Validation of Photovoltaic Modeling Tool HelioScope Against Measured Data

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A20-72155
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Suggested Citation
Guittet, Darice L., and Janine M. Freeman. 2018. *Validation of Photovoltaic Modeling Tool HelioScope Against Measured Data*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72155. https://www.nrel.gov/docs/fy19osti/72155.pdf.

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303-275-3000 • www.nrel.gov

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1 Introduction

HelioScope is a cloud-based solar design software developed by Folsom Labs to model photovoltaic (PV) array systems. Folsom Labs was selected for a Small Business Voucher from the U.S. Department of Energy for the National Renewable Energy Laboratory to validate the performance of HelioScope's simulation engine against measured PV system performance. This study builds on previous validation work by NREL of other PV modeling tools (Freeman et al. 2013, 2014; Freeman and Simon 2015), using the same fixed-tilt systems with available system specifications. HelioScope designs were set up using the same system specifications and concurrent meteorological year data as were used in previous studies. The predicted performance results from the HelioScope simulations were compared to measured data and to performance predictions by other PV modeling tools.

2 About the Tools

HelioScope was validated by comparing results to those of three PV modeling tools: the System Advisor Model (SAM)[1] 2014.1.14, PVSyst 6.11, and PV*SOL. All simulation results for HelioScope[2] were calculated using the web-based solar design software between February 2018 and May 2018. Each PV modeling tool differs in which internal submodels are offered and used as default and in which system losses are applied and how they are calculated. While the choice of model and variation of losses will affect the output, each tool is designed with default models and values. The default submodels used by each tool are given in Table 1.

Value	SAM 2014.1.14	PVSyst 6.1.1	PV*SOL	HelioScope
Modeling timestep	hourly	hourly	hourly	hourly
Decomposition of global horizontal irradiance (GHI)	N/A	Erbs model	Reindl	N/A
Transposition to plane-of-array irradiance	Perez	Perez	Hay Davies	Perez
Radiation components	Direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI)	user selection	GHI	GHI and DHI
Module model	California Energy Commission (CEC) single-diode model	Shockley's single-diode model	enhanced single-diode model	Shockley's one-diode model
Thermal model	NOCT	thermal balance equation	thermal balance equation	Sandia National Laboratory
Inverter model	CEC	grid inverter model	grid inverter model	CEC
Albedo	0.2	0.2	0.2	0.2
Module cover/IAM loss	Model-dependent	ASHRAE	ASHRAE	ASHRAE
DC-AC ratio	1.2	user selection	user selection	user selection

Table 1. Default Internal Models of the Tools

[1] See sam.nrel.gov.
[2] See www.helioscope.com.

To provide consistency between tools, the simulations were created using the default mode for each tool except in the case of which radiation components were used. From prior validation studies, the Total (GHI) and Beam (DNI) weather file inputs were used for SAM, PVSyst, and PV*SOL. However, HelioScope uses Total (GHI) and Diffuse (DHI) as its only irradiance input option. Using different irradiance input options, GHI and DNI versus DNI and DHI, was shown in SAM to result in up to 2.3% difference in annual energy production error, where the magnitude and direction of the error was inconsistent between systems (Freeman et al. 2013). However, there is no indication as to which pair of irradiance values produces greater accuracy.

The default loss percentages were used because each PV modeling tool has its own set of losses and zero-loss configurations have shown higher root-mean-squared errors (RMSE) by not accounting for losses experienced in real systems. The default losses for each tool are given in Table 2. For those losses that are applied as a fixed assumption for some tools and calculated in a submodel in other tools, the value is reported as calculated when appropriate. Not all the power losses that may occur in a system are listed, as some such as thermal losses due to system configuration are modeled explicitly.

System Losses	**SAMv1**	**PVsyst**	**PV*SOL**	**HelioScope**
Deviation from wavelength spectrum	N/A	N/A	1%	N/A
Annual soiling loss	5%	0%	0%	2%
Total Environmental Derate	**0.95**	**0.99**	**0.99**	**0.98**
Mismatch	2%	1%	2%	Calculated
Diodes and connections	0.5%	0%	0.5%	*N/A*
DC wiring	2%	1.5%	Calculated	Calculated
Tracking error	0%	N/A	N/A	N/A
Nameplate	0%	Module-dependent	0%	2.5%
Total DC Derate	**0.96**	**0.95**	**0.975**	**Calculated**
AC wiring/cabling losses	1%	0%	*N/A*	0.50%
Step-up/external transformer	0%	0%	*N/A*	*N/A*
Interconnection/AC Derates	**0.99**	**1.00**	**1.00**	**0.995%**

Table 2. Default Loss Assumptions of Each Tool

3 Methodology

Seven PV systems were modeled by NREL in HelioScope; see Freeman et al. (2014) for detailed system specifications. Table 3 shows some of the important features of each system. The Years Modeled column describes which set of concurrently-measured meteorological year weather and performance data (previously quality-controlled to remove sensor errors and system or component downtime) was used for each system (Freeman et al. 2013, 2014). At the time of building the simulations in HelioScope, neither utility scale system (FirstSolar 1 or FirstSolar 2) could be modeled in its entirety as one simulation, so the systems were scaled down to representative ~550-kW blocks. After running the simulations, the performance data were scaled back up to the correct system size.

System	Size	System Type	Racking Type	Years Modeled
Forrestal	Commercial	Fixed tilt	Flush mount	2009–2010 (1 yr)
S&TF	Commercial	Fixed tilt	Fixed tilt	2011
RSF 1	Commercial	Fixed tilt	Flush mount	2011
RSF 2	Commercial	Fixed tilt	Flush mount	2012
Visitor Parking	Commercial	Fixed tilt	Carport	2012
FirstSolar 1[a]	Utility	Fixed tilt	Fixed tilt	2011
FirstSolar 2	Utility	Fixed tilt	Fixed tilt	2011

[a] FirstSolar 1 was not modeled in PV*SOL because the number of modules exceeded the Expert version limit.

Table 3. PV Systems Modeled in HelioScope

Within each Racking Type, there are additional parameters such as spacing and height that reflect HelioScope's specialization in system design. Though these parameters were set to be representative of each system to produce as accurate a model as possible, not all of these parameters are inputs common to all the other models. Instead, the appropriate thermal model configuration was chosen in each tool, thus allowing each tool to explicitly calculate the shading and thermal losses due to system design; inputs for the other tools are listed in Freeman et al. (2014).

In HelioScope, the shading loss has contributions from two main factors: (1) "near shading" due to racking type and module spacing, and (2) shading from external structures in the environment. Because these systems are mostly unshaded and because external shading was not considered during the previous validation studies, external structures were not drawn into HelioScope's map-based system design interface, precluding the latter type of shading from being a factor of the total shading loss. As a type of calculated loss, near shading losses are inseparable from the performance simulation in HelioScope and so are included in these results.

4 Results

4.1 Annual Results

The annual error of prediction quantifies the overprediction or underprediction of energy production over the entire year, normalized by the measured energy production. It is calculated as (modeled-measured)/measured. Figure 1 shows the annual prediction errors for the four tools. For the FirstSolar1 system, no simulation was performed in PV*SOL as explained above, but the results are shown for the other three tools.

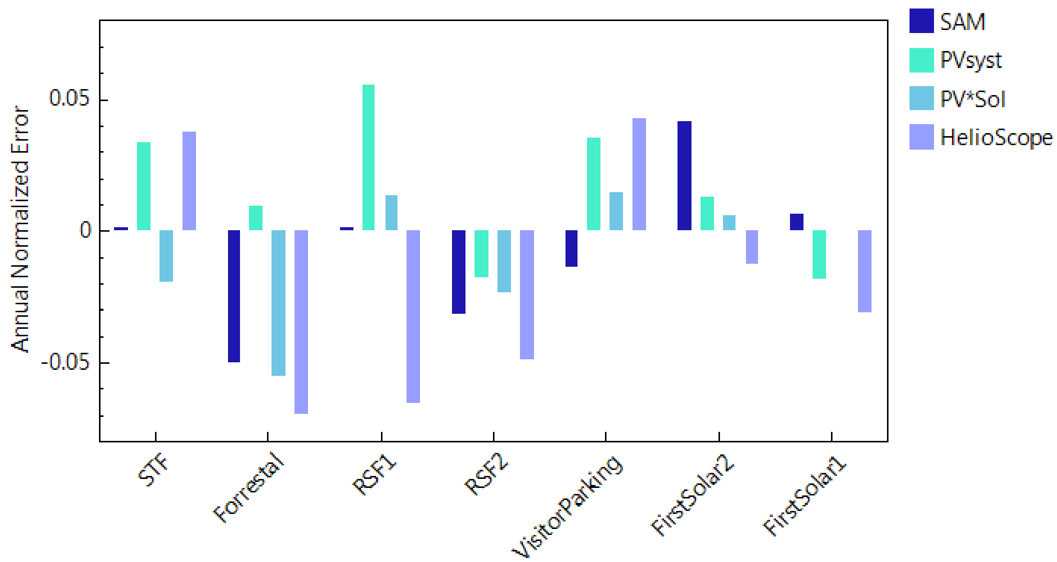

Figure 1. Annual normalized error for each tool by system

No data for PV*SOL for FirstSolar1.

HelioScope's error range falls between -7.0% and 4.3%, which is similar to the range of other tools examined in previous validation studies where the errors are within ±7%. There is no clear pattern as to which tool is more accurate for any type of system, nor is there a pattern to relative overpredicting or underpredicting. The error range for the six systems that were modeled in all four tools (STF, Forrestal, RSF1, RSF2, Visitor Parking, and FirstSolar2) is given in Table 4.

Tool	Error Range
SAM	-5.0%–4.1%
PVsyst	-1.7%–5.5%
PV*Sol	-5.5%–1.4%
HelioScope	-7.0%–4.3%

Table 4. Range of Annual Errors for STF, Forrestal, RSF1, RSF2, Visitor Parking, and FirstSolar2

4.2 Hourly Results

The hourly root-mean-square error (RMSE) is commonly used to evaluate the accuracy on an hourly basis. The normalized RMSE is calculated by taking the square root of the average of squared differences and dividing by the maximum value of the measured data. Figure 2 shows all tools to have an hourly RMSE of 6.6% or less. HelioScope's hourly RMSE range is between 2.9% and 6.6%.

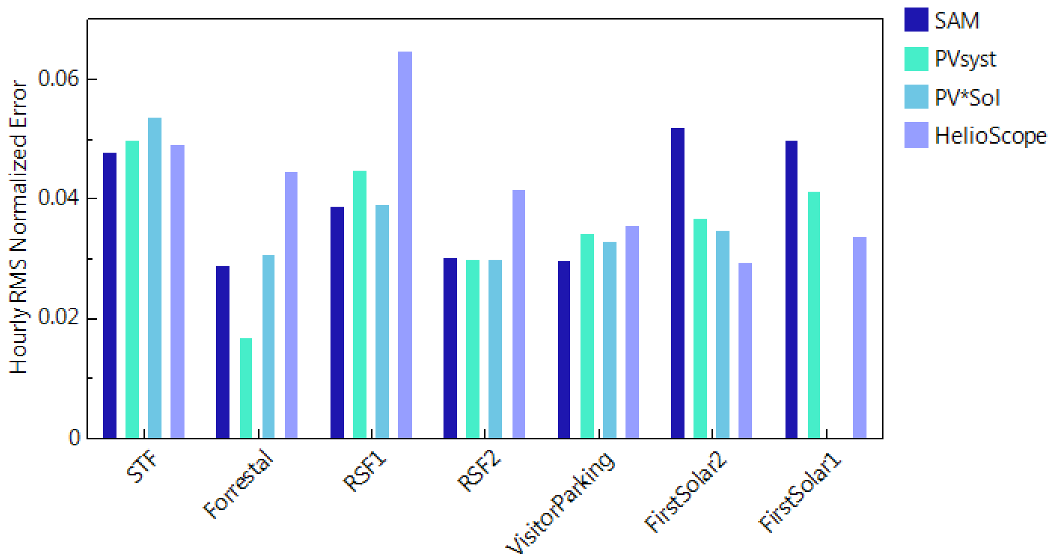

Figure 2. Hourly normalized root-mean-square error for each tool by system

No data for PV*SOL for FirstSolar1.

5 Conclusion

Seven fixed-tilt systems, of which five were commercial scale and two were utility scale (built as scaled-down units), were modeled in HelioScope in order to validate system performance predictions against measured data and to compare against other PV simulation tools. Unlike the simulations in the other tools, HelioScope's simulations were run using GHI and DHI as input. As with the other simulation tools, external shading was ignored; but unlike the other tools, row-to-row shading effects are an inherent part of HelioScope's calculations and so were factored into these results. HelioScope predictions were comparable with those of other tools, with an annual normalized error range of -7.0% to 4.3% and an hourly normalized RMSE range of 2.9% to 6.6%. Further validation with a greater variety of system types would provide additional information about the strengths and weaknesses of HelioScope. This study does not comment on the usability of the product.

6 References

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