 2 year period was 19.6%, just under the predicted 21.4%.

Conclusions

- Significant bifacial gain's are obtainable in various real world applications
- Maximizing BGE generally does not make financial sense
- Financial optimization is the key
- All the site variables must be considered when designing the system. This includes cost of electricity

Thank You

Additional questions:

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