Improving Forecasts of PV power output using real-time measurements of PV output of 100 residential PV installs

Vincent P. Lonij 1, Vijai Thottathil Jayadevan 1, Adria E. Brooks 1, Kevin Koch 2, Mike Leuthold 1, and Alexander D. Cronin 1

1 University of Arizona, Physics, Tucson, AZ 85721
2 Technicians For Sustainability, Tucson, AZ 85705

ABSTRACT

We compare and combine three different techniques to forecast the variability in irradiance due to clouds. We implemented each of these techniques in the Tucson, AZ region: (1) a numerical weather model, (2) measurements from a network of PV systems, and (3) images from an all-sky camera. We utilize and present animated (video) data for each of forecasting method. Our numerical weather model provides forecasts of irradiance up to several days in advance. Our network of PV systems can forecast output an hour in advance. Our images from an all-sky camera, and associated image analysis can be used to forecast 10 minutes in advance. We will show how using results from a numerical weather model as an input to the other forecasts improves accuracy of 45-minute ahead forecasts.

INTRODUCTION

Solar power utilization at the utility-scale is a Grand Challenge. A major problem is the intermittent output of solar power plants due to passing clouds and nighttime. Intermittency limits the adoption solar power by utility companies and industry because they require reliable power. Intermittency can be mitigated with energy storage, spinning reserves, or demand response. However, optimal management of these three methods requires accurate forecasts of PV power output on several timescales.

Several methods exist to forecast PV power output [1,2] including

1. Numerical weather models,
2. Measurements of PV power from a regional network of PV systems,
3. Block motion analysis of ground based camera images.

We will discuss the advantages and drawbacks of each of these methods and we will show that combining these methods can improve the accuracy of our forecasts. In particular, using predicted wind speeds at cloud altitude from a numerical weather model, or using cloud velocity measurements from an all-sky camera improve the forecasts that use measurements of a network of PV systems.

NUMERICAL WEATHER MODEL

Numerical weather models can forecast up to several days in advance. Figure 1 shows forecasts of DNI and GHI based on our implementation of the WRF (Weather Research and Forecasting) numerical atmospheric model made 30 hours in advance. While Figure 1 shows excellent agreement with satellite images, forecasting the exact timing of cloud events is still challenging (see Figure 2). This implementation of the WRF utilizes a 448-node Beowulf cluster and requires approximately 4 hours of computation to provide forecasts every 2 minutes on a 2-km grid across North America up to 50

Figure 1: a) 30 hour ahead forecast of GHI in the Arizona region, b) DNI forecast, c) Satellite image of the same region. Movie available at [3].
hours in advance.

Figure 2: One-day ahead forecasts of Plane of array irradiance in a single location compared to measurements of PV power output.

MEASUREMENTS OF PV POWER FROM A REGIONAL NETWORK OF PV SYSTEMS.

We used measurements of PV power output of many systems spread out over a large geographical area to forecast power output. Measurements are taken at 15-minute intervals. Figure 3 shows final yield for 83 systems in the Tucson area plotted on a map for three different times. The dark points (indicating low output, due to a cloud) shift from the southeast to the northwest of the Tucson valley over the course of 1 hour.

PV output from one system at location \((x,y)\) at time \(t+\Delta t\) can be directly forecast from the output at time \(t\) of a system at location \((x',y') = (x-v_x \Delta t, y-v_y \Delta t)\) using

\[
y_f(x, y, t + \Delta t) = y(x - v_x \Delta t, y - v_y \Delta t, t)
\]

where \(y_f(t)\) is the yield (kW/kWpeak) at time \(t\), and \(v_x\) and \(v_y\) are the x and y components of the wind vector respectively. If no PV system exists near location \((x',y')\), a forecast will be unavailable.

The main challenge is to determine the wind velocity at the altitude of the clouds. Ground based measurements of wind (also indicated in figure 3) are not an accurate measure of the velocity of clouds. We can infer cloud velocity from ground based irradiance measurements as well by finding the closest solution to

\[
y_f(x, y, t) = y(x - v_x \Delta t, y - v_y \Delta t, t - \Delta t)
\]

for \(v_x\) and \(v_y\) based on measurements of \(y\) for all systems.

However, in the case of data taken at 15-minute intervals, eqn. (2) cannot be used until a cloud has shaded one or more systems for at least 15 minutes. Alternatively, the numerical weather model described above can be used to obtain more accurate estimates for cloud velocity.

Figure 4 shows forecasts of PV power production at a single location using eqn. (1) and using a known wind velocity.
Figure 4: Forecasts of PV performance based on measurements of a network of 83 PV systems.

One significant advantage of this method is that PV power output can be directly inferred from the output of other PV systems. That is, we do not need to know about the density, spectral properties or location of clouds, as we do in the other two methods discussed here.

**BLOCK MOTION ANALYSIS OF GROUND BASED CAMERA IMAGES.**

Ground-based cloud imaging can be used to forecast intermittency due to clouds about 10 minutes in advance (the time it takes for a cloud to move from the edge of the frame to the center). Similar to [2] we used block-motion estimation to estimate the velocity of clouds in different parts of the image (see Fig 5) [6].

Figure 5: Image taken with a camera mounted on a dual axis tracker pointed at the sun. Red arrows indicate motion vectors obtained from block motion estimation analysis. Movie available at [4].

These forecasts can predict cloud arrival times with an accuracy of a few minutes. (see Figure 6).

REFERENCES


[3] [http://www.atmo.arizona.edu/?section=weather&id=wrf](http://www.atmo.arizona.edu/?section=weather&id=wrf)

