pvfit.app

Spectral and Diffuse-Angular Corrections in PVfit

Mark Campanelli[†] and Carl Osterwald

[†]Intelligent Measurement Systems LLC, Bozeman, MT, USA, May 2024

pvfit.app

PVfit Performance Model

Model is based on the single-diode equation (SDE):

$$I = I_{\mathrm{ph}} - I_{\mathrm{rs}}\left(e^{\frac{q(V+IR_{\mathrm{s}})}{N_{\mathrm{s}}nk_{\mathrm{B}}T}} - 1\right) - \frac{V + IR_{\mathrm{s}}}{R_{\mathrm{p}}},$$

with auxiliary equations formulated w.r.t.

Effective Irradiance Ratio $F = \frac{I_{\mathrm{sc}}}{I_{\mathrm{sc0}}}$

and Cell Temperature T.

I_{ph} is derived from the SDE at $V = 0$ and $I = I_{\mathrm{sc}}$:

$$\begin{aligned} I_{\mathrm{ph}} &= I_{\mathrm{rs}}\left(e^{\frac{q\,I_{\mathrm{sc}}\,R_{\mathrm{s}}}{N_{\mathrm{s}}nk_{\mathrm{B}}T}} - 1\right) + \frac{I_{\mathrm{sc}}\,R_{\mathrm{s}}}{R_{\mathrm{p}}} + I_{\mathrm{sc}} \\ &= I_{\mathrm{rs}}\left(e^{\frac{q(F\,I_{\mathrm{sc0}})R_{\mathrm{s}}}{N_{\mathrm{s}}nk_{\mathrm{B}}T}} - 1\right) + \frac{F\,I_{\mathrm{sc0}}\,R_{\mathrm{s}}}{R_{\mathrm{p}}} + F\,I_{\mathrm{sc0}}. \end{aligned}$$

F may be determined several ways. A new method here uses spectral-irradiance, spectral-response, and MET-station data, including diffuse-angular effects.

PV Reference Device

$$F = \frac{I_{\mathrm{sc}}}{I_{\mathrm{sc0}}} = M(T, T_0)\,\frac{I_{\mathrm{sc,ref}}}{I_{\mathrm{sc,ref_0}}} \quad \begin{pmatrix}\text{temperature and} \\ \text{IAM matched}\end{pmatrix}$$

Sandia Array Performance Model

$$\begin{aligned} F = \frac{I_{\mathrm{sc}}}{I_{\mathrm{sc0}}} &= E_{\mathrm{e}}\left(1 + \alpha_{\mathrm{sc0}}\,(T - T_0)\right) \\ &= f_1\,\frac{f_2\,G_{\mathrm{b}} + f_{\mathrm{d}}\,G_{\mathrm{d}}}{G_0}\left(1 + \alpha_{\mathrm{sc0}}\,(T - T_0)\right) \end{aligned}$$

Acknowledgments

Special thanks to Anton Driesse at PV Performance Labs and the PV Performance Modeling Collaborative (PVPMC) for collecting/publishing spectral-irradiance and module-QE data.

Contact Information

- Email: mark.campanelli@gmail.com
- Phone: +1 (406) 600-3597
- Github (PVfit's Python code is open source): https://github.com/markcampanelli/pvfit

Key Result

PVfit's single-diode model formulation, using the *effective irradiance ratio* $F = I_{\mathrm{sc}}/I_{\mathrm{sc0}}$, accommodates spectral and diffuse-angular corrections using device-spectral-response (equivalently, QE), spectral-irradiance, and MET-station data.
This methodology complements F's alternative determination by PV reference device or the Sandia Array Performance Model.

Derivation of Effective Irradiance Ratio using Spectral and Angular-Diffuse Corrected MET-Station Data

$$F = \frac{I_{\mathrm{sc}}}{I_{\mathrm{sc0}}} = \frac{I_{\mathrm{sc},T_0}\left(1 + \alpha_{\mathrm{sc0}}\,(T - T_0)\right)}{I_{\mathrm{sc0}}} = \frac{A\int_{\lambda=0}^{\infty} S(\lambda, T_0)\,E_{\mathrm{eff}}(\lambda)\,d\lambda\,\left(1 + \alpha_{\mathrm{sc0}}\,(T - T_0)\right)}{A\int_{\lambda=0}^{\infty} S(\lambda, T_0)\,E_0(\lambda)\,d\lambda} = \underbrace{\frac{\int_{\lambda=0}^{\infty} S(\lambda, T_0)\,E_{\mathrm{eff}}(\lambda)\,d\lambda}{\int_{\lambda=0}^{\infty} S(\lambda, T_0)\,E_0(\lambda)\,d\lambda}\left(1 + \alpha_{\mathrm{sc0}}\,(T - T_0)\right),}_{\text{spectral correction}}$$

where, by the assumption of current linearity w.r.t total irradiance, the effective spectral irradiance, E_{eff}, is scaled so that it equals the effective POA irradiance G_{eff}:

$$\int_{\lambda=0}^{\infty} E_{\mathrm{eff}}(\lambda)\,d\lambda = G_{\mathrm{eff}} = G_{\mathrm{dir,eff}} + G_{\mathrm{cir,eff}} + G_{\mathrm{sky,eff}} + G_{\mathrm{hor,eff}} + G_{\mathrm{grd,eff}} = \underbrace{g_{\mathrm{dir}}(\theta_{\mathrm{sun}})\,G_{\mathrm{dir}}}_{\text{IAM correction}} + \underbrace{g_{\mathrm{cir}}(\theta_{\mathrm{sun}})\,G_{\mathrm{cir}} + g_{\mathrm{sky}}(\theta_{\mathrm{tilt}})\,G_{\mathrm{sky}} + g_{\mathrm{hor}}(\theta_{\mathrm{tilt}})\,G_{\mathrm{hor}} + g_{\mathrm{grd}}(\theta_{\mathrm{tilt}})\,G_{\mathrm{grd}}}_{\text{diffuse-angular correction [Marion, \textit{Solar Energy}, 2017]}}.$$

- Irradiance components derived from, e.g., Perez model with MET-station measurement of GHI, DHI, and DNI, or a POA irradiance decomposition.
- Measured shape of $E_{\mathrm{eff}}(\lambda)$ is assumed invariant w.r.t. incident angle. Missing "tails" must be extrapolated, here by $E_0(\lambda)$ scaled to match tail integrals.
- Short-circuit temperature coefficient at STC, α_{sc0}, approximates temperature dependence of spectral response $S(\lambda, T)$. More precisely, α_{sc} depends on spectrum.
- Relative measurement of PV device's spectral response at STC, $S(\lambda, T_0)$, is sufficient due to cancellation of any scalar multiplier, including active area A.

Demonstration of Spectral and Diffuse-Angular Corrections in PVfit

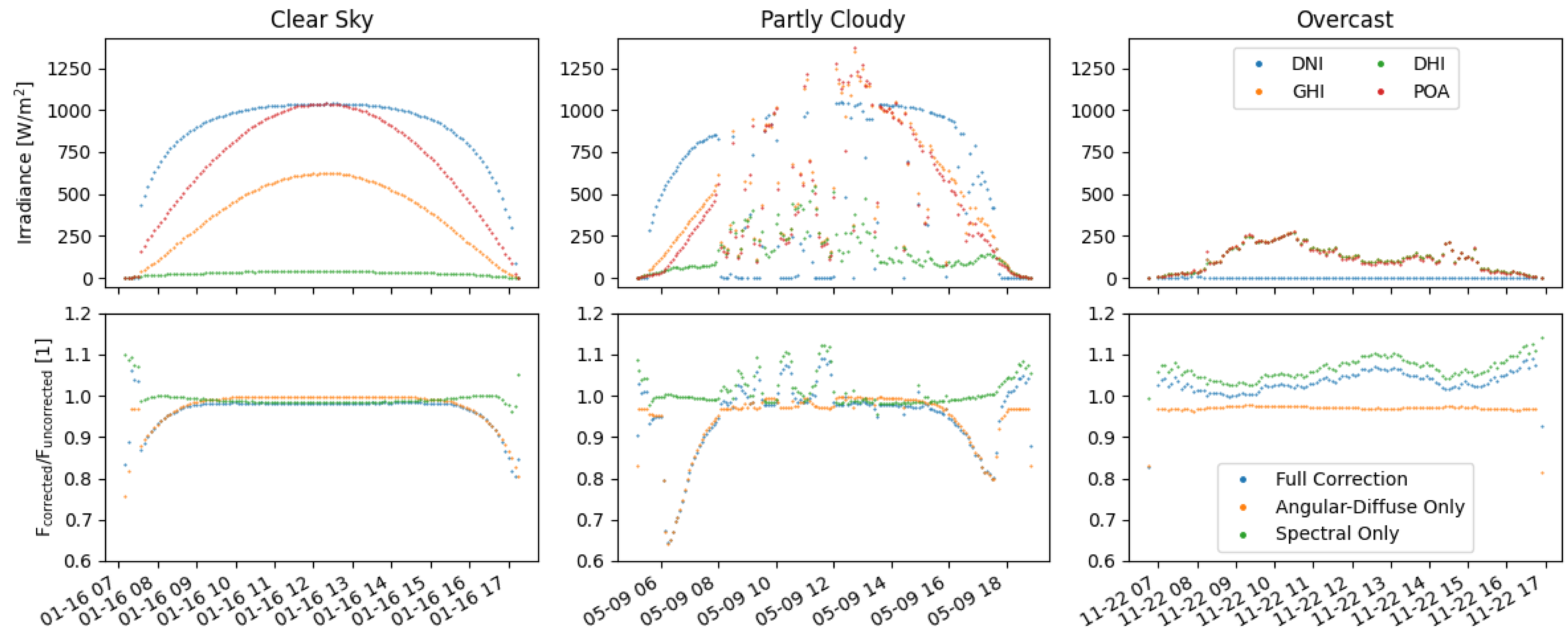

Figure 1: Irradiances and relative F corrections for a x-Si monofacial PV module tilted south 35°, using 5-min MET-station and global normal spectral irradiance measurements in Albuquerque, NM, USA.