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Quantifying Solar PV Variability at Multiple Timescales for Power Systems Studies

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Presentation Structure

1. Problem Introduction
2. Solar PV Plant Variability Metrics
3. Metrics Validation & Applications
4. Conclusion

Problem Introduction

Motivation

How do we improve modeling of individual and group of solar PV plants in a region in multi-timescale power systems studies?

- Can changes in solar PV plant output impact frequency response studies, or calculation of Control Performance Standard (CPS) scores?

Paper's Focus

Develop metrics to quantify the variability of solar PV plants at multiple temporal and spatial scales

What approach should we adopt to develop these metrics?

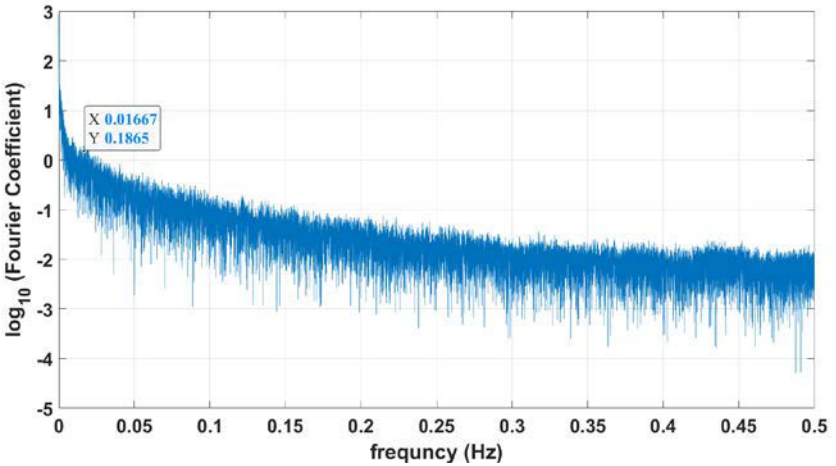
Analytical vs. Data-based

- Analytical approaches are computationally expensive and very difficult to initialize with publicly available data for high temporal and spatial resolutions
- We decided to use the data-based approach and develop two metrics
  - Fourier Coefficients of Irradiation
  - Average Irradiation Ramps
- Quantifying multi-timescale variability, particularly at high temporal resolutions is our paper's distinguishing feature

Solar PV Plant Variability Metrics

Fourier Coefficient Metric

- Calculated using the Discrete Fourier Transform (DFT)
- One Fourier coefficient per day per desired temporal resolution is calculated
- The more variations there are at the frequency corresponding to the desired temporal resolution, the higher will be magnitude of the Fourier coefficient metric



D=15 hours of data sampled at 1 Hz; $f = dft(D)$; 5min Fourier Coefficient metric for the day is at 0.0167 Hz as shown

Average Ramp Metric

- Calculates ramp sizes over the desired temporal resolution in three steps

  Example: irradiation data for a day is $\{x_{1min}, x_{2\min} \dots x_{100min}\}$

  - **Step 1**: Obtain a series of averages of solar irradiation

    $$\bar{x}_1, \bar{x}_2, \dots \bar{x}_{20} = \left(\frac{1}{5}\right)\sum_{j=1}^{5} x_j\,, \left(\frac{1}{5}\right)\sum_{j=6}^{10} x_j\,, \dots \left(\frac{1}{5}\right)\sum_{j=96}^{100} x_j$$

  - **Step 2**: Obtain a series of magnitudes of irradiation ramps

    $$r_1, r_2, \dots r_{19} = |\bar{x}_2 - \bar{x}_1|, |\bar{x}_3 - \bar{x}_2|, \dots |\bar{x}_{20} - \bar{x}_{19}|$$

  - **Step 3**: Average ramp metric $= \frac{r_1 + r_2 + \dots + r_{19}}{19}$

Metrics Validation & Applications

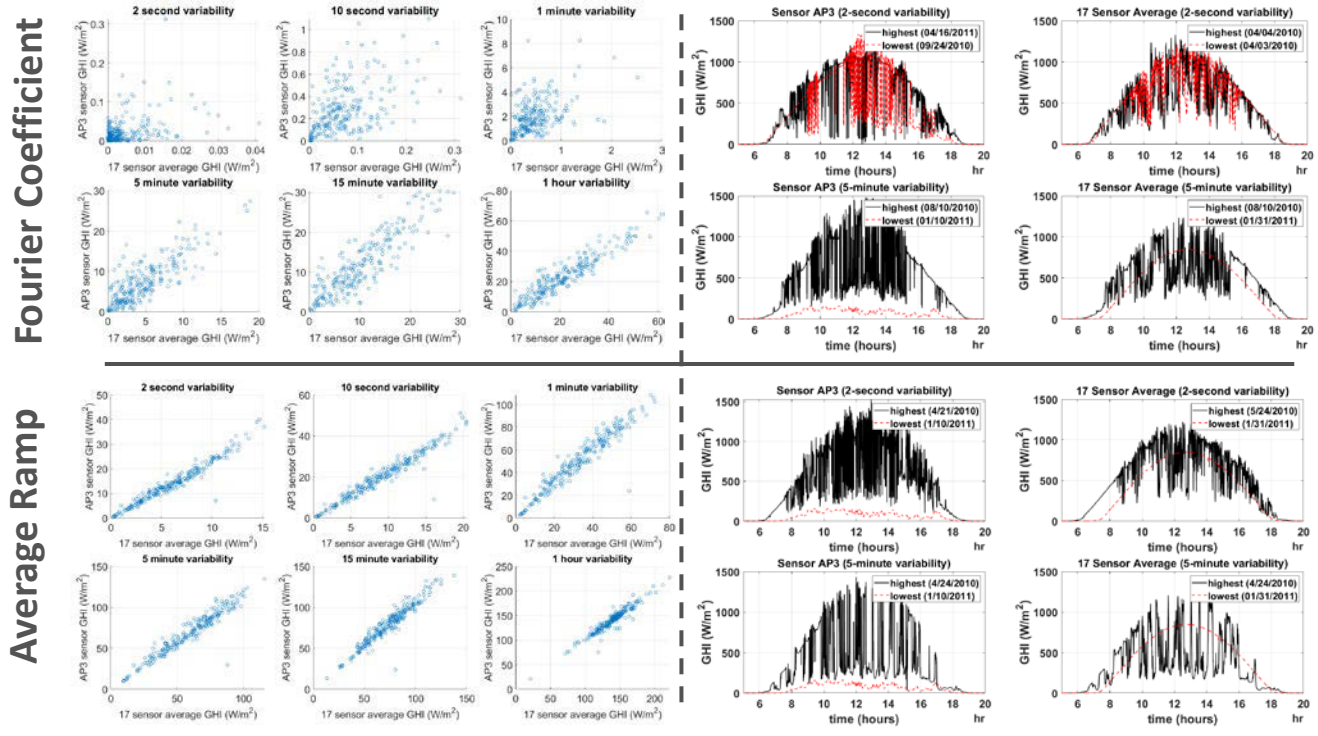
Datasets for Validation and Variability Analysis

Station	State	Latitude/Longitude	Resolution	Dataset Length	Number of Sensors
Oahu	HI	21.31N/158.09W	1 second	10 months	17
SolarTAC	CO	39.76N/104.62W	1 minute	1 year	1
NREL Station	CO	39.74N/105.18W	1 minute	1 year	1
UNLV	NV	36.11N/115.14W	1 minute	1 year	1
UAT (OASIS)	AZ	32.23N/110.96W	1 minute	1 year	1
UTPASRL	TX	26.31N/98.17W	1 minute	1 year	1

- **Oahu dataset (17 sensors spread over 1 sq. km)**– metrics validation and single PV plant variability analysis
- **Other datasets** – variability analysis for single and multiple solar PV plants spread across a region

Source: MIDC database - https://midcdmz.nrel.gov/

Metrics Validation

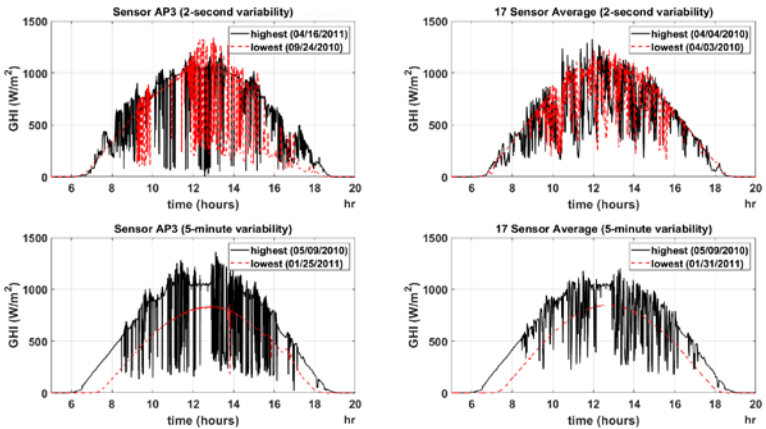


Variabilities from 1 vs 17 sensors **Highest & Lowest Variability Days**

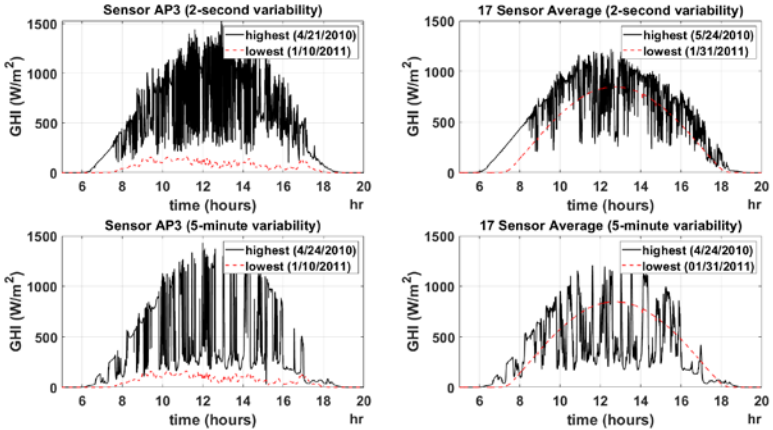
- Single sensor exaggerates plant level variability
- Highest and lowest variability days show marked difference in the amount of solar irradiation variation

Metrics Comparison

Highest & Lowest Variability Days



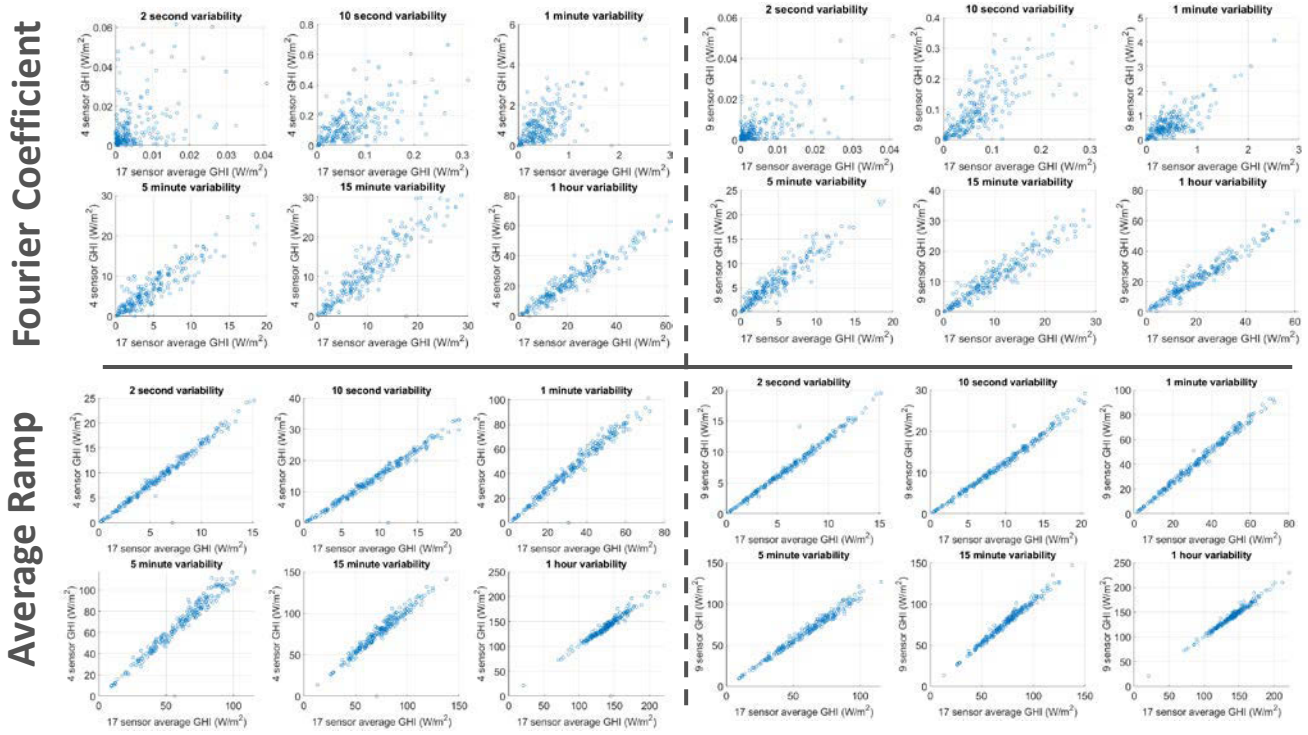
Fourier Coefficient



Average Ramp

- Average ramp metric performs better than the Fourier coefficient metric at sub-minute temporal resolutions
- Higher sampling rate than 1 Hz should improve the performance of the Fourier coefficient metric

Key Observations for Single PV Plant Variability



Variabilities from 4 vs 17 sensors **Variabilities from 9 vs 17 sensors**

- Seconds-level solar PV plant variability obtained from one sensor may significantly exaggerate its impact on the grid
- Few appropriately spaced sensors perform better than a single sensor

Solar Variability at Different Locations

Maximum Average Ramps (W/m^2) for the Six Datasets (using the average ramp metric)

Station	State	1-min	5-min	15-min	60-min
Oahu	HI	60	120	120	240
SolarTAC	CO	67	127	135	244
NREL Station	CO	61	120	157	304
UNLV	NV	62	112	132	255
UAT	AZ	91	153	131	255
UTPASRL	TX	103	134	136	242

- Maximum ramp sizes at the four temporal resolutions are very similar between the six geographical locations that are very far away from each other
- **Implication** - a reasonable size of the worst solar irradiation ramp can be approximated for various locations from the ramps given in the table

Solar Variability Across a Region

Comparison Of Ramps (W/m^2) From SolarTAC, NREL Station, and the Combined Output of these Two Stations (using the average ramp metric)

Station	1-min	5-min	15-min	60-min
Combined	97	173	198	423
NREL Station	122	240	314	608
SolarTAC	134	254	270	488
% reduction in combined w.r.t NREL Station	20%	28%	37%	30%
% reduction in combined w.r.t SolarTAC	28%	32%	27%	13%

- Maximum ramp size in the combined output is smaller by at least 13% compared with the case if the solar GHIs were completely correlated
- Average variability reduction for the combined output is 24%, 30%, 32%, and 22% for 1, 5, 15, and 60-minute time resolutions, respectively

Conclusion

- Even a cluster of few appropriately placed sensors may provide significantly better variability results for a single PV plant than a single sensor
- Largest solar irradiation ramps at an existing solar PV plant or at a future plant location at 1-minute and lower temporal resolutions may be approximated by the largest ramps observed at existing sensors in the region, which *do not* need to be in proximity of the plant
- High quality and high spatial density solar irradiation datasets with seconds-level temporal resolution should be created because of their value in modeling solar PV plant variability in power system studies

Thank you

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