Baseline assessment of SunPower's existing simulation tool (PVSim) and identification of priority areas for model refinement

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Introduction

SunPower Corporation develops and maintains a custom photovoltaic (PV) simulation tool called PVSim[1] for producing estimates of PV system power production (kW), energy (kWh) and yield (kWh/kWp). Although there exist sophisticated third-party "off-the-shelf" PV simulation tools, SunPower has chosen to develop its own custom tool to provide maximum flexibility to meet the changing modeling needs of the company. In particular, in-house development enables us to quickly adapt the model to accurately reflect new module and mounting products and allows us to make use of measured performance data from over 450 MW on 600+ systems for model-level and system-level validation.

The accuracy of system-level models implemented in PVSim is evaluated by comparing calculated energy production with measured production at a number of "benchmarking" sites. These sites vary in Commercial Operation Date from the 1990's to present. Data from the first year of operation for each site is used for benchmarking purposes to most closely compare to New and Clean operation. Benchmarking sites are established by quality checking at least one full year of measured weather and energy production data for an installed system. Measured local meteorological conditions are loaded into PVSim along with detailed metadata to fully describe the layout, components, and response mechanisms of each Benchmarking system. All periods during which system operation does not represent "typical operating conditions" are excluded from the data set. Examples of non-typical operating conditions are: snow on the system or irradiance sensor, inverter outages, and irradiance sensor shading or outages. Benchmarking site selection targets systems with minimal data exclusions. In total, twenty-five benchmarking sites have been established to date.

PVSim Baseline Accuracy Assessment

SunPower evaluates the accuracy of PVSim at each release of the software in which changes are made to the models. The following formula is used to calculate the annual mean bias error (MBE) at each site:

$$Error = (Simulated\ Energy - Measured\ Energy) / (Measured\ Energy)$$

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[1] *PVSim and System Performance Modeling*, SunPower White Paper, May 24, 2010

A positive MBE indicates over-prediction of the system production, and a negative MBE indicates under-prediction. Table 1 summarizes the MBE of each Benchmarking system for PVSim v.1, along with:

- MBE grouped by interval (1 hour and native interval)
- MBE grouped by product type
    - PowerGuard—horizontal fixed tilt
    - RMR—custom rooftop fixed- tilt
    - T5—5° fixed tilt
    - T10—nominal 10° fixed tilt
    - T0—horizontal north-south tracker
    - T20—20°-tilted north-south tracker,
- MBE and standard deviations for all Benchmarking systems.

Figures 1-6 below show the monthly MBE for six of the twenty five Benchmarking sites, for both the current versions of PVSim (R1.1) and previous released versions (R1.0). These figures each demonstrate a significant seasonal correlation to bias. This effect is a common effect[2]; the best available irradiance models used to transform global horizontal irradiance onto the plane of the array (POA) result in seasonal biases which typically over-estimate POA irradiance in the winter months and under-estimate POA irradiance in summer months, primarily due to spectral response differences between measurement device and PV material.

Soiling can have a strong impact on system performance. PVSim has a dynamic soiling model which uses rainfall and manual wash date information, along with area specific soiling buildup rates to estimate the soiling level on a given date. This system is currently configured for California only.

The physical equations used to calculate PV module output are strongly correlated to cell temperature. The current cell temperature model used in PVSim uses a simple correlation based on Irradiance, ambient temperature and wind speed. The current model is known to be overly simplistic, for example not accounting for the relationship between forced and natural convection between windy and stagnant days.

PVSim R1.1 is a manual user-input software tool capable of reading weather inputs in several formats (e.g. TMY2 and internal measured weather database). The architecture does not currently support data with sub-minute resolution. Output of PVSim is currently to XLS files which do not perform well with extremely large data sets (e.g. 525k records for a year of 1-minute data). PVSim R1.1 takes approximately 30 seconds to simulate a 1-year time range at 1-hour resolution. The calculation time scales linearly and calculation time for 10 second resolution would be approximately 3 hours (30 hours for a 1-second resolution).

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[2] Christopher P. Cameron, William E. Boyson, Daniel M. Riley, *Comparison of PV system performance-model predictions with measured PV system performance*, 33rd IEEE PVSC, San Diego, CA 2008

Table1. Mean annual bias error between measured and PVSim R1.1 simulated energy at 1-hour and native intervals for all benchmarking systems.

Location	Product	Module	1 Hour Interval		15 Minute Interval	
			System	Product	System	Product
Sarasota, FL	PowerGuard	Sharp 208	0.10%	-1.32%	0.37%	-1.31%
Mountain View, CA	PowerGuard	SPWR 210	-0.50%		-0.47%	
Las Vegas, NV	PowerGuard	AstroPower 75	0.27%		0.39%	
Mauna Lani, HI	PowerGuard	Schott ASE-300	-2.09%		-1.98%	
Los Angeles, CA	PowerGuard	Shell SQ-75	-2.85%		-3.59%	
Parsippany, NJ	PowerGuard	SPWR 210	-3.40%		-3.78%	
Torrance, CA	PowerGuard	Shell SP-75	-1.53%		-0.12%	
Guenching, Germany	T0 –Tracker	Sharp 175	-1.17%	-1.16%	0.54%	-0.73%
Minihauf, Germany	T0 –Tracker	Sharp 175	-0.34%		0.40%	
Muelhausen, Germany	T0 –Tracker	Sharp 175	-3.28%		-2.28%	
Las Vegas, NV	T0 –Tracker	Evergreen 190	-1.04%		-0.93%	
Las Vegas, NV	T0 –Tracker	Sharp 208	-1.97%		-1.27%	
North Carolina	T0 –Tracker	Sanyo 200	-0.56%		-0.89%	
Rocky Mount, NC	T0 –Tracker	Sanyo 190	-1.60%		-1.98%	
Santa Clara, CA	T0 –Tracker	SPWR 315	-0.41%		-0.56%	
Las Vegas, NJ	T0 –Tracker	Sharp 208	1.86%		2.12%	
Skillman, NJ	T0 –Tracker	Sharp 208	-3.12%		-2.45%	
Orange, CA	T10	SPWR 305	0.09%	-0.88%	1.30%	-0.44%
Fresno, CA	T10	Sharp 208	0.17%		0.17%	
Bakersfield, CA	T10	SPWR 210	-7.56%		-6.23%	
Manteca, CA	T10	SPWR 220	-12.33%		-11.41%	
Margate, NJ	T10	Sharp 208	0.70%		1.50%	
Napa, St. Helena	T10	Sharp 208	-4.48%		-4.76%	
Las Vegas, NV	T20 – tracker	SPWR 230	-1.51%	-0.71%	-2.15%	-1.34%
Las Vegas, NV	T20 – tracker	SPWR 230	0.17%		-0.17%	
Las Vegas, NV	T20 - tracker	SPWR 230	-0.80%		-1.70%	
El Sobrante, CA	RMR	SPWR 210	-3.92%	-3.92%	-4.94%	-4.94%
Redlands, CA	T5	SPWR 305	0.48%	0.48%	0.90%	0.90%
	Totals	**Average**	**-1.22%**		**-1.05%**	
		Stdev	**1.59%**		**1.88%**	

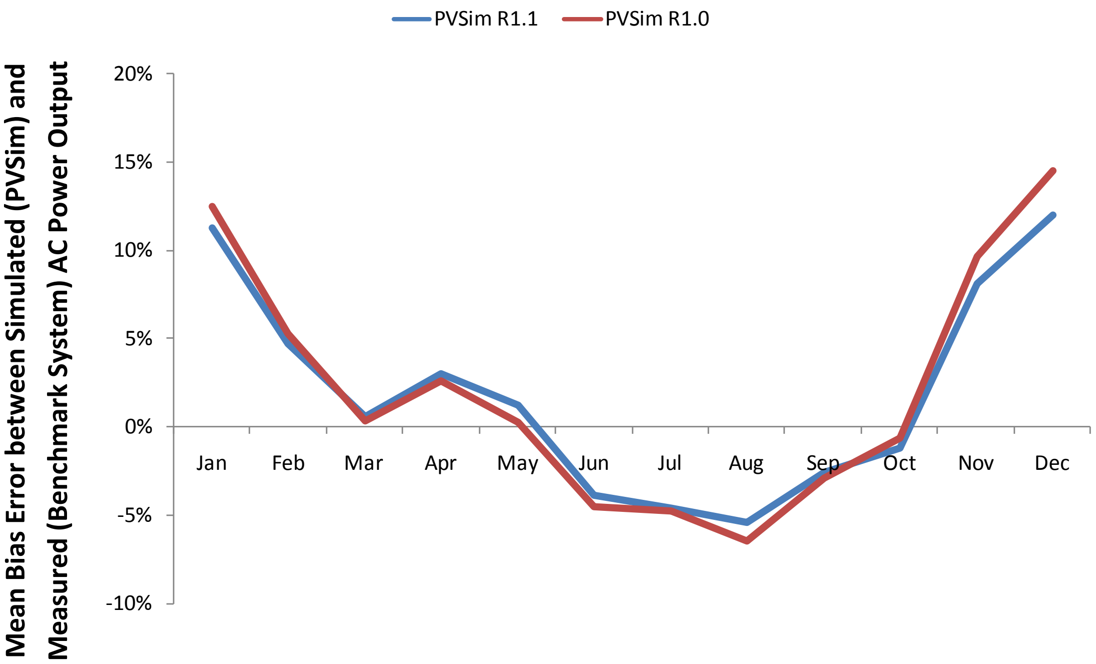

Figure 1. Progressive accuracy of PVSim (PowerGuard system in Las Vegas, NV)

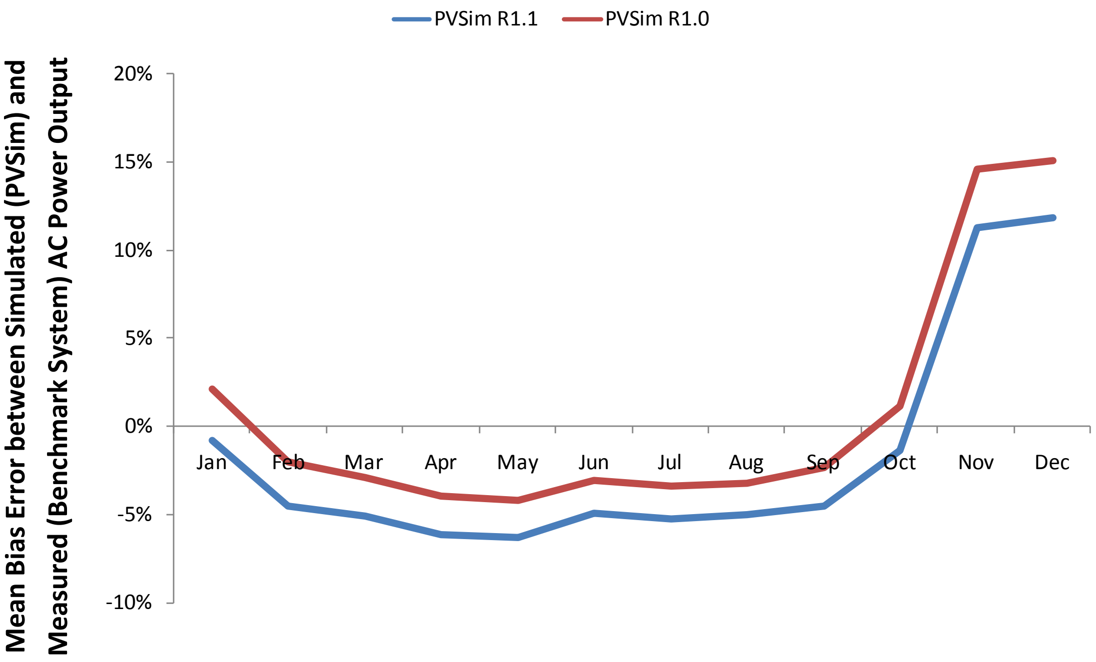

Figure 2. Progressive accuracy of PVSim (PowerGuard system in Los Angeles, CA)

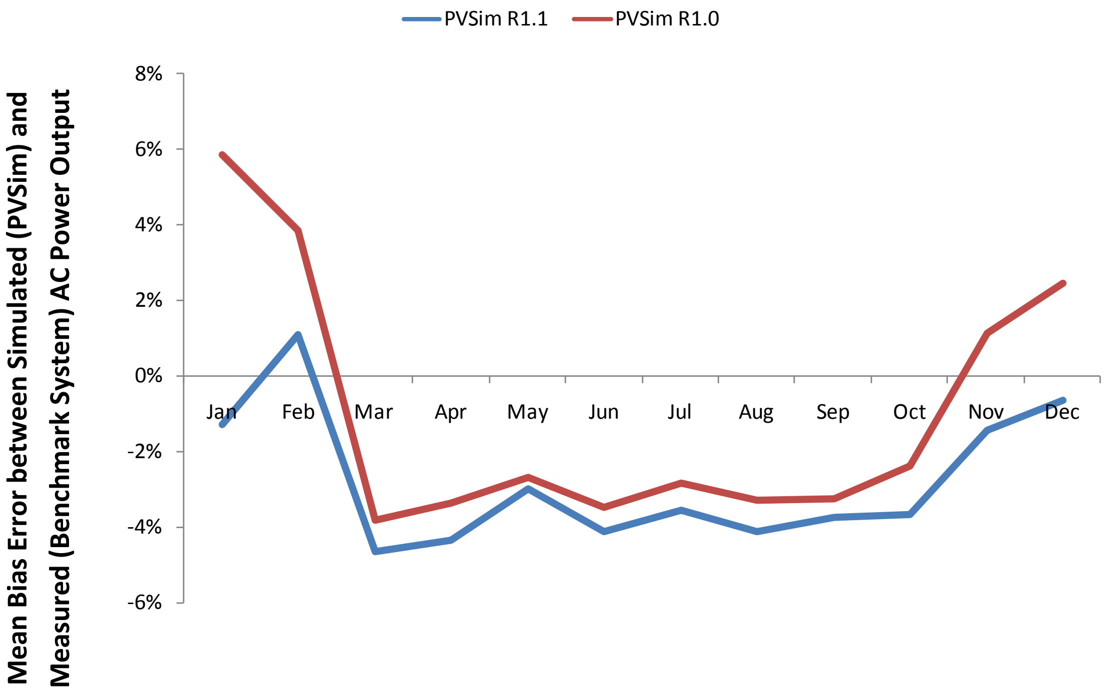

Figure 3. Progressive accuracy of PVSim (PowerGuard system in Parsippany, NJ)

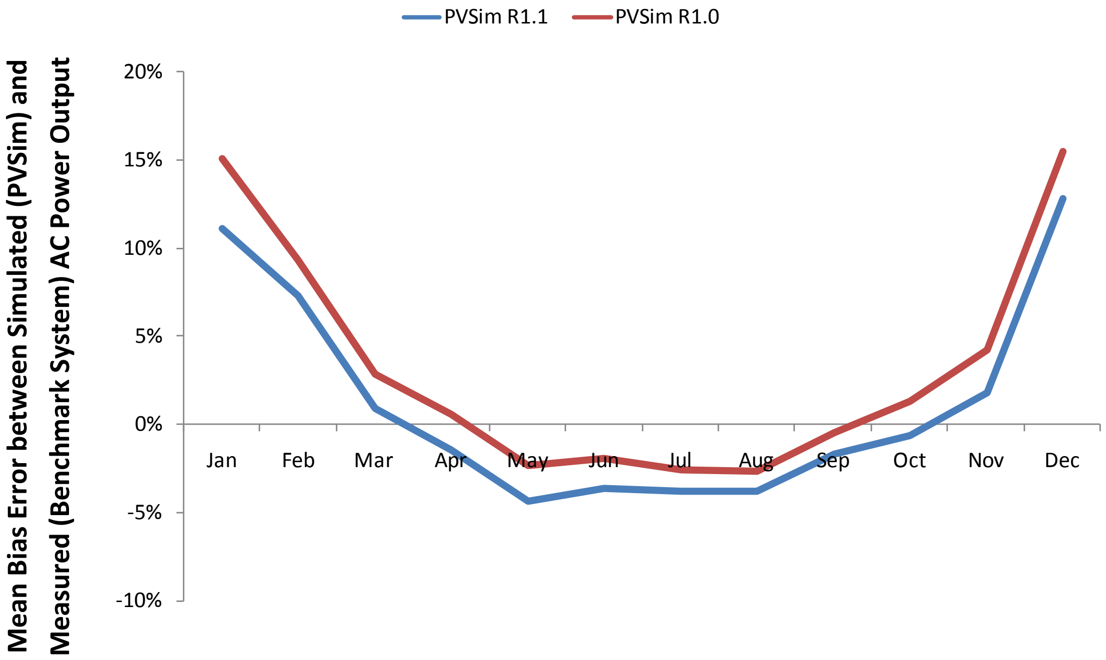

Figure 4. Progressive accuracy of PVSim (PowerGuard system in Torrance, CA)

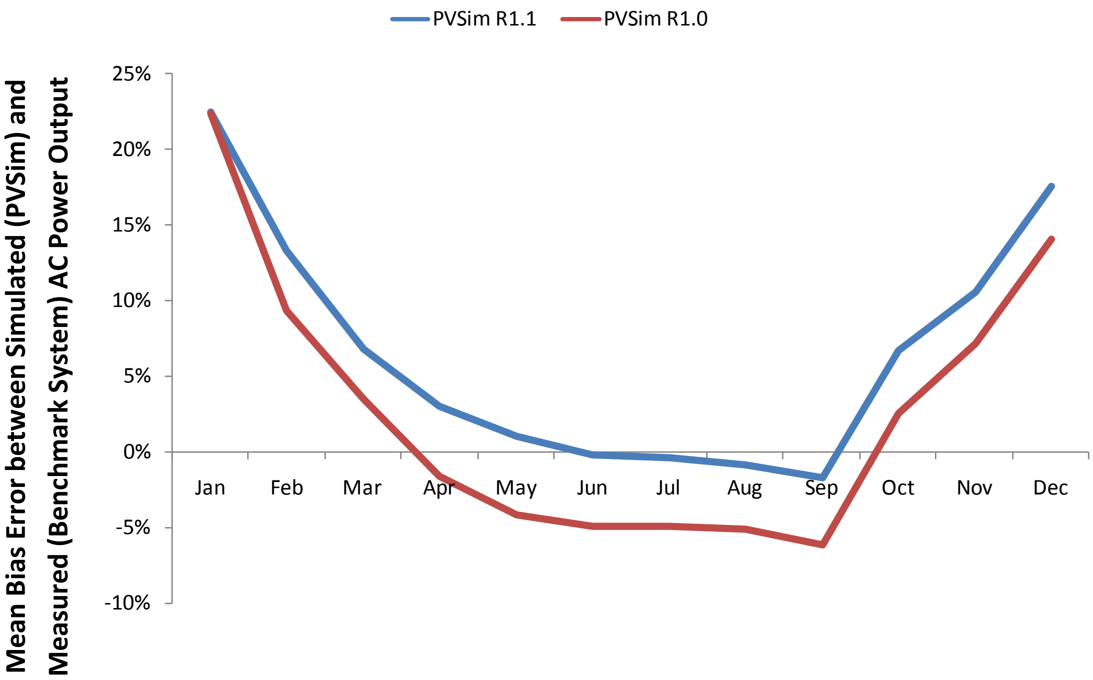

Figure 5. Progressive accuracy of PVSim (T0 in New Jersey)

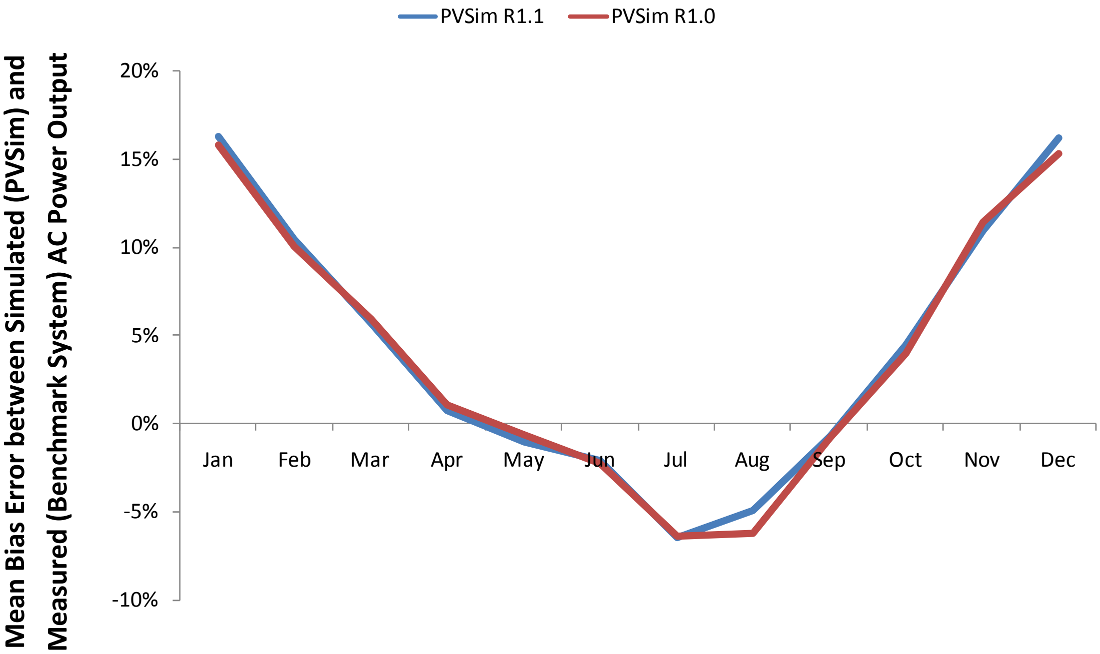

Figure 6. Progressive accuracy of PVSim (T10 in New Jersey)

Identification of priority areas for model refinement

The following primary areas have been identified for model development and/or refinement in support of this program:

Area	Issue	Action
Irradiance model	The best available irradiance models used to transform global horizontal irradiance onto the plane of the array (POA) result in seasonal biases which typically over-estimate POA irradiance in the winter months and under-estimate POA irradiance in summer months.	Methods to improve this, likely related to decomposition/recomposition of irradiance based on spectral characteristics will be investigated.
Soiling model	The dynamic soiling model is currently configured for California only	This model will be improved and expanded to other locations.
Temperature model	PV module performance is strongly correlated to cell temperature. Even with application of the current temperature model, cell temperature is a major contributor to mean bias error.	Improvements to this model will be made.
Automation of batch calculations	PVSim R1.1 is a manual user-input software tool	The system will be updated to allow for automation of calculations using AWS atmospheric data as inputs for locations and site configurations desired to feed Transmission and Distribution model scenarios.
Additional Input and Output methods	PVSim R1.1 is capable of reading weather inputs in several formats (e.g. TMY2 and internal measured weather database).	Additional methods will be needed to read data from the immense dataset that AWS will provide. Output methods will need to be updated to support KEMA's needs.
Handling of high resolution data	PVSim R1.1 is not capable of handling data with a resolution less than one minute currently. Furthermore, for simulations with high resolution data and long-ranging simulation times, the simulation output file can become prohibitively large and laborious to process.	The tool will be improved to both handle sub 1-minute time intervals and more efficiently process the outputs.
Speed improvements	PVSim R1.1 takes approximately 30 seconds to simulate a 1-year time range at 1-hour resolution. The calculation time scales linearly and calculation time for 10 second resolution would be approximately 3 hours (30 hours for a 1-second resolution).	Work will be done to significantly improve calculation speed to support the high resolution, and numerous simulations required for this program.