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Performance Validation and Data Collection at the Regional Test Centers

Joshua Stein | Sandia National Laboratories

The University of Vermont

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

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Reducing Cost and Improving Value of PV

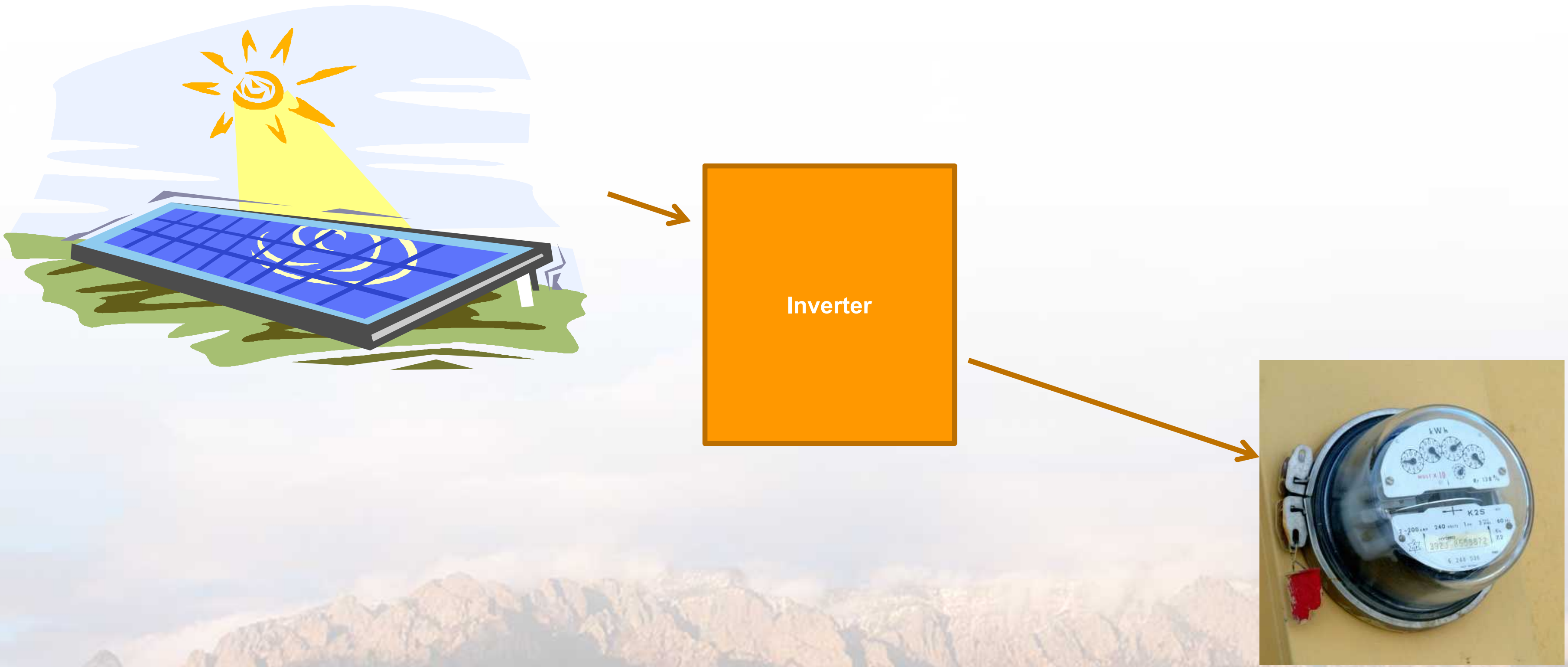
- **While PV costs are coming down, they are still too high to compete with traditional generation on a large scale.**
  - PV costs are up front (except O&M)
  - Risk is perceived to be higher than for conventional generation
- **PV technology is in flux, limited long-term experience, and performance and reliability vary significantly with region and climate.**
- **Standards for validating performance do not exist.**
- **Investors must be experts to make wise choices.**
- **Result: Investors demand high return on investment and RE companies pay more for scarce funds.**

Technical Barriers to Investment in PV

- **PV plants designs are custom**
  - Permitting and interconnections are local, Technology choices and system designs are always changing.
- **Component and system performance is difficult to predict**
  - Rating conditions do not reflect field conditions, modeling approach not standard. Sufficient characterization data is not available
- **Reliability is unknown (focus on warrantees)**
  - Many failure modes are not understood
  - Accelerated testing protocols are immature
  - O&M standards not established
- **Investors want to know a few things:**
  - How much energy will be produced?
  - How much will it cost to maintain?
  - What is the likelihood that the answers above will change?

Modeling PV Performance

Seems like a simple problem, right?



Reality is More Complicated

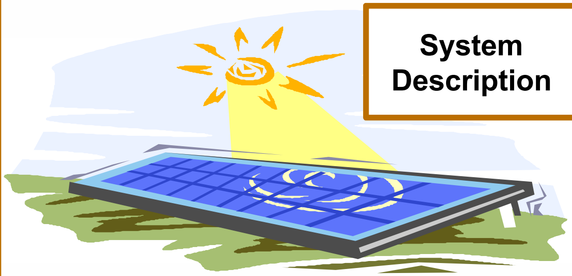
Traditional Central Inverter System

Environment

Irradiance and Weather

Incident Irradiance

Shading and Soiling Losses



System Description

Array Voltage

PV Array

Cell Temperature

Module Output

DC and Mismatch Losses

Inverter

DC to DC MPPT

DC to AC Conversion

AC Losses

Inverter

In an operating system, the inverter adjusts array voltage to optimize output.

Most models calculate module Vmp and propagate that forward to determine the dc input voltage at the inverter

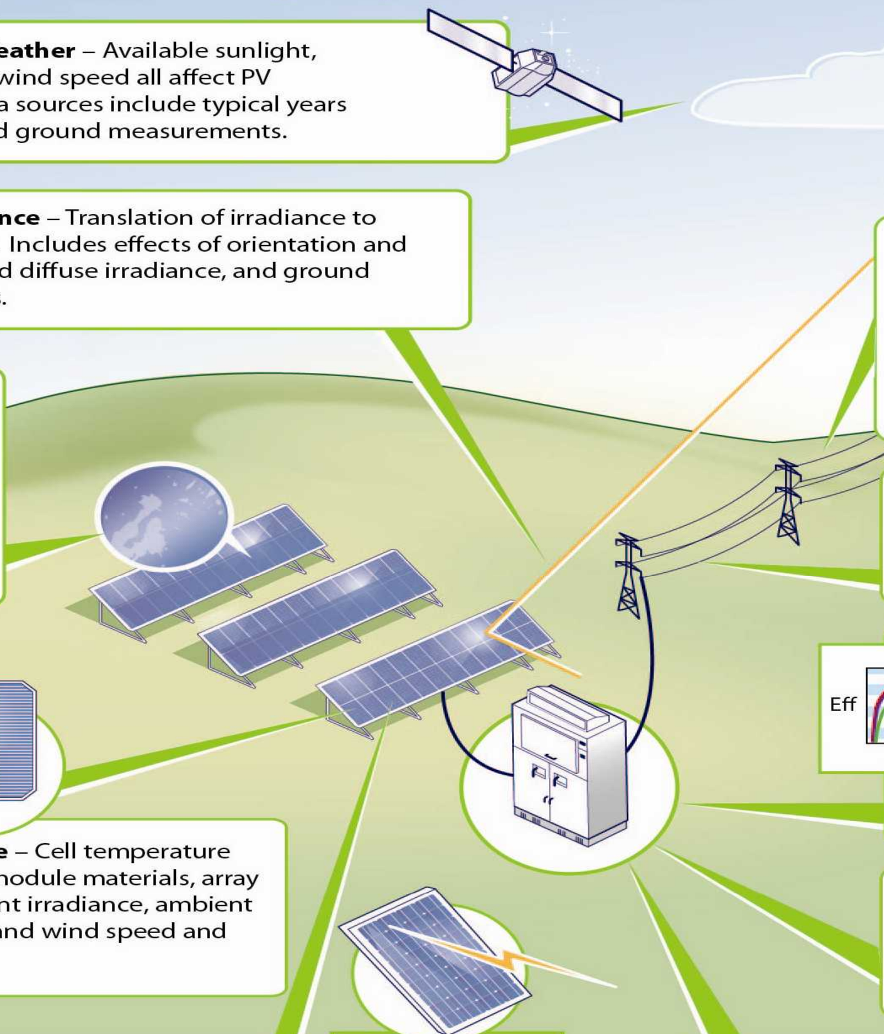
PV Performance Modeling Steps

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

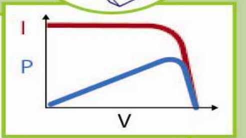
2. **Incidence Irradiance** – Translation of irradiance to the plane of array. Includes effects of orientation and tracking, beam and diffuse irradiance, and ground surface reflections.

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.



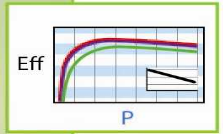
5. **Module Output** – Module output is described by the IV curve, which varies as a function of irradiance, temperature, and cell material.



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.

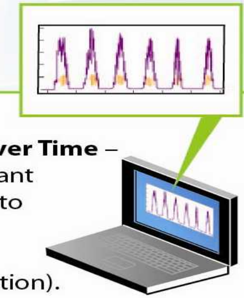
7. **DC to DC Max Power Point Tracking** – A portion of the available DC power from the array is lost due to inexact tracking of the maximum power point.

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



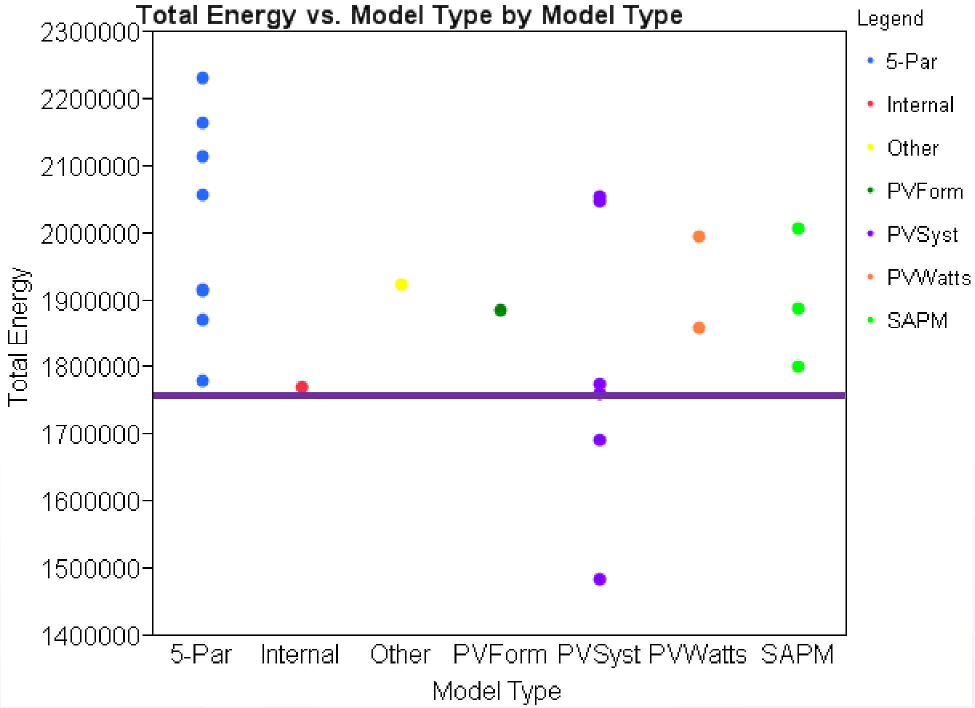
9. **AC Losses** – For large plants, there may be significant losses between the AC side of the inverter and the point of interconnection (e.g., transformer).

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



Wide Variation in Modeling Results

- **Variable levels of detail and sophistication in available models**
- **Models Do Not Always Agree**
  - Field validation is rarely available to improve confidence
- **Model accuracy and uncertainty have not been generally and independently verified**
  - Uncertainty (x ± y) generally not stated
  - No validation standards
- **New technology faces a barrier to inclusion into models**
  - Rely on component databases with little QA or consistency



- **Sandia Blind Study (2010)**
  - **20 modelers**
  - **7 models**
- **Results differ within and between models**

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RTC Approach: Validation Steps

- **Design Phase:**
  - System Design and Review
  - Baseline Module Characterization and Testing
  - Develop Performance Coefficients
- **Installation Phase:**
  - Installation Study
  - Acceptance Testing (Capacity test, performance test)
- **Performance Phase:**
  - Performance Monitoring and Real-Time Analysis
  - Periodic Testing
  - In-Depth Analysis and Validation of Performance, Reliability and Predictions
  - Reliability Assessments
- **Decommissioning Study**

- **What data is needed? How should it be documented? What is the verification process?**

Baseline Module Characterization

- **Module flash testing**
  - Indoors to confirm manufacturer's binning and to define distributions
  - Outdoors for method development and validation
  - IEC 61853-1 (variable irradiance and temperature)
  - Preconditioning studies
- **Dark IV**
  - Sensitive to cell-level performance and reliability issues
- **Photos**
  - Infrared, EL, Visual
  - Sensitive to cell damage, faulty diodes, encapsulant degradation, document backsheet problems.
- **Periodic retests to detect changes and identify problems.**

Validation of Performance

- **RTC will compare “identical” systems in different climates**
  - System designs
  - Weather instruments
  - Monitoring system
  - Calibration procedures
- **System performance will be simulated using measured weather and characterization data and then compared with measured performance.**
- **Detailed studies will examine the modeling errors to identify how to improve the performance models for all sites.**
  - Attempt to detect degradation
  - Trade-off studies (e.g. how much data is needed?)
- **Develop standards describing how to validate performance**
  - Monitoring data requirements
  - Standard tests before and after installation

Operations and Maintenance Studies

- **Extensive and formal O&M procedures are an important feature of all established industries.**
  - Think automobiles, power plants, etc.
  - O&M can develop into a separate industry (e.g., Jiffy Lube, auto parts, etc.)
- **There are no existing standards for operation and maintenance (O&M) of PV plants.**
  - Unclear what is the best strategy (many "failures" have minor effect of performance).
  - Monitor and fix, preventative maintenance, or install and forget?
- **RTC systems will be "over" monitored in order to detect component problems and provide detailed data for use in developing O&M standards.**
  - String-level monitoring
  - Soiling and snow detection

What Data Will Be Collected?

- **Weather station (1 minute)**
  - Irradiance (DNI, GHI, DHI, POA)
  - Temperature (air and module)
  - Wind speed, humidity, pressure
  - Site camera (snow monitoring)
- **Electrical Performance (1 minute)**
  - DC current and voltage (system, inverter, sting)
  - AC current, voltage, power quality (system, inverter)
- **O&M events**
- **Periodic string IV curves**

- **Data will be collected and combined into a database for all sites.**

Success: What Does it Look Like?

- **RTC partners get:**
  - High quality performance data from their systems
  - Expert advice on how to accurately predict performance for their technology and designs in a variety of climates.
  - Opportunity to try new technologies and ideas in the field (e.g., 1500 V)
- **Industry gets:**
  - Transferable set of test and monitoring procedures that have been validated at the RTCs.
  - Franchise model?
- **U.S. gets:**
  - Unique set of facilities to support the SunShot goals and objectives
  - Technology validation approach which, if successful, can be replicated for related industries (CSP, smart grid, etc.)

Challenges and Opportunities

- **Funding to build not to operate.**
  - Need to find a sustainable operational model (Partnerships?)
- **No current industry partners for VT RTC**
  - Notice of Technical Assistance (NOTA)
- **How to expand value proposition for RTCs?**
  - Add accelerated testing (technology hub?)
  - Module-scale conversion?
  - Smart-grid applications?
  - Inverter-level investigations?
- **Utility interactions (interconnection, ownership, etc.)**
- **Work Force Development**
- **O&M Training**
- **Other business models**
- **We need to look to other industries for successful examples.**

THANK YOU