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# Modeling solar irradiance smoothing for large PV power plants using a 45-sensor network and the Wavelet Variability Model

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**Abstract**

With increasing penetrations of solar photovoltaic (PV) power on the electric grid, the variability of solar irradiance, and therefore power, is important to understand because variable resources can challenge grid operations. Predicting PV variability using one irradiance sensor does not account for the smoothing of irradiance over the area of a power plant. Smoothing is examined using two methods: averaging measurements from many irradiance sensors, and using the Wavelet Variability Model developed by Lave et al. (2013). This work provides new experimental testing: comparison of the smoothing over a 30 MW power plant using the average of 25 sensors to the WVM. The results show that an aggregation of 25 sensors predicts more variability than the WVM on short timescales, suggesting that more than 25 sensors would be required in order to predict the same power variability as the WVM. In addition it is shown that the reduction in daily Variability Index depends on the daily cloud speed scaling coefficient.


*Keywords:* Solar variability; Wavelet; Spatial smoothing; Photovoltaics

## 1. Introduction

Electrical energy generation in the US has historically come from non-variable generation sources – largely fossil fuels, hydroelectricity, and nuclear. These energy sources are considered non-variable because output is controlled by the operator and so can be turned on, off, or modulated as needed (subject to some physical limitations, of course, but largely controllable on demand). Variable generation sources such as wind and solar PV, in contrast, may be ramped down, but their upper limit of available power is subject to the availability of the solar and wind resources at a given time. Variable sources such as wind and solar power are increasingly contributing to electricity generation in the US. Solar PV and wind sources contributed an essentially negligible amount to overall electricity generation in 1985 (17 million kW h generated out of a total of about 2500 billion kW h in the US), but grew to 3.7% of energy served in 2012 (U.S. Energy Information Administration, 2013b). The contribution of renewable energy sources, especially solar and wind, to electricity generation is projected to grow faster than that of fossil fuels through 2040 (U.S. Energy Information Administration, 2013a).

Maintaining the reliability of the electric grid requires understanding and planning for both the uncertainty and variability inherent in the system. Every generator and transmission line has some probability of failure; the demand for electricity has variability throughout the day.

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With the addition of variable generation sources like wind and solar PV, generation variability likewise becomes a factor. The system must be prepared and physically capable of responding to this variability. This work focuses on the variability of utility-scale solar PV.

Solar PV power plants are variable generation sources, partly because of the entirely predictable motion of the sun through the sky, which causes increasing power in the morning hours and decreasing power in the afternoon. The other main source of variability is the less predictable, shorter timescale effects of clouds. The less predictable component of variability is of interest to grid operators and is the focus of this work. Cloud motion over a single irradiance sensor can show large changes in irradiance on a second-to-second basis. If this represented the variability of a large PV power plant, and if many of such generators existed on the grid, it would negatively affect the stability of the grid. In reality, though, as clouds move over a PV plant, each PV module is impacted at a different time, depending on the location of the module and cloud characteristics. This is referred to as spatial smoothing and it results in less variability of the true power plant output than of the single point irradiance measurement. The irradiance integrated over the area of the power plant footprint will have smaller fluctuations than the irradiance point sensor. Since power is approximately proportional to aggregate irradiance (Hoff and Perez, 2011), the plant's power fluctuations are expected to be proportional to the smaller, spatially smoothed fluctuations, not the fluctuations from a single point sensor.

Spatial smoothing is illustrated in Fig. 1 which shows irradiance measurements over a one hour period. In this example, the irradiance measured at one location (top plot) is quite variable. When the irradiance is measured at 25 locations within a few hundred yards of the first sensor (middle plot), it is observed that the clouds affect each sensor at a different time. Finally, if these 25 sensors are averaged together, the bottom plots show that the average irradiance would be less variable than the single sensor irradiance.

Because solar PV generation is rapidly increasing in capacity and will soon be a significant contributor to portions of the electricity grid, and due to the potentially negative impact of large fluctuations in PV power, it is important to understand the spatial smoothing of solar PV power plants. The goal of this project was to determine what the spatial smoothing is over the area of large PV power plants and compare models for predicting the smoothing.

## 2. Background

Spatial smoothing was studied using a network for 45 irradiance sensors. The data from the network was used to test and compare two models for predicting spatial smoothing. This section details the sensor network and summarizes available spatial smoothing models.

### 2.1. Experimental setup

This work utilizes data from a network of 45 solar irradiance sensors which was deployed north of Flagstaff, Arizona as part of a Wind and Solar Variability Study completed by Northern Arizona University, NextEra Energy Resources, and WindLogics. The irradiance sensors were deployed over a one-square mile grid. Fig. 3 shows the sensor layout. The sensors are on a 590 ft (178 m) grid in the center part of the network and on a grid of up to 1770 ft (539 m) in the less dense outer parts of the network.

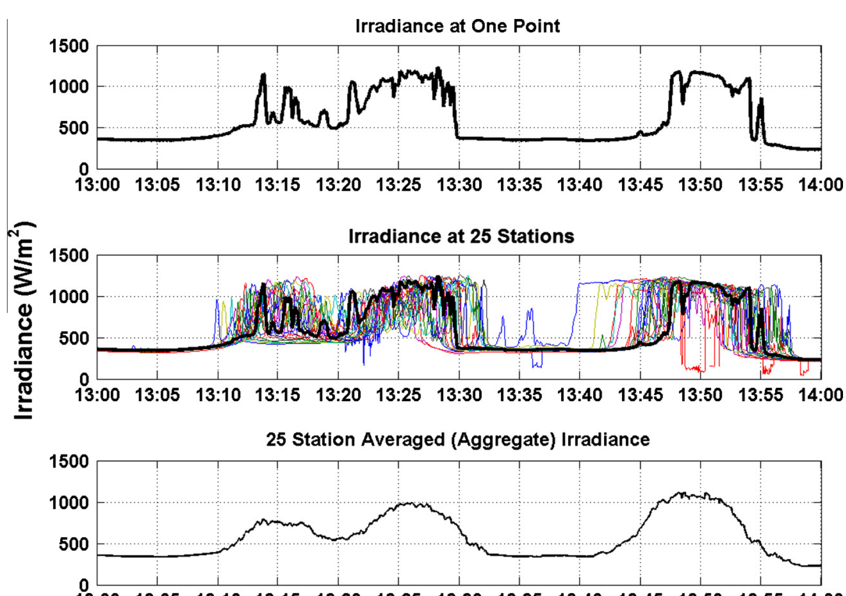


Fig. 1. The spatial smoothing on April 12, 2013 is considered by comparing the single irradiance sensor measurement (top plot) to measurements at 25 sensors (middle), and to a smoothed irradiance signal (bottom) which accounts for the aggregated irradiance over the size of a PV power plant.