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ARRA
American Recovery and Reinvestment Act of 2009

ARRA Project Analysis: Smoothing Metrics

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Abstract:

The American Reinvestment and Recovery Act of 2009 (ARRA) provided funding to various renewable resource projects nationwide, including research and development of photovoltaic (PV) generator sites. Sandia's role is to provide independent, technical analyses of completed energy storage projects funded through ARRA; in particular batteries utilized by utilities to perform specific duties (i.e. PV smoothing, peak energy shifting). In order to provide a thorough analysis of a system, a set of metrics is needed to fully quantify the effects of the battery systems. The metrics were identified, developed, and initially applied to a PV plant using batteries for PV smoothing.

Introduction:

The term 'PV smoothing' is used to denote the use of an energy system (i.e. battery) to take a potentially highly variable PV power source and remove the rapid fluctuations associated with cloud cover. These fluctuations are an unfavorable characteristic of PV systems and it is preferable to remove them before the power is supplied to the grid. By using batteries to absorb or supply power at the appropriate time, PV power can effectively be smoothed. The following metrics were developed to characterize the degree to which the power can be smoothed.

Methods:

Mean Removal:

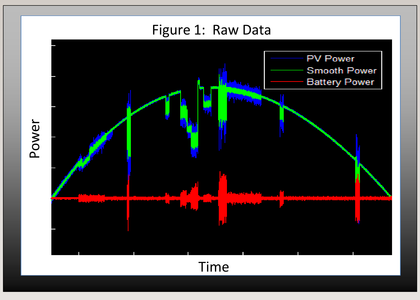
Assuming the data for a PV site is collected over the course of one day, the power will likely follow the diurnal trend of the sun (i.e. when the sun peaks overhead, the PV power output also peaks). This causes a data set from a power meter to be statistically 'non-stationary in time'. Removing this trend allows for a statistical treatment of the fluctuations to be performed. While several approaches were taken to remove the trend, the following two metrics were chosen:

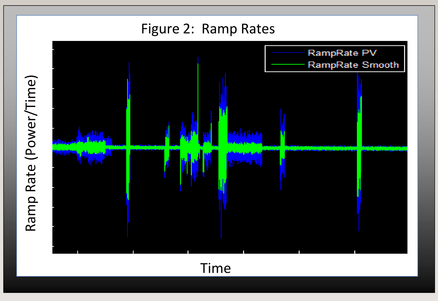
1.) **Moving Average** (i.e. low-pass filter, subtract result from data, results in zero-mean)
2.) **Ramp Rate** (i.e. Discrete Time Derivative, resulting in zero-mean)

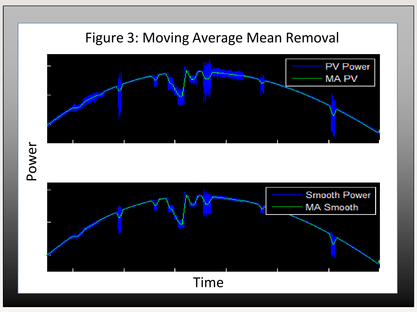
Statistical Treatment:

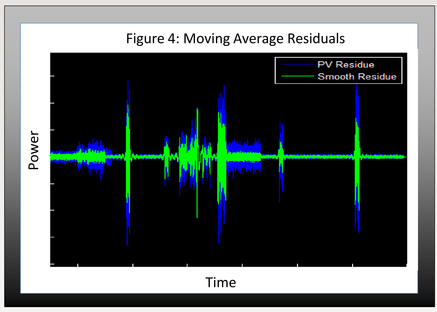
Once the mean is removed from the data, the 1st and 2nd order statistics are calculated (i.e. mean, variance, standard deviation). The percent reduction in standard deviation is calculated and used as the 'smoothing metric'. Other statistics of interest are the extreme points and their reduction (i.e. maximum and minimum points of both the unsmoothed and smoothed powers).

Illustrations:









Data Source: Computer Generated Model Data

Results:

The results of the comparison between the percent reduction in standard deviation of ramp rates vs. the de-trended data (by moving average) show a high agreement between the methods. When tested on different days with varying cloud cover, the percent of difference between the two (confidence interval) is roughly +/- 2%. The mean of each resulting data set is approximately zero and each distribution approximately fits a Laplacian (similar to Gaussian) probability density function. When these metrics are applied to physical systems, accurate results can be expected.

Discussion:

The results above indicate that the developed metrics have potentially broad use. Assuming a system to collect data from both the raw PV power and the post-smoothing power is employed, the metric can theoretically be applied to any PV system using any method for smoothing. If the two sets of data are available, the metrics developed can be applied to them to quantify how well the system will smooth the PV power. This is useful to entities interested in investing in or current owners of an energy storage system used for PV smoothing.

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NNSA National Nuclear Security Administration

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