Performance Analysis of Photovoltaic Installations in a Solar America City

Michael Gostein[1], Robert Hershey[2], Lawrence Dunn[1], and Bill Stueve[1]
[1]Atonometrics, Inc., 2515 Mountain View Drive, Austin, Texas 78704
[2]Independent consultant

ABSTRACT

We present our findings from a recent analysis of monitoring data collected on over 480 residential and commercial PV installations in Austin, Texas between 2005 and 2008. These systems were installed under a city rebate program administered by the city-owned electric utility, Austin Energy, and recognized under the Solar America initiative. The majority of these systems were residential installations with rated power under 4kW. In conjunction with the utility, we have undertaken an analysis of the accumulated data in order to quantify long-term performance. The primary analysis goals were to statistically compare the output of existing installations to predictions based on the PVWatts calculator developed by the National Renewable Energy Laboratory (NREL) [1], and to identify trends linking underperforming or over-performing installations. In addition, we wished to establish a simple methodology for the utility to use in assessing the long-term performance of residential and commercial PV installations.

Data

Each system design was analyzed by the installer prior to installation to determine an estimated yearly energy output, using the NREL PVWatts calculator. The PVWatts ratings were tabulated in a database together with data on the module and inverter manufacturers and models. Subsequently, the actual monthly energy output of each installation was determined from on-site meter readings performed by utility company staff during each billing cycle. Fig. 1 illustrates a typical data set from one of the installations. It is evident that the data display seasonal variations as well as statistical fluctuations. The study began with just over 40 systems in January 2005 and included over 480 systems by late 2008.

Methodology

Analysis of the monitoring data poses a number of challenges. The data consist of ~13,000 monthly data points from over 480 installations, and the historical time period for each installation in the study is different, since the number of installed systems increased throughout the study period. The varying historical time periods result in different seasonal impacts on the output of each system.

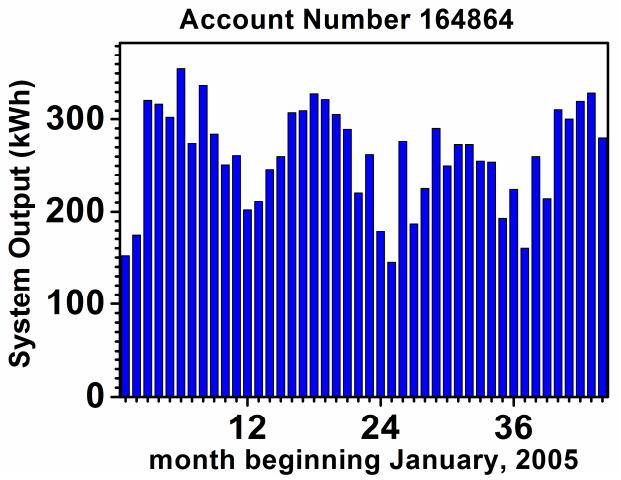

Fig. 1. Typical monthly PV output energy of a single site.

In order to compare the data from different installation sites while accounting for the varying system ratings and seasonal factors, we define the average Performance Ratio PR_{avg} for each system as follows:

$$PR_{avg} = \sum_{j=1}^{N} \frac{1}{N} \cdot PR_j \qquad (1)$$

where

$$PR_j = \frac{E_j}{SR^{PVWatts} \cdot \left(I_j^{PVWatts} \middle/ I_{Yr}^{PVWatts} \right)}. \qquad (2)$$

In equations (1) and (2), N is the number of months of data for the respective installation, PRj is the Performance Ratio in month j, E_j is the system energy produced in month j (in kWh), $SR^{PVWatts}$ is the system rating from PVWatts (in kWh/year), $I_j^{PVWatts}$ is the solar irradiance estimate from PVWatts integrated for month j (in kWh/m^2), and $I_{Yr}^{PVWatts}$ is the solar irradiance estimate from PVWatts integrated over one year (in kWh/m^2).

In implementing Equation (1) we used PVWatts estimates of the solar irradiance in the Austin, Texas area for each month of the year. These estimates are in good agreement with irradiance data collected at the University of Texas at Austin during 2005-2008. Furthermore, we

assume that all PV installation sites in the greater Austin area receive approximately the same amount of sunlight. This assumption is in good agreement with weather station data collected from a private source.

Results

Fig. 2 and Table 1 show the distribution of Performance Ratio results for 480 sites in the study. An important conclusion from the distribution results is that a significant number of the installed systems performed below expectations. While the average Performance Ratio is 0.92, 25% of installations have a Performance Ratio at or below 0.84, and 10% of the installations have a Performance Ratio at or below 0.67.

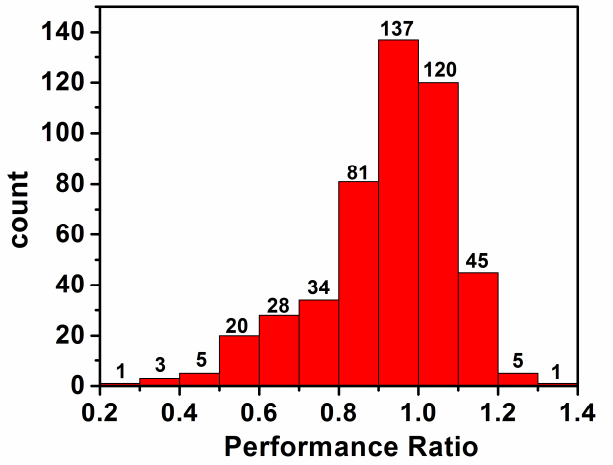

Fig. 2. Performance Ratio distribution of 480 sites in the study. The number above each bar indicates the number of sites within the corresponding Performance Ratio range.

Performance Ratio	Percent
<0.5	1.9%
0.5 to 0.6	4.2%
0.6 to 0.7	5.8%
0.7 to 0.8	7.1%
0.8 to 0.9	16.9%
0.9 to 1.0	28.5%
1.0 to 1.1	25.0%
1.1 to 1.2	9.4%
>1.2	1.2%

Table 1: Performance Ratio Distribution

Fig. 3 shows the distribution of Performance Ratio results broken down by module manufacturer, with the module manufacturer identities intentionally omitted. The diamonds indicate the confidence limits of each result, as shown in the legend. Results for 11 of the 12 module manufacturers show Performance Ratios close to 1.0, within statistical uncertainties.

However, for Manufacturer #4, the results show an average Performance Ratio of only 0.63 +/- 0.06. This indicates performance significantly lower than expectations for the 39 installation sites using modules from this manufacturer. Further investigation is needed to assign the root cause. Significantly, over 90% of the installations using modules from Manufacturer #4 were performed by the same installation company.

Note that these results illustrate the importance of analyzing aggregate data from a large group of sites, because problems with a particular module manufacturer or installation company would be difficult for an individual home or business owner to detect alone.

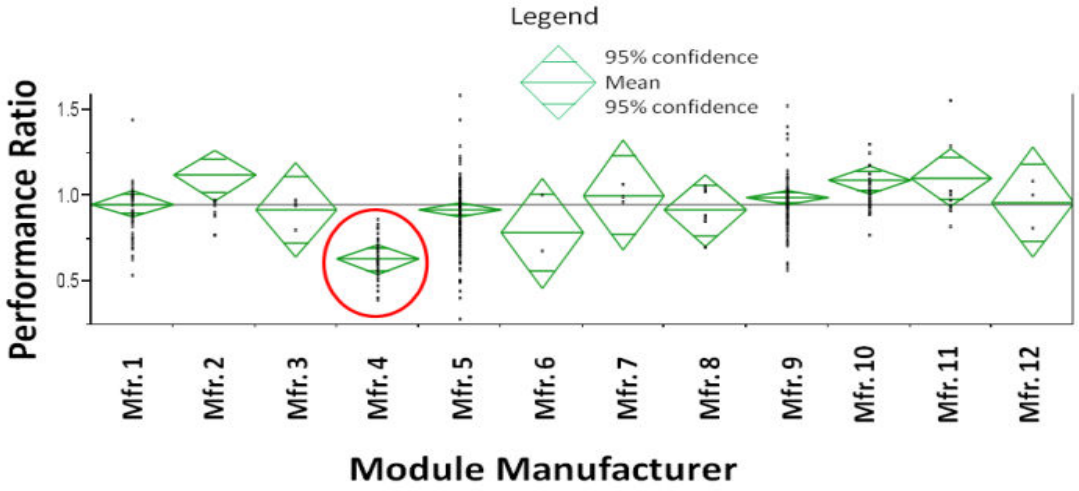

Fig. 3. Performance Ratio breakdown by module manufacturer. The solid horizontal line across all data indicates the average Performance Ratio of all installations analyzed. The data from manufacturer 4 is enclosed within a red circle to highlight the fact that its average Performance Ratio is only 0.63 +/- 0.06.

With the results from Manufacturer #4 excluded, a significant number of under-performing systems remain in the data. Further review of these systems is needed.

We also analyzed the Performance Ratio results by inverter manufacturer, with 10 different manufacturers represented in the study group. However, no statistically significant correlations were observed.

Conclusions

We have established a simple methodology for our local utility for ongoing assessment of PV installation performance, based on a "Performance Ratio" metric. Using this metric, we find that a significant number of rebated PV systems within the utility's service area performed below expectations. The average Performance Ratio for all systems is 0.92, but 10% of installations performed at ratios of 0.67 or below. In particular, installations using a specific module manufacturer were found to show a Performance Ratio of only 0.63. Further investigation is needed to determine the root cause of the poor results for this group, with possibilities including problems with the module quality as well as errors in system installation. A subsequent phase of this study may involve site visits to further isolate root causes of observed under-performance. Overall, the results indicate the importance of monitoring PV site installations to identify problems, and the particular value of analyzing aggregate data from many sites

Acknowledgements

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References

[1] http://www.nrel.gov/rredc/pvwatts/