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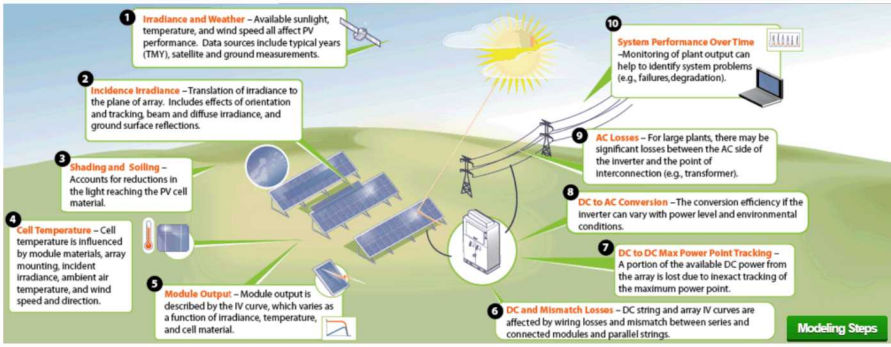


Photovoltaic And Renewable Energy Systems Research

Clifford W. Hansen

SW Regional Energy Workshop

March 14, 2018

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Premier PV module laboratory

Purpose

- Focus on Emerging Technologies
- Minimum 1-year installations
- Data used to validate energy yield predictions
- Evaluate system reliability and degradation rates

Configuration and Capacity

- 750kW grid tie capacity
- 225 kW currently installed
- 100-125kW near term expansion (just need modules and inverters)
- 225-275kW mid term expansion (need site prep, racking, electrical runs)

Instrumentation

- DC Voltage and Current (string and combiner)
- AC Voltage, Current and Power Factor
- Module Temperature
- Full weather station

Indoor Module and Cell Characterization

Solar Simulator

- Spire 4600SLP
- Characterize IV behavior of modules as a function of irradiance
- 200-1100 W/m^2
- room temperature operation only

Module Inspection

- Reltron PV Electroluminescence Inspection System
- Custom enclosure and module mounting

Light-soaking/Pre-conditioning Chamber

- Temperature controlled light-soaking chamber, integrated IV sweep capability

Cell characterization workbench

Sandia manages the US DOE Regional Test Center (RTC) Program

1. **Demonstrate Performance of Product: "It Works"**
2. **Demonstrate long-term Field Performance: "It lasts"**
3. **Demonstrate long-term Field Performance: "It lasts here"**

Regional Test Centers

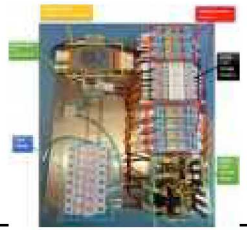
Differentiating PV Quality

pvrtc.org

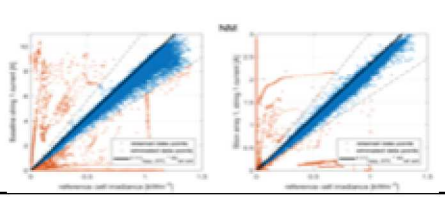
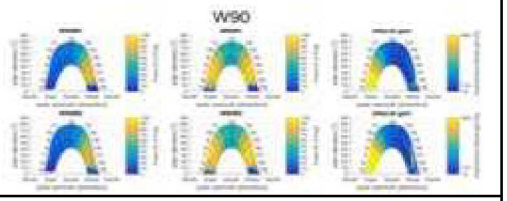
Industry Benefits from RTC Program

- Multi-climate field studies

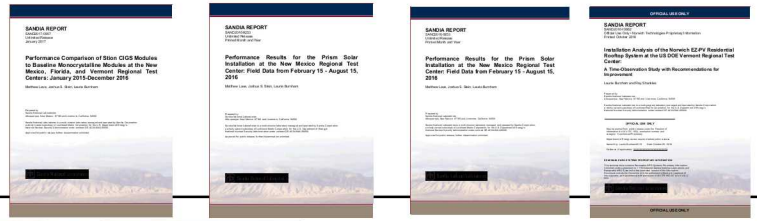

- High-fidelity performance and meteorological data



- Performance analysis

- Bankability/technological validation

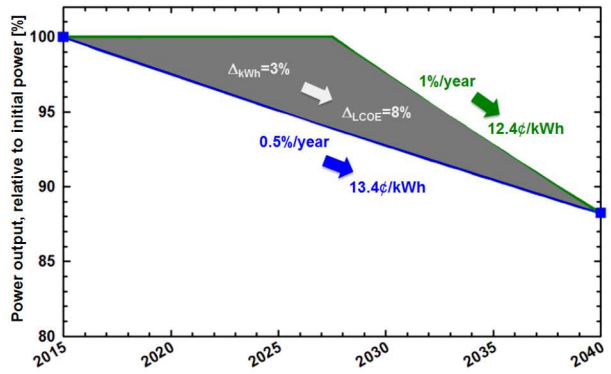


- Product development: access to lab capabilities and expertise



PV Lifetime Project

- Develop and standardize methods for measuring PV module and system degradation.
  - The path of degradation matters to LCOE.
- Apply methods to selected commercial PV modules
- Three sites: New Mexico, Colorado, and Florida
- 700 modules total (~50 in each manufacturer sample)
  - Targeting top-selling module manufacturers (in US market) and a range of current cell technologies (focus on Si)
  - Statistical characterization of variation in degradation within a module population



Bifacial Research Project

Collaborative project between Sandia, NREL and University of Iowa
(https://pvpmc.sandia.gov/pv-research/bifacial-pv-project/)

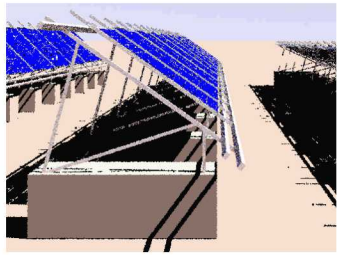
Task 1: Measure Outdoor Bifacial Performance

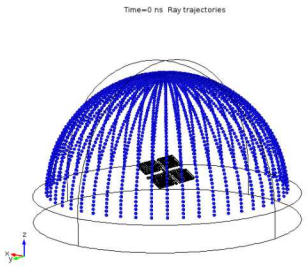
- Module, string and system scale
  - Adjustable rack with 4 modules
  - Fixed tilt racking with varying tilt and azimuth
  - Single axis and two-axis trackers
  - Arid sunny (NM and NV) and cold snowy climates (VT)
  - Irradiance measurements (rear-facing, spatial)
- Quantify
  - Performance of mono- and bifacial modules in similar deployments
  - Bifacial gain – see next slide
  - Spatial variability in backside irradiance
  - Effects of backside obstructions and shading

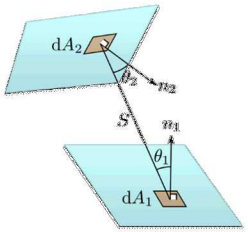
Bifacial Research Project (cont.)

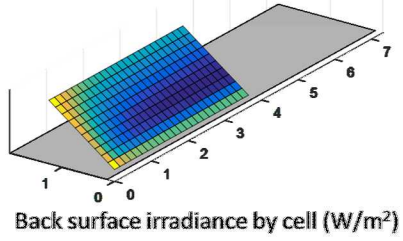
Task 2: Develop Performance Models

- Irradiance modeling
  - Ray tracing methods – Sensitivity studies
  - View (Configuration) Factor methods : 2D for conventional arrays, 3D for cell-by-cell irradiance
- Module performance models





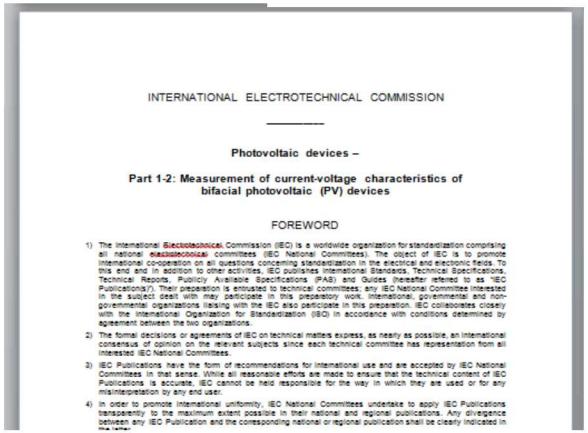




Back surface irradiance by cell (W/m²)

Task 3: Support Rating Standards

- Support new bifacial rating standard (IEC 60904-1-2 - Draft)



INTERNATIONAL ELECTROTECHNICAL COMMISSION

Photovoltaic devices –

Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international cooperation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

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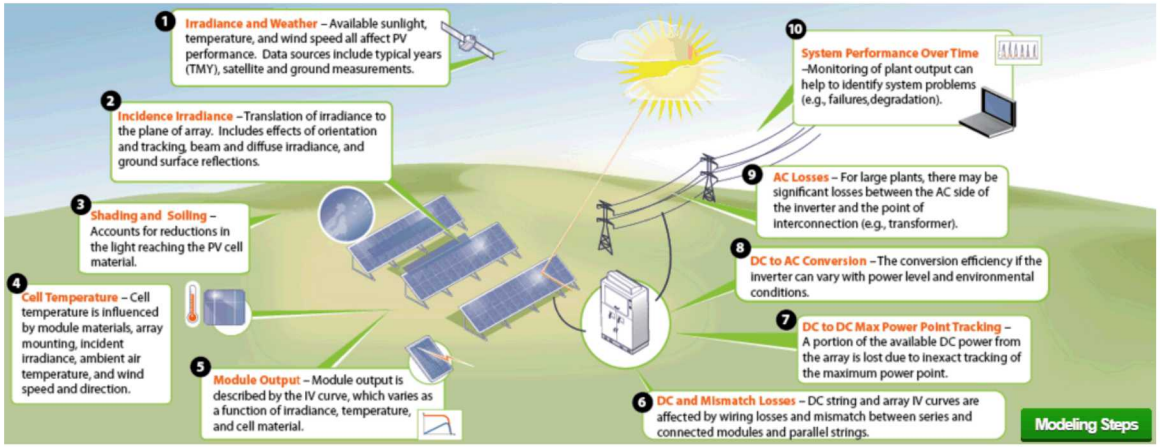
Publications at https://pvpmc.sandia.gov/pv-research/bifacial-pv-project/

PV Performance Modeling Collaborative

- pvpmc.org
  - Online reference for PV system modeling
- PVLib for Matlab and pvlib-python
  - Open source implementation of PV modeling tools
- **Registration Open!!** 2018 10th PV Performance Modeling and Monitoring Workshop in Albuquerque, New Mexico USA (1-3 May 2018)
  - Performance modeling, EPRI/SNL Systems Symposium, PVLib user group



PVPerformance MODELING COLLABORATIVE

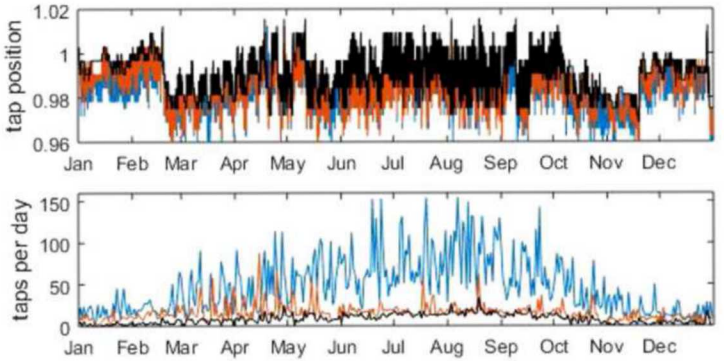
pvlib

Quasi-Static Time-Series (QSTS) methods for distribution system analysis

Why do we need QSTS?

QSTS simulations are needed today to understand:

- Rapid fluctuations due to high variable PV
- Impact to voltage regulators and switched capacitors
- Temporary extreme conditions before controls react
- Research new distribution control strategies



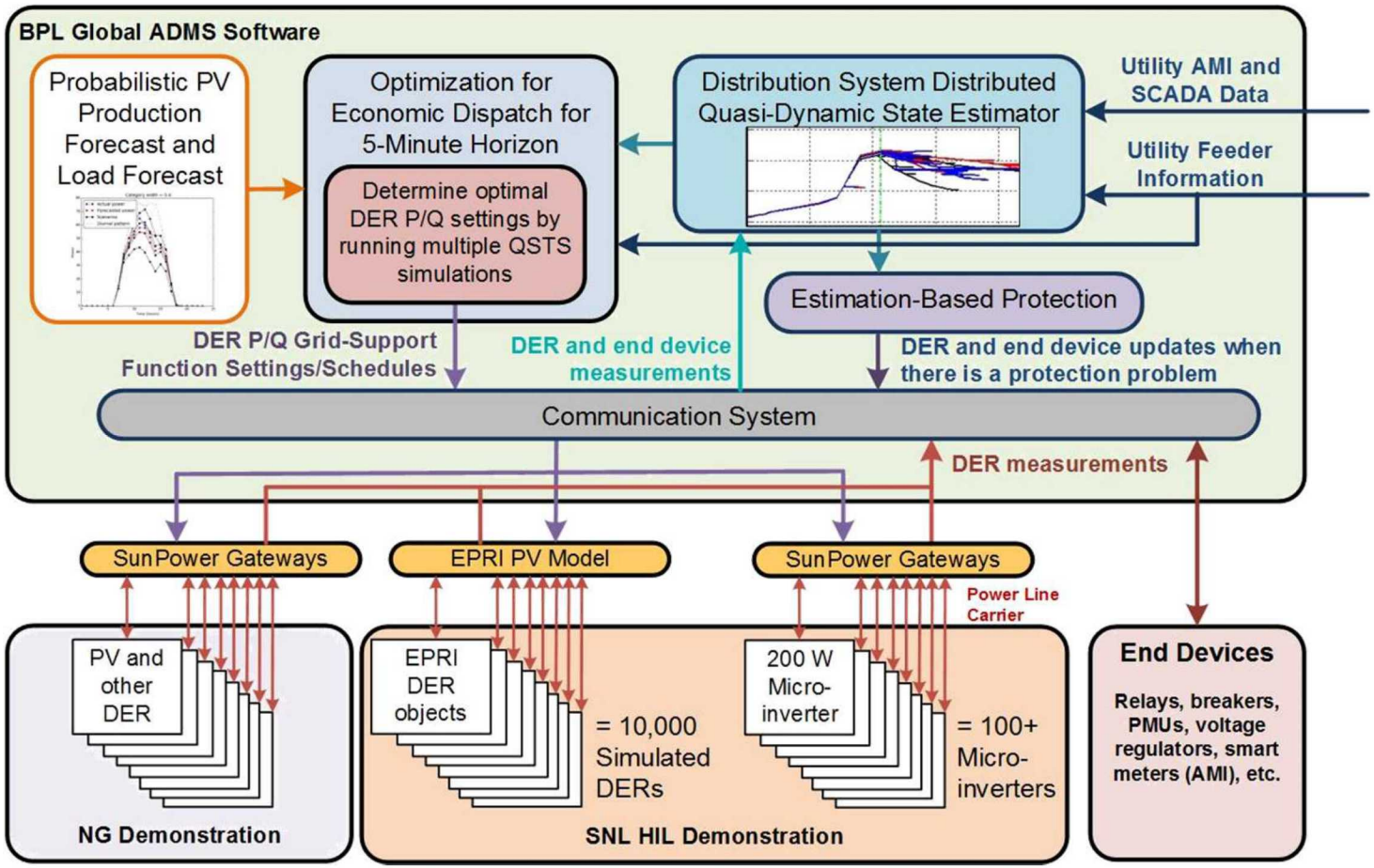
Yearlong QSTS for Regulator Tap Position

Distribution System Analysis Methods and Tools

	Extreme Voltages	Thermal Loading	Regulators Tap Changes	Capacitor Switching	Time outside ANSI	Losses	Computation Time[1]
Snapshot	Good	Good	-	-	-	-	<1 sec
Hourly Timeseries	Great	Great	-	-	Good	Great	5 sec
1 day QSTS	Poor	Poor	Decent	Decent	Poor	Poor	5 minutes
1 year QSTS	Great	Great	Great	Great	Great	Great	36 hours
New Rapid QSTS Algorithms	Great	Great	Great	Great	Great	Great	30 sec

ProDROMOS (open-source components for Virtual Power Plants)

- Programmable Distribution Resource Open Management Optimization System (ProDROMOS)



Cybersecurity for DER

SunSpec/Sandia DER Cybersecurity Workgroup

Communication and Protocol Security

- **Define requirements and draft language for data-in-transit security rules.**
- Lead: TBD
- Authentication
- Encryption requirements
- Acceptable transport protocols

Secure Network Architecture

- **Create DER control network topology requirements and interface rules.**
- Lead: Candace Suh-Lee (EPRI)
- Segmentation
- Perimeter control
- Physical security

Started

Access Controls

- **Classify data types, associated ownership, and permissions. Define set of protection mechanisms.**
- Lead: TBD
- Access control lists
- Password control
- Data privacy

DER/Server Data and Communication Security

- **Define standardized procedure for DER and server vulnerabilities assessments.**
- Leads: Cedric Carter (Sandia) and Danish Saleem (NREL)
- Known equipment vulnerabilities
- Establish certification and auditing procedures (e.g., UL 2900, IEC 62351 Parts 3 and 4)
- Maintaining compliance, requirements for patching

Started

Stochastic Unit Commitment Algorithms

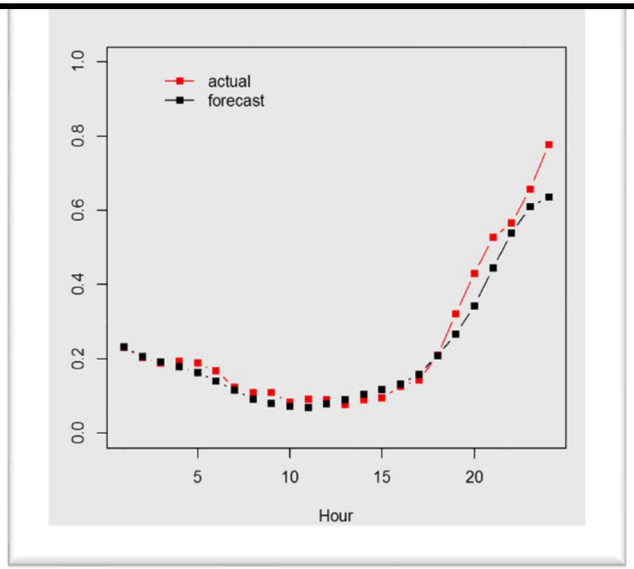
- Reduce operating costs due to variable generation and imperfect forecasts
  - Leverage stochastic optimization engines
  - Methods for representing forecast uncertainty

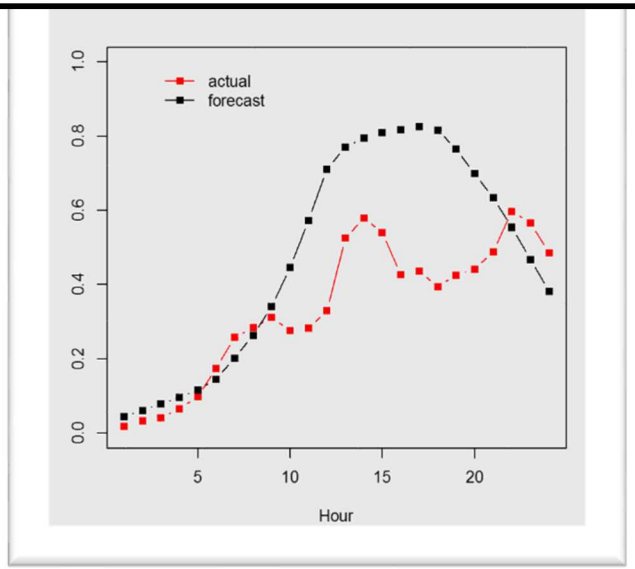
2016 R&D 100 WINNER

PYOMO

PySP

Day-ahead hourly wind generation forecasts (Bonneville Power Authority)





Deterministic UC vs. Stochastic UC

Deterministic: 2017-03-18
CP: 0 – 0.01 – 0.5 – 0.99 – 1

Stochastic: 2017-03-18
CP: 0 – 0.01 – 0.5 – 0.99 – 1