O13 #520

PVSC 42 New Orleans USA

Area: Sub-Area 9.3:
Models for Energy Prediction

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Improved PV Performance modelling by combining the PV_LIB Toolbox with the Loss Factors Model (LFM)

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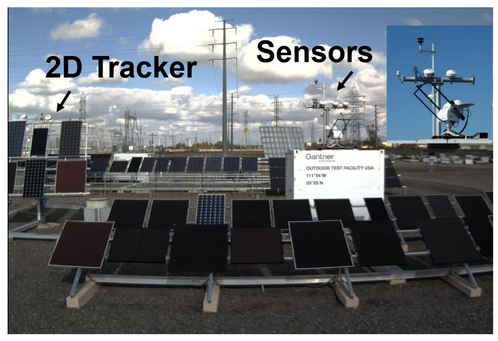
INTRODUCTION

- PV project investments require continuous, accurate and traceable plant monitoring data to determine the actual vs. design performance and to fulfil owner/investor expectations.
- Algorithms from the PV Library (PV_LIB) from "PV Performance Modeling Collaborative" and "Loss Factors Model" (LFM) are being combined to test their prediction improvements at Gantner Instruments' Outdoor Test facility at Tempe AZ on multiple Tier 1 technologies including c-Si, CdTe and CIGS (not shown here).
- The validation and comparisons of the measured vs. predicted (long term) performance will be demonstrated to quantify the potential of IV scan monitoring.
- This will give recommendations on parameters and methods to be used by investors, test labs, and module producers.
- Validated functions are available in the Gantner.webportal for advanced utility scale analysis and prediction for more accurate performance analysis, indication of abnormal loss or trends leading to more effective O&M and risk reduction for owners.

OUTDOOR MEASUREMENTS (Data studied from GANTNER, SANDIA and NREL)



Gantner Instruments
OTF Tempe, Arizona.

Name	Description	Units
G_H	Global Horizontal Irradiance	kW/m²
D_H	Diffuse Horizontal Irradiance	kW/m²
B_N	Beam Normal Irradiance	kW/m²
G_I	Global Inclined Irradiance (Pyranometers and c-Si ref cells)	kW/m²
T_{AMB}	Ambient Temperature	C
T_{MOD}	Back of Module Temperatures	C
WS	Wind Speed	ms^{-1}
WD	Wind Direction	°
RH	Relative Humidity	%
G(λ)	Spectral Irradiance G(350– 1050nm)	W/m²/nm

IV curves and weather data are measured every minute for 24 fixed modules and 6 on a 2D tracker
Running since July 2010 with a 98.9.% uptime.

COMBINING AND VALIDATING PV_LIB AND LOSS FACTORS MODEL ALGORITHMS

Calculations were made with the PV_LIB routines and checked with meteorological measurements (including irradiance, temperature, spectrum etc.) and PV performance

PV_LIB TOOLBOX

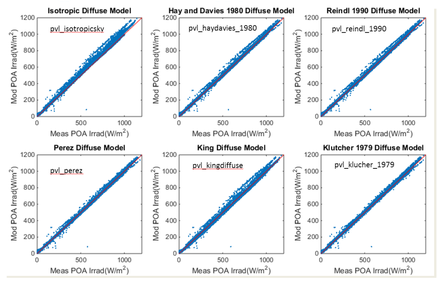
The PV_LIB Toolbox was originally developed at Sandia National Laboratories and has been expanded by contributions from members of the PV Performance Modeling Collaborative (PVPMC).

Available in both Matlab and Python versions, PV_LIB Toolbox is a library of open source functions for PV modelers to use to learn about and construct custom models of PV performance. The toolbox has about 40 functions that allow a user to convert typical weather (e.g., irradiance, temperature, wind speed, etc.) data along with a basic PV system design and simulate the DC and AC power output from a PV system.

The software has been downloaded by over 2,000 users and is used in many universities and companies worldwide.

PVPMC Website: https://pvpmc.sandia.gov

1) Tilted plane irradiance (G_I W/m²) checking Modeled(y) vs. Measured(x)

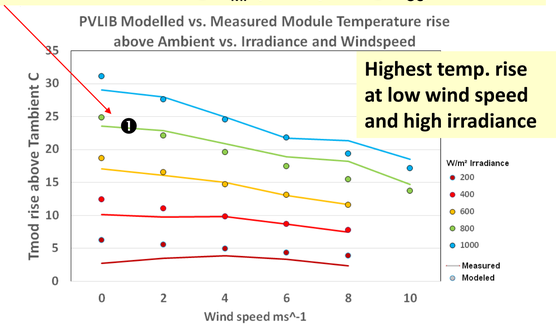


- Six different PV_LIB diffuse sky models were compared with measured tilted plane irradiance (GI Tempe)
- Perez model performs best with low bias and random errors. The Klucher and King models are nearly as good.

→ **Validates PV_LIB *pvl_isotropicsky, pvl_haydavies_1980, pvl_reindl_1990, pvl_perez, pvl_kingdiffuse, pvl, klucher_1979, as well as numerous PV_LIB functions used to generate inputs.***

2) Module temperature (C) vs. G_I,WS checking Modeled vs. Measured

❶NOCT conditions +24C @ V_{MP} (usually 27C @ V_{OC})



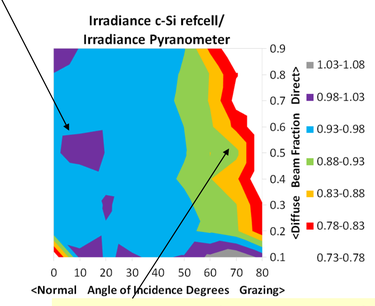
Highest temp. rise at low wind speed and high irradiance

- PV_LIB ***pvl_sapmcelltemp*** for free back CdTe (GI Tempe)
- Good temperature agreement, most discrepancies <2C

→ **Validates PV_LIB *pvl_sapmcelltemp***

3) $G_{I.c\text{-}Si\ Refcell}/G_{I.PYRANOMETER}$ (W/m²) vs. AOI and Beam Fraction

Expect $G_{I.c\text{-}Si}/G_{I.PYR}$ ~ 100% (±spectral correction) for low aoi



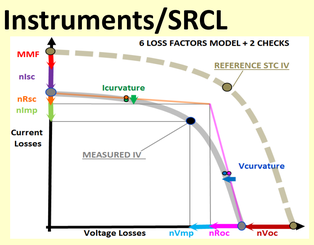
$G_{I.c\text{-}Si}/G_{I.PYR}$ falls as aoi increases → (reflectivity vs. aoi)

Pyranometer predicts ~5% worse low light coefficient than c-Si sensor at 65 deg AOI (due to reflectivity vs. aoi)

→ **Determines irradiance sensor reflectivity vs. AOI**

LOSS FACTORS MODEL

Gantner Instruments/SRCL

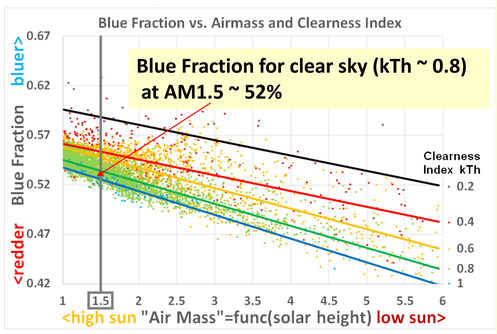


- LFM analyses IV curves at different outdoor conditions (irradiance, module temperature, spectrum, angle of incidence etc.)
- Six normalized orthogonal parameters characterize a module's performance and can identify the cause and any rate of change of limiting parameters.
- Product of parameters gives the normalized efficiency (also known as the DC performance ratio PR_{DC}).

Further details http:// www.steveransome.com

4) Find spectral blue fraction from Solar Height(Air Mass), Clearness Index kTh

$$\textbf{Blue Fraction} = \frac{\text{"Blue end of spectrum"}}{\text{"Spectrum absorbed by cSi"}} = \frac{\sum G_{350-650\ nm}}{\sum G_{350-1050\ nm}}$$



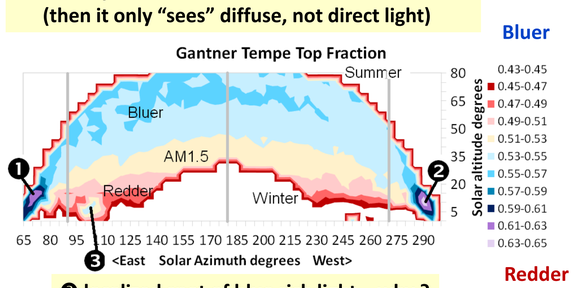
Blue Fraction falls ~2% /"integer AM" increase →

Blue fraction rises as clearness falls → "Cloudy skies are bluer"

→ **Estimates Blue Fraction from Solar height, clearness index**

5) Average spectral blue fraction vs. Solar altitude and Azimuth

❶ ❷"very blue rich" when sun is behind module (then it only "sees" diffuse, not direct light)



Bluer

Redder

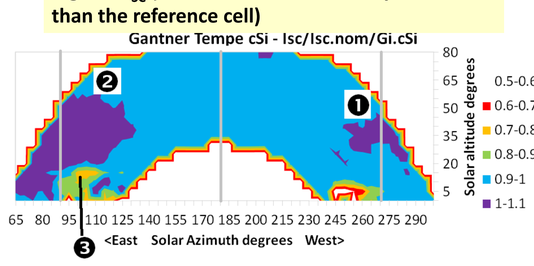
❸ **localized spot of blue rich light – why ?**

Blue fraction easier to understand than APE
→ **Shows average spectrum vs. solar position for sunny site**

6) Find I_{SC}/Irradiance vs. Solar altitude and Azimuth

$$\textbf{normalized } I_{SC} = nI_{SC} = \frac{I_{SC.MEASURED}}{I_{SC.NOMINAL} * G_{I_{cSI\ REFCELL}}}$$

❶❷ **c-Si module anti reflection coating gives higher nI_{SC} (= better of axis reflectivity than the reference cell)**



❸ **Current falls 20-30% from expected indicating shading – red sun "hidden" so spectrum goes bluer**

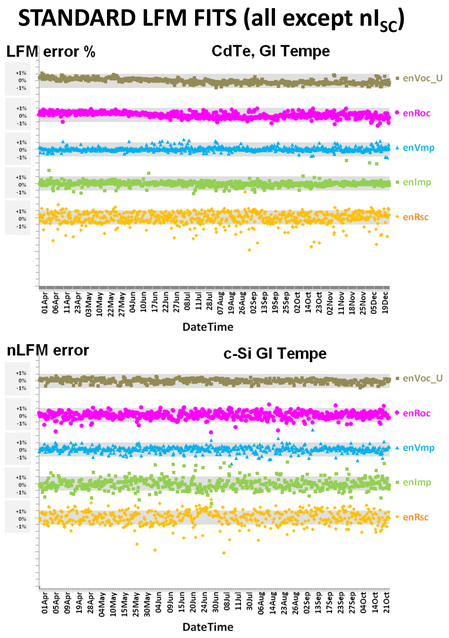
Also differentiate aoi (vs. x axis) from spectral (vs. y axis) effects
→ **Indicates shading and/or AOI differences module:sensor**

LFM PERFORMANCE VALIDATION IMPROVEMENTS USING PVLIB Solar position and AOI calculations

For well behaved modules the standard LFM fit procedures previously published are usually good for <±1% (i.e. within the grey bars) for the 5 parameters except nI_{SC} which is also affected by :-

- Shading
- Soiling
- Snow
- Spectral response
- Reflectivity vs. Angle of incidence
- etc.

STANDARD LFM FITS (all except nI_{SC})

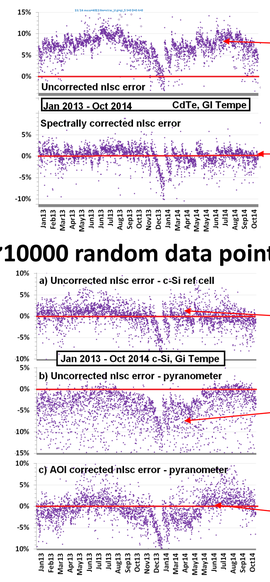


PVLIB IMPROVEMENTS

Improving **CdTe** nI_{SC} fit from an empirical **Spectral Response** correction

Improving **c-Si** nI_{SC} fits from an empirical **Angle Of Incidence / beam fraction** correction pyranometer vs. c-Si ref cell

GI MEASURE 2013-14



COMMENTS

Uncorrected SR :
→Large bias, seasonal error

PV_LIB Corrected SR :
→ Much better, flat fit

Uncorrected AOI c-Si ref cell :
→No AOI error

Uncorrected AOI pyranometer :
→Large error at high AOI

PV_LIB corrected AOI :
→ Much better fit

GANTNER WEB PORTAL

- **The gantner.webportal is an Independent real-time analysis platform for data acquisition, storage and control which offers Investors solid and reliable information to evaluate their PV portfolios performance (financial KPIs, performance analysis, preventive maintenance strategies, tickets, inventory, ..).**
- **PV_LIB and LFM functions are utilized enabling more accurate and automated utility scale performance verification, analysis and prediction.**
- **Performance guarantees – target versus actual performance – can be validated more reliable as the difference can be linked to the integrated loss stages.**
- **This identifies abnormal losses or trends and its optimization potential (in terms of kWh or $) leading to more effective O&M and risk reduction for owners.**
- **More details demo.gantner-webportal.com**

GLOSSARY

AM	Air Mass	Solar path length through atmosphere
APE	Average Photon energy	Average eV from photons over pyranometer wavelength range
AOI	Angle of incidence	Angle between solar beam and module normal
BF	Beam Fraction	Beam Horizontal/ Global Horizontal = 1 - DF
TF	Blue Fraction	Blue light/c-Si captured light G(350-650nm)/G(350-1050nm)
kTh	Clearness index	"Global Horizontal"/"Extra-terrestrial Horizontal" irradiance
GI	Irradiance	POA instantaneous irradiance (kW/m²)
NOCT	Nominal operating Cell Temperature	800W/m², AM 1.5, $T_{AMBIENT}$=20C, Wind speed 1ms^{-1}
nIsc	Normalised I_{SC}	Isc.measured/Isc.STC/GI
POA	"Plane of array"	of the modules
SR	Spectral response	Cell performance vs. wavelength nm
STC	**S**tandard **T**est **C**onditions	1kW/m², 25C T_{MODULE}, AM1.5, 0 ms^{-1} wind
T_{AMB}	Ambient temperature (C)	Air Temperature
T_{MOD}	Module temperature (C)	Usually measured on the back of the module
WS	Wind speed (m s^{-1})	

See also poster N36 (513) "PV_LIB Python 2015" Holmgren et al

CONCLUSIONS

- **PV_LIB is being integrated into Gantner Instruments measurement data**
- **LFM is compatible in line with PV_LIB algorithms and will gain further understanding for modelling**
- **Standardization of algorithms, reduction of site specific impacts allow plant benchmarking within the portfolio**
- **Gantner Instruments will introduce LFM and PV_LIB to an open platform (web portal) which enables faster utility scale monitoring and analysis**
- **Validated functions are available in the gantner.webportal (real time platform) for advanced utility scale analysis and prediction in an automated way**
- **Sandia National Laboratories plans to incorporate the LFM model into the next release of the PV_LIB Toolbox.**

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