Performance of PV System Technologies on the Big Island of Hawaii

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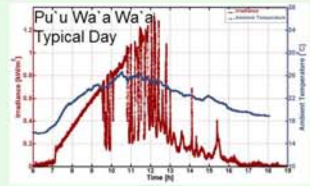
Pu`u Wa`a Wa`a
Big Island of Hawaii
700 m elevation

Hawaii is experiencing an increase in grid-tied solar photovoltaic (PV) installations due to an abundant solar resource, high cost of electricity, and generous tax incentives. New solar products including thin film PV modules and micro-inverters offer more options to installers and residents. The Hawaii Natural Energy Institute of the University of Hawaii at Manoa has initiated a test program to evaluate PV system performance in Hawaii. Grid-tied PV systems in eleven different locations on Oahu, Maui and Big Island representing diverse micro-climates of the islands have been instrumented . Test sites include weather stations and high-speed data acquisition systems to collect environmental and performance data of the PV modules and inverters. PV modules from seven different manufacturers representing a variety of technologies including mono and poly-crystalline, amorphous, and heterojunction with intrinsic thin layer (HIT) are being tested in a side by side configuration on the Big Island of Hawaii.

This poster presents the initial results on the performance of the PV systems tested at Pu'u Wa'a Wa'a on the Big Island.



RESEARCH OBJECTIVES AND SCOPE

- Assess PV system performance under different micro-climate conditions
  - Mono, poly-crystalline and new technologies such as CIGS, CdTe, micro-amorphous…
  - Micro and string inverters
- Establish a database to support analysis of the impact of intermittency on grid performance

Brand	Technology	Efficiency $\eta_{PV,STC}$	P_{MAX} W	MPPT
SunPower (SP)	Mono, rear	17.3%	215	BZ
Kyocera (KY)	Poly	13.8%	205	BZ
Sanyo (SA)	HIT, a/mono	16.7%	210	Enphase, M210
Suntech (ST)	Mono	13.7%	175	Enphase, M190
BP Solar (BP)	Poly	13.9%	175	Enphase, M190
SolarWorld (SW)	Mono	13.4%	175	Enphase, M190
Uni-Solar (UN)	Amorphous	6.1%	136	Enphase, M190

Table 1: PV Systems at Pu`u Wa`a Wa`a

Pu`u Wa`a Wa`a Test Bed Description

- 7 modules / 4 technologies side by side for comparative analysis
- 20° tilt, ground mounted, open back (except UN on a small roof)
- Maximum Power Point Tracker (MPPT) operation: Individual modules connected to charge controllers (BZ) or to grid-tied microinverters (Enphase)
- 1 Hz Data Acquisition System: weather station, performance of PV modules
- DC Performance Ratio used for comparison between PV systems

Comparison of PV System Performance: Performance Ratio (PR)

Manufacturer's module specifications provide information on the maximum power and/or the module efficiency η_{PV} (refer to Table 1) evaluated at standard conditions (STC). The specifications do not necessarily indicate the real-life performance of the PV modules, which are impacted by the operating cell temperature, the sun light reflection on the module, and the efficiency of the maximum power point tracker. The **DC Performance Ratio (PR),** measured DC PV energy output divided by the DC PV energy theoretically produced at the test location, is used in the following analysis to compare performance of the PV modules. PR gives the operational efficiency relative to the efficiency specified by the manufacturer at STC.

$$PR = \frac{measured\ PV\ energy\ output}{theoretical\ PV\ energy\ ouput} = \frac{\eta_{PV}}{\eta_{PV,STC}}$$

The theoretical PV energy output is calculated using the irradiation at the location and the efficiency specified by the manufacturer at STC.

(STC: Irradiance 1000 W/m2, Cell Temperature 25°C, Air Mass 1.5, 1 m/s Wind Speed)

Table 2 shows the performance of the PV modules connected to microinverters. For each module manufacturer, 2 modules are tested selecting the best performing module for the analysis. All pairs of modules exhibit 1% PR difference. Only SA has 4% PR difference between the 2 tested modules. In order to visualize the impact of the weather conditions, results are averaged using all days (574 recorded from July 2010 to March 2012) and by selecting the sunniest days (23 sunny days with irradiation > 6 kWh/m^2) or the cloudiest (25 cloudy days with irradiation < 2 kWh/m^2).

PV Module – Technology	Sunny Days PR %	All Days PR %	Cloudy Days PR %
SW – mono	95.6	97.5	102.9
SA – HIT, a/mono	94.4	96.3	100.1
ST – mono	91.1	92.5	96.9
UN – amorphous	88.5	90.4	93.8
BP – poly	89.0	90.0	92.3

Table 2: Average performance ratio for all days, sunny and the cloudy days

Performance Ratio

- PR ranges from 90% (BP) to 97.5% (SW) for all days analysis.
- PR is higher on cloudy days and lower on sunny days.
- PR increase on cloudy days compared to sunny days depends on the module: from 3.3% for BP to 7.3% for SW.
- PR range between PV modules is larger on cloudy days (10.6%) than on all days (7.5%) and sunny days (7.1%).
- PR above 100% suggests a possibility of conservative rating of the PV modules by some manufacturers (or wider performance variability within stock).

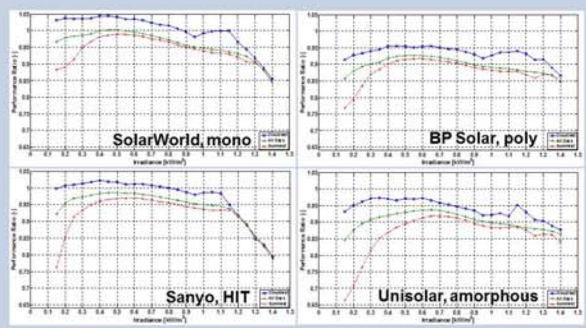


Figure 2: Performance ratio of the 4 tested PV technologies versus irradiance for different weather conditions

Figure 2 shows the performance of the 4 tested technologies as a function of irradiance level for 3 different weather conditions: all days, sunny, and cloudy.

The ST mono-crystalline module is not presented in Figure 2 because the observed PR is similar to the other crystalline modules (SW, BP).

Sunny days with irradiation > 6 kWh/m^2 are characterized as clear sky during most of the day. Lower irradiance levels correspond to sunrise and sunset when the sun light has high incidence angle, is highly filtered by the atmosphere, and reflected off the surface of the module.

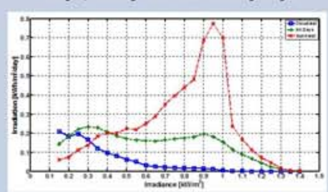


Figure 1: Irradiation (Energy/m^2/day) versus irradiance (Power/m^2) for different weather conditions (all, sunny and cloudy days)

Irradiation Characterization

Figure 1 shows the solar energy collected per level of irradiance for 3 different weather conditions (all days, sunny, and cloudy). This is a bar graph plotted as a line graph for better visualization.

- Cloudy days collect most of the solar energy at low irradiance levels < 500 W/m^2.
- Sunny days shift the solar energy at high irradiance levels with a peak at 950 W/m^2.
- All days collect energy at all irradiance levels showing 2 peaks at 300 W/m^2 and 900 W/m^2.

- For all technologies and irradiance levels, PR is higher on cloudy days and lower on sunny days compared to the PR for all days.
- Cloudy days PR shows a bump at high irradiance above 950 W/m^2. This is caused by very short periods of high irradiance levels inducing operation of the PV module at a temperature lower than its normal operating temperature.
- At high irradiance level > 1.1 kW/m^2, most modules (SA, SW, BP, ST) produce power above the inverter capability. Saturation depends on the module power rating and on the weather conditions. Maximum impact of saturation on PR was estimated below 0.12% (SA).
- Weather conditions affect each module differently at low irradiance levels showing slight a decrease in PR on cloudy days and an increased impact for all days and sunny days. This is due to higher light reflection on sunny days. Higher impact of the light reflection is observed on the amorphous technology modules (UN, SA). PR degradation for UN occurs up to 700 W/m^2.
- Modules showing the least PR degradation at low irradiance on cloudy days exhibit the highest impact of the weather conditions on their average performance.

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