SAND2017-10067C

PVPerformance MODELING COLLABORATIVE

PV Performance Modeling Methods and Practices

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PVPS

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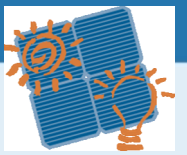


PV Performance Modeling Collaborative (PVPMC)

- Model agnostic, focus on algorithms, methods, data, etc.
- Three Pillars of Communication and Collaboration
  1. **Website** (*PVPMC.sandia.gov*) (>10,000 visits per month)
     - Detailed Modeling Steps (~150 technical webpages)
     - Past workshop presentations (over 300 available for download)
     - Document library, datasets, blog, events, …
  2. **Open Source Software**
     - **PVLIB** - Modeling function libraries for Matlab and Python (50+ functions), BSD 3-clause licenses
     - **Wavelet Variability Model** – calculates geographic smoothing of PV plant power.
     - **GridPV** – Matlab code for analysis of distribution systems with PV
  3. **Workshops**
     - Planning for the 9th and 10th Workshops in China and US is underway

PV Performance Modeling Steps

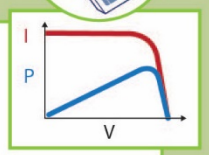
1. **Irradiance and Weather** – Available sunlight, temperature, and wind speed all affect PV performance. Data sources include typical years (TMY), satellite and ground measurements.

2. **Incidence Irradiance** – Translation of irradiance to the plane of array. Includes effects of orientation and tracking, beam and diffuse irradiance, and ground surface reflections.

3. **Shading and Soiling** – Accounts for reductions in the light reaching the PV cell material.

4. **Cell Temperature** – Cell temperature is influenced by module materials, array mounting, incident irradiance, ambient air temperature, and wind speed and direction.

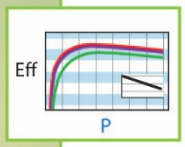
5. **Module Output** – Module output is described by the IV curve, which varies as a function of irradiance, temperature, and cell material.



6. **DC and Mismatch Losses** – DC string and array IV curves are affected by wiring losses and mismatch between series connected modules and parallel strings.

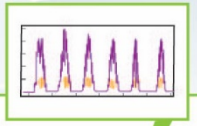
7. **DC to DC Max Power Point Tracking** – A portion of the available DC power from the array is lost due to inexact tracking of the maximum power point.

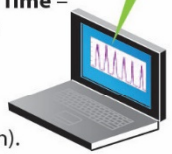
8. **DC to AC Conversion** – The conversion efficiency of the inverter can vary with power level and environmental conditions.

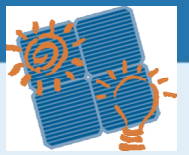


9. **AC Losses** – For large plants, there may be significant losses between the AC side of the inverter and the point of interconnection (e.g., transformer).

10. **System Performance Over Time** – Monitoring of plant output can help to identify system problems (e.g., failures, degradation).





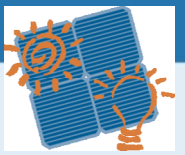


PVLIB for Matlab : Irradiance and Weather

- **pvl_readtmy3, pvl_readtmy2 –** Reads TMY formatted weather files
- **pvl_getISDdata, pvl_readISH –** Reads data from the Integrated Surface Database (source of global weather data)
- **pvl_ephemeris, pvl_spa –** Calculates Sun position
- **pvl_extraradiation –** Calculates extraterrestrial radiation
- **pvl_alt2pres, pvl_pres2alt –** Converts between altitude and air pressure
- **pvl_relativeairmass, pvl_absoluteairmass –** Calculates air mass both relative and absolute
- **pvl_disc, pvl_dirint, pvl_erbs, pvl_louche, pvl_orgill_Hollands, pvl_reindl_1, pvl_reindl_2 –** Estimates DNI from GHI
- **pvl_clearsky_haurwitz, pvl_clearsky_ineichen –** Calculates clear sky irradiance
- **pvl_calcPwat –** Estimates precipitable water in the atmosphere from air temperature and relative humidity

Download PVLIB for Matlab (1.3.2) at
- https://pvpmc.sandia.gov/applications/pv_lib-toolbox/
- https://github.com/sandialabs/MATLAB_PV_LIB

Report issues, submit code, etc. via github



PVLIB for Matlab : Incident Irradiance (POA)

- **pvl_grounddiffuse** – Calculates ground reflected irradiance
- **pvl_isotropicsky** – Isotropic model for sky diffuse irradiance on POA
- **pvl_perez, pvl_reindl1990**, **pvl_kingdiffuse, pvl_klucher1979, pvl_haydavies1980** - models for sky diffuse irradiance on POA
- **pvl_getaoi** – Calculates to the angle of incidence on a tilted plane.

- **pvl_detect_clear_times** – Identify clear periods in irradiance time series
- **pvl_detect_shadows** – Detect the effect of shadows in measured irradiance data (e.g., overhead wires, trees, poles, etc.)

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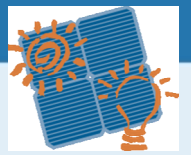

PVLIB for Matlab : PV Models

- **pvl_sapmmoduledb**, **pvl_SAMLibraryReader_CECModules**, **pvl_SAMLibraryReader_SNLInverters** – Reads in PV module coefficients
- **pvl_physicaliam**, **pvl_martinruiziam**, **pvl_ashraeiam** – Models for estimating incident angle modifiers
- **pvl_Fsspeccorr** – First Solar model for spectral corrections
- **pvl_calcparams_Desoto** & **pvl_calcparams_CEC** & **pvl_calcparams_Pvsyst** – Calculates PV module parameters for the single diode model
- **pvl_singlediode** – Implements the single diode model
- **pvl_sapm** – implements the Sandia PV Array Performance Model
- **pvl_huld** – Implements the Huld performance model
- **pvl_snlinverter**, **pvl_adrinverter** – inverter performance models
- **pvl_singleaxis** – Calculates single axis tracker positions and angles
- **pvl_sapmcelltemp** – Calculates PV cell temperatures from air temp, irradiance, and wind speed.

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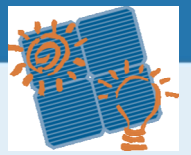

pvlib-python

- Object-oriented implementation of PV modeling functions
- Location class:
  - Container for latitude, longitude, altitude, timezone data
  - Methods for solar position, clear sky models, air mass models, TMY readers
- PVSystem class:
  - Container for system description data, e.g.: tilt, azimuth, albedo, module and inverter, system topology
  - Methods for POA irradiance, module and inverter performance models
- ModelChain class:
  - Container for a Location and a PVSystem object
  - Specify choice of models using keywords, e.g., clearsky_model='ineichen'
  - Methods for power and energy simulations, e.g., 'prepare_inputs()', 'run_model()'

Pvlib-python v0.5.0 at
- https://github.com/pvlib/pvlib-python

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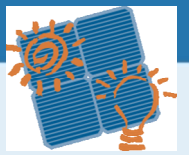


PVPMC Workshops

- 1st PVPMC Workshop (Albuquerque, NM, Sept. 2010)
- 2nd PVPMC Workshop (Santa Clara, CA, May 2013)
- 3rd PVPMC Workshop (Santa Clara, CA, May 2014)
- 4th PVPMC Workshop (Cologne, Germany Oct 2015)
- 5th PVPMC Workshop (Santa Clara, CA, May 2016
- 6th PVPMC Workshop (Freiburg, Germany, Oct 2016)
- 7th PVPMC Workshop (Lugano, Switzerland, March 2017
- 8th PVPMC Workshop (Albuquerque, NM, May 2017)
- ***9th PVPMC Workshop (Weihai, China, Dec 5-7, 2017)***
- ***10th PVPMC Workshop (Albuquerque, NM, April or May 2018)***

4th PV Performance Modelling Workshop

TÜV Rheinland, Cologne, Germany, 22-23 October, 2015.

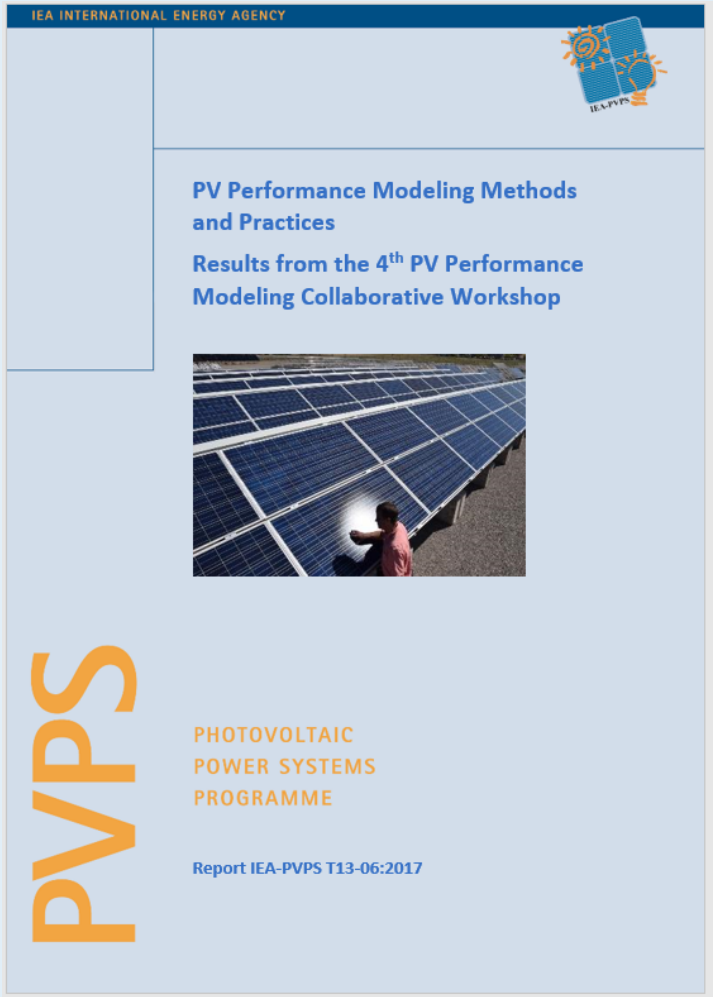
- 220 attendees from over 30 countries
- ~45 presentations
- Sessions
  - Solar Resource and Uncertainty
  - Effects of spectrum on PV performance
  - Soiling
  - Bifacial PV
  - Modelling tools
  - Monitoring PV

- Presentations are available on pvpmc.sandia.gov

PVPS

PV Performance Modeling Methods and Practices

- Report completed and approved March 7,2017
- Report is divided into two parts:
  - Introduction to PV performance modeling methods
  - Workshop report with summaries of each presentation made in Cologne
    - Most speakers contributed summaries of their presentations for the report.



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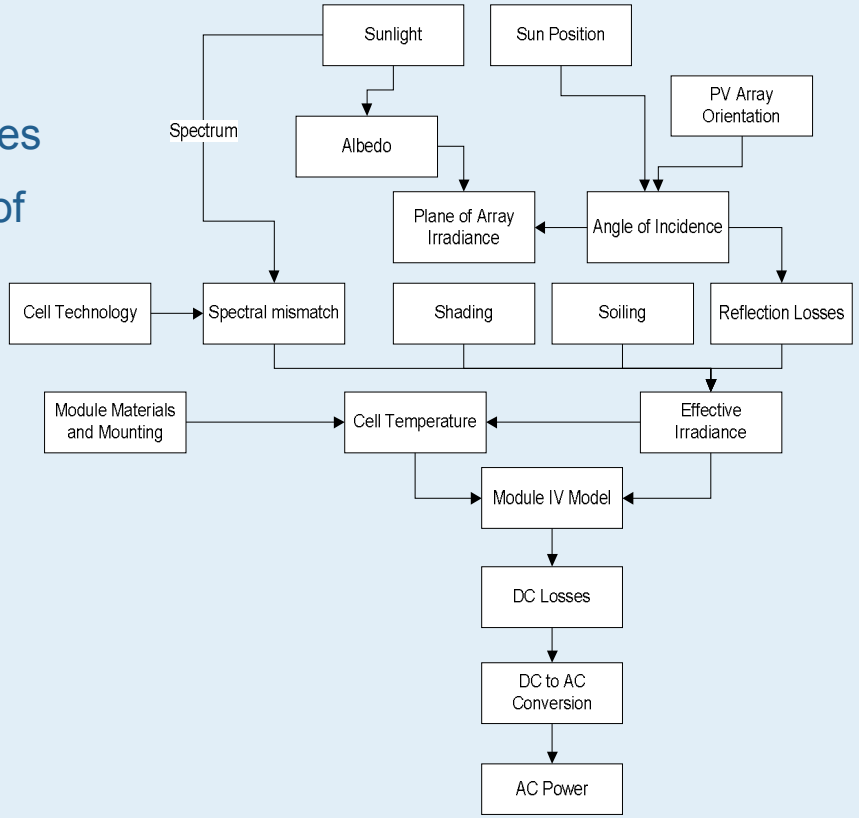
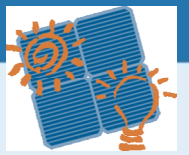
Report is available from IEA-PVPS.org (under Task 13)

Report Outline (Section 1-2)

- 1 Introduction
- 2 Performance Modeling of PV Systems
- 2.1 Standard Sequence of PV Performance Modeling Steps
- 2.2 PV System Design Parameters
- 2.3 Irradiance and Weather Data Sources
- 2.4 Translating Irradiance to the Plane of the Array
- 2.5 Estimation of Shading, Soiling, and Reflection Losses
- 2.6 Effective Irradiance
- 2.7 Estimation of Cell Temperature
- 2.8 Current and Voltage (I-V) Models
- 2.9 DC Wiring and Mismatch Losses
- 2.10 DC to AC Conversion Efficiency
- 2.11 AC Wiring and Transformer Losses

PV performance modeling process for a grid-connected PV system from sunlight to AC power.





Report Outline (Section 3)

- 3 Workshop Presentation Summaries
- 3.1 Session 1: Solar Resource Data and Uncertainty
- 3.2 Session 2: Spectral Corrections for PV Performance Modelling
- 3.3 Session 3: Soiling and Snow, and Other System Derates
- 3.4 Session 4: Bifacial PV Modeling Challenges
- 3.5 Session 5: PV Modelling Applications: Modelling Tool Updates
- 3.6 Session 6: Field Monitoring and Validation of PV Performance Models
- 3.7 Poster Session (summary and table; no written descriptions).

5th PV Performance Modelling Workshop

Organized in collaboration with EPRI in Santa Clara, CA; 9 May, 2016.

- 165+ attendees, ~21 presentations, international audience
- Sessions
  - Solar Resource and Uncertainty
  - PV Performance Modeling
  - Modeling Tools Update
  - Bifacial Modeling
  - PV Performance During Operations
- 1st PVLIB Users Group meeting (May 10)
  - Room full (~40 participants)

6th PV Performance Modelling Workshop

Fraunhofer ISE, Freiburg, Germany; 24-26 Oct., 2016.

- 150 attendees, international audience
- Sessions
  - Solar Resource Data and Uncertainty
  - Forecasting for PV Grid Integration
  - PV Modeling Applications: Modeling Tool Updates
  - Field Monitoring and Model Validation
  - Ray-tracing to Address Bifacial PV Arrays and Shade
  - PV Performance Characteristics
- Technical tours:
  - Fraunhofer ISE
  - Rappenecker Hütte

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7th PV Performance Modelling Workshop

- SUPSI, Lugano, Switzerland; 30-31 March., 2017
- 100 attendees, international audience
- Sessions
  - Energy rating standards and methods
    - Focus on IEC 61853 standard
  - PV module modeling methods
  - Cell and module calibration methods and uncertainties
  - Energy prediction of new technologies or features

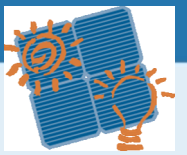
8th PV Performance Modelling Workshop

CFV Solar Laboratory, Albuquerque, NM USA; 9-10 May, 2017.

- ~115 Participants, international audience.
- Sessions
  - Energy rating standards and methods
    - Focus on IEC 61853 standard
  - PV module modeling methods
  - Cell and module calibration methods and uncertainties
  - Energy prediction of new technologies or features

Future Workshops

- Dec 5-7, 2017: 9th PVPMC Workshop (7-Sept is technical tour)
  - Weihai, China (hosted by Harbin Institute of Technology, Fraunhofer ISE, and Sandia National Labs)
  - Abstracts due October 2, 2017
  - *pvpmc.hitwh.edu.cn*
  - Confirmed speakers from: PVsyst, SunPower, First Solar, Trina, Meyer Berger, Sandia, Fraunhofer ISE, NREL, and others…
- April or May 2018: 10th PVPMC Workshop
  - Sandia/CFV Solar, Albuquerque, NM USA
  - Abstract call out soon.
- Future workshop in Europe



How to Get Involved?

- Visit website (pvpmc.sandia.gov)
  - Sign up for email alerts (~1 per month)
  - Contribute news items, content
- Use PVLIB, GridPV, WVM
  - Contribute new functionality to these packages.
- Attend PVPMC workshop
  - Consider presenting your work