Improvements to PVWatts for Fixed and One-Axis Tracking Systems

Aron P. Dobos*, Janine M. Freeman, Nate J. Blair****

Envision Digital Corporation*, National Renewable Energy Laboratory**

aron.dobos@envision-digital.com

Abstract

This work presents improvements to the widely used NREL PVWatts photovoltaic system energy model to improve modeling accuracy for typical fixed and one axis system designs. These improvements allow users to more credibly and quickly evaluate competing system designs in early stage feasibility, and are shown to improve PVWatts' system performance prediction capabilities without major impact to ease of use.

Introduction

The NREL PVWatts model is a simple-to-use photovoltaic system energy model that is widely accepted in the industry for initial feasibility assessment and quick analysis. We anticipate that the enhanced feature set presented here will be made available via the open-source code and in the SAM software development kit, and a subset of the features described here will be added to the implementation in the SAM desktop software, PVWatts application programming interface (API), and the PVWatts web application.

Model Changes

Our changes to the standard PVWatts Version 5 model presented in this work include:

1. **Module types and loss assumptions.** The updated assumptions for the three different module types in PVWatts are listed in the table below.

Type	STC η	Cover	γ_{mpp}
Standard	~17.0 %	Glass	-0.38 %/°C
Premium	~20.1 %	AR Glass	-0.30 %/°C
Thin film	~15.6 %	Glass	-0.28 %/°C

   The lumped DC system loss parameter is revised to approximately 6 %, which represents non-modeled losses including mismatch, wiring, and light induced degradation (LID).

2. **Self-shading loss.** The self-shading losses are calculated using the semi-empirical model of Deline, et. al. (2013). For fixed rack or tracking systems, the ground coverage ratio (GCR) defines the array layout. Modules are assumed an aspect ratio of 1.7 and an STC rating of 300 Watts, from which the number of total modules can be calculated, as well as an approximation of the number of rows assuming a "square" array layout. Fixed systems are assumed to have a 2-up portrait configuration, while one axis trackers are in a 1-up portrait setup.
3. **Module cover loss.** The module cover model is improved beyond PVWatts version 5 to include diffuse angular effects.
4. **Spectral loss.** A simple air mass modifier spectral correction is added according to the approach of Desoto (2004).
5. **Snow loss.** Snow losses are accounted for using the Marion, et. al. model (2017), as implemented in NREL's System Advisor Model (SAM) software, for both fixed and one axis tracking systems.
6. **Loss diagram outputs.** New outputs are added to inform on the individual losses, which are relative to the previous energy value.
7. **Bifacial modules.** By setting a new module *bifaciality* input parameter to greater than zero, the Marion, et al. (2017) view factor model is enabled for back side irradiance gain estimation, and is reported as a positive value in the loss diagram.
8. **Tracker wind stow.** In high wind conditions, one axis trackers are designed to stow to prevent damage to the system installation, which reduces POA irradiance. This loss is estimated by forcing a tracker to a stow angle if the average hourly wind speed exceeds a threshold setting.
9. **Step-up transformer.** In larger installations, a step-up transformer is needed to connect a PV system to the grid. A simple two parameter model is implemented to account for load and no-load loss behavior of typical transformers.
10. **Plant controller.** A plant-level controller may enforce a maximum inverter output equal to the grid interconnection limit. The AC maximum delivery power is set as a fraction of the rated system AC power.
11. **Diffuse stow.** When diffuse light comprises a significant portion of the total available irradiance, annual energy yield may be increased by tracking to a more horizontal position during cloudy periods. We implement a simple search that finds the best tracker angle at every time step to maximize total POA irradiance.
12. **Soiling and albedo inputs.** Monthly and daily soiling and albedo input options allow for users of PVWatts greater flexibility in modeling specific scenarios.

Results

Self-shading loss. Fig. 1 show losses for different system designs as a function of the ground cover ratio (GCR), relative to a nearly completely unshaded condition (GCR=0.1). For silicon modules, the row-to-row shade impact on a one-axis tracker is quite pronounced as non-linear electrical losses quickly predominate as the GCR is increased. Employing a backtracking strategy can reduce losses. For thin-film modules, backtracking may incur greater losses than standard tracking.

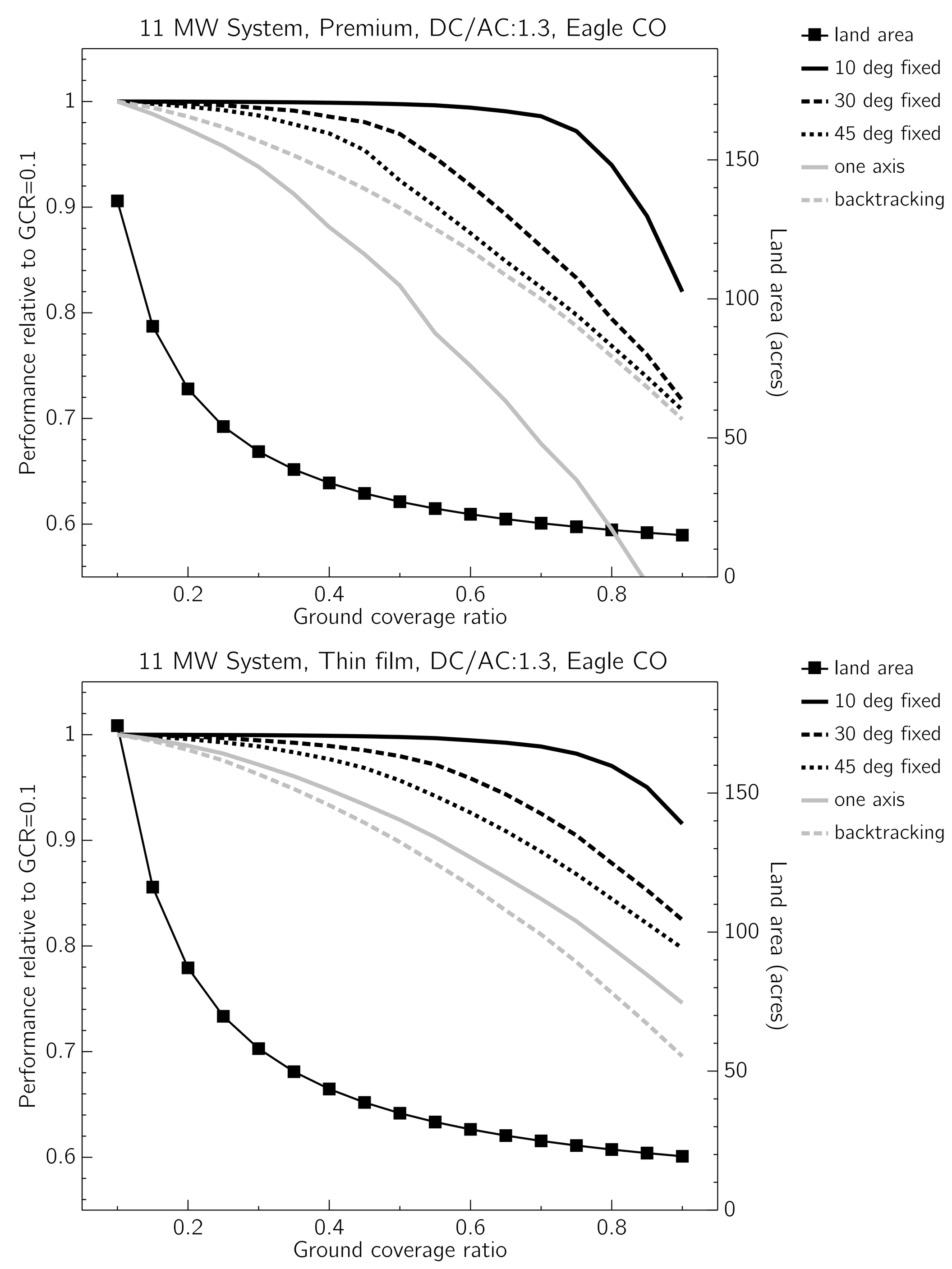

Figure 1: Relative performance for different system designs with respect to the unshaded condition.

Snow loss. Fig. 2 shows annual energy output for five different system designs, accounting for snowfall. For a low tilt fixed system, the loss can be over 9 % for a typical year in Eagle, CO.

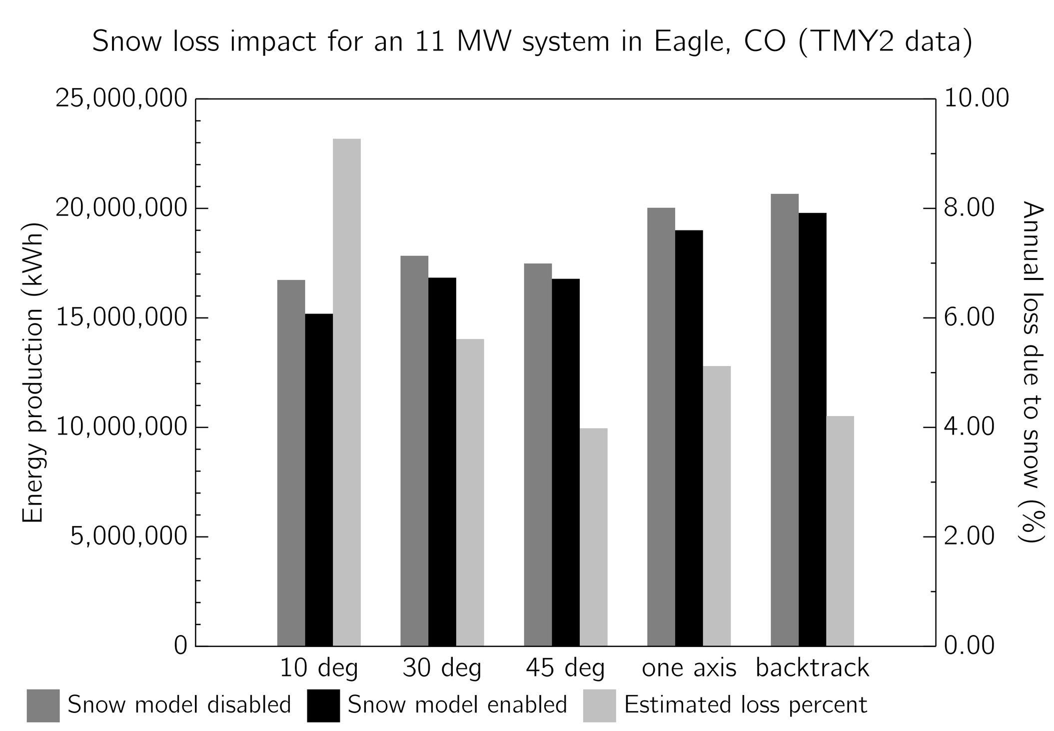

Figure 2: Estimation of energy losses due to snow for a system in Eagle, CO.

Diffuse stow tracking. We evaluate our diffuse stow one axis tracking algorithm in Wilmington, Delaware. On an annual basis, PVWatts predicts that a monofacial tracking system with diffuse light stow optimization yields about 0.6 % more energy in Wilmington. The same system with bifacial modules shows a bifacial gain of 3.9 %, but the diffuse stowing gain is reduced to about 0.3 %. Since a tracker with bifacial modules would tend to stow horizontally to maximize the front side sky view factor, the rear side view factor is simultaneously reduced, thereby reducing the potential total irradiance gain from stowing relative to a true-tracked position.

This behavior is clearly visible in Fig. 3, which shows tracker angles on four representative days in January. The first and second days are primarily cloudy, and the monofacial diffuse stow-enabled tracker spends more time close to a zero degree angle. With bifacial modules, the optimum position is somewhere in between the true-tracked and the monofacial case, explaining the reduced potential gain from diffuse stowing with bifacials. The third day shows behavior under high wind stow, and on the fourth day, all tracker angles are the same and point to the sun due to the relatively high beam irradiance conditions.

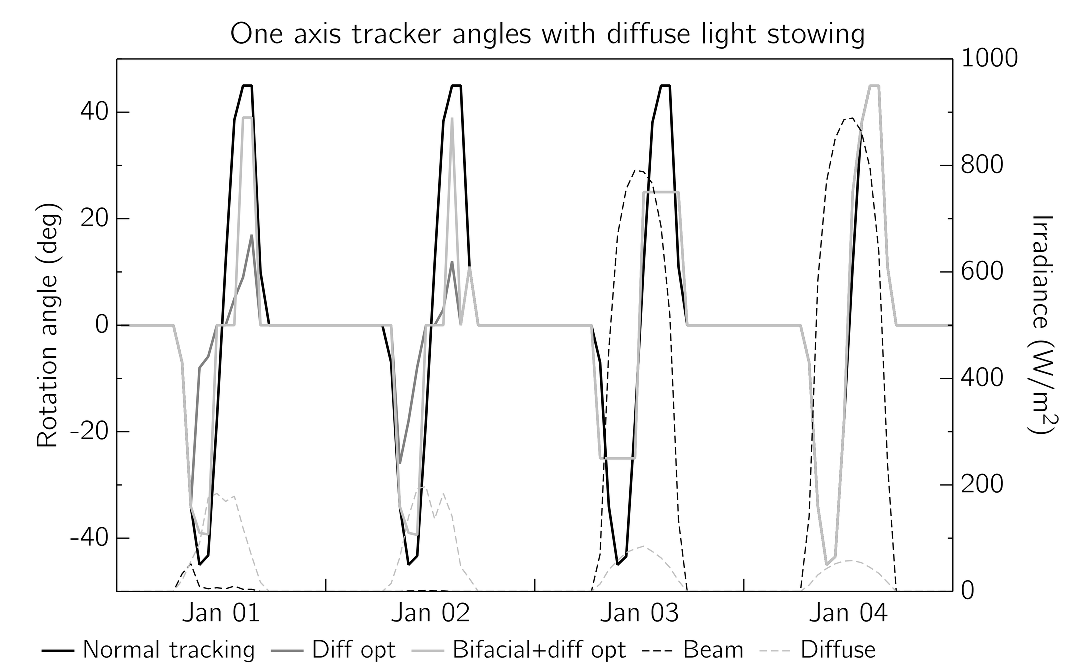

Figure 3: Tracker rotation angles for different tracking strategies across four representative days.

Comparison with real systems. We leverage past NREL PV model validation work to compare our expanded PVWatts model with measured system performance data for nine operating photovoltaic plants.

System	PVWatts Version 5 (%)	Improved Version (%)
STF	-1.4	1.1
Forrestal	-6.9	-3.1
RSF1	-0.9	1.6
RSF2	-3.2	0.2
VisitorParking	-0.5	2.8
MesaTop	0.1	2.1
FirstSolar2	-4.0	-5.6
DeSoto	-9.6	-7.4
FirstSolar1	-6.9	-8.7
Average	-3.7	-1.9

In general, we see that the errors are similar to PVWatts V5 for most cases. The average error across the 9 systems for PVWatts V5 is -3.7%, while for the improved PVWatts model it is -1.9%. Note that the exact GCR is unknown for many of these systems, or the installed GCR may differ from the system specifications.

Conclusions

Improvements to the PVWatts algorithms for modeling typical fixed and one-axis tracking photovoltaic system designs were presented. The enhancements allow PVWatts to better predict energy output as a function of typical design parameters and environmental conditions with minimum set of input parameters. We anticipate that these model algorithm updates will be made available in a future release of the open source NREL PVWatts code and SAM software development kit, and a subset of these features will be added to the SAM desktop software and the PVWatts web application and API.

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