Bifacial PV system mismatch loss estimation

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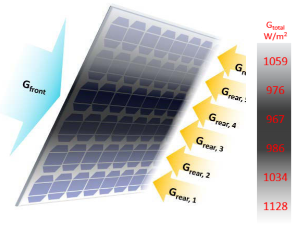
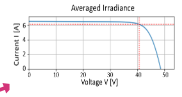
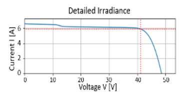
Nonuniform rear-irradiance on bifacial PV systems can cause additional **mismatch loss,** which may not be appropriately captured in PV energy production estimates and software.



Averaging Irradiance for the module ~1031 W/m²



P_0



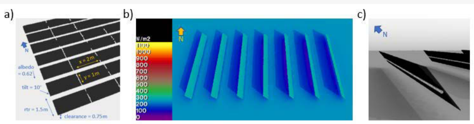
P_1

Detailed Irradiance value

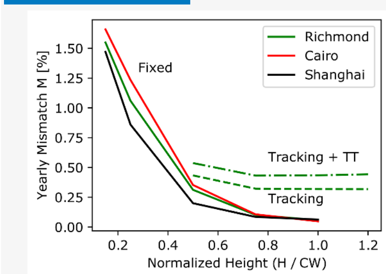
$$L_{DC} = M = 1 - \frac{P_1}{P_0}$$

Simulations: Fixed Tilt + Tracking + Tracking w TT

System	Height	Albedo	GCR	Tilt	# modules
Rooftop	0.15 – 1 m	0.62	0.67	10°	1-landscape
Tracking	1.0 – 2.4 m	0.2	0.33	--	1-portrait



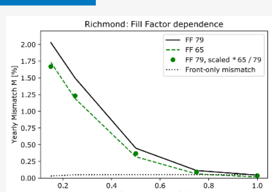
Annual mismatch loss %

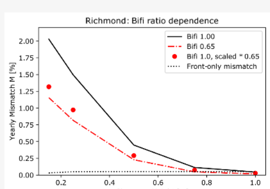


Slight climate dependence is visible for the high-albedo rooftop simulations
For HSAT simulations, the effect of climate was similarly modest but reversed from what was is shown in the high-albedo rooftop simulations, possibly due to the greater influence of diffuse irradiance in a low-albedo tracking scenario.

Fill Factor and Bifaciality Factor dependency

Modules exhibiting lower FF are susceptible to reduced mismatch loss. This is expected due to the smaller slope *-dP/dI* in low-FF modules.





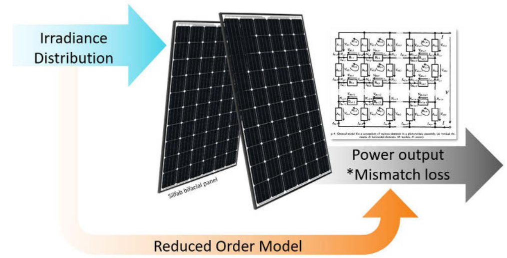
Sample mismatch curves calculated for fixed values of *FF* and ϕ_{Bifi} can be applied more generally due to a linear dependence.

$$M[\%]_{FF1} = M[\%]_{FF_0}\frac{FF_1}{FF_0}$$

$$M[\%]_{\phi_{Bifi,1}} = M[\%]_{\phi_{Bifi,0}}\frac{\phi_{Bifi,1}}{\phi_{Bifi,0}}$$

Reduced Order Model

A simplified empirical relationship was found that links the spatial variation of irradiance (to the resulting mismatch loss factor



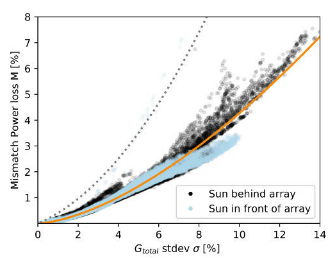
Stdev

$$\sigma[\%] = \frac{1}{\bar{G}_{total}}\sqrt{\frac{\Sigma(G_{total,i}-\bar{G}_{total})^2}{n-1}} \text{ x } 100\%$$

MAD Mean absolute difference

$$\Delta[\%] = \frac{1}{n^2\bar{G}_{total}}\sum_{i=1}^{n}\sum_{j=1}^{n}\left|G_{total,i} - G_{total,j}\right| \text{ x } 100\%$$

Irradiance distribution vs. Power Mismatch, Fixed



Hourly simulation showing power mismatch M[%] as a function of Gtotal spatial standard deviation. Two overlaying fits and a comparison fit from Janssen et al shown.

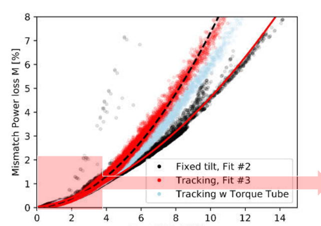
$$M[\%]_{Fit1} = e^{1.57 * \ln(\sigma[\%]) - 2.2}$$

$$M[\%]_{Fit2} = 0.15\,\sigma[\%] + 0.027\,\sigma[\%]^2$$

$$M[\%]_{\text{Janssen}} = 0.33\,\sigma[\%] + 0.0745\,\sigma[\%]^2$$

Irradiance distribution vs. Power Mismatch, Tracking

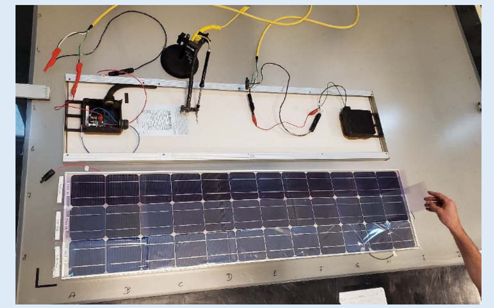
For the two tracking scenarios, results do not fall directly in line with the curves established for fixed-tilt simulations.



Similar curve form, but different empirical-fit parameters.

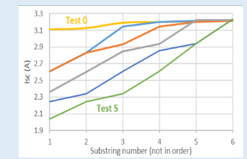
Agreement is much better at $\Delta < 4$, where bulk of the energy is at.

Experimental Validation

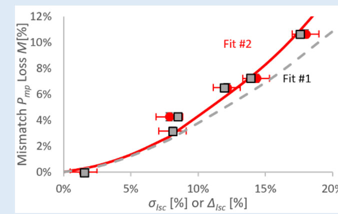


A Spire 4600 long-pulse flash I-V curve simulator was used, along with two Siemens SM55 36-cell monocrystalline modules (mono-facial, FF = 0.7) to investigate the effect of irradiance mimsatch using filters to achieve artificial shading.

Test#	M1 str1 (%)	M1 str2 (%)	M1 str3 (%)	M2 str1 (%)	M2 str2 (%)	M2 str3 (%)
0	-	-	-	-	-	-
1	90	-	84	-	-	-
2	90	-	84	-	-	90
3	90	7	84	-	-	90
4	90	75	84	70	-	90
5	64	75	84	70	-	90



Measured substring I_{sc} for each of the shading tests



Measured mismatch loss *M*[%] for each of the shading tests vs σ_{Isc} or Δ_{Isc} which have similar value in this experiment.
Empirical models shown for comparison using the same coefficients given in Fit 1 and 2, adjusted for FF.

Application to Performance Models

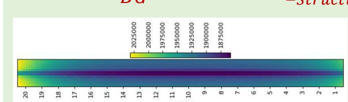
Mismatch loss factors for bifacial or monofacial simulations are considered by a single annual DC loss factor *X*, applied after array power is calculated. This value is often ~10x higher than system-level mismatch numbers shown here.

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

$$P_1 = (G_{F_0} + G_{R_0}\cdot\varphi)\cdot\eta_0\cdot(1 - M)$$

$$P_1 = (G_{F_0} + (1 - L_{Rear})G_{R_0}\cdot\varphi)\cdot\eta_0$$

$$L_{Rear} = \frac{M}{BG} + M \qquad L_{Rear} = L_{Inherent\ Mismatch} + L_{Structural\ Shading}$$



Future steps: explore edge effects on additional mismatch losses. (i.e. 6% annually for HSAT case at 0.75 H.)

MORE DETAILS:
Deline, C., Ayala Pelaez, S., MacAlpine, S., Olalla, C. «Estimating and Parameterizing Mismatch Power Loss in Bifacial Photovoltaic Systems», (submitted PinPV)
Deline, C., Ayala Pelaez, S., MacAlpine, S., Olalla, C. «Bifacial PV System Mismatch Loss Estimation and Parameterization»», 36° EU PVSEC, Marseille FR

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