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Performance Monitoring using Pecos

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Overview

- What is Pecos?
  - Performance monitoring for time series data
- Why use Pecos?
  - Collect large amounts of data on multiple systems and locations
  - Run automatic quality control tests on that data
  - Alert system operators when the system has changed
  - Generate reports
  - Collect performance statistics to track long term system health
  - Compare system performance across sites
- Pecos was developed specifically for solar photovoltaic system monitoring, but it can be customized for other applications

TOA5	CR1000	46385	CR1000.Std.24	CPU:ABQ_RTC_MET_2013_03_21.CR1	58869	DataOut
TIMESTAMP	Global_Wm2_Avg	Direct_Wm2_Avg	Diffuse_Wm2_Avg	Pressure_mBar_Avg	WS_ms_Mean	Wdir_Mean
TS						Deg
	Avg	Avg	Avg	Avg	WVc	WVc
3/26/2013 0:00	-1.16195	-0.45458	0	832.121	6.338	135.7
3/26/2013 0:01	-1.14918	-0.5455	0	832.123	5.8	136.4
3/26/2013 0:02	-1.14918	-0.52277	0	832.106	5.988	131.2
3/26/2013 0:03	-1.14918	-0.45458	0	832.0875	6.838	139.6
3/26/2013 0:04	-1.14918	-0.45458	0	832.0799	6.825	136.8
3/26/2013 0:05	-1.14918	-0.45458	0	832.0693	6.775	137
3/26/2013 0:06	-1.14919	-0.40155	0	832.0547	6.825	135.2
3/26/2013 0:07	-1.14919	-0.31063	0	832.0114	6.85	137.4
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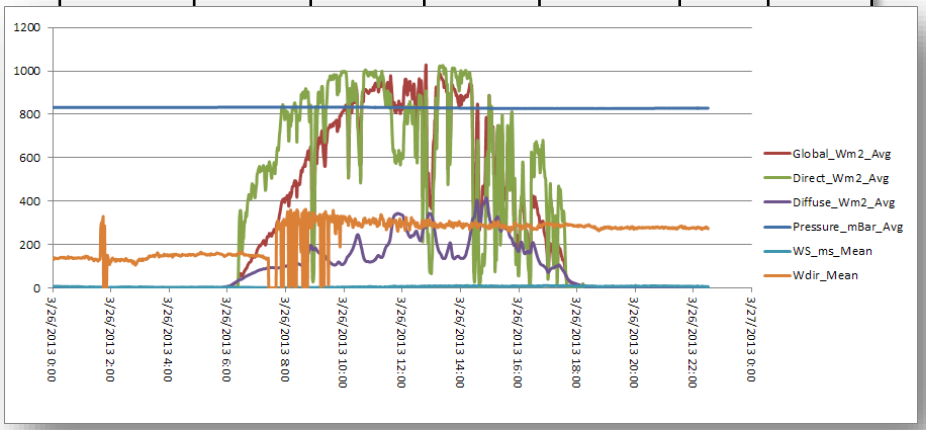
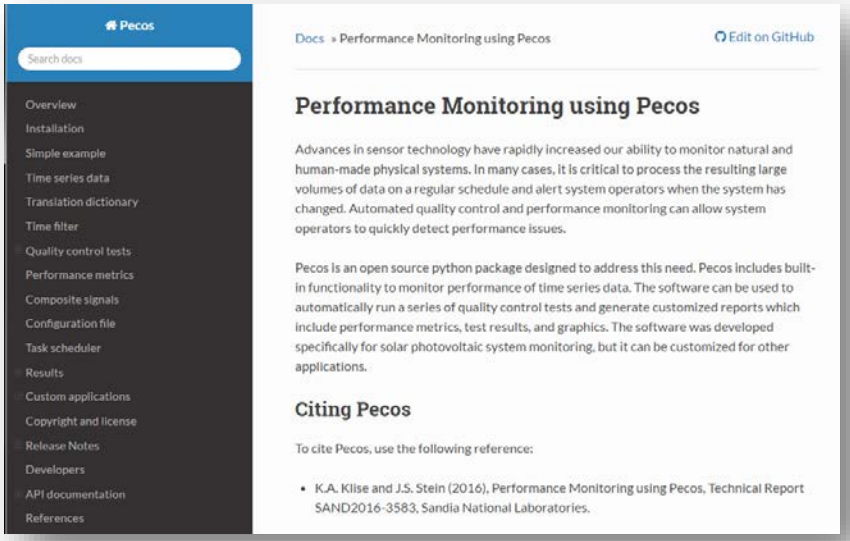
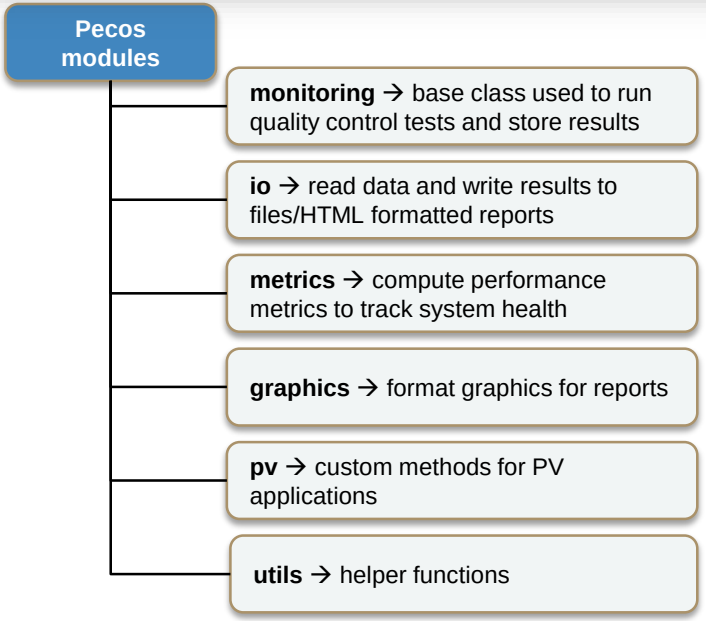
3/26/2013 0:10	-1.14922	-0.45459	0	832.0093	6.063	136.4
3/26/2013 0:11	-1.14921	-0.45459	0	832.0027	6.825	134.6
3/26/2013 0:12	-1.14921	-0.45459	0	831.9932	6.813	135.8
3/26/2013 0:13	-1.14921	-0.36367	0	831.9811	6.65	137.2
3/26/2013 0:14	-1.14921	-0.28791	0	832.0098	7	137.1
3/26/2013 0:15	-1.14921	-0.45459	0	832.0153	6.738	138.6
3/26/2013 0:16	-1.1492	-0.45459	0	831.9963	6.613	141.1
3/26/2013 0:17	-1.1492	-0.60612	0	832.0099	6.125	139.8
3/26/2013 0:18	-1.1492	-0.84099	0	832.0046	6.113	139.9



Software Framework

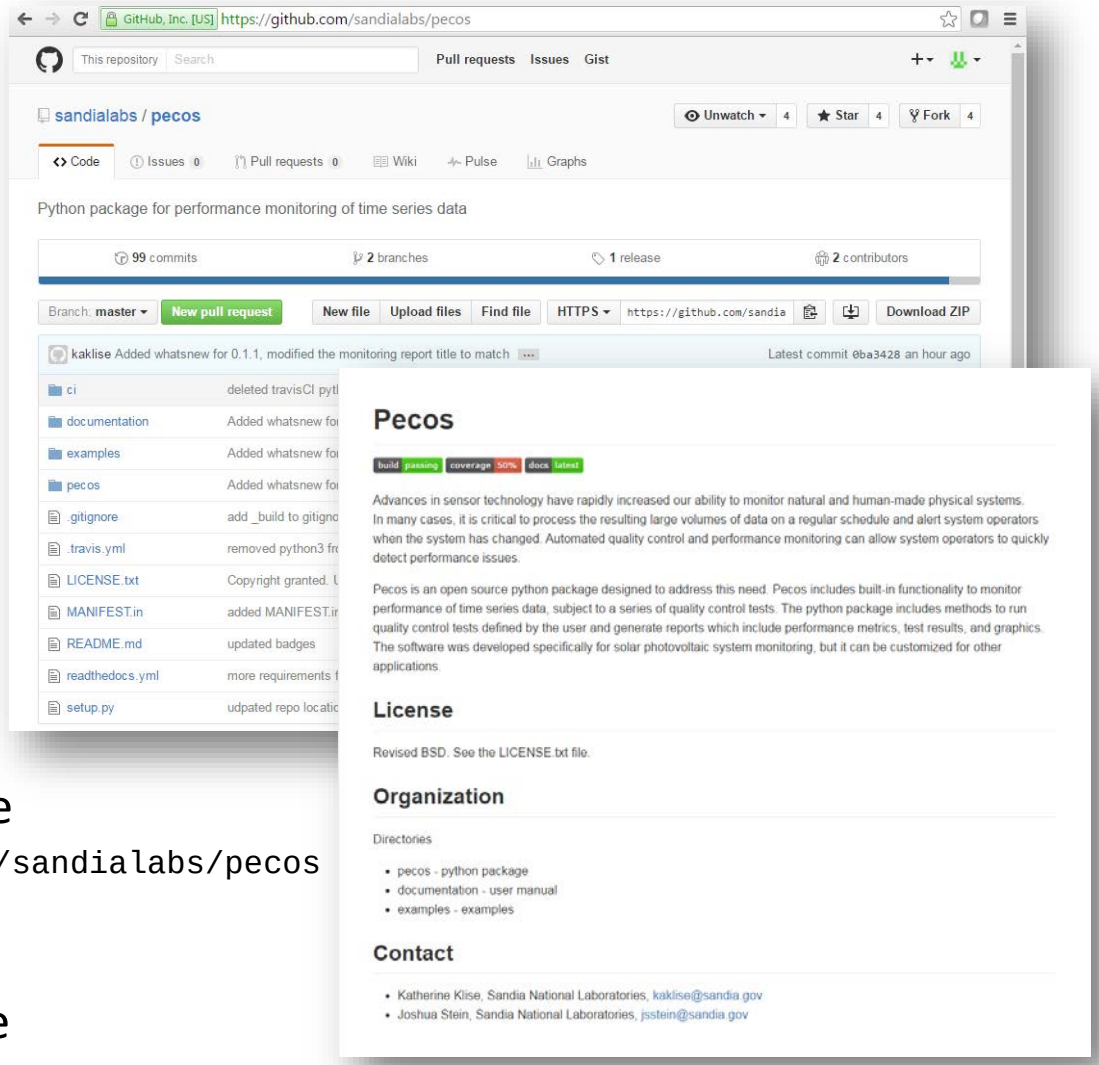
- Open-source python package
  - Revised BSD License
- Software repository
  - https://github.com/sandialabs/pecos
- Documentation
  - http://pecos.readthedocs.io
  - Includes API documentation
- Software testing results
  - https://travis-ci.org/sandialabs/pecos
  - https://coveralls.io/github/sandialabs/pecos
- 'Getting started' examples included with the software
  - simple
  - pv
  - metrics
  - dashboard





Installation

- Required dependencies
  - Python 2.7
  - pandas
  - numpy
  - Matplotlib
- Optional dependencies
  - pvlib
  - pyyaml
  - win32com
  - nose



- Building pecos from source

```
git clone https://github.com/sandialabs/pecos
cd pecos
python setup.py install
```

- Installing the latest release

```
pip install pecos
```

Basic Workflow

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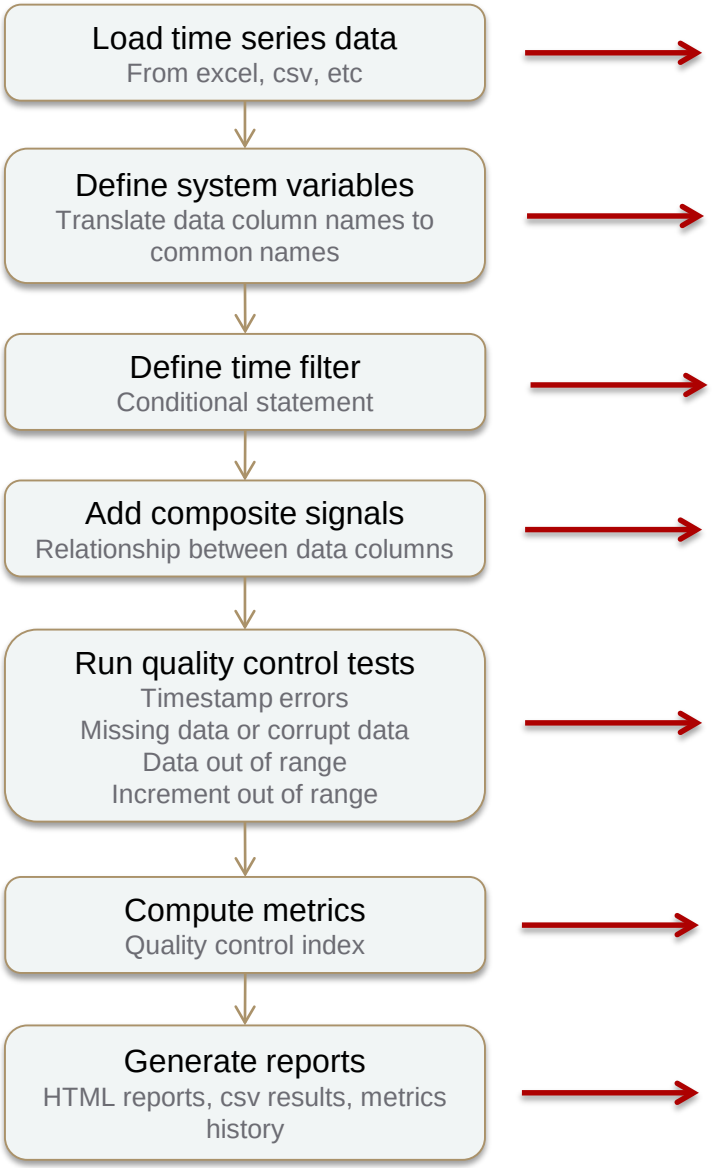
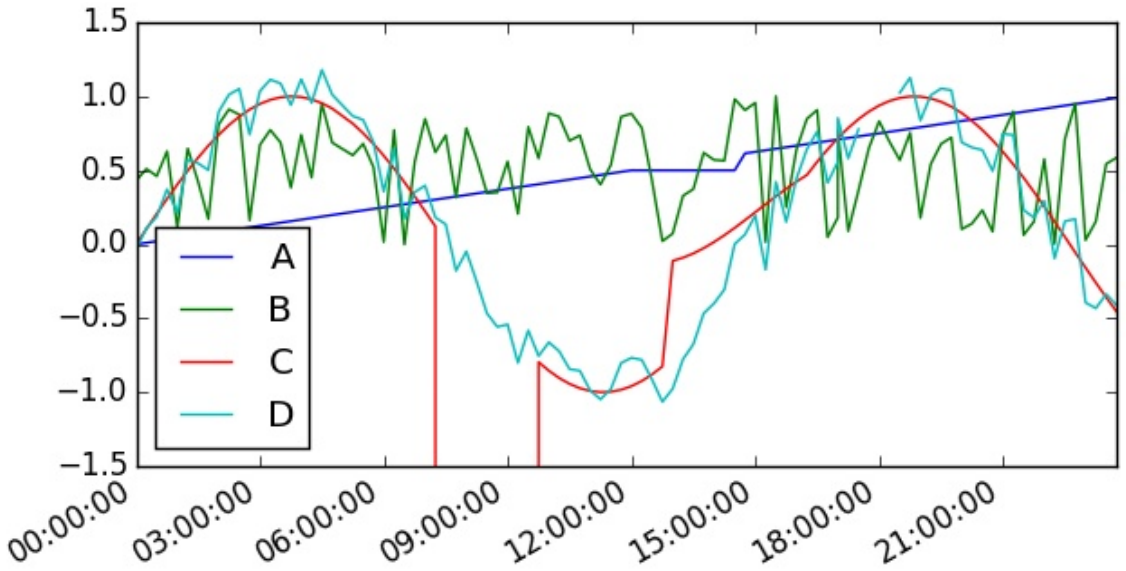


- Monitoring reports (html) include
  - Custom graphics
  - Table and graphics of test results
  - Performance metrics
- Test results file (csv) includes
  - System/variable name
  - Start and end time of failure
  - Number of time steps involved
  - Error flag
- Performance metrics file (csv) includes
  - Running history of stats
- Dashboards (html) includes
  - System summary
  - Link to monitoring report

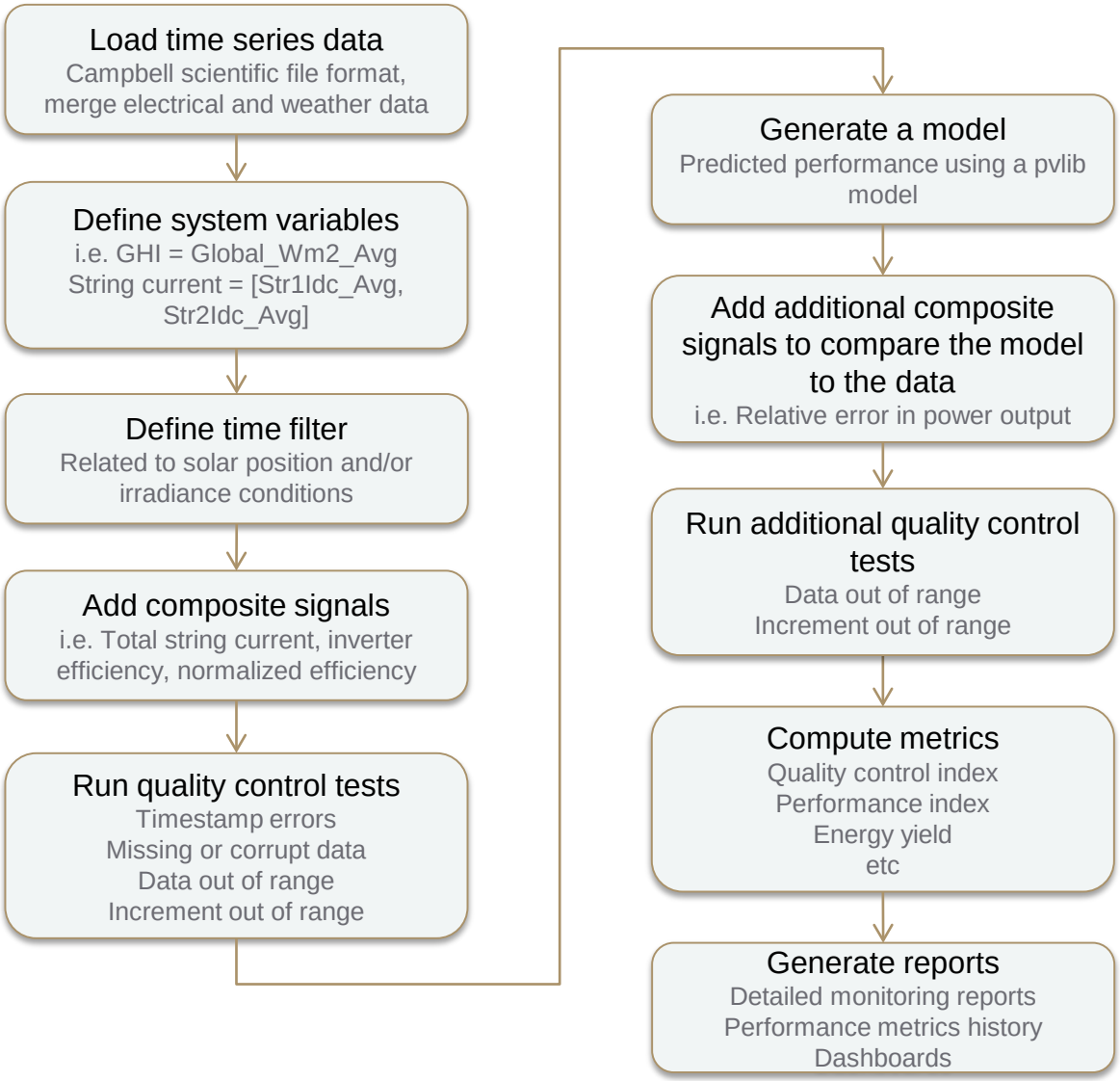
```
pecos.io.write_monitoring_report(…)
pecos.io.write_test_results(…)
pecos.io.write_metrics(…)
pecos.io.write_dashboard(…)
```

Basic Example

- simple_example.py
  - The data includes missing timestamps, duplicate timestamps, non-monotonic timestamps, corrupt data, data out of expected range, data that doesn't change, and data that changes abruptly.
  - A = elapsed time in days
  - B = uniform random number between 0 and 1
  - C = sin(10*A)
  - D = C+(B-0.5)/2

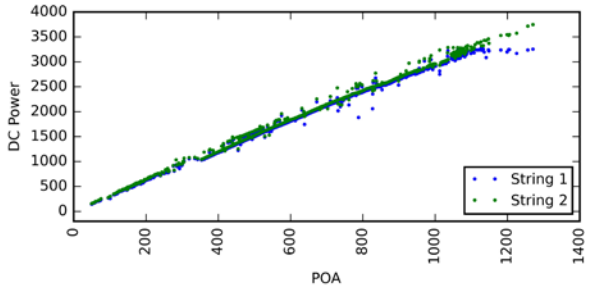


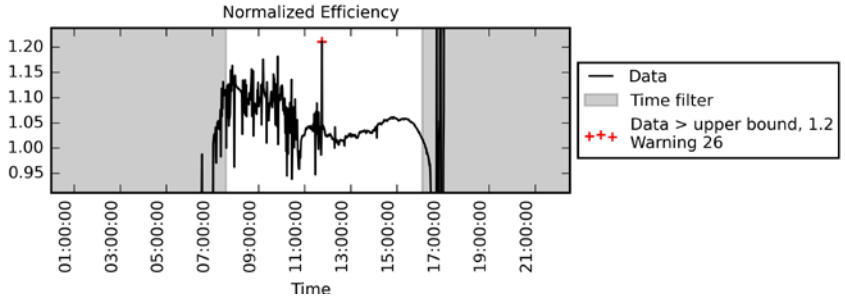
PV Workflow

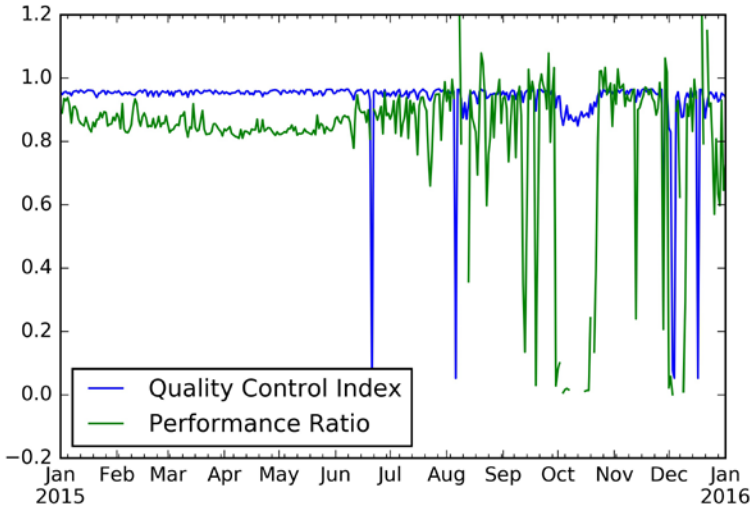

Load time series data
Campbell scientific file format, merge electrical and weather data
Define system variables
i.e. GHI = Global_Wm2_Avg
String current = [Str1Idc_Avg, Str2Idc_Avg]
Define time filter
Related to solar position and/or irradiance conditions
Add composite signals
i.e. Total string current, inverter efficiency, normalized efficiency
Run quality control tests
Timestamp errors
Missing or corrupt data
Data out of range
Increment out of range
Generate a model
Predicted performance using a pvlib model
Add additional composite signals to compare the model to the data
i.e. Relative error in power output
Run additional quality control tests
Data out of range
Increment out of range
Compute metrics
Quality control index
Performance index
Energy yield
etc
Generate reports
Detailed monitoring reports
Performance metrics history
Dashboards

PV Examples

- pv_example.py
  - YAML configuration file
  - Electrical and weather data
  - Time filter based on sun position
  - pvlib performance model and metric
- metrics_example.py
  - Track long term system health
  - Performance metrics from daily analysis



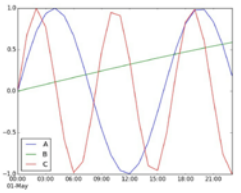
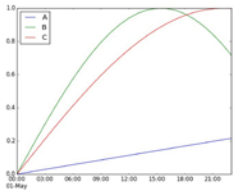
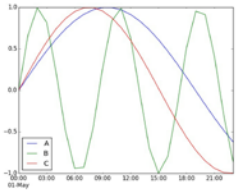
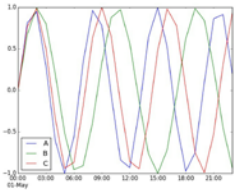
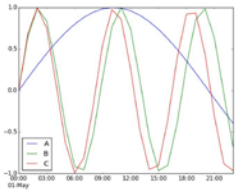
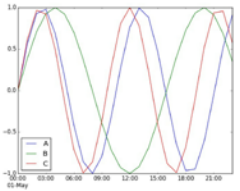




Dashboard Example

- dashboard_example.py
  - Compare performance of several systems
  - Generic dashboard
  - Includes text, graphics, table and link

Pecos Dashboard

	location1	location2
system1	Example text for location1_system1  Quality Control Index 0.784314 Link to Report	Example text for location2_system1  Quality Control Index 0.72549 Link to Report
system2	Example text for location1_system2  Quality Control Index 0.555556 Link to Report	Example text for location2_system2  Quality Control Index 0.6 Link to Report
system3	Example text for location1_system3  Quality Control Index 0.384615 Link to Report	Example text for location2_system3  Quality Control Index 0.461538 Link to Report

This report was generated by Pecos 0.1.1, 05/02/2016

Dashboard Example

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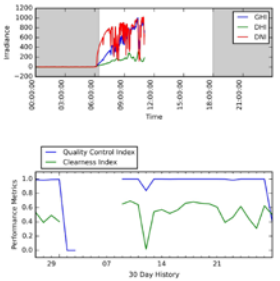
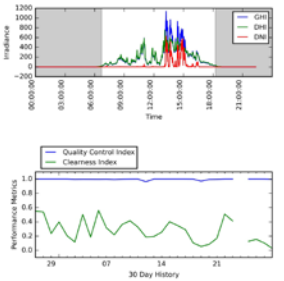
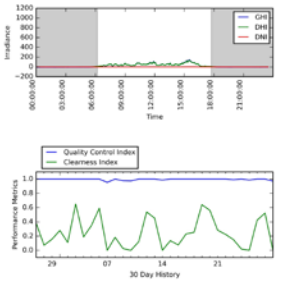
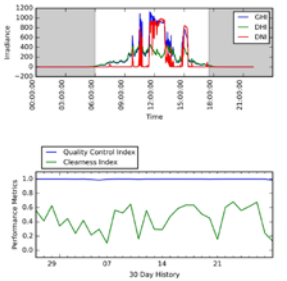
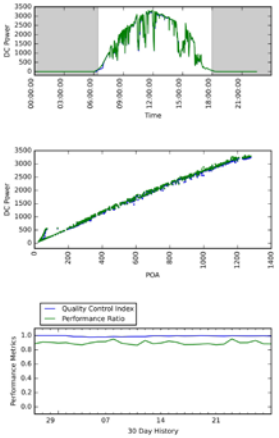
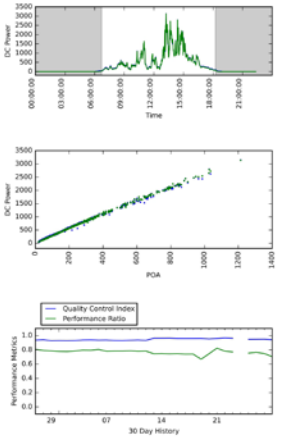
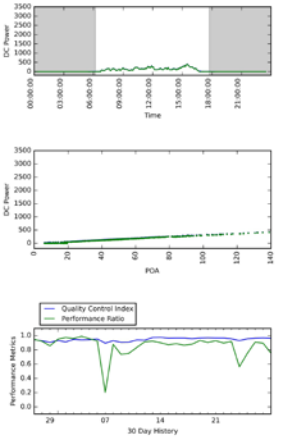
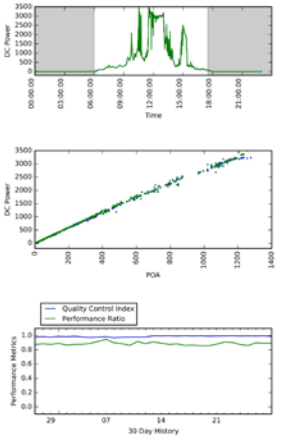
Pecos Dashboard for 2016-03-28

	Location 1	Location 2	Location 3	Location 4
Weather				
	Quality Control Index: 0.392238 Clearness Index: 0.499177	Quality Control Index: 0.997323 Clearness Index: 0.029179	Quality Control Index: 0.971821 Clearness Index: 0.000057	Quality Control Index: 0.984104 Clearness Index: 0.128900
	Link to Detailed Report	Link to Detailed Report	Link to Detailed Report	Link to Detailed Report
Baseline				
	Quality Control Index: 0.992929 Performance Ratio: 0.882932	Quality Control Index: 0.942320 Performance Ratio: 0.705677	Quality Control Index: 0.962247 Performance Ratio: 0.754065	Quality Control Index: 0.988573 Performance Ratio: 0.893605
	Link to Detailed Report	Link to Detailed Report	Link to Detailed Report	Link to Detailed Report

Future Development

- Tighter integration with IEC 61724
  - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis
  - Four types of filters
    - Range, missing data, dead value , abrupt change
  - Example quality control tests
    - Power sensor is out of range if the value < -0.01*rating or > 1.02*rating
    - Irradiance sensor is dead if the derivative < 0.0001 W/m2 while value > 5 W/m2 (15 minute data)
    - Temperature sensor is erratic if the derivative > 4 C (15 minute data)
  - Bounds depend on precision requirements (Class A,B,C) and calibration accuracy
  - Data binned into times when inverters are on and off line
  - Integrated performance model and performance metrics
- Community input