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High-Frequency Data for Distribution Grid PV Impact Studies: Importance and Availability

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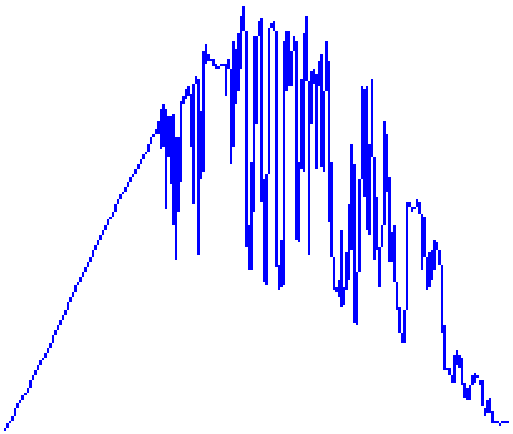
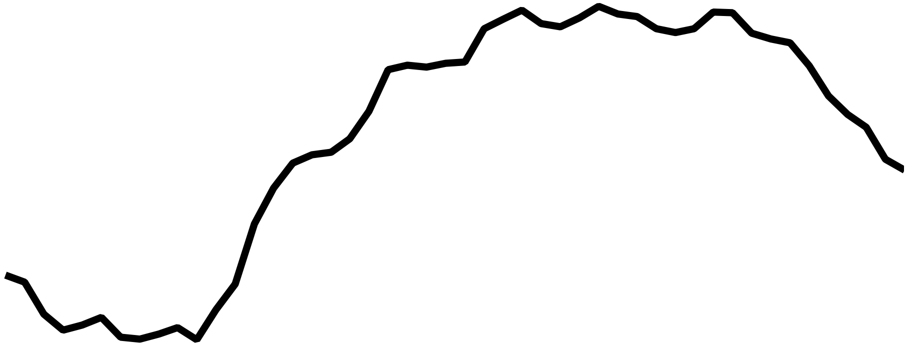
BACKGROUND: WHAT IS THE ISSUE?

Overview

- PV power is variable due to:
  - **Passing cloud shadows**
  - Movement of sun through sky
  - Other effects (shading, temperature, inverter behavior, soiling, etc.)



- Load is variable too.
  - **Devices turned on/off**
  - Daily/seasonal demand

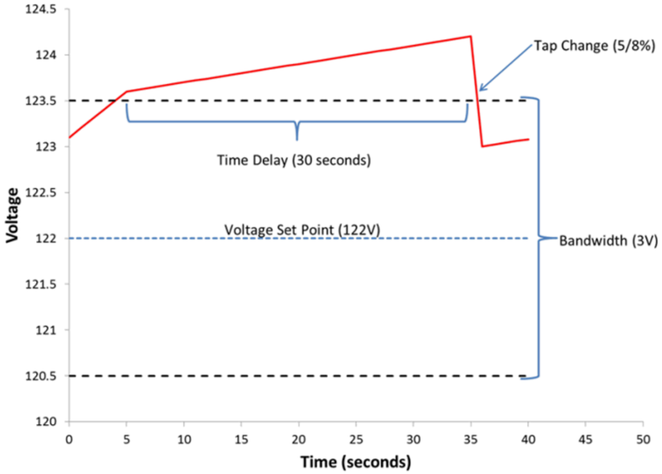


- PV power variability adds to net load variability.
  - Distribution systems were not designed for this much variability.

Voltage Regulation

Distribution grids are designed to handle load variability:

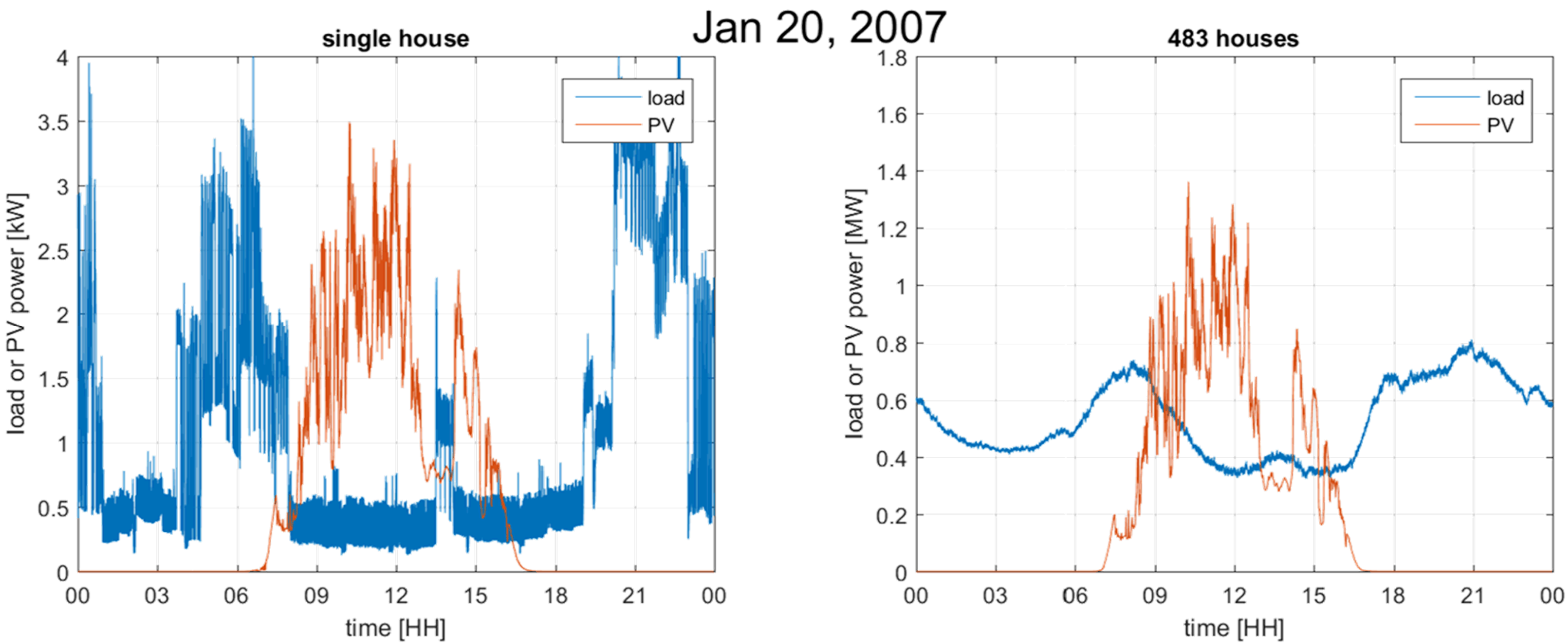
- Load Tap Changers (LTCs) and Voltage Regulators (VREGS)
  - Regulate the voltage by changing the tap of a transformer while maintaining current flow
  - Changes taps to keep the output voltage at the VREG setpoint within a certain bandwidth
  - Time delay (generally 30 to 60 seconds) from the voltage going out of band until the control action
- Tap changes create wear and tear on the device



HOW DO LOAD AND PV VARIABILITY COMPARE?

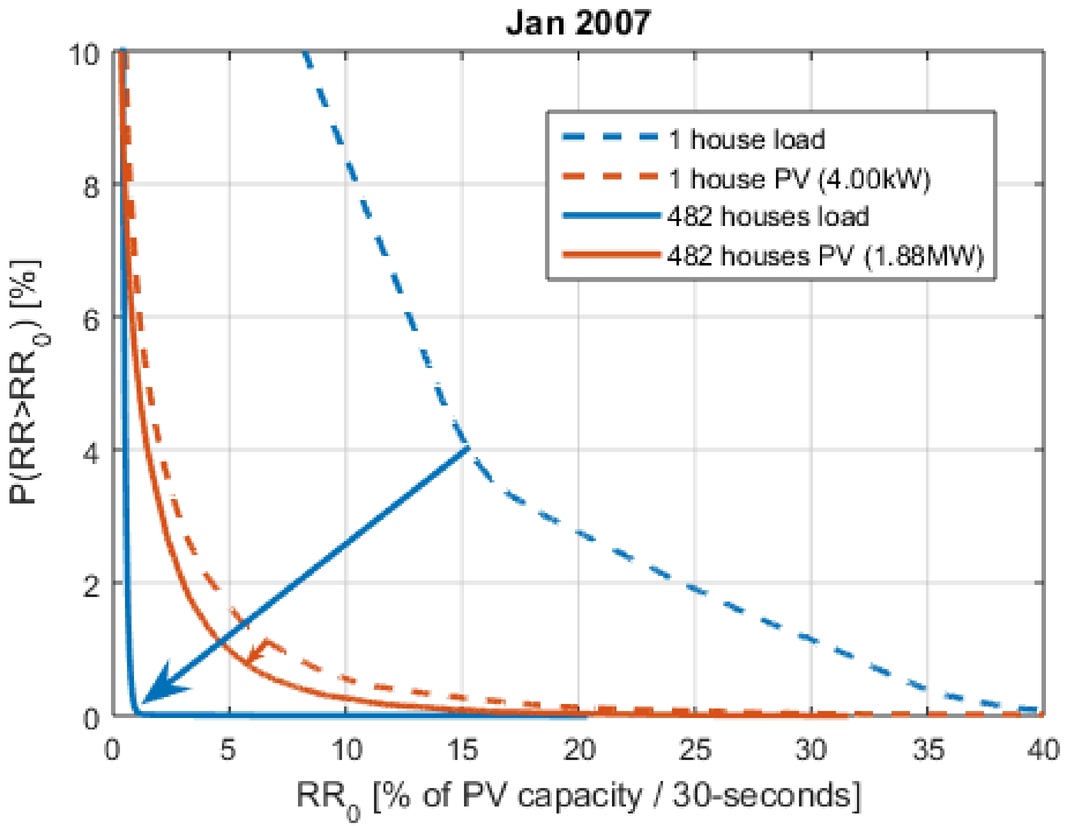
Load vs. PV Variability

- At a single house: load variability > PV variability
  - Load devices (e.g., heater) switched on instantaneously (<1 sec)
  - Clouds shadows pass over seconds to minutes.
- When aggregated, load variability << PV variability
  - Both smoothed due aggregation



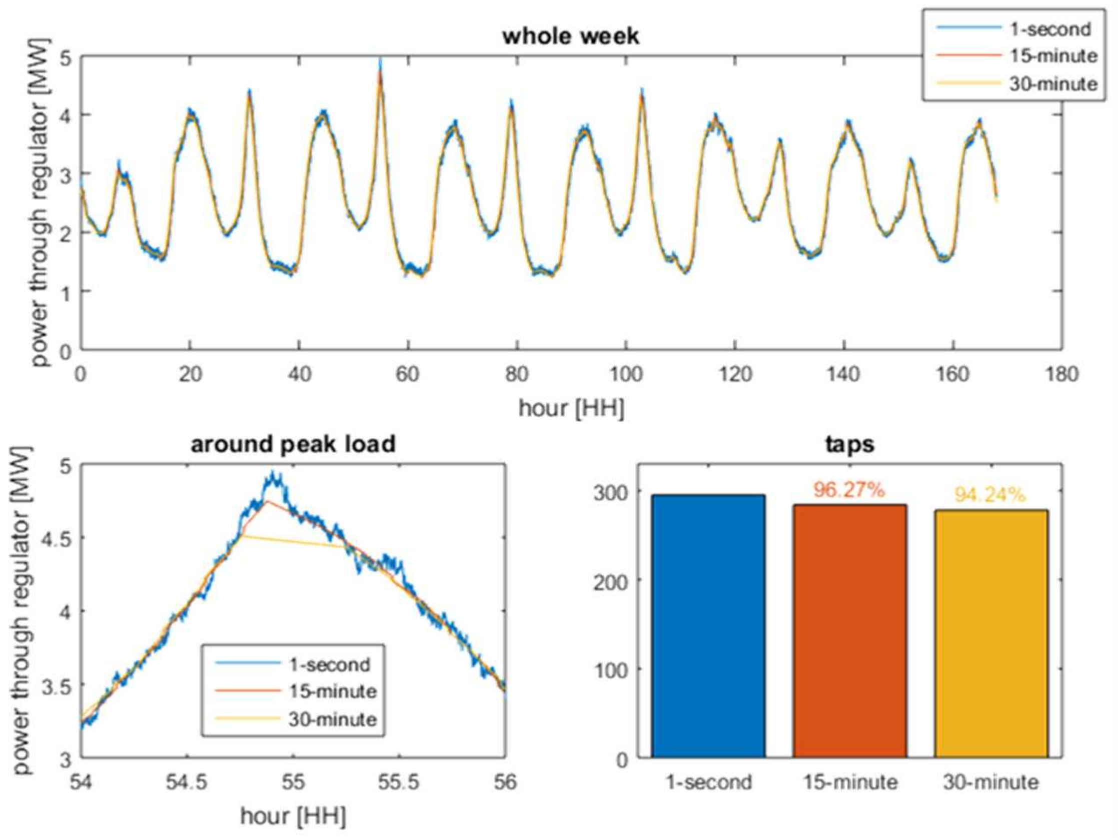
Load vs. PV Ramp Rates

- Load uncorrelated so heavily smoothed due to aggregation.
- PV smoothed, but less so: weather and hence PV output more correlated than load.



High-Frequency Load

- Usually only measured/available from utility.
- Typically measured at 15-minute intervals.
  - Relatively little difference (<10%) between high- and low-frequency load for aggregates.
- High-frequency load could be important for inhomogeneous loads.

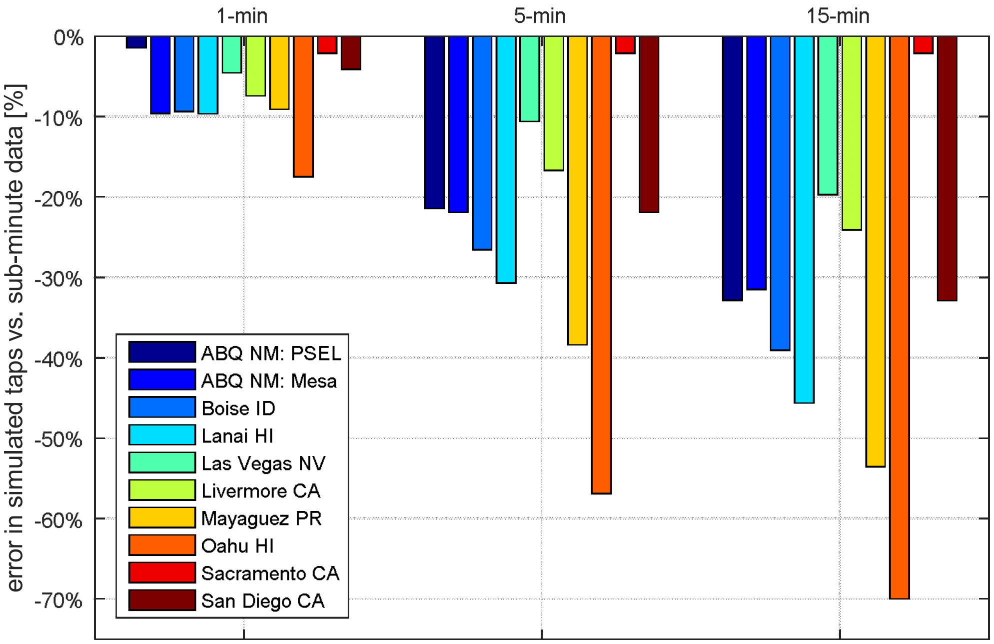


High-Frequency PV

- PV power output maybe available from utilities, PV monitoring companies, inverter manufacturers, etc.
  - Difficult to obtain, typically needs an NDA
  - PV location is often approximate to protect customer privacy.

Irradiance data available from:

- Ground pyranometers
  - Spatially sparse, especially for high-frequency measurements.
  - Up to 1-second resolution, often 1-minute.
- Satellite-derived irradiance
  - Available for US and some other locations: nsrdb.nrel.gov
  - 15-minute resolution

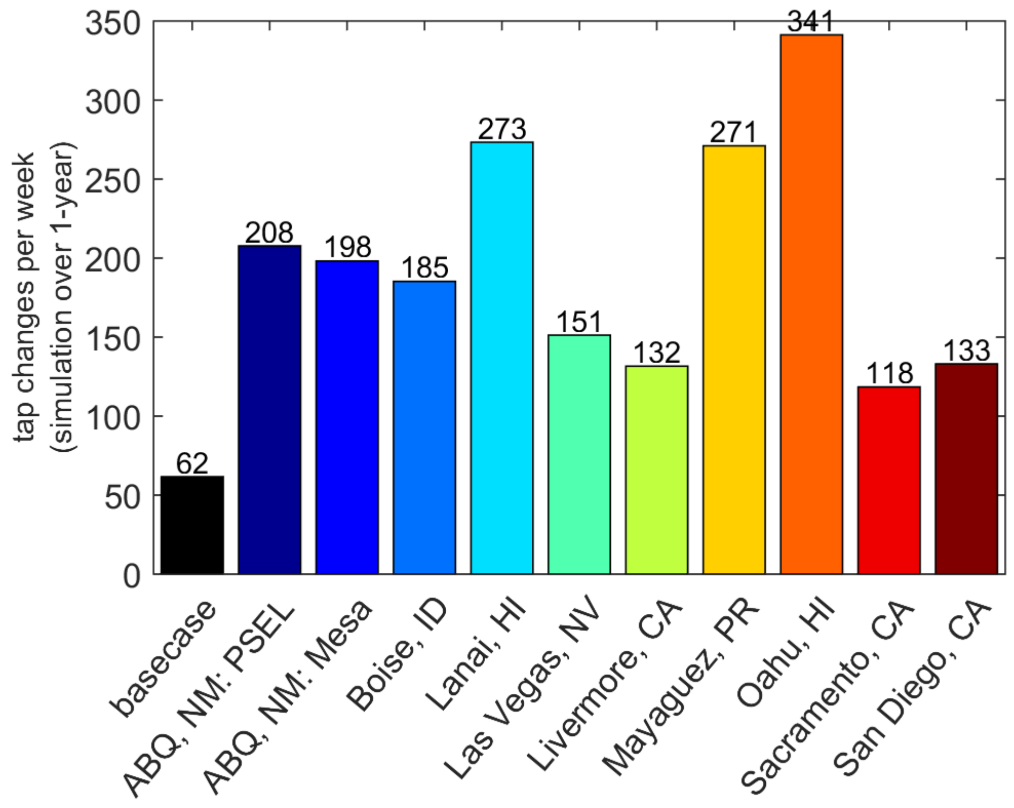


DO I NEED LOCAL SOLAR VARIABILITY, OR CAN I USE ANY HIGH-FREQUENCY SOLAR VARIABILITY SAMPLE?

Importance of Local Solar Variability

Accurately representing the local solar variability is essential!

- Up to 300% difference in tap change operations when using different solar variability samples.



WHAT IF THERE ARE NO HIGH-FREQUENCY MEASUREMENTS AT MY LOCATION?

Solar Variability Datalogger (SVD)

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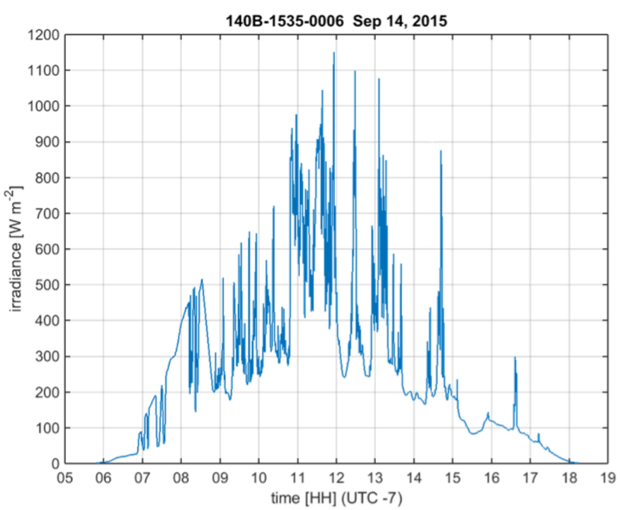
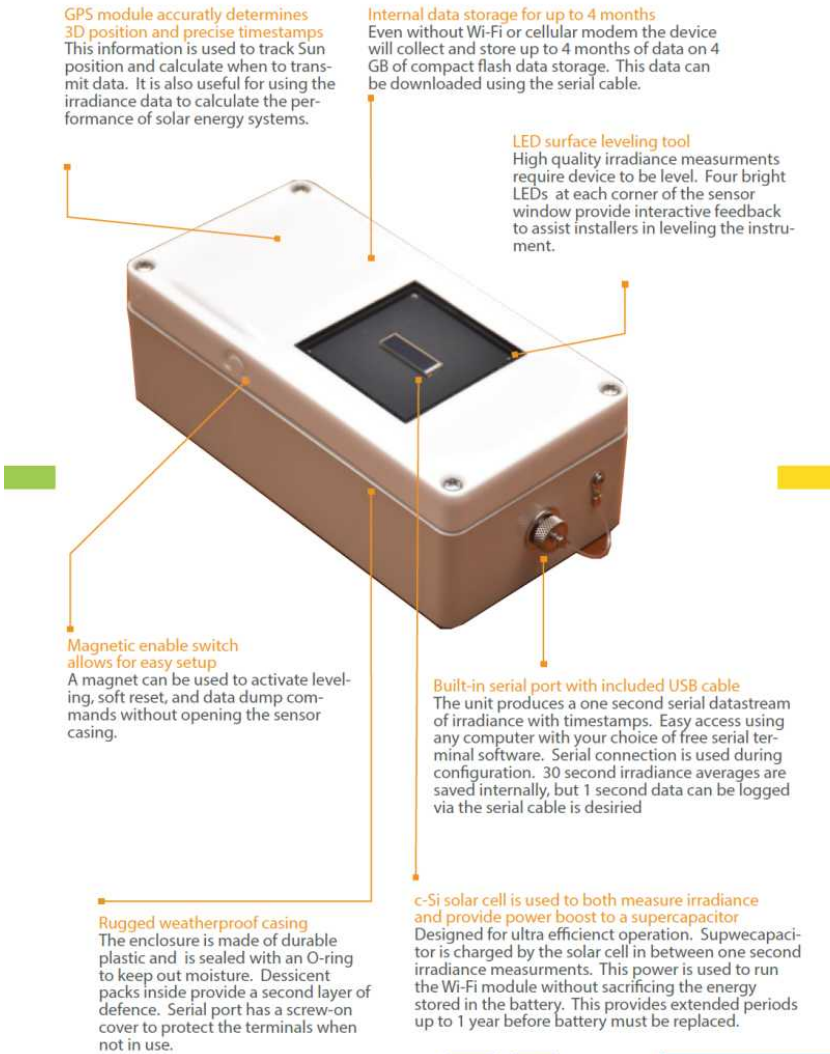
To make it easier to measure solar variability, we have developed an integrated solar variability datalogger.

- Designed for low-cost.
- PV cell to measure irradiance
- On-board data storage: 30s resolution timeseries
- Wi-Fi or cell modem data transmission
- Battery powered: expected battery life of ~1-year

SVD measurements from Albuquerque, NM





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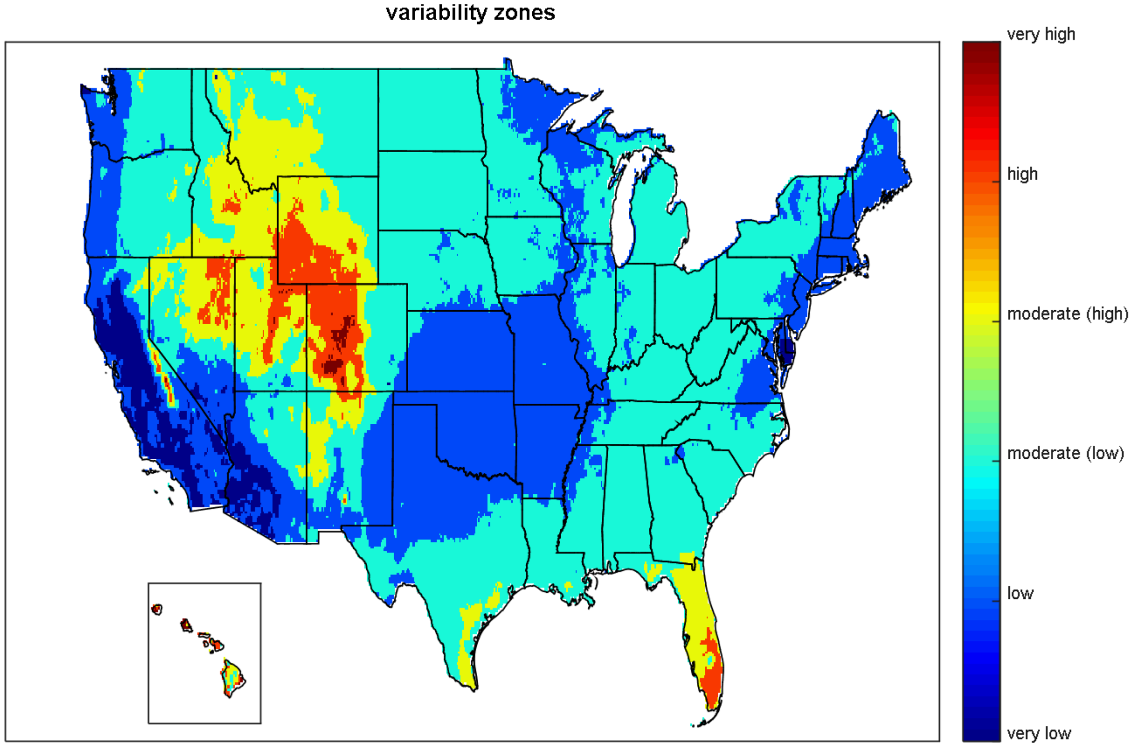
High-Frequency PV Models

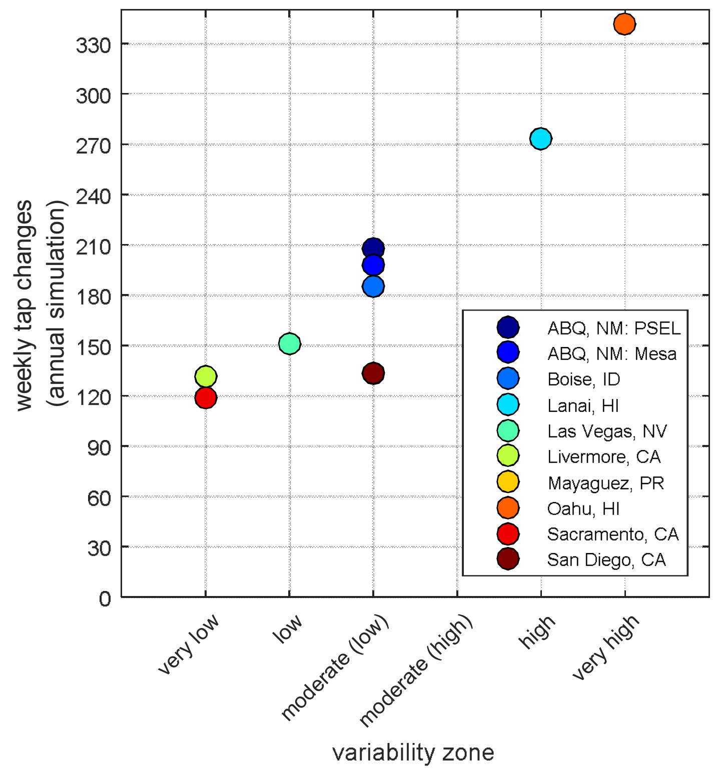
- Since measured high-frequency (sub-minute) data is scarce, there are models to fill in data-poor locations
- NREL HRIA
  - Downscale 15-minute satellite irradiance to 1-minute (then 4-seconds) using cloud classification and nearby pixels.
  - Output: synthetic high-frequency irradiance with statistics that match high-frequency variability.
- Sandia Solar Variability Zones: https://pvpmc.sandia.gov/applications/pv-variability-datasets/
  - Determine appropriate proxy data from a database of ground measurements.
  - Output: Measured high-frequency irradiance with high-frequency variability statistics similar to the location of interest.

Solar Variability Zones

https://pvpmc.sandia.gov/applications/pv-variability-datasets/

- Solar variability zones determined from satellite data
- Zones can be used to pick representative proxy data for locations without measurements
  - Locations within same zone have similar impact to distribution grids (e.g., # of taps)



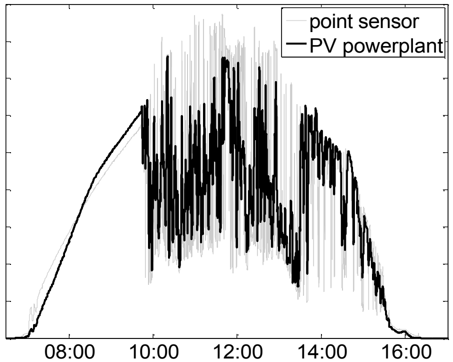


I HAVE HIGH-FREQUENCY SOLAR VARIABILITY, AM I READY TO SIMULATE THE GRID IMPACT OF PV?

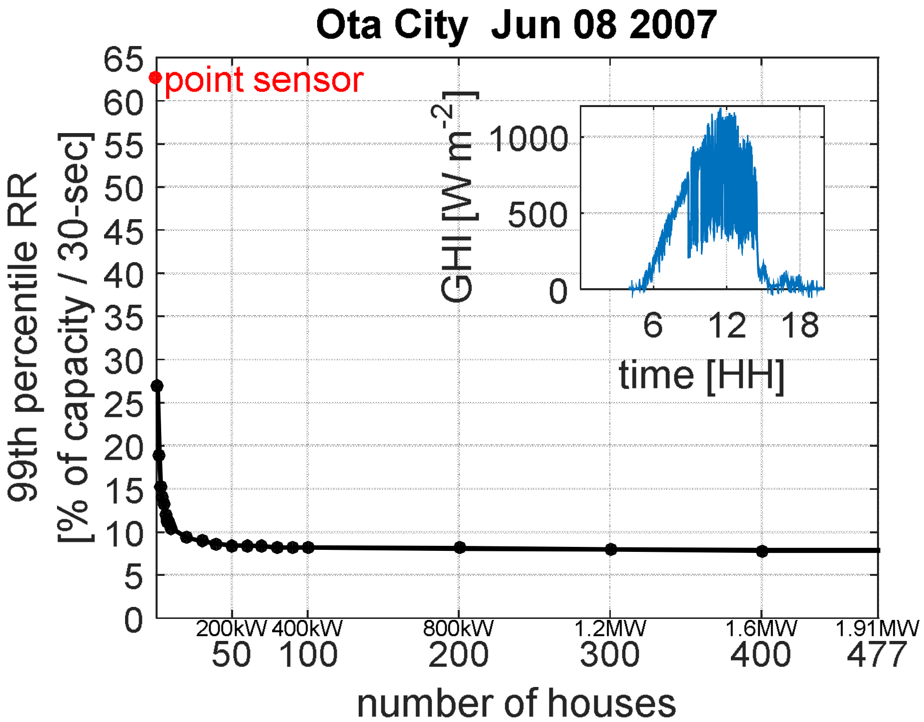
PV Variability Smoothing

Irradiance point sensor variability ≠ PV power variability

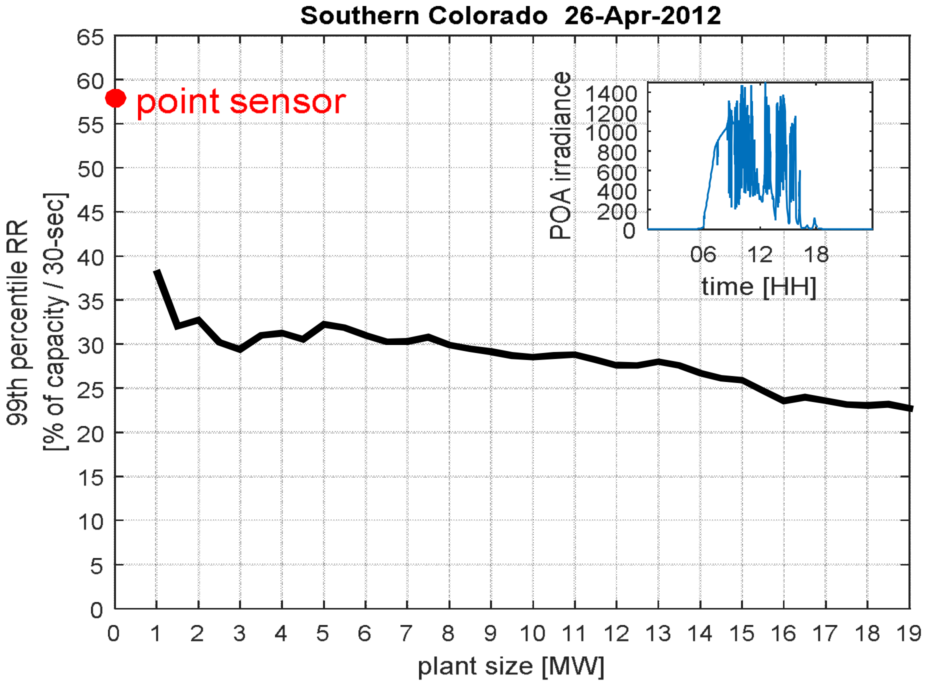
- PV output is smoothed due to spatial diversity of PV modules.
- Smoothing depends on cloud speed, distance between PV modules, and timescale considered.



distributed rooftop PV



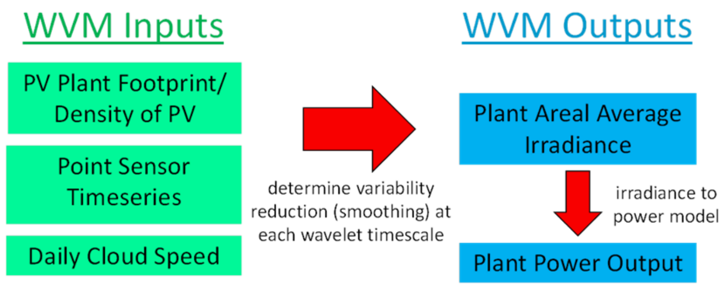
central PV plant



To Create Simulated PV Power

To simulate PV power for distribution grid studies (e.g., for future high-pen scenarios or for locations without high-frequency PV measurements):

1. Obtain high-frequency solar irradiance timeseries.
   - Measure with pyranometer or solar variability datalogger (SVD)
   - Model using proxy data (solar variability zones) or downscaling (HRIA)
2. Use a model such as the Wavelet variability model (WVM) to account for spatial smoothing



3. Translate the measured irradiance (often, GHI) to the plane of the PV.
4. Use an irradiance to power model, such as the Sandia Array Performance Model (SAPM) with the Sandia Inverter Model (SIM) to convert plane-of-array irradiance to AC PV power.

Takeaways

- Both PV and load variability at high-frequency can cause tap change operations.
- PV variability generally larger than load variability when many systems are aggregated.
- Can be large errors when using low-frequency PV.
  - High-frequency PV inputs are very important to distribution grid sims.

- High-frequency PV variability should account for:
  - Location
    - Local measurements (pyranometer; SVD)
    - High-frequency models (HRIA; solar variability zones)
  - PV plant size/distribution
    - Spatial smoothing model.

Thank You!

- Thanks to Matthew Reno, Robert Broderick, and Joshua Stein for their contributions to this work.
- Contact: mlave@sandia.gov