Analyzing low-light performance in PAN files

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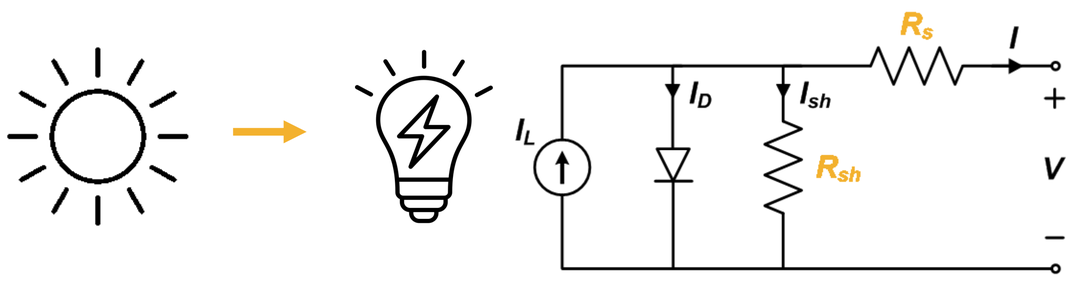
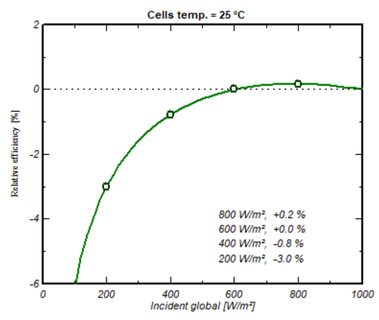
Background



I_L: light current
I_D: voltage dependent current [$f(I_0)$]
I_0: diode reverse saturation current
R_s: series resistance
R_{sh}: shunt resistance
n: diode ideality factor



The one-diode model

Many modeling programs use the one-diode model to make the jump from irradiance to current and voltage and ultimately generation. The one-diode model has five input parameters which must be fit to the specific module characteristics. The characteristics are not typically measured or specified in technology spec sheets, but they dictate how a solar project will perform under any given irradiance and temperature conditions.

How is low-light performance modeled?

We can use current and voltage characteristics in the module specification sheet to determine some factors, but others must be solved for or estimated. Series and shunt resistance play important roles in modeling module low-light efficiency.

Introduction

We have noticed that low-light efficiencies can have a material impact on final generation of a solar project, but it can be difficult to quantify how reasonable a PAN file really is. In this analysis we look at typical low-light efficiency profiles and how well various sources match those profiles.

Module testing

T_{cell}	Irr	P_{mpp}
25	600	319.8
25	800	429.3
25	1000	538.1

We can use these testing matrices to benchmark how the one-diode parameters in our PAN files align with measured module performance at different irradiance levels.

IEC 61853-1 Testing

When module testing labs create PAN files, they will often determine the one-diode model parameters by fitting the one-diode model to the results of IEC 61853-1 testing. This testing measures P_{mpp} (and other module metrics) under specific cell temperature and irradiance conditions.

Setting one-diode parameters

Accessibility

Lab optimization

Module testing labs will often use the results of their own testing to determine the parameters of the one-diode model and create a PAN file. The optimization process is often proprietary.

Algorithmic optimization

Modelers can take the results from third-party testing and generate their own optimization algorithms for one-diode parameterization. This takes time, trial, and error.

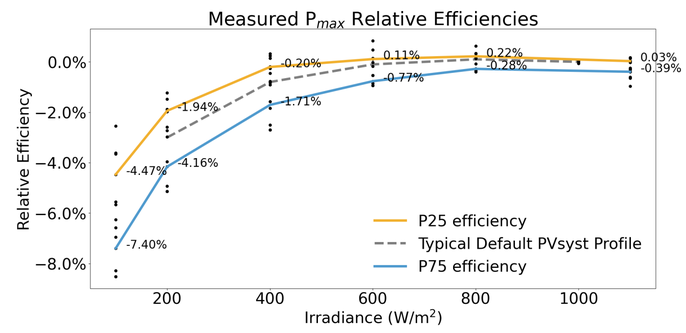
PVsyst® defaults

PVsyst® has recommendations for how these parameters should be set, with or without IEC testing matrices.

Benchmarking performance

All Data: What's normal?

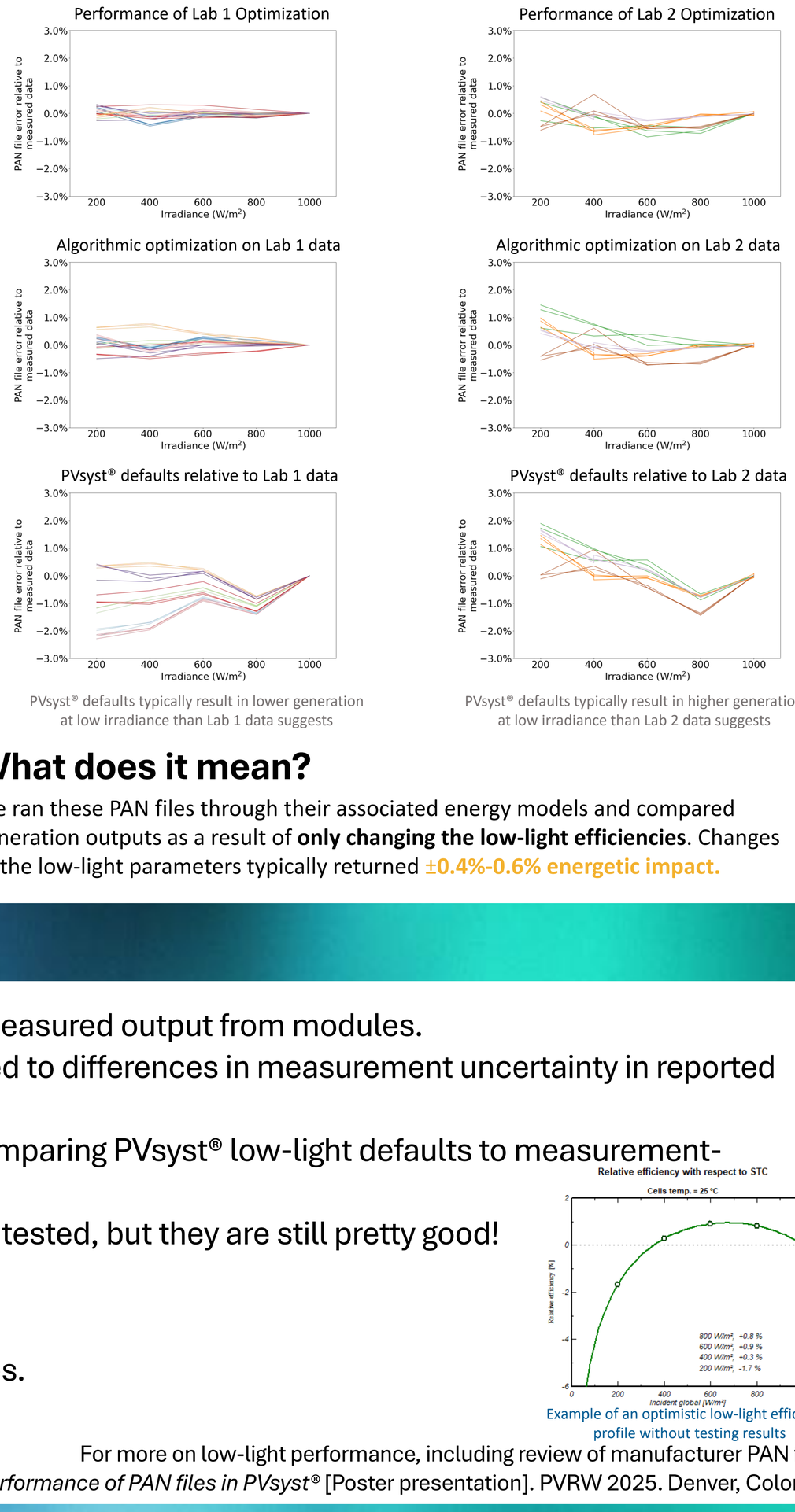
We combined the efficiencies across irradiance levels from each of our 33 module samples. We have also included a typical default efficiency profile from PVsyst for reference.



Performance by lab relative to measured data

Dataset 1: 7 Module technologies, 21 modules sampled

Dataset 2: 4 Module technologies, 12 modules sampled



PVsyst® defaults typically result in lower generation at low irradiance than Lab 1 data suggests

PVsyst® defaults typically result in higher generation at low irradiance than Lab 2 data suggests

What does it mean?

We ran these PAN files through their associated energy models and compared generation outputs as a result of **only changing the low-light efficiencies**. Changes to the low-light parameters typically returned **±0.4%-0.6% energetic impact.**

Conclusions

- Module testing labs generate PAN files that closely match measured output from modules.
- The specific module testing lab matters. This could be related to differences in measurement uncertainty in reported results.
- It is common to have a ±0.4%-0.6% energy impact when comparing PVsyst® low-light defaults to measurement-informed PAN files.
- PVsyst® defaults have the highest error of the three systems tested, but they are still pretty good!

Recommendations

- Review PAN file low-light performance against typical ranges.
- Ask OEMs for PAN file test reports!

Example of an optimistic low-light efficiency profile without testing results

For more on low-light performance, including review of manufacturer PAN files:

Westphal E., Croft N. (2025, March). *A Review of Modeled Performance of PAN files in PVsyst®* [Poster presentation]. PVRW 2025. Denver, Colorado.

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