Field Validation of the Clean Power Estimator's Obstruction Analysis Algorithm

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This paper validates the Clean Power Estimator (Estimator) obstruction analysis algorithm based on results produced by the Solar PathfinderTM (SPF). Results indicate that the Estimator provides acceptable estimates of an obstruction's impact on a PV system's energy generation. The Estimator improves upon the SPF's analytical capability by accounting for energy loss due to obstructions as a function of the PV system's tilt and orientation. The SPF's data collection function could be profitably combined with the Estimator's analytical capability to produce superior obstruction analysis results.

Introduction

The Estimator is an Internet-based PV economic evaluation program available in the US and several other countries [1]. A strength of this program resides in its versatile economic evaluation engine that accounts for local utility rates and PV deployment incentives. The program is also capable of letting users specify array size and geometry, and can provide immediate answers to any selected configuration. Typical Estimator users include prospective residential and commercial PV buyers, PV system dealers and installers, and institutions. The program is not designed for detailed system engineering.

Traditional PV simulation programs (e.g., PVFORM [2]) are based upon time series analysis. These programs are versatile and adequate for many applications, but are less appealing for user-oriented Internet applications that put a premium on "instant gratification."

The Estimator's irradiance calculation engine was developed with the objective of minimizing calculation time and data transfer, while retaining enough accuracy and flexibility to generate information pertinent to users. The Estimator was recently validated against rigorous simulation codes and performed well for its stated purpose: predicting PV output for arbitrary geometries/sizes as a function of time of day and time of year [3].

Obstruction Analysis Algorithm

An obstruction analysis algorithm was recently added to the Estimator because obstructions (e.g., trees, other buildings) degrade energy production for many applications, especially residential applications. A premium was placed on the ease of execution, involving a straightforward way of measuring obstructions and a simple program interface (see Fig.1)

The obstruction analysis algorithm is built using the same logic as the tilted irradiance calculations (see [3]). For any given location, calculations are based on two pre-calculated (using a rigorous model) monthly-hourly PV output tables for two configurations: horizontal and south-facing at 30o-tilt. These tables are used to generate the primary PV-weighted solar resource components using mid-month solar geometry quantities: direct, isotropic diffuse, reflected and circumsolar diffuse. These components may be recombined to generate PV output on arbitrary orientations.

The user enters a mean obstruction elevation in 12 azimuthal directions to perform the obstruction analysis. Elevations can be entered directly if the user has access to an inclinometer or other means of gauging elevations (e.g., using a Solar PathfinderTM with an angle grid). Alternatively, the user can measure obstructions' elevations using a simple but robust approach described in many field manuals (e.g., see [4]) requiring only a stick, and a measuring tape. The Estimator provides detailed instructions to guide the user through this process (see Fig. 2). The method can be extended to provide obstruction profiles when it is difficult to be at

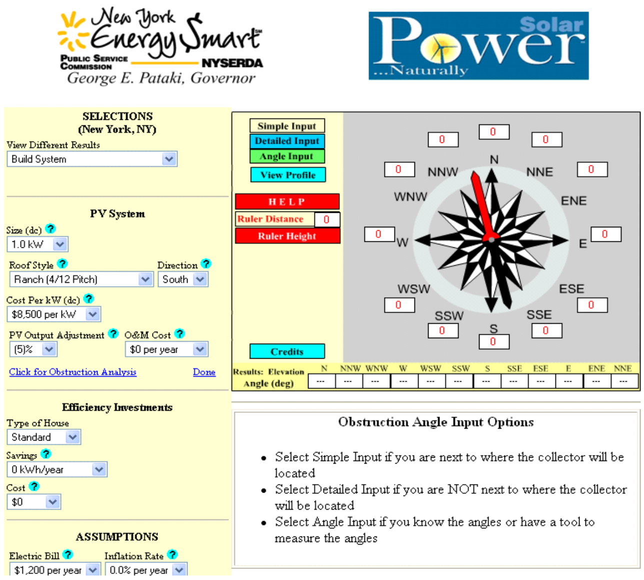

Figure 1: Clean Power Estimator entry Screen for obstruction analysis

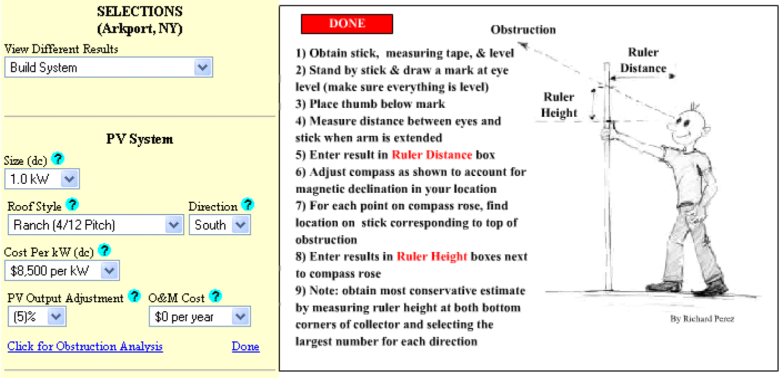

Figure 2: One of the obstruction input help screens

the solar collector location (e.g., on an inaccessible, not-yet-built roof).

Once obstruction elevations are known, their impact is quantified by calculating the fraction of the primary resource components (diffuse, circumsolar and direct) lost to the obstruction at each hour for each month's mid-point. Because calculations are performed only once a month and once an hour, the apparent angular size of the sun is set at 10o to account for point source motion.

Performance Verification

The Solar PathfinderTM (SPF) is a de-facto standard for PV system shading analysis in the U.S.A. because of its widespread utilization by installers. The SPF consists of a see-trough ~ fish eye reflector where an image of the local horizon can be seen when viewed from a vertical standpoint. The user draws the horizon outline on a sun-path diagram for the appropriate latitude range, and estimates the percentage of collectable energy lost graphically (see Fig. 3).

The objective of this paper is to provide a performance evaluation that fits the scope of Estimator applications. Thus, the paper presents a field validation of the obstruction algorithm versus results produced by the SPF

The SPF is useful to gather field data, but lacks flexibility in terms of system analysis because it does not account for varied system slopes and orientations. In addition, data must be collected exactly where the array is to be installed, which may sometime be difficult.

The Estimator's obstruction algorithm is validated against the SPF method based upon two locations and two arbitrary obstruction profiles. The validation metric consists of a comparison of the energy output degradation due to shading as estimated by the Estimator and by the SPF method.

The two case studies (representing latitude extremes in the State of New York) include New York City (Queens) at 40.6^{o} latitude and Plattsburgh at 44.7^{o} latitude. The two arbitrary obstruction profiles include the entrance canopy of an office building (CESTM-building) and a residence in the Albany area (House-Y). The CESTM-building profile features pronounced obstructions (building wings) in the east and the west, affecting primarily summer output. The House-Y profile has pronounced obstruction due south. The two obstruction profiles are illustrated in Fig. 4.

Two horizontal SPF sun path diagrams were selected for each profile, corresponding to the two considered latitudes and covering respectively the 37^{o}-43^{o} and 43^{o}-49^{o} latitude ranges. According to specifications, the selected diagrams are appropriate for collector tilts ranging from 20^{o} to 90^{o}.

In addition, the evaluation was performed for four PV array geometries:

- 4/12 south facing (18.5^{o} tilt)
- 12/12 south facing (45^{o} tilt)
- 12/12 East-South-East (45^{o} tilt, 60^{o} azimuth)
- Vertical South facing

The SPF transparent angle grid was used to input the obstruction elevations in the Estimator's azimuthal regions in order to minimize possible source of

Figure 3: Solar PathfinderTM and sun-path diagrams

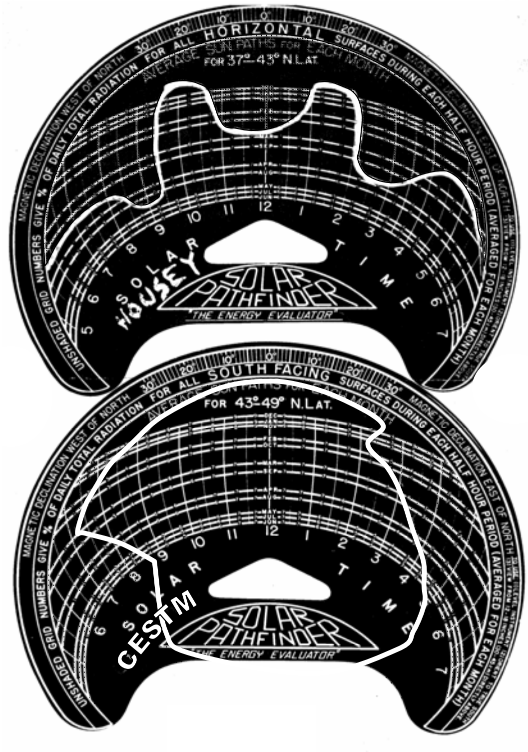

Figure 4: Selected obstruction profiles (House-Y, top, and CESTM building, bottom)

discrepancy between the SPF and the Estimator method.

Results

Table 1 reports the unobstructed monthly energy production of each selected array at the two selected locations. The impact of obstructions on the monthly energy generation of each orientation/location as determined from the Estimator analysis is reported in Figure 5.

Discussion

Several observations can be made based on Figure 5. First, the Estimator faithfully replicates the SPF's results for collectors that are facing south at a moderate tilt.

Second, the Estimator accounts for different obstruction impacts as a function of PV system geometry. Among the selected case studies, differences are most pronounced for the south-east facing roof in summer when east/west obstructions are large (top two graphs in Figure 5).

Differences become very significant in cases of off-south orientations combined with asymmetric obstruction profiles. In order to illustrate this point, a third obstruction profile was created by removing the west-facing obstructions of the CESTM profile. The annual energy lost as a function of orientation and tilt is presented in Figure 6. While the Estimator and SPF are fairly close for a "standard" array, such as a 4/12 south-facing roof, they yield significantly different results for east and west facing arrays, especially as array tilt increases. For example, a west-facing vertical system has no losses due to obstructions while an east-facing vertical system loses more than 40 percent of its output.

Conclusions

This paper validates the Clean Power Estimator (Estimator) obstruction analysis algorithm based on results produced by the Solar Pathfinder^{TM} (SPF). Results indicate that the Estimator provides acceptable estimates of an obstruction's impact on a PV system's energy generation. The Estimator improves upon the SPF's analytical capability by accounting for energy loss due to obstructions as a function of the PV system's tilt and orientation. The SPF's data collection function could be profitably combined with the Estimator's analytical capability to produce superior obstruction analysis results.

References

(1) Hoff, T. E. (1999): Clean Power Estimator. ASES-1999 Conference, Portland, Worldwide version of the Estimator may be found at http://www.bpsolar.com

(2) Menicucci D.F., and J.P. Fernandez, (1988): User's Manual for PVFORM. Report # SAND85-0376-UC-276, Sandia Natl. Labs, Albuquerque, NM

(3) Perez R., R. Reed and T. Hoff, (2003): Validation of a Simplified PV Simulation Engine. Proc. ASES Annual Meeting, Austin, TX (and Solar Energy – In Press)

(4) The Boy Scout Handbook, published by Boy Scouts of America.

TABLE 1
Unobstructed PV production for selected PV array geometries
(KWh per installed kW-dc)

	NYC (Queens)				Plattsburgh			
	4/12 South	12/12 South	Vertical South	12/12 ESE	4/12 South	12/12 South	Vertical South	12/12 ESE
January	62	78	73	58	59	75	72	54
February	86	101	86	80	81	97	85	74
March	101	107	78	89	105	114	86	94
April	123	119	70	109	118	116	72	104
May	129	115	57	112	134	122	63	116
June	141	121	54	121	135	118	56	115
July	135	118	55	116	133	118	58	113
August	126	118	64	112	126	120	69	110
September	109	112	75	96	101	106	75	91
October	92	103	83	83	76	88	74	70
November	57	69	62	52	45	56	52	41
December	54	69	66	50	40	51	49	36
Year	1,216	1,229	824	1,077	1,152	1,179	811	1,018

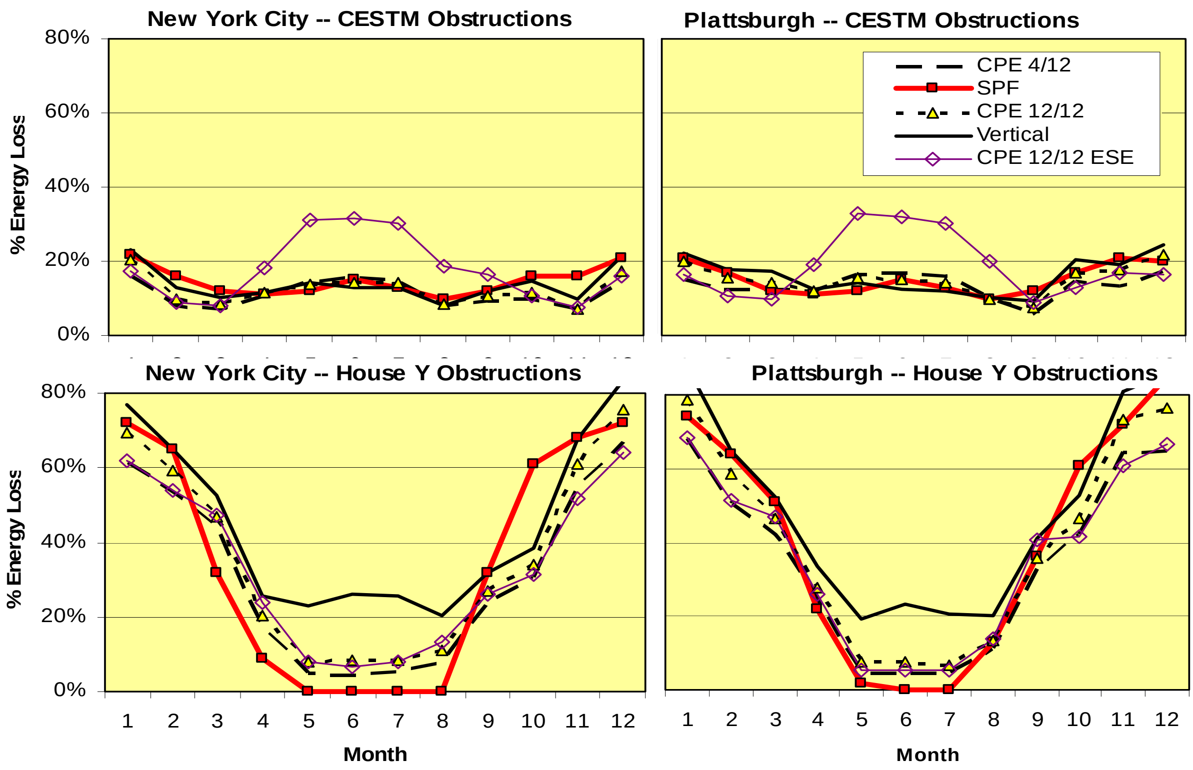

Figure 5: Percentage of monthly energy lost to shading for:

- *2 locations (NYC using 37°-43° SPF chart, and Plattsburgh using 43°-49° SPF chart)*
- *2 obstruction profiles (CESTM and House-Y)*
- *4 array geometries (4/12-south, 12/12 south, Vertical South and 12/12 east-south-east)*
- *2 methodologies (SPF and Estimator)*

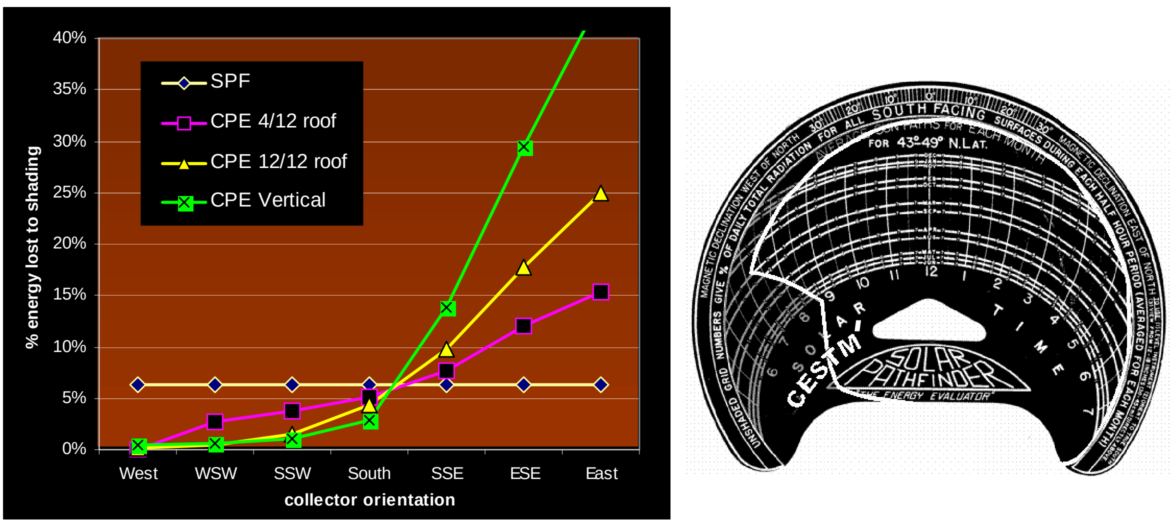

Figure 6: Annual energy lost to shading as a function of collector slope and azimuth for an asymmetric obstruction profile