

# Specifications for Representation of PV Output Variability in Simulation

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By: Carl Lenox, SunPower Corporation, 10/7/2011*

## Introduction

Fundamentally, the output of any PV system is driven by the level of direct and diffuse irradiance available. Conversion of photons to electrons within the photovoltaic cells occurs in microseconds and typically inverter switching is in the range of several to tens of kHz. Therefore, from the standpoint of the electrical grid, light energy is converted to AC electricity effectively instantaneously.

At the same time, any PV system is spread over a discrete physical area and interconnected electrically, so that the response of the system is aggregated at the point of interconnection. The area utilized will depend on the specific technology involved and where the PV system is mounted, but an example typical value for a ground mounted system is approximately 200 kW<sub>DC</sub> per acre. This means that the response of a PV system to changing irradiance conditions is directly related to the average change over the total array area, not the instantaneous change at any one point. Likewise, the aggregate response of multiple PV systems, spaced apart but electrically interconnected to the same utility electrical system, will also be the average of the individual responses.

The primary weather phenomenon which drives relatively fast changes in PV system output is clouds. The impact of cloudy weather on PV output variability depends on a number of factors including ceiling height, opacity, transit speed and direction, and the scale or size of individual clouds. The resulting variability from PV system(s) depends on the physical size of each PV system as well as other factors (tracking versus fixed, dimensions in the direction of cloud movement) as well as the separation distance between PV systems.

The cloud conditions that are of primary concern are those which drive the highest output variability – that is, large ramps over short durations. Generally speaking, this appears to occur under conditions of low, broken, rapidly moving cloud cover. These conditions can drive very rapid changes in irradiance as measured at a point, e.g., by an irradiance sensor. Changes of 80% per minute, and as much as 75% within 10 seconds, have been observed in some locations.

However, research has shown that the aggregate effect across multiple dispersed PV plants and even over the physical area of a single PV plant can have dramatic impacts on the observed output variability of the plant or fleet of plants<sup>i, ii, iii, iv, v</sup>.

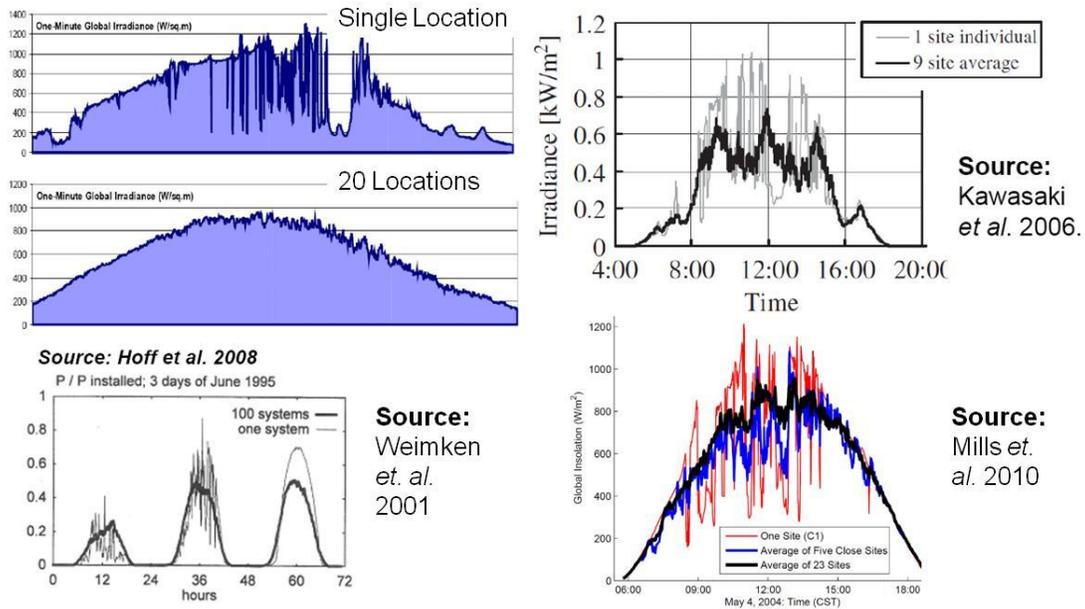


Figure 1 - Examples from Literature Illustrating Geographical Diversity

This body of research is demonstrating that changes in output from minute to minute are generally uncorrelated for two measurement points (including complete PV system) separated by approximately one kilometer under highly variable conditions. Furthermore, shorter duration changes have been shown to become uncorrelated starting at lesser separation distances, and longer duration changes starting at longer distances<sup>vi</sup>.

This lack of correlation is the mathematical representation of this geographic diversity. For systems where changes in output are uncorrelated (correlation coefficient is zero), the changes in output will be in the opposite direction as often as they are in the same direction.

The separation distances and / or physical area occupied by arrays are small enough for short timeframes to make geographical diversity relevant even within relatively small systems or between relatively close systems. As discussed above, the benefits of diversity have been demonstrated within a multi-MW system at up to 1 minute. At shorter intervals, such as one second, recent research indicates that the distance between systems at which changes in their output is uncorrelated may be much shorter, as little as 20 meters.

The implication is that to properly model the influence of PV output variability on the utility system (i.e. at the 1-second to 1-minute timescale), in most cases geographical diversity must be taken into account. This has not necessarily been the assumption in the past, in particular when looking over fairly short physical distances such as distribution feeders. Accounting for this diversity properly is increasingly critical as the timeframe of interest becomes shorter.

For instance, using 1-minute averaged irradiance from a sensor as an input to develop the 1-minute output profile of a PV system that is a few hundred kilowatts will probably not overstate the variability to a great degree, if at all. However, if the timeframe of interest is one second (for instance, to evaluate the potential for flicker) the use of 1-second irradiance data would not be appropriate.

Therefore, input profiles representing irradiance, for use in distribution system modeling must incorporate two principles to achieve accuracy. First, the representative irradiance profile must be one that is averaged over the area of each PV system modeled, rather than a point irradiance measurement. Second, in cases where multiple PV systems are being modeled simultaneously, the input profiles need to have the correct relationship in terms of how well correlated they are. Simply using the exact same input profile (i.e. perfectly correlated) would result in inaccurate findings. A unique input profile must be developed for each system. These profiles would ideally have identical statistical characteristics in terms of distribution of ramp rates, because they would represent the same overall weather conditions occurring simultaneously in two locations, but be composed of unique time-series data to capture the correct correlation relationship.

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<sup>i</sup> Mills, A. and Wiser, R. (2010). *Implications of Wide-Area Geographic Diversity for Short-Term Variability of Solar Power*

<sup>ii</sup> Kato, T. and Inoue, T. (2010). *Impact of Large-scale Penetration of Photovoltaic Power Generation Systems on Fluctuation Property of Electricity Load.*

<sup>iii</sup> Wiemken E. et al. (2001) *Power Characteristics of PV Ensembles: Experiences From The Combined Power Production Of 100 Grid Connected PV Systems Distributed Over The Area of Germany.*

<sup>iv</sup> Mills, A. and Wiser, R. (2009). *Spatial and Temporal Scales of Solar Variability: Implications For Grid Integration of Utility-Scale Photovoltaic Plants* (Presentation at Utility-scale PV Variability Workshop).

<sup>v</sup> Mills, A. et al. (2009). *Understanding Variability and Uncertainty of Photovoltaics for Integration with The Electric Power System.*

<sup>vi</sup> Hoff, T and Perez, R. (2011). *PV Power Output Variability: Calculation of Correlation Coefficients Using Satellite Insolation Data.*