PRODUCT AWARENESS NOTIFICATION # 020.01.10

Title:	**Simulators: Basic explanation and PVSyst default edit Instructions.**
Scope:	**PV Products commonly modeled in simulator engines**
Groups:	**Product Management / Performance Engineering/ RLC Apps**
Technical Contact:	**Mark Shields, Ben Bourne, Oliver Koehler, Luis Rangel**
Intended Exposure	**Internal (VAR level), External (UPP level)**

Objective: The objective of this document is to give general background on simulator engines, suggesting which simulators should be used in which situations, and supplying a list of edits for the most functional, publically available simulator engine, PVSyst. The intended audience is current simulator users.

Background and Guidelines: With so many emerging PV markets and products, there are opportunities to discover many different versions and qualities of PV simulator software. Consequently, "the devils we know are better than the devils we don't know". PVSim is most accurate for results across the top 15-20 PV suppliers, but is not publically available. For *publically available* simulators, PVSyst, PVSol and SAM are lacking, but are more reliable than any specific regional version of a rebate/tariff calculator or array simulator. PVSyst can be updated to display simulation results close to those seen in PVGrid/PVSim when the user knows how to manually edit the module and array defaults.

Sandia NL is working a on a baseline/certification for simulator models. Yet, until their program is complete, here's a quick checklist to assist in revealing which simulators should be considered *least favorable* for modeling PV system performance (with random rebate/tariff calculators or start-up simulators being in the *least favorable* category);

- The first question to any "new" simulators should be "How many global weather references does it have?" If it has no references, has only one regional weather reference or a handful of city references, then it is in the "*least favorable*" category.
- If the modeling result doesn't have a System Loss diagram or loss table, it's in the "*least favorable*" category.
- If the tilt or alignment of the array cannot be changed in the simulator, it's in the "*least favorable*" category.
- If the simulator calculates all other types of energy as well; wind, geothermal, hydroelectric, then it is *most likely* in the "*least favorable*" category (not enough PV-specific technology data/knowledge and validation).
- **The CSI-EPBB Calculator** is in the *least favorable* category. Mainly due to its intended use as stated in its Users Guide: "*to calculate an appropriate PV system incentive amount based on a reasonable expectation of performance for an individual system. The results of the calculator* ***should not*** *be interpreted as a guarantee of system performance and that the actual performance of an installed PV system is influenced by numerous factors, and may differ from the results summarized in the CSI calculator.*" In addition, the CSI EPBB Calculator uses PVWatts as its base model. The best use of PVWatts is as a hypothetical calculator for experimental modules or modules which are not yet in the Sandia or the CEC models. PVWatts sources a database of name-plate and marketing-sheet values, it does not reference actual performance data like the Sandia model or accredited 3rd-party test data like the CEC model. NREL has improved their simulator entitled SAM (Solar Advisor Model) which, after this recent upward revision, has displayed a much higher degree of accuracy when referencing the Sandia model than when referencing PV Watts (see references for white paper). Whenever calculating incentives using the CSI calculator, we suggest running the same

simulation in SAM using the Sandia Model or the CEC model to get a more realistic performance reference to the PV Watts incentive results.

PVSyst, PVSol and SAM;

PVSyst is more advanced than PVSol, but both are currently under-estimating SunPower's actual performance, and over-estimating thin film performances with their default parameters. We say "currently" because both are open to working with us across real-life parameters to improve their over-all modeling accuracy. We have personnel working with both simulator tools for updates to their next revisions (PVSyst and PVSol updates are both tentatively due before the end of the summer). Although we do not have a large amount of experience with SAM, we reference SAM because it suggests using the Sandia Model as the base for performance modeling (like PVSim), and has proven to be *6% more accurate than PV WATTS, on average. For modules which are not listed in the Sandia Model, NREL suggest using SAM with the CEC model (CEC/Wisconsin 5-parameter model). However, SAM is limited in allowing edits to its default parameters.

- Currently, PVSol is more extreme than PVSyst; PVSol under estimates SunPower performance and severely over-estimates thin-film performance. Neither PVSol nor PVSyst are capable of automatically modeling SunPower's advantages in LID (light induced degradation) into a given simulation. However, PVSol is very limited in allowing the user to customize/edit the module or array parameters. We suggest PVSyst in place of PVSol when possible.

- During our work with PVSyst over the last 28-months, they have expanded their model. The current models of **PVSyst** allow for more default-edits. PVSyst makes it possible to capture part of our low-light performance advantage by allowing edits to "R-Shunt" and allowing manual "Incident Angle Modifications" within the module or array parameters. PVSyst also makes it possible to incorporate SunPowers lack of LID into their array model, along with allowing corrections to a couple of other industry average defaults which PVSyst automatically applies to each model. PVSol does not have a way for the user to make any such adjustments.

- In the appendix of this document, we have listed which PVSyst parameters to change (and why) in order for the SunPower modeling results to be closer to real-life performance levels.

Suggestions for Modeling Solutions:

- For internal SunPower modeling and supplier comparisons, the choice should be PVSim: http://halprod01/PVSim/Simulation/Location/Location.aspx

- For North America: Use NREL's SAM as the publically available alternative to anything referencing PV WATTS. SAM recently added the more accurate *Sandia Model as an option as opposed to only using PV Watts. NREL has also recently improved PVWatts (PVWatts V2), using temperature-coefficient references from the Sandia Model. However, PVWatts V2 is still best for experimental modules or modules not yet in the Sandia or the CEC models, and should not be used for performance modeling of known, existing products. Run NREL's SAM using the Sandia Model or the CEC/Wisconsin Model. SAM link https://www.nrel.gov/analysis/sam/downloadVerification.php). SAM downloads and simulations are free.

- Use PVSyst if needing a publically available simulator for use in multiple simulations of EU locations or of global locations. We suggest PVSyst also to be used for supplier-comparisons which are not available in PVGrid/PVSim. http://www.pvsyst.com/ch/index.php Be sure to incorporate the Detailed Loss edits and R-shunt instructions in **the appendix of this document.**
  - A full license of PVSyst costs 900-Euros.
  - If a PVSyst user in your office already has a full license, additional licenses for the location can be added for 150-Euros.

Filter the comparison field: Before running comparisons in any simulator, the user should ask if there are any space restrictions per the planned location. *Efficiency* is SunPowers main advantage – especially in space-limited residential and small-commercial retrofits. Without space and size limitations, any supplier can compete against any other supplier in power output. Often, less efficient competitors are eliminated when the space is restricted. Understand in advance which metric is targeted to be most important in evaluating the model.

REFERENCES:

1. *COMPARISON OF PV SYSTEM PERFORMANCE-MODEL PREDICTIONS WITH MEASURED PV SYSTEM PERFORMANCE.* 33rd IEEE PVSC, San Diego, CA 2008. Christopher P. Cameron, William E. Boyson, Daniel M. Riley, Sandia National Laboratories, Albuquerque, NM 8718.
2. *Power Loss in Photovoltaic Arrays Due to Mismatch in Cell Characteristics*, Bucciarelli, Louis L., Solar Energy, vol 23 pp 277-288.
3. *THE EFFECT OF SOILING ON LARGE GRID-CONNECTED PHOTOVOLTAIC SYSTEMS IN CALIFORNIA AND THE SOUTHWEST REGION OF THE UNITED STATES; IEEE 2006 Mitchell Kimber soiling study/ SunPower Soiling Study*

APPENDIX I: PVSyst Default Edits.

- There are several model parameters in PVSyst which can be edited from the default settings to achieve more accurate simulation results for SunPower modules, based on extensive outdoor characterization measurements at the Sandia National Lab. These settings are consistent with those used in PVSim and with measurements from modules and installed systems:
- **Simulator modeling preference parameters to be edited**;

1. **Preferences,** Preferences, Irradiance Transposition Model
2. **Preferences,** Edit Hidden Parameters, System Sizing Limit settings.

Modeling system parameters to be edited;

3. Module Parameters, "R-shunt"
   a. R-shuntcurve = *R-shunt Sandia curve*
4. Module Parameters, R-series
5. Detailed Losses - **Module Quality, Module Efficiency Loss**
6. Detailed Losses - **Mismatch Losses, Power Loss at MPP**
7. Detailed Losses - **Ohmic losses, Global Wiring**
8. Detailed Losses – **Soiling Loss**
9. Detailed Losses – **IAM Losses**
10. Detailed Losses – **Thermal Parameters**

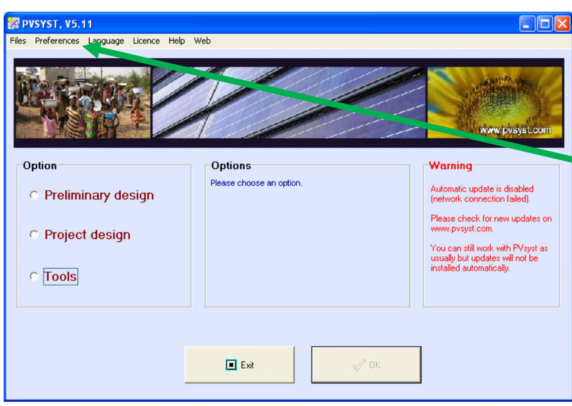
EXPLANATIONS;

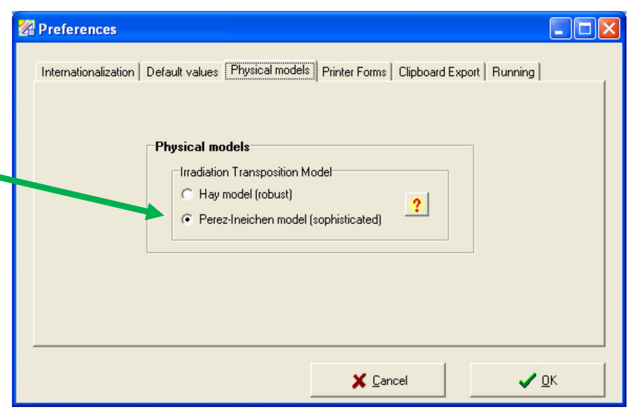
1. Preferences: Perez-Ineichen model

Adjustment: Replace the PVSyst default Hay tilted-plane (transposition) model with the Perez-Ineichen model.

Why the change? : SunPower has worked directly with Richard Perez to incorporate the most current representation of the Perez tilted-plane (transposition) model into PVSim. We have done extensive validation to demonstrate that the plane-of-array irradiance calculations are accurate over a range of mounting systems and climatic conditions*.

- **Preferences/Perez –Ineichen model**





2. Preferences – Simulation Limits (Guideline document, 001-61562, pages 8 through 12).

1. **Adjustment:** Change the warning ranges on DC system size to allow larger DC/AC system sizing.
2. **Why the change? :** In some cases—particularly for large utility-scale PV systems—it is desirable to generate more peak DC power than is allowable by the AC capacity of the central inverter. This operational DC power to inverter AC capacity ratio, commonly referred to as the DC/AC ratio (a.k.a. "Pnom ratio" in PVSyst), may exceed values that are currently allowed in PVSyst. These adjustments will relax the sizing constraints which restrict a user from running a simulation with high DC/AC ratios.

System Modeling parameters

3. Parameter: Module Parameters, "R-shunt" (Guideline document, 001-61562, pages 17 through 23)

1. **Adjustment:** Replace the PVSyst default shunt resistance (Rsh).

2. **Why the change?** : The performance of a module under low-light or low-irradiance conditions is partially controlled by the module's inherent shunt resistance (R-shunt, Rsh). The default R-shunt values used by PVSyst for SunPower modules do not allow a simulation to match measurements made by Sandia National Lab. In addition, the PVSyst single-diode model, as implemented, does not allow the Sandia-measured performance curve to be matched with the R-shunt of the modules tested by Sandia. Consequently, we use modified R-shunt values to allow the PVSyst model to match measured module performance, though these values are not representative of measured values in SunPower modules.

Cell Count	SunPower Measured Shunt Resistance (Ohms)	Shunt Resistance Required in PVSyst (Ohms)
72	2665	22500
96	3551	30000
128	4738	40000

4. Parameter: Module Parameters, "R-series" (Guideline document, 001-61562, pages 18 through 23)

Adjustment: Replace the PVSyst default series resistance (Rs)

Why the change? : The performance of a module under mid- to high-irradiance conditions is partially controlled by the module's inherent series resistance (R-series, Rs). The default R-series values used in PVSyst represent conservative industry averages, and do not sufficiently characterize the series resistance measured across the line of SunPower cells and modules. We use modified R-series values to allow the PVSyst model to match measured module performance, though these values are not representative of measured values in SunPower modules.

Cell Count	SunPower Measured Series Resistance (Ohms)	Series Resistance Required in PVSyst (Ohms)
72	0.329	0.300
96	0.430	0.435
128	0.584	0.580

****

5. Parameter: Detailed Losses - Module Quality, Module Efficiency Loss (Guideline document, 001-61562, pages 24 through 28)

1. **Adjustment:** PVSyst has a default of 3.0% (-3%). Change this value to 0.0%.
2. **Why the change?** : PVSyst defines this as "Deviation of the average effective module efficiency by respect to manufacturer specifications." This deviation from manufacturers' nameplate ratings is not clearly defined, but results from a combination of:

i. **Mean bias in the flash test rating of all modules when tested prior to leaving the factory**: The industry tolerance standard on module flash have improved recently, and most manufactures should be delivering modules which flash—on average—very close to their nameplate rating with a distribution of no greater than ±5%. For this reason, the flash mean bias component of Module Quality setting should be close to 0%. This is true for all SunPower modules (-3%/+5%).

ii. **Light-induced degradation (LID) for module technologies which lose up to 2% of their peak power rating when exposed to natural light for approximately 6 hours:** Most crystalline and thin-film PV technologies undergo some degree of either short-term or long-term LID. SunPower's n-type cell technology does not experience any LID.

6. **Parameter: Detailed Losses - Mismatch Losses, Power Loss at MPP** (Guideline document, 001-61562, pages 29 through 30)
   1. **Adjustment:** PVSyst has a default of 2.0%. Change this value to 1.0%.

   2. **Why the change? :** If present, module voltage mismatch within a string and string current mismatch at the inverter may result in a system loss. Research has demonstrated that the voltage mismatch associated with current module tolerance standards (±5% normal distribution) will result in a loss in system power of approximately 0.5%**. Consequently, the SunPower Systems Electrical Engineering group recommends 0.5% for module voltage mismatch loss and 0.5% for string current mismatch, resulting in a total mismatch of 1.0%.

7. **Parameter: Detailed Losses - Ohmic losses, Global Wiring** (Guideline document, 001-61562, pages 31 through 32)
   1. **Adjustment:** PVSyst defaults a value of 4.0% (-4.0%). Change to 2.0% if modeling a residential system and 1.5% for modeling commercial systems.
   2. **Why the change?** : The PVSyst default is a little too large for what is normally seen in SunPower systems. PVSim, from data feedback and observation of the PV industry's largest installation base, shows a conservative average of 2.0% for residential systems and based on the design and production from SunPower's fleet of nearly 600 installed UPP/Large scale systems, SunPower's Systems Electrical Engineering group recommends a 1.5% DC wiring loss as a dependable assumption for standard commercial- and utility-scale systems..

8. **Parameter: Detailed Losses – Soiling Loss** (Guideline document, 001-61562, pages 33 through 34)
   1. **Adjustment:** PVSyst has a default of 0.0%. Change this number to 1.0%.
   2. **Why the change?** : SunPower has extensive empirical data that support a simple rule of thumb for estimating soiling loss across a range of climates:
      1. 1% soiling in climates which experience at least 7.5mm of precipitation in any 24-hour period at least every 60 days (e.g. Germany, US east coast, England, US Great Lakes region, Nordic countries, etc.)
      2. 5% soiling in climates which typically have long periods (>60 days) of no precipitation during the peak irradiance period (e.g. California, southern Europe, Southwest US, etc.)
      3. A 2% annual reduction in soiling loss with each manual wash, with a lower annual soiling loss limit of 1% for all climates

Exceptions: SunPower understands that exceptions to this rule of thumb may exist, and often evaluates potential exceptions on a case-by-case basis.

9. Parameter: Detailed Losses – IAM Losses (Guideline document, 001-61562, pages 35 through 44)

IAM stands for **Incident Angle Modifier. Adjustment:** The Incident Angle Modifier (IAM) functions describe the optical response of the glass laminate surface to the incoming solar beam at a given solar position for two different glass surfaces

- **Standard glass laminate**
- **Anti-reflective (AR) coating**

Why the change? The PVSyst defaults for this parameter are based on the Fresnel optical transmission law (ASHRAE model) for a single layer of standard glass in contact with the solar cell. SunPower modules use high-grade mono-silicon, a backside mirror, high quality low-iron/high transmission glass, stippling and other light-trapping advantages which are not common across the PV industry. For these reasons the SunPower modules excel in capturing in-coming light. The included table defines the contour of a polynomial function which resulted from measurements of SunPower modules made by Sandia National Labs.

Note: The IAM settings in PVSyst are associated with a specific Project, and not with a specific module in the database. It is therefore necessary to define an IAM profile for each simulation Project.

- **Sandia Angle of Incidence inputs for PVSyst IAM.**
  - Standard PV Glass, Sandia/Fanney
  - Anti-reflective PV Glass, Sandia AR

Modified Sandia/Fanney			
PVSyst Points			PVSyst-Rounded
#	AOI		IAM
1	0.0		1.00
2	20.5		1.00
3	32.8		0.99
4	42.9		0.98
5	51.3		0.97
6	55.5		0.96
7	60.1		0.94
8	65.1		0.90
9	67.5		0.87
10	70.0		0.83
11	72.4		0.78
12	75.0		0.71
13	77.4		0.63
14	80.1		0.52
15	82.4		0.40
16	85.1		0.23
17	88.1		0.00
18	90.0		0.00

Modified Sandia AR			
PVSyst Points			PVSyst-Rounded
#	AOI		IAM
1	0.0		1.00
2	53.0		1.00
3	60.1		0.99
4	64.5		0.97
5	68.9		0.93
6	71.7		0.89
7	76.0		0.80
8	77.4		0.76
9	80.1		0.67
10	82.4		0.57
11	84.9		0.44
12	87.0		0.31
13	90.0		0.00
14			
15			
16			
17			
18			

10. Parameter: Detailed Losses – Thermal Parameter (Guideline document, 001-61562, pages 45 through 46)

1. **Adjustment:** Set U_c = 25.0 and U_v = 1.2

2. **Why the change?** The thermal parameters U_c (constant term) and U_v (wind-dependent term) describe how rapidly heat retained in the cells—and within the module laminate—is transferred back into the surrounding environment. As the ratio of U_c to U_v increases, the model dictates that the operating

temperature of the cells becomes less dependent on wind, and thus on the accuracy of the wind measurement in the weather data. As an extreme example, U_v = 0.0 implies that the cell/module operating temperature is completely independent of wind speed. SunPower typically recommends U_c = 18.0 and U_v = 4.0 for open-rack systems, and adjusts the wind speed measured at 10 meters to the height of the PV array using standard wind speed profile formulae. PVSyst does not make the wind speed adjustment according to PV height relative to the height of the wind speed measurement, and therefore requires that U_c/U_v be greater than the SunPower-recommended ratio to account for the greater 10-meter wind speeds.