Measurement and Modeling of Solar and PV Output Variability

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MEASUREMENT AND MODELING OF SOLAR AND PV OUTPUT VARIABILITY

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ABSTRACT

This paper seeks to understand what temporal and spatial scales of variability in global horizontal radiation are important to a PV plants and what measurements are needed to be able to characterize them. As solar radiation measuring instruments are point receivers it is important to understand how those measurements translate to energy received over a larger spatial extent. Also of importance is the temporal natural of variability over large spatial areas. In this research we use high temporal and spatial resolution measurements from multiple sensors at a site in Hawaii to create solar radiation fields at various spatial and temporal scales. Five interpolation schemes were considered and the high resolution solar fields were converted to power production for a PV power plant. It was found that the interpolation schemes are robust and create ramp distributions close to what would be computed if the average solar radiation field was used. We also investigated the possibility of using time averaged solar data from 1 sensor to recreate the ramp distribution from the 17 sensors. It was found that the ramping distribution from using appropriately time averaged data from 1 sensor can reasonably match the distribution created using the 17 sensor network.

1. INTRODUCTION

Solar energy reaching the earth's surface is influenced by clouds, aerosols, water vapor and other atmospheric constituents thereby introducing variability in the amount of solar radiation reaching the earth's surface. Each of these constituents influences solar radiation at its own inherent time and space scale. Therefore modeling solar variability becomes an inherently complicated problem.

The issue of variability in PV plant output has become important in the last couple of years as utility scale PV plants go online [1, 2]. Understanding variability in PV plant output requires an understanding of (a) the spatial and temporal variability of solar radiation; (b) the influence of solar variability on PV plant output. Some studies have been conducted in Spain to relate PV plant power output and measured Global Horizontal Irradiance [3, 4].

Pre-feasibility and feasibility studies for utility scale PV plants involve, among other things, the determination of solar resource at potential deployment sites. While a plant may be feasible based on the availability of solar resource at a location the impact of deploying a large quantity of variable renewable generation on the grid requires additional studies. For such studies it is important that realistic, high temporal resolution PV production estimates for various size plants be available over large regions. As such studies need to be done in advance of putting large quantities of power on the grid, actual PV production data will not generally be available to conduct such studies. In the absence of actual production data it is important that a capability for simulating such scenarios be developed. One way to create such simulations is to deploy a large number of solar sensors in highly dense grids. Such highly dense solar grids are expensive to deploy and maintain and are therefore not feasible at multiple locations. Another option is the possibility of using single solar sensors that can measure at high resolution and filtering the data to create datasets resembling sensor networks. This data can then be used to create PV plant out for various size plants.

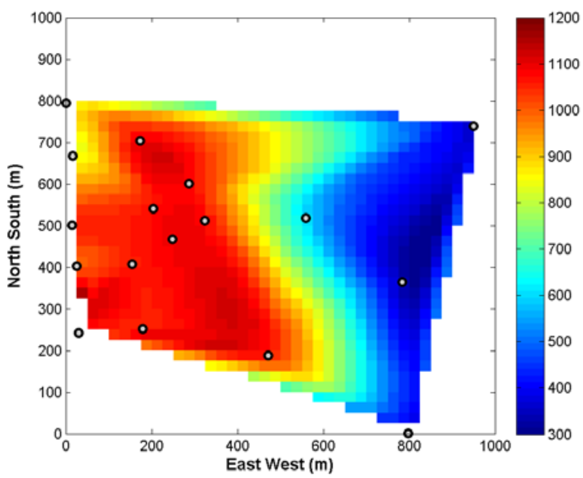

Figure 1: GHI distribution from 17 GHI measurements at a site in Hawaii. The sensors, represented by dots, are distributed over an approximately 1 square kilometer area and measurements are made every second.

To test the viability of using single sensors to model utility scale PV plants a dense solar sensor network was set up in Oahu, HI. This dense sensor network contains 17 sensors spread over a 1 square kilometer area. GHI is measured at 1 second resolution using Licor Model LI200SB Pyranometer , Campbell CR800 data loggers with GPS time synchronization capability.Data has been continuously available since March 2010.

In this study we use 1 month of 1 second data. As 1 second solar measurements are equivalent to instantaneous point measurement the data was averaged to a minimum of 10 seconds to create a representative measurement for a small region surrounding the measurement point. Other averaging periods such as 1 minute and 5 minutes were also considered for this study.

2. METHODOLOGY

There are two parts to this study. The first part of the study is to determine whether the high-density solar network is capable of producing a robust high resolution solar field using interpolation methods. The second part of the study investigates the possibility of using data from a single sensor to model variability in the high-resolution solar field created using the high-density network.

2.1 High-resolution solar fields

Four interpolation schemes were chosen to create 50 m resolution data. Averages of all the sensors were also considered. The interpolation methods considered were –

(1) Nearest Neighbor: Effectively the nearest observation to the interpolated grid is considered after Delauney triangulation [6] of the measurement points.

(2) Natural Neighbor: This spatial interpolation method is based on Voronoi tessellation [7] of a discrete set of spatial points created using the Delauney triangulation method. This method provides a smoother approximation to the underlying distribution than other methods such as the nearest neighbor method. Effectively the method uses a weighted average of members

(3) Linear: This method again uses Delauney triangulation and then linearly interpolates to create the high-resolution solar datasets.

(4) Cubic: This method too uses Delauney triangulation and then uses a cubic fit to the data to produce smoother surfaces than the nearest neighbor or linear method.

(5) Average: The data is averaged to produce a single radiation value for the whole area.

After creation of high resolution solar fields the GHI data is used to compute PV output using the PV Watts model. The PV output is then used to create ramps or changes in output production from one time to the next. The ramp distributions are then analyzed to determine the sensitivity of those distributions to the interpolation scheme used.

2.2 Single sensor comparisons

The goal of this work is to investigate the possible of creating solar and PV output datasets that have similar ramp characteristics to those produced by the dense sensor network. The simplest way to produce the characteristics of a large solar field using a single sensor is to temporally average the data over various time intervals. Other sophisticated schemes that consider cloud height winds and weight the temporal data can be devised but in our case we use simply box filters.

3. RESULTS

Data from the month of July 2010 was used in this study. While the measurements were taken at 1 second the analysis was done at resolutions of 10 seconds, 60 seconds and 300 seconds. The GHI data from the 17 sensors were averaged to the 3 time resolutions. The time-averaged datasets were then used to create 50 m resolution GHI fields using the 5 schemes described in Section 2.1. The GHI field was then used in PVWatts [5] to create power out from a PV plant. The rated capacity of the PV plant was calculated to be 42 MW under the assumption that a 1 MW plant covers 20,000 square meters in area. The PV panels were assumed to be at fixed horizontal tilt for this analysis.

Ramps or changes in power production per relevant time interval (10, 60 or 300 seconds) were calculated and the distributions of those ramps are shown in Figures 2, 3 and 4. Note that only ramps greater than 1 MW in magnitude are considered as our primary goal is to be able to capture ramps that occur due to cloud passage.

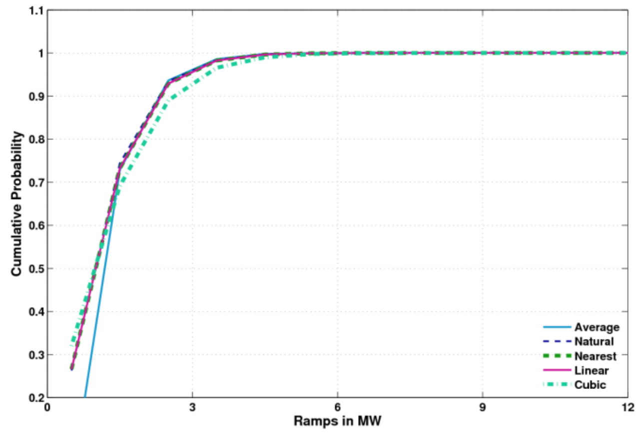

Figure 2: Cumulative Probability distribution of ramps in MW for power output at 10 second resolution. Note the robustness of the schemes shown by the relative insensitivity of ramp rate statistics to the interpolation method used.

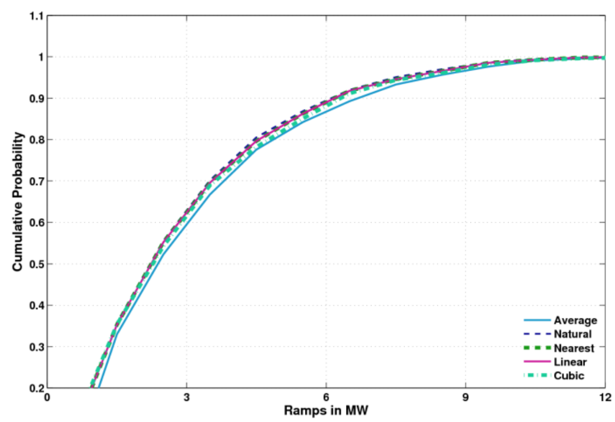

Figure 3: Cumulative Probability distribution of ramps in MW for power output at 60 second resolution

It is observed that the ramp distributions are relative insensitive to the interpolation method used to create the solar fields. We can therefore assume that any of the interpolation schemes considered can be used to create PV output from GHI measurements and the results will be similar to the other methods.

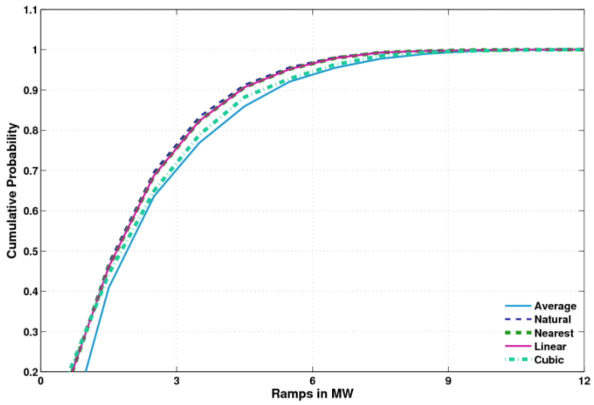

Figure 4: Cumulative Probability distribution of ramps in MW for power output at 300 second resolution.

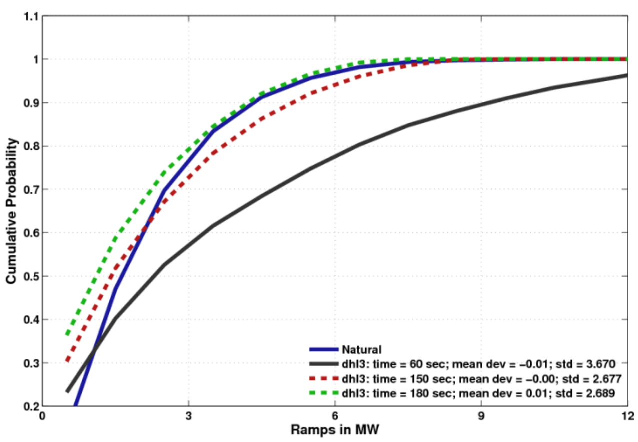

Figure 5: 60 second ramp probability distribution for a single sensor compared to the power output created from multi-sensor high-density solar field. The upper solid blue line represents the multi-sensor array. The lower black line is represents the single-sensor with 60 second averaging. The lower and upper dotted red and green lines represent 150 and 180 second averaging.

The next step in the analysis involved using data from 1 sensor to create radiation fields that are representative of the distributions shown in Figures 2, 3 and 4. A sensor at the middle of the array was considered for creating the time averages.

Figures 5 and 6 show the results of averaging a single sensor measurement in order to create ramp distribution similar to that observed by multi-sensor arrays. For the 60 second ramps considered in Figure 5 it is seen that comparable distributions can be created by averaging the single sensor data to 150 – 180 seconds. When we consider the 5 minute ramps, Figure 6 shows that the single sensor averages need to be close to 450 seconds.

4. CONCLUSIONS AND FUTURE WORK

It is found that interpolation schemes used to create high-resolution GHI fields from multi-sensor datasets are robust and relatively insensitive to the method used. It is therefore reasonable to assume that any of the schemes can be used to create high resolution GHI fields which can then be used to create power output from a PV plant under certain assumptions.

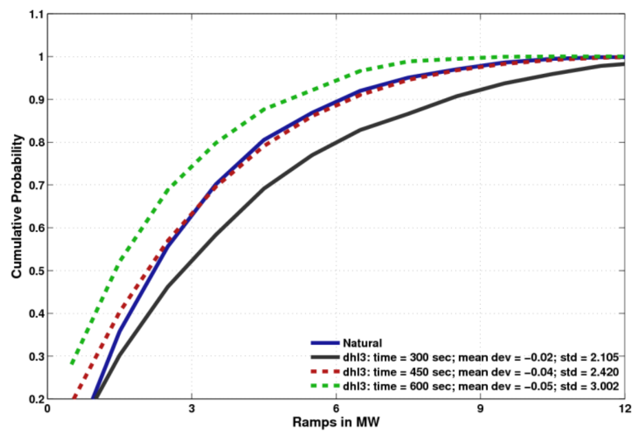

Figure 6: 300 second (5 minute) ramp probability distribution for a single sensor compared to the power output created from multi-sensor high-density solar field. The solid blue line represents the multi-sensor array. The black line is represents the single-sensor with 60 second averaging. The dotted red and green lines represent 450 and 600 second averaging.

As multi-sensor arrays are generally not available because of the inherent cost of setting up and maintaining such arrays it is useful to create models that can simulate multi-sensor fields using single sensor output. It is found that simple low-pass filters such as those shown in Figures 5 and 6 are capable of producing reasonably close approximations to the multi-sensor fields.

The current results were derived for a PV plant size of 42 MW. Various size PV plants as well as other ramping interval need to be considered in order to create comprehensive base level filters for potential scenarios. Other atmospheric parameters such as cloud height winds need to be considered as are seasonal impacts. Additional work to model single axis trackers is also needed.

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