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Application of IEC 61724 Standards to Analyze PV System Performance in Different Climates

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Katherine Klise[1], Joshua Stein[1], Joseph Cunningham[2]

1 Sandia National Laboratories, Albuquerque, NM

2 Sunny Energy, Tempe, AZ

U.S. DEPARTMENT OF ENERGY NNSA

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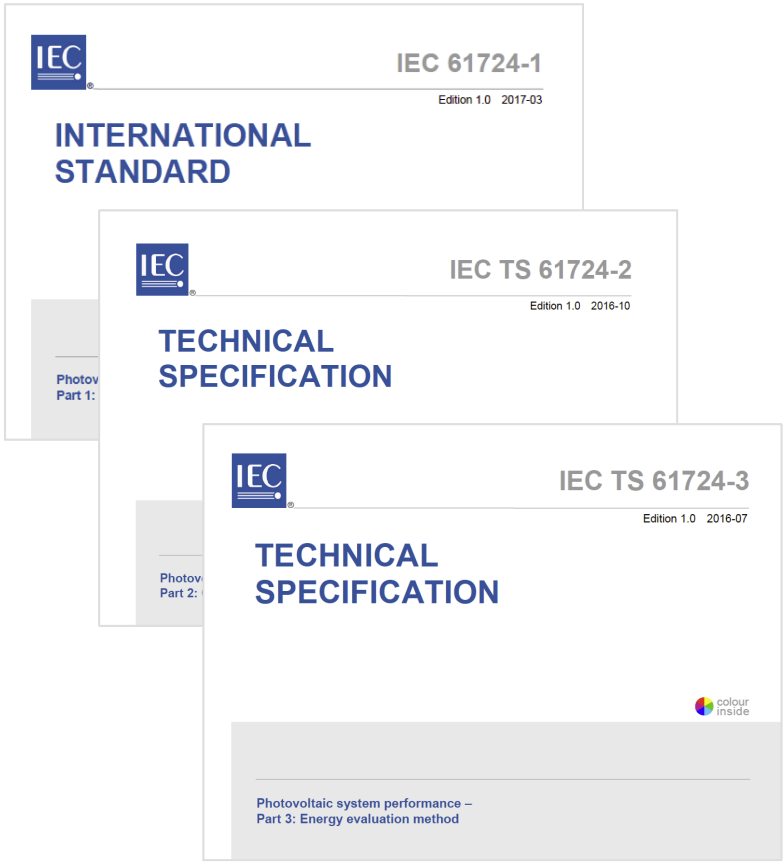
IEC 61724

- Standards for PV monitoring and evaluation
- **Part 1: Monitoring**
  - Guidance on monitoring equipment, data collection
  - Number, location, maintenance, sampling and recording frequency
  - Class A, B, C systems
- **Part 2: Capacity evaluation method**
  - Evaluation of power output during reference conditions (a few relatively sunny days)
- **Part 3: Energy evaluation method**
  - Evaluate performance over the full range of operating conditions (1 year)



Available at https://webstore.iec.ch

Part 3 Energy Evaluation

- Compare measured energy to expected energy given measured weather conditions over the course of one year
- $EPI = \frac{Measured\ Energy}{Expected\ Energy}$
- EPI is computed for times when the system is available (in-service EPI) and over the entire year (all-in EPI)
- Guidelines outlined in IEC 61724-3 should be customized for a particular system
  - Requirements can depend on the system size, instrumentation, and intended purpose of the analysis
  - A system performance model must be defined along with data filtering methods and thresholds used in data quality control tests

- Goal: Apply methods outlined in IEC 61724-3 to diverse data sets using open source software tools

Regional Test Center Data

- Regional Test Center Baseline and Weather systems
  - New Mexico, Nevada, Florida, Vermont
  - 2 strings of 12 Suniva Optimus 270 Black modules
- Basic quality control analysis is run daily (near real-time), results emailed to stakeholders
- Summary reports are generated each year
  - 2016 data, recorded at 1 minute time interval
  - ~ 25 million data points per site
- Sensor failure and system downtime is expected to be higher for these systems, as compared to production-level systems

Module specs: Pmax = 270 W, Vmp = 31.2 V, Voc = 38.5 V, Imp = 8.68 A, Isc = 9.15 A

Weather data	Baseline PV data
GHI, DNI, DHI, air pressure, wind speed, wind direction, air pressure, relative humidity	POA, module temperature, ambient temperature For each string: DC voltage, DC current, AC voltage, AC current, AC power, power factor, frequency, reference cell irradiance, and reference cell temperature

Open Source Software Tools

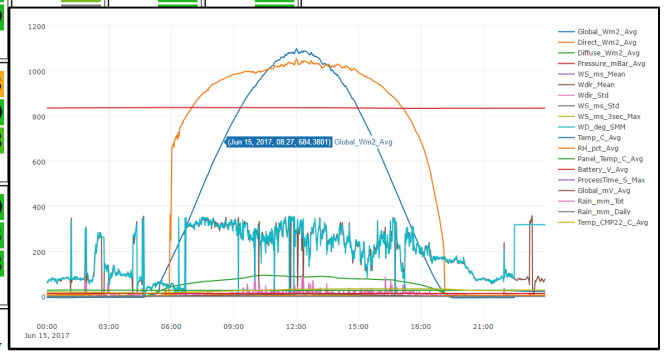
- Open source Python packages for automated quality control and performance monitoring of PV data
- PVLIB includes methods to:
  - Estimate system performance
  - Compute sun position, used to filter data collected in the early morning/late afternoon
  - https://github.com/pvlib/pvlib-python
- Pecos includes methods to:
  - Run quality control tests
  - Compute performance metrics to track long term system health
  - Generate reports and graphics
  - https://github.com/sandialabs/pecos

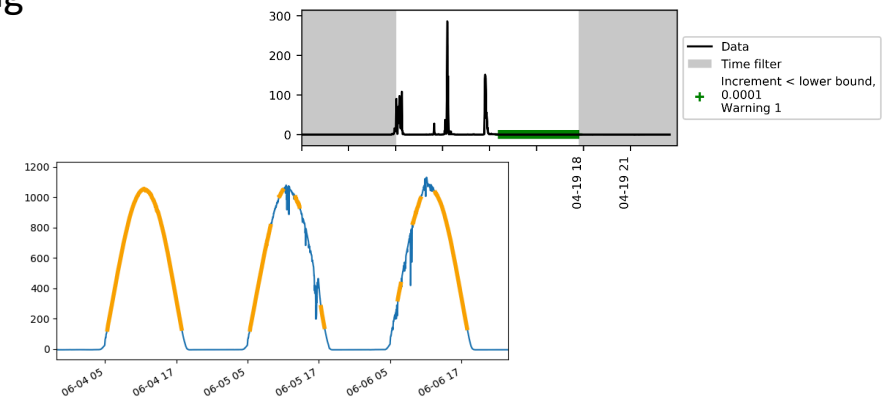
pvlib-python

Pecos✓

	System 1	System 2	System 3	System 4
Location 1	DA 1.00 QCI 1.00 EPI 0.99	DA 0.13 QCI 0.78	DA 1.00 QCI 1.00	DA 1.00 QCI 1.00
Location 2	DA 0.43 QCI 1.00 EPI 0.88			
Location 3	DA 1.00 QCI 0.93 EPI 0.98			

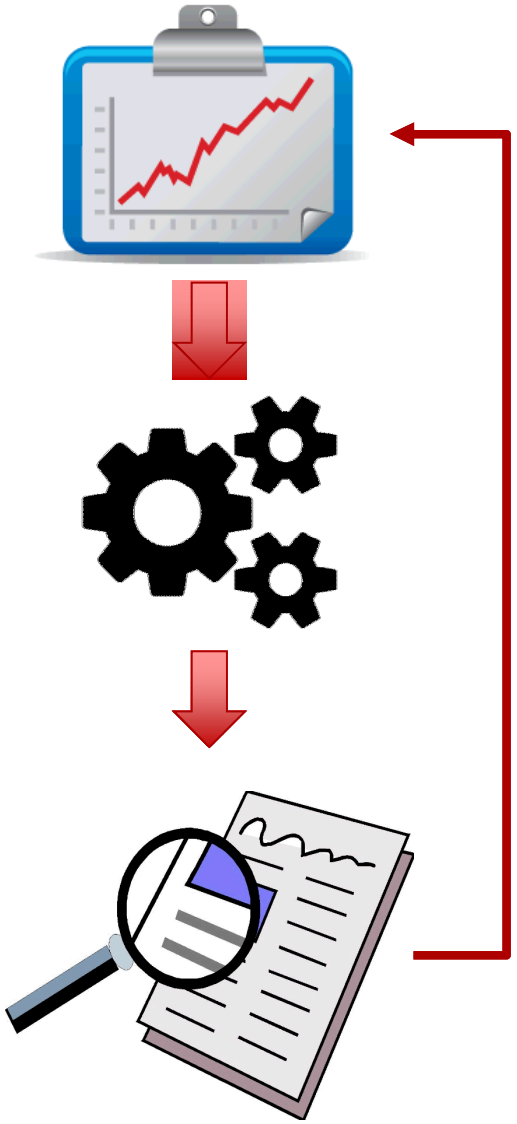
DA = Data availability
QCI = Quality control index
EPI = Energy performance index





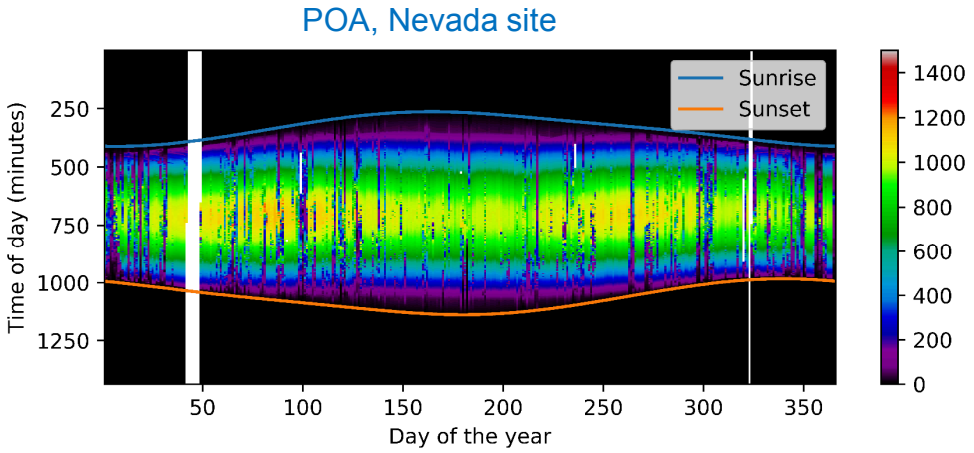
Analysis Procedure

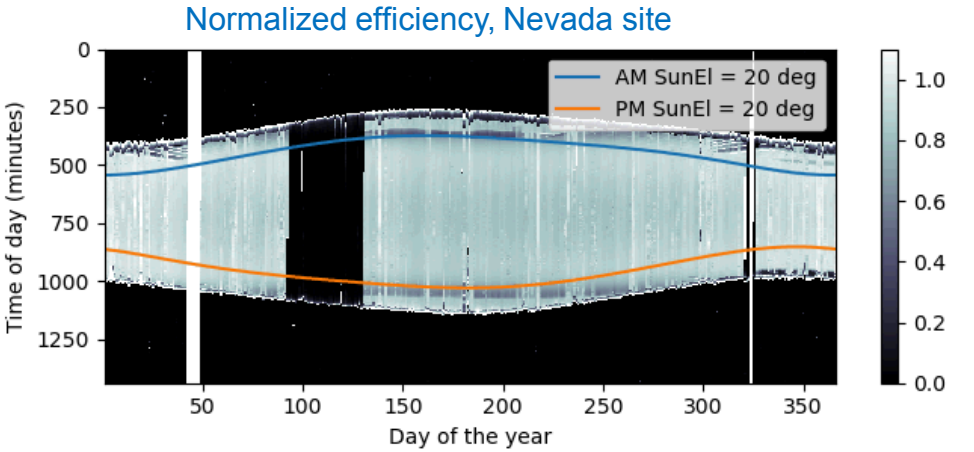
- Gather data
  - Data type and frequency
- Define analysis
  - Filters
  - Composite data
  - Quality control analysis
  - Performance model
- Compute metrics
  - In-service EPI
  - All-in EPI
  - System availability
  - Data availability
  - Percent of data that passed quality control tests
- Generate reports and graphics



Preliminary Data Inspection

- Day-of-year vs. time-of-day heatmaps
  - Identify systematic errors and trends
  - Identify large data gaps
  - Define filters
  - Define quality control thresholds
- Compare measurement to a model
- Compare data at different sites
- Fill large data gaps with historical data, duplicate sensors, or modeled data

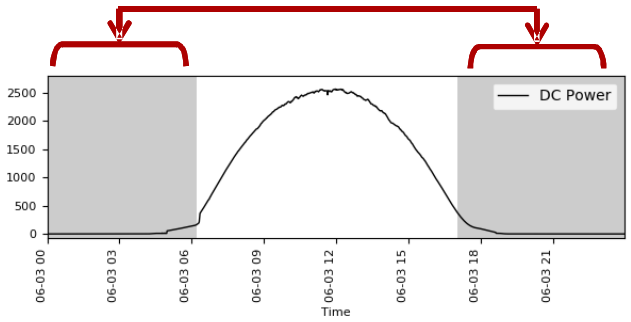




Analysis

- Filter data
  - Sun elevation < 20 degrees
- Composite data
  - DC power
  - Inverter efficiency
  - Normalized efficiency
  - Module temperature deviation
  - Power performance index
- Performance model
  - PVWatts
- Quality control tests
  - Missing data
  - Data outside expected range
  - Dead sensors
  - Sensors that change abruptly

Time filter based on sun position



Module temperature

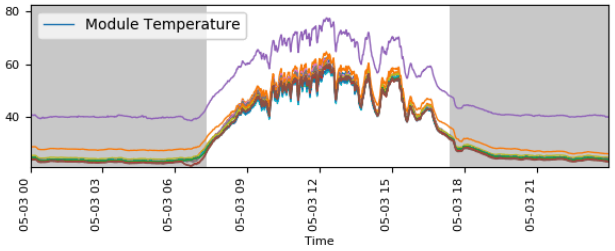


Table 3 – Example of data filtering criteria, to be adjusted according to local conditions

		Suggested criteria for flag (15 min data)			
Flag type	**Description**	**Irradiance** W/m²	**Temperature** °C	**Wind speed** m/s	**Power (AC power rating)**
Range	Value outside of reasonable bounds	< –6 or > 1 500	> 50 or < –30	>32 or < 0	> 1,02 × rating or < –0,01 × rating
Missing	Values are missing or duplicates	n/a	n/a	n/a	n/a
Dead	Values stuck at a single value over time. Detected using derivative.	< 0,0001 while value is > 5	< 0,0001	?	?
Abrupt change	Values change unreasonably between data points. Detected using derivative.	> 800	> 4	> 10	> 80 % rating
May be adjusted depending on the tilt of the system and the season of data acquisition.					

From IEC 61724-3

Quality Control Thresholds

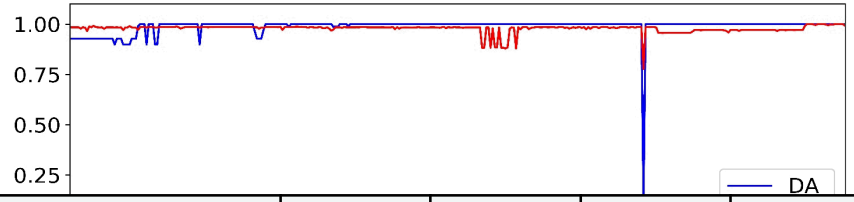
Variable	Expected range	Dead sensor threshold	Abrupt change threshold
DC current and AC current (A)	> 0 and < Imp·1.5 for 2 hours	< 0.0001 in 5 hours	
DC voltage (V)	> 0 and < Vmp·N·1.2 * for 2 hours	< 0.0001 in 5 hours	
AC voltage (V)	> 230 and < 250 for 2 hours	< 0.0001 in 5 hours	
DC power ** and AC power (W)	> 0 and < Pmp·N·1.2 * for 2 hours	< 0.0001 in 5 hours	
Power factor	> -1 and < 1 for 2 hours	< 0.0001 in 5 hours	
Frequency (Hz)	> 57 and < 63 for 2 hours	< 0.0001 in 5 hours	
POA, DNI, GHI, and ref cell irradiance (W/m^2)	> -6 and < 1500 for 2 hours	< 0.0001 in 5 hours	
DHI (W/m^2)	> -6 and < 500 for 2 hours	< 0.0001 in 5 hours	
Wind speed (m/s)	> 0 and < 32 for 2 hours	< 0.0001 in 5 hours	
Wind direction	> 0 and < 360 for 2 hours	< 0.0001 in 5 hours	
Air pressure (mbar)	> P·0.97 and < P·1.03 * for 2 hours	< 0.0001 in 5 hours	> 25 in 15 minutes
Relative humidity	> 0 and < 100 for 2 hours	< 0.0001 in 5 hours	> 50 in 15 minutes
Ambient temperature (°C)	> -30 and < 50 for 2 hours	< 0.0001 in 5 hours	> 20 in 15 minutes
Module and ref cell temperature (°C)	> -30 and < 90 for 2 hours	< 0.0001 in 5 hours	> 20 in 15 minutes
Inverter efficiency**	> 0.5 and < 1 for 2 hours		> 0.25 in 15 minutes
Normalized efficiency **	> 0.8 and < 1.2 for 2 hours		> 0.25 in 15 minutes
Module temperature deviation (°C) **	> -10 and < 10 for 2 hours		
Power performance index **	> 0.8 and < 1.2 for 2 hours		

* N is the number of series connected modules and P is the expected air pressure based on site elevation
** Composite signal

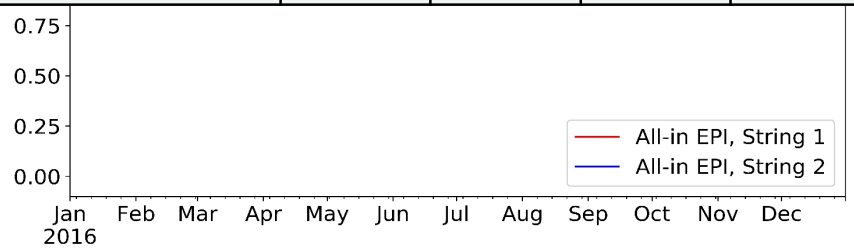
Metrics

- Data availability (DA): percent of expected data that was recorded
- Quality control index (QCI): percent of available data that passed all quality control tests
- System availability (SA): percent of data associated with power, inverter efficiency, normalized efficiency, and power performance index that passed all quality control tests
- Energy performance index (EPI): ratio of measured energy to expected energy (in-service and all-in)

New Mexico site



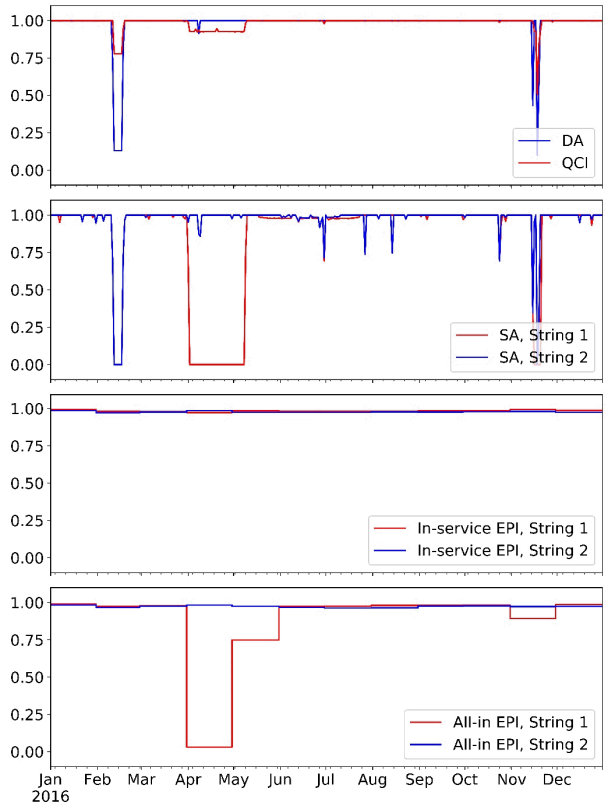
	NM	NV	FL	VT
DA	99%	98%	96%	95%
QCI	98%	99%	98%	92%
SA, String 1	98%	86%	83%	72%
SA, String 2	98%	97%	84%	72%
In-service measured energy (kWh)	11517	10476	8693	5528
In-service expected energy (kWh)	11608	10679	9104	5802
All-in expected energy (kWh)	11696	11390	9911	7305
In-service EPI	99%	98%	95%	95%
All-in EPI	98%	92%	88%	76%



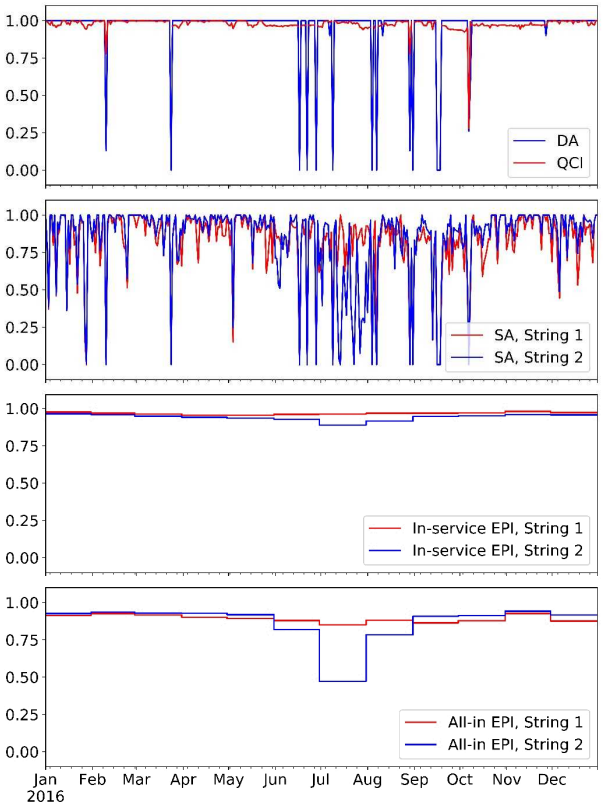
Energy Evaluation

- System availability is highly variable in Florida and Vermont
- Large data gap in Vermont and lower QCI

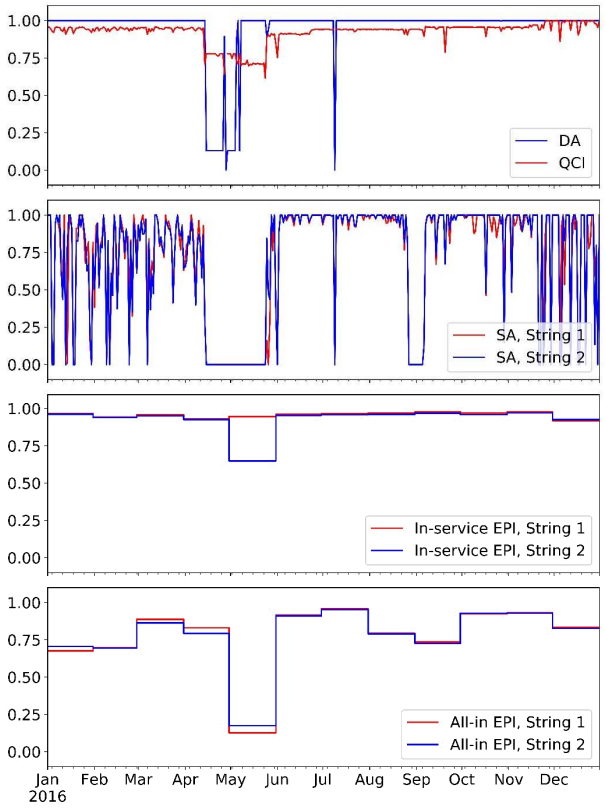
Nevada site



Florida site



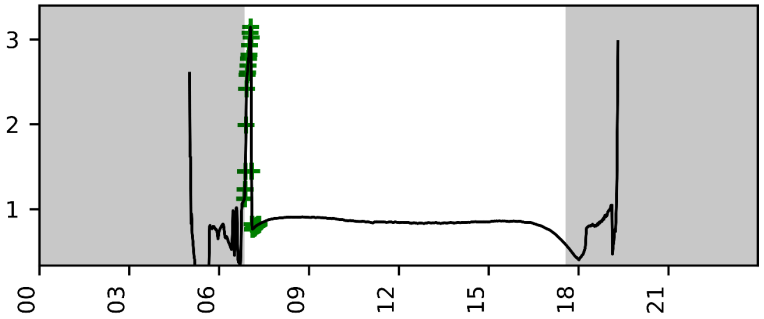
Vermont site



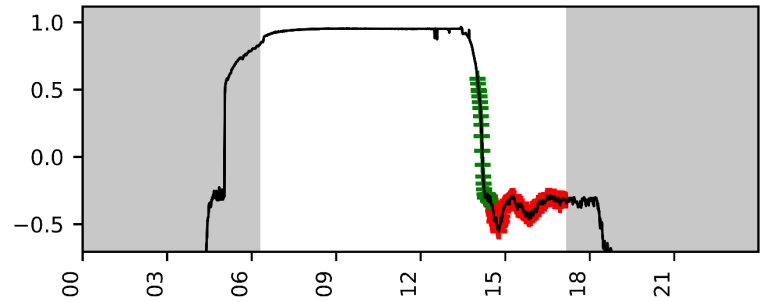
Quality Control Issues

- Datalogger/file transfer issues
- Calibration issues
- Unexpected shading
- Dead sensors
- Sensors that change erratically
- Sensor drift
- Underperforming inverters

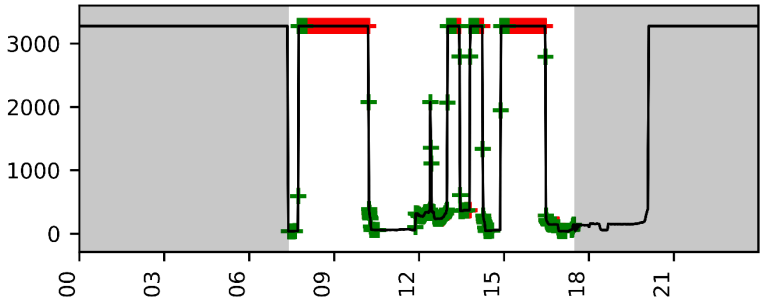
Normalized Efficiency, New Mexico site



Inverter Efficiency, Nevada site



Module Temperature, Florida site

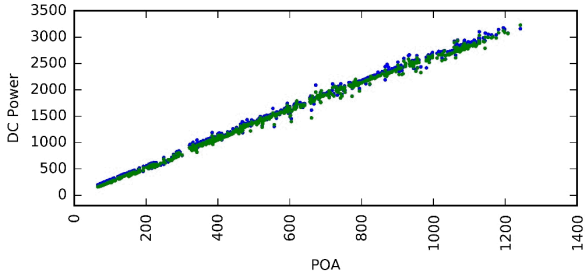


Daily Reports

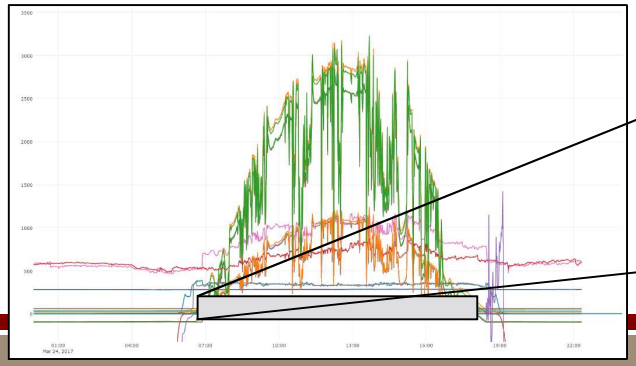
Red/yellow/green dashboard with links to details and interactive graphics

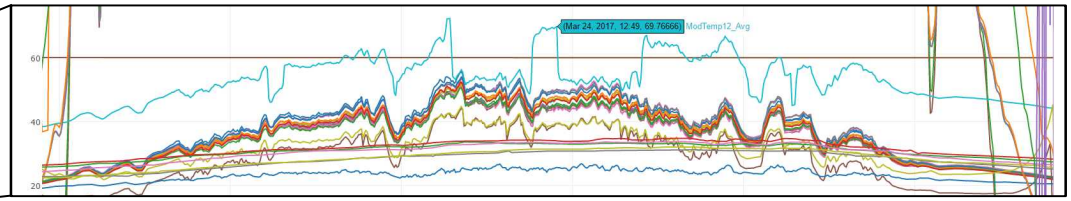
RTC Dashboard for 2017-03-24

	New Mexico	Florida	Vermont	Nevada
Weather	Irradiance 1.00 Wind 1.00 Air Pressure 1.00 Humidity 1.00 Rainfall 1.00 Datalogger 1.00 Detailed Report Interactive Plot	Irradiance 1.00 Wind 1.00 Air Pressure 1.00 Humidity 1.00 Rainfall 1.00 Datalogger 1.00 Detailed Report Interactive Plot	Irradiance 0.57 Wind 1.00 Air Pressure 1.00 Humidity 1.00 Rainfall 1.00 Datalogger 1.00 Detailed Report Interactive Plot	Irradiance 1.00 Wind 1.00 Air Pressure 1.00 Humidity 1.00 Rainfall 1.00 Datalogger 1.00 Detailed Report Interactive Plot
Baseline	Irradiance 1.00 Temperature 1.00 Current 1.00 Voltage 1.00 Power 0.64 Detailed Report Interactive Plot	Irradiance 1.00 Temperature 0.19 Current 1.00 Voltage 1.00 Power 0.93	Irradiance 1.00 Temperature 1.00 Current 0.27 Voltage 1.00 Power 0.24 Detailed Report Interactive Plot	Irradiance 1.00 Temperature 1.00 Current 1.00 Voltage 1.00 Power 1.00 Detailed Report Interactive Plot



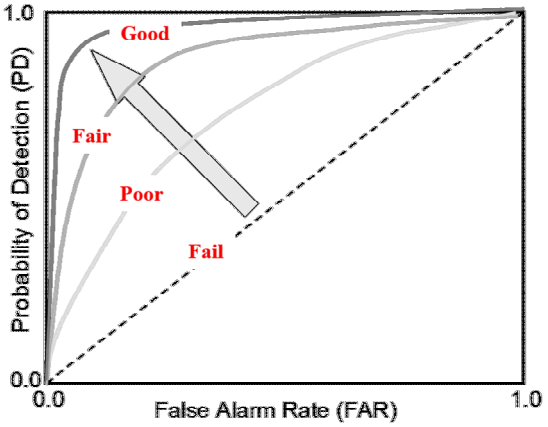
ModTemp12_Avg Temperature Deviation





Next Steps

- Validate methods with system logs
  - Probability of detection
  - False alarm rate
- Scale-up analysis for larger systems
  - Known bottleneck in using moving window computation
- Software development
  - Publish Python scripts used to run the energy evaluation
  - Continue adding analysis, graphics, and dashboards to support IEC-61724



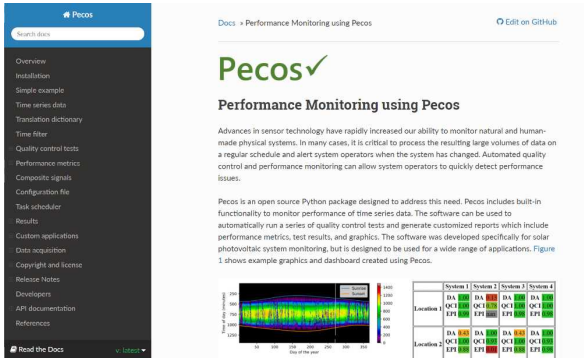


Photo from NREL/DOE