Case Studies Comparing System Advisor Model (SAM) Results to Real Performance Data

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WREF 2012: CASE STUDIES COMPARING SYSTEM ADVISOR MODEL (SAM) RESULTS TO REAL PERFORMANCE DATA

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ABSTRACT

NREL has completed a series of detailed case studies comparing the simulations of the System Advisor Model (SAM) and measured performance data or published performance expectations. These case studies compare PV measured performance data with simulated performance data using appropriate weather data. The measured data sets were primarily taken from NREL onsite PV systems and weather monitoring stations.

The results of this case study activity show a good match (delta of less than 6% for any month) between measured and simulated data after adjustments as described in the paper. These adjustments include removing bad or missing data periods from the measured data, removing periods with significant snow cover which is difficult to model and, in some cases, adjusting the default annual derate values. As such, the case studies point out several systemic issues with such comparisons. For example, the default derate values in SAM are not the best match to the performance data generally. The default assumptions around snow cover and soiling performance impacts also appear to be inappropriate for these data sets.

The case studies highlight modeling techniques in SAM. These include modeling systems with components not found in current SAM libraries, finding appropriate satellite weather data and the use of building load data in conjunction with PV performance and complex utility rates.

In addition to providing an overview of the individual case study reports and the issues they raise, we will also discuss the process of determining appropriate weather data and financial inputs to enable detailed comparison and validation efforts using SAM.

1. INTRODUCTION

During 2010, the System Advisor Model (SAM) team collected data for four PV systems. The goals of this effort included real-world validation of an entire system (and not sub-component validation which is often done) and to build examples for SAM users to review in building their own systems. We attempted to get a spread of systems across a range of sizes and markets. Comparisons were performed between the SAM model output and measured performance data, reported cost data or with reported annual performance values. Four of the system comparisons were released with the SAM model release version 12.2.2011. The case studies and their associated SAM project file are distributed with the SAM download.

1.1 Systems Examined

For the four released PV case study systems, some hourly performance data were available for all of them and over a year of data for all but one of them. The four sites include:

1.1.1 James Forrestal Building (Forrestal)

The James Forrestal Building is the U.S. Department of Energy's (DOE) headquarters in Washington, D.C. The 205 kW rooftop PV array was installed in 2008 with the goal of producing up to 8% of the building's peak energy needs in order to fulfill the Transformational Energy Action Management (TEAM) Initiative. The market was commercial building.

1.1.2 NREL Research Support Facility (RSF) Building

The RSF building is part of NREL's South Table Mountain campus located in Golden, CO. The RSF's rooftop PV array has a nameplate capacity of 449 kW, contributing to the building's net-zero energy standard. The market is Commercial PPA (for third party ownership).

1.1.3 NREL Science and Technology Facility (S&TF)

The S&TF Building is part of NREL's South Table Mountain campus located in Golden, CO. The S&TF's rooftop PV array has a nameplate capacity of 94.5 kW. The market is Commercial PPA (for third party ownership).

1.1.4 Oklahoma City Residence (OKCity)

The Zero-Energy Home in Oklahoma City, Oklahoma features a roof-mounted 5.3 kW PV array which serves as the energy source for the building. The residential PV system began generating energy in November 2005. The market is residential.

1.2 Data Acquisition

One of the more difficult tasks in comparing system output to simulations is getting the system description data, cost data, the "appropriate" local weather data and the system output data. To be useful to SAM users, the system description data at least had to be public information. In the cases above, the performance data was also sharable but some of the weather data was only available within NREL at this time (becoming public within the next year). Note that the use of the OpenPV database to determine approximate system cost was necessary, as no public cost data were available for any of these cases. The OpenPV database allows the user to select the year of installation and filter by system size (and location if there are enough systems at that granularity to provide a good average).

"Appropriate" local weather data is ideally data measured at the site for the same time period as the data measurements. In many cases this is not possible. Using a TMY2 file and comparing to an actual year of measured data would be inappropriate. The use of NREL PV and weather data systems was invaluable in making it possible to gather high-quality, time-syncronous measured data. Without this local resource, we would have created appropriate datasets from the "Perez Satellite Data" set of 10k gridded data. This data is publically available via the NREL Solar Prospector (http://maps.nrel.gov/prospector) from 1998-2005. It will soon be available for more current years.

Within each individual case study document, a table has also been built to capture which SAM inputs have been changed from the default value to a value more appropriate for that case.

TABLE 1: DESCRIPTION OF THE PRIMARY DATA AVAILABLE FOR EACH OF THE CASE STUDIES.

Site	Performance Data Source	Cost Data Source	Weather Data Source
Forrestal	DOE Solar Program (Dec. 2009 to June 2010)	OpenPV.NREL.Gov [1]	DOE Solar Program (measured at the system)
NREL RSF	SunEdison Client Connect Portal [2](June 2010 - May 2011)	OpenPV.NREL.Gov	NREL's SRRL site data[3]
NREL S&TF	SunEdison Client Connect Portal (Jan. 2010 – Dec. 2010.)	OpenPV.NREL.Gov	NREL's SRRL site data
OKCity	Measured Data used in prior NREL report[4]	OpenPV.NREL.Gov	Proprietary Perez Satellite data for 2006

2. COMPARISONS WITH MEASURED DATA

2.1 Missing Data

In all four cases, the system measured performance data did not initially match the simulated data. For example, as you can see in Figure 1, there are several months that didn't match output very well (especially January, February and March in this case).

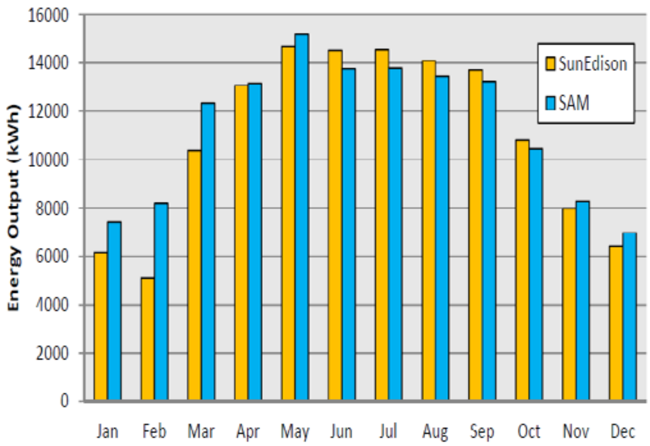

Fig. 1: Initial Comparison between SAM and Measured Data for the NREL S&TF Building

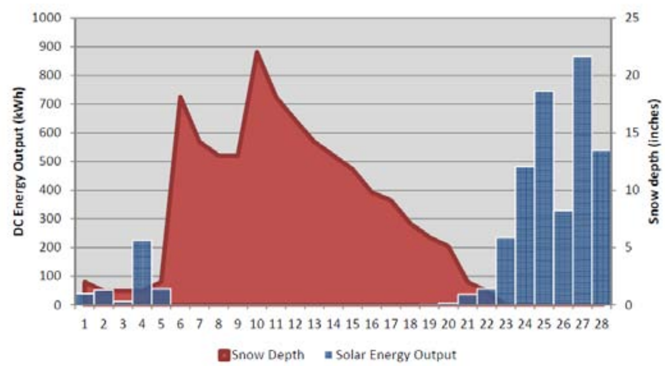

Fig. 2: Snow depth (red) and DC energy output (blue) for each day in February 2010, clearly showing the two Mid-Atlantic blizzards (6th and 10th) and the impact on solar energy generation.

In this case and the other cases, several factors were found to be responsible for these disparities. These factors were generally consistent across the four case studies. The first issue was missing data within the measured performance data. This happened in OK City, NREL RSF, and NREL S&TF. This was noticeable because the weather file used indicated incident radiation but no output was detected in the measured data. If both the weather data and performance data indicated no radiation and no output, the SAM model would have also predicted no system output.

2.2 Snowfall

Another major discrepancy was due to snowfall causing a reduction in measured output. This was a major issue in comparing to simulated data for all systems. Figure 2 shows the relationship between snowfall and system output for the Forrestal system. The snowfall data was taken from the online Farmer's Almanac[5] and Forrestal performance data was obtained from DOE. This significantly skews the results for each system during months with significant snowfall. While some weather data sets include snowfall, it's currently not possible to accurately determine how long that snow remains on the panels or how much of the array remains covered by snow. While an annual derate adjustment can calibrate the annual simulated output, this doesn't impact hourly results significantly. Another factor to remember when using the current version of SAM is that if a climate file contains snow data, the ground albedo for snowy days increases and actually enhances the simulated system performance, when in reality the output should be reduced due to snow cover, in most cases. This issue is being investigated further.

2.3 Derate

The final factor that seems to consistently lead to underprediction of performance values by SAM is the overall derate value. The SAM default derates (based on the derates first presented in PVWatts[6]), are conservative when looking at this very small sample set of relatively new systems. As you can see in Figure 3, the overall derate (composed of a variety of derate factors such as nameplate derate, soiling, wiring losses, mismatch, etc.) should be roughly 87% which is a higher than the default values for this case. The Forrestal building case study didn't examine modifying the derate and the Oklahoma City case study didn't have a consistent under-prediction (but rather a seasonal pattern) so no consistent conclusion should be drawn. However, the default derate values for SAM should reflect recent technical improvements and improved performance precision by the industry and work is being initiated in this area. With various subsidy programs basing their calculations on values that include these derates, accurately updating them is important to do. However, users should consider adjusting the derate values to accurately match measured data if available.

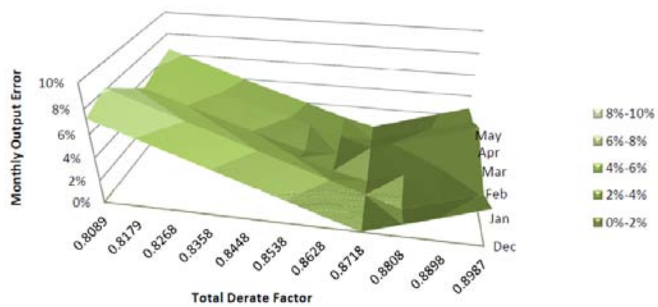

Fig. 3: For the NREL RSF system, a total derate factor in SAM of about 87% would minimize the difference between SAM's calculated output values and the measured values.

Related to the issue of appropriate general derates, the Forrestal system raised the issue of the episodic impact of heavy soiling on the system. The system on the roof of the Forrestal building is flat. The capacity factor for the system increases dramatically after each rain event. An example of this is shown in Figure 4. This exemplifies the fact that significant soiling can occur both on flat systems and systems in urban areas (or areas with significant dust). SAM has included annual soiling derates (and now includes monthly soiling derate factors) to allow users to capture the impact of soiling on radiation getting to the module, but getting soiling data (or anticipated soiling data) is difficult. Research is needed to better capture and anticipate soiling impacts.

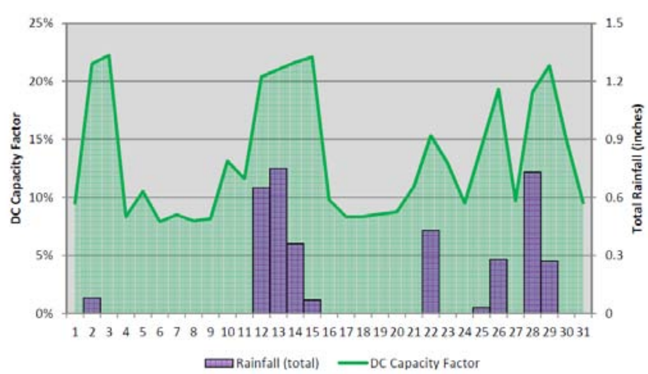

Fig. 4: For the Forrestal building, a strong correlation between DC capacity factor (green) and total rainfall (purple) during March 2010 is shown

3. RESULTS

3.1 S&TF System

With the corrections to measured data for snowfall, derate and missing data, good agreement was found between SAM and the measured data for each system. Figure 5 shows this for the S&TF system. After accounting for days with snow cover or system malfunction, we calibrated the derate value and were able to get within 0.3% of the measured annual output and within 3.7% of the measured value for every month except November and December which had an output error of less than 5%.

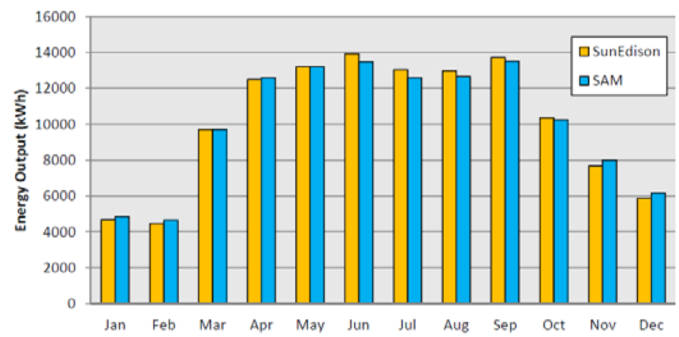

Fig. 5: Final comparison graph of the measured data vs. the SAM estimates after removing flawed data and calibrating the derate factor for the NREL S&TF system.

3.2 Forrestal Building

After adjusting for snow cover in the winter months, the SAM model showed good agreement with the measured data at the monthly level. Five of the seven months studied were within 2.5% of the measured data while the other two (December 2009 and January 2010) were within 5.6% of the measured DC output values.

3.3 Oklahoma City Zero Energy Building

After calibrating the derate value to fit the system, SAM results were within 1.9% of the measured system output for each of the 8 months that did not include flawed data or array performance issues.

3.4 NREL RSF System

After accounting for days that had snow cover or system maintenance and calibrating the derate value, SAM results were within 1.5% of the measured energy output for each of the 6 months that were studied.

TABLE 2: STANDARD SAM METRICS TABLE

Metric	SAM value
Net Annual Energy	8,758 kWh
LCOE Nominal	31.06 ¢/kWh
LCOE Real	24.73 ¢/kWh
First Year Revenue without System	$ -1,180.39
First Year Revenue with System	$ -683.00
First Year Net Revenue	$ 497.39
After-tax NPV	$ -17,313.95
Payback Period	1e+099 years
DC-to-AC Capacity Factor	18.8 %
First year kWhac/kWdc	1,646
System Performance Factor	0.81
Total Land Area	0.02 acres

Additionally, for each of the case studies, the standard metrics table from SAM was presented (an example from the Oklahoma City Building is shown in Table 2). This includes performance values as well as economic values. Because the actual cost data used was representative (and the actual system costs are proprietary), we can't effectively compare the simulated LCOE (Levelized Cost of Energy) values with actual or reported values.

4. SUMMARY

NREL has completed four case studies related to the System Advisor Model (SAM). Specifically, we modeled four PV systems, making generally minor changes to the SAM default values to model the systems (we typically had minimal information about the system other than component names). These case studies are included in the 12.2.2011 SAM release. As illustrative case studies, they can guide the SAM user in setting up their own systems.

In the case of the Oklahoma City system, building load data was also available so we were able to demonstrate to the SAM user how to include load data and link this to a time of use rate.

After adjusting the measured system output for snow days and missing data, reasonable agreement was achieved. Calibrating the overall SAM derate value to minimize the differences further, improved agreement to within 1% for all four cases at an annual level.

These case studies have revealed several issues:

(1) It remains difficult to obtain high quality measured PV system output and synchronous radiation and meteorological data.

(2) The treatment of snowfall and snow cover has a major impact on most large systems and isn't generally captured in the models accurately. In fact, snow cover raises the ground albedo in SAM simulations, thereby increasing system output.

(3) Evidence suggests that the default values used for derates in SAM (and PVWatts from which the data comes) should be updated (based on several of these systems where an annual derate increase of several percent improved the agreement between measured and simulated data). With improvements to module information and changes in technology, current default values are dated. Additionally, specific situations can lead to very large soiling derates.

5. ACKNOWLEDGMENTS

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[1] PV system cost data available at: http://openpv.nrel.gov/ and then filtered by installation year and system size for appropriate but nationally averaged values.

[2] Because the system is maintained and owned by SunEdison, measured performance data was acquired from SunEdison's Client Connect portal (https://my.sunedison.com/). A password is required to gain access to the data, which we obtained because NREL is the site owner.

[3] This study used climate data collected at NREL's Solar Radiation Research Laboratory (SRRL) located at the South Table Mountain site.

[4] Barker, G. "Report on PV System Performance." NREL Subcontract # LAX-1-30480-02. 24 April 2006.

[5] Historical snowfall data from the Farmer's almanac: http://www.farmersalmanac.com/weather-history/