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Characterizing Local High-frequency Solar Variability for use in Distribution Studies

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Background: Distribution Studies

- Distribution studies model the impact of PV to the distribution grid.
  - Determine if PV will cause voltage or thermal issues on distribution feeders.
- One important question is: Does PV variability lead to increased voltage regulator operations?
  - More voltage regulator operations mean increased maintenance costs.
  - Voltage regulators typically have time constants of 30-seconds to 1-minute.
    - High-frequency (sub-minute) PV output profile is essential for accurate simulations.
- Some previous distribution studies have used artificial ramps or proxy PV data from different locations.
  - May lead to a false impression of the local impact of PV variability.

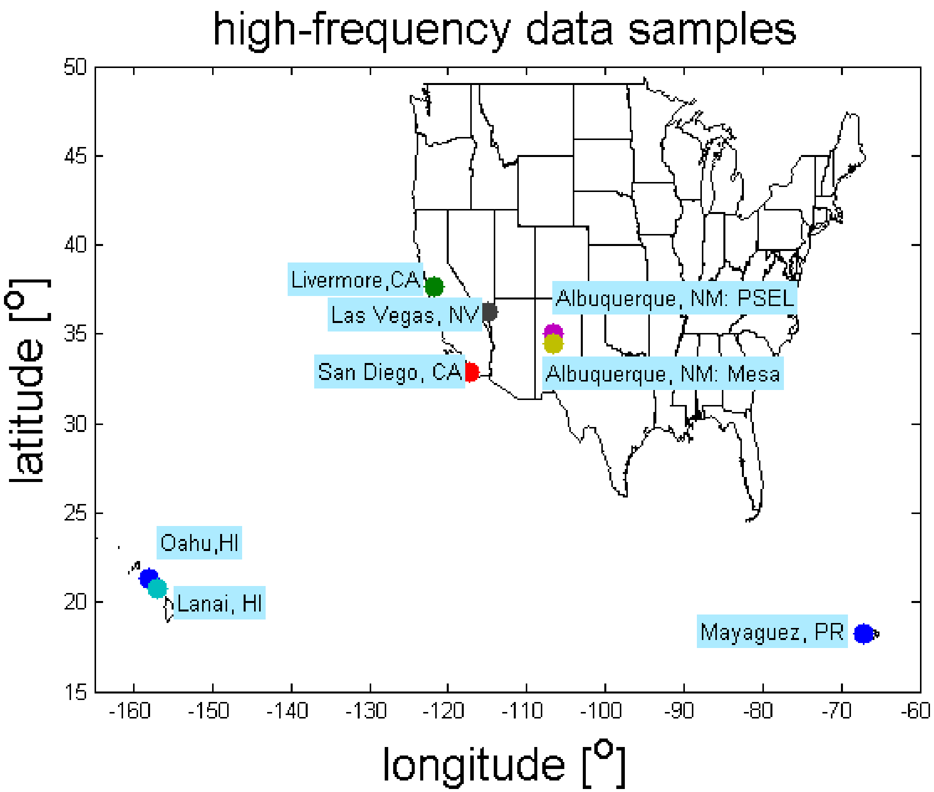
Overview

To understand how PV variability changes by location and what impact this will have on distribution studies, we:

1) Collected a database of high-frequency irradiance samples.
2) Examined the locational differences in ramp rate distributions and developed a metric to quantify variability based on these ramp rate distributions.
3) Ran distribution simulations using each of the different locational irradiance profiles scaled to represent a 3MW PV plant. This showed the differences in voltage regulator operations based on the locational solar inputs used.

High-Frequency Data

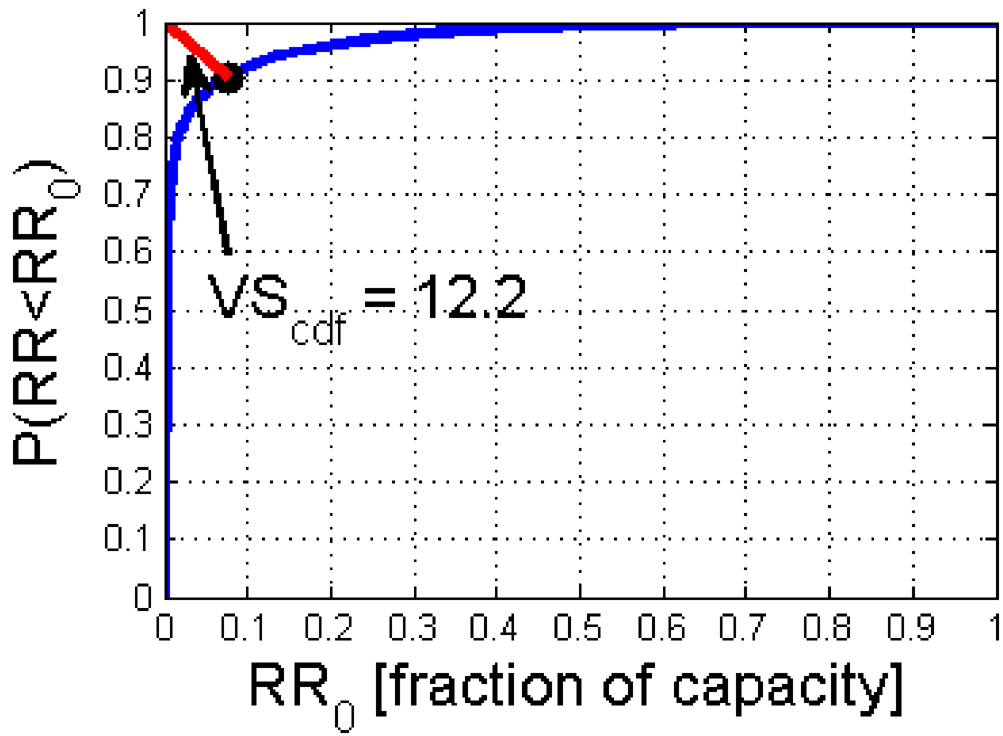
- Analyzed 8 different high-frequency GHI samples.
- All at 30-second or better temporal resolution.
- Approximately 1-year of data at each location.
- **Always looking for more locations!**
  - If you have high-frequency irradiance data and are willing to share, please contact me: mlave@sandia.gov.



Variability Score from CDF

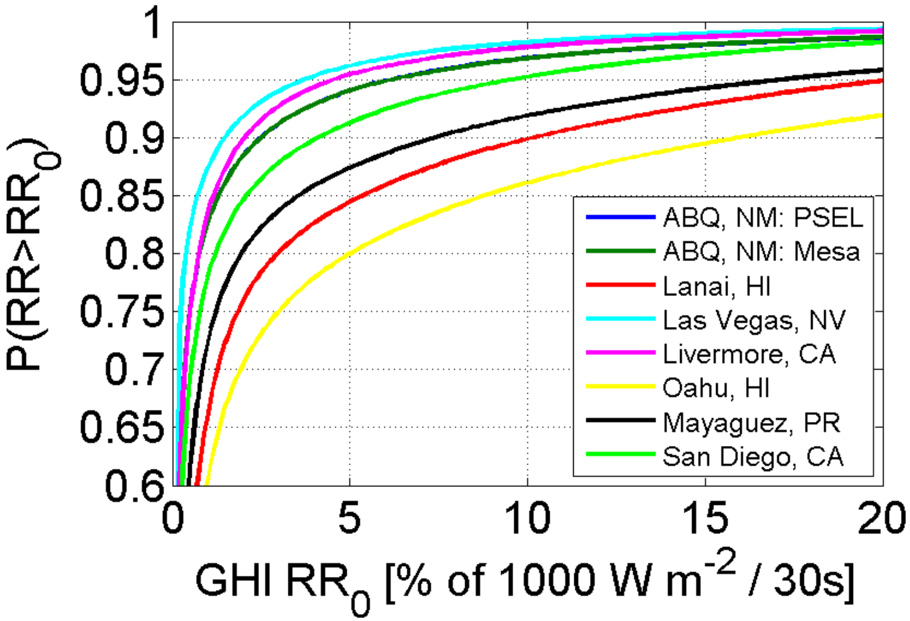
- We propose a new variability score based on the cumulative distribution of ramp rates.
- Way to reduce variability to a single number.
- Similar to variability index (VI), but VS_{cdf} is
  - more applicable across different timescales (could compare different timescales).
  - More easily applied to power variability (don't need a clear-sky curve)
- Larger VS_{cdf}, more variability.
- $VS_{cdf} = 0$: no variability.

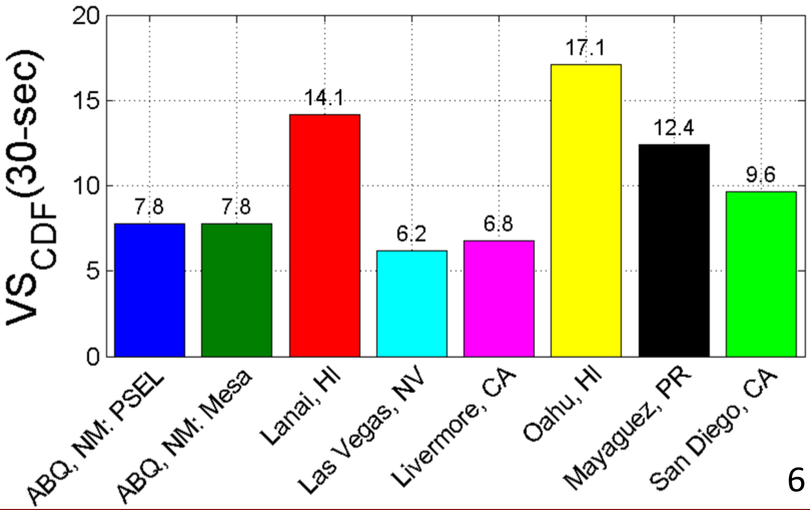
$$VS_{cdf} = \min\left(\sqrt{(cdf_x - 0)^2 + (cdf_y - 1)^2}\right) \times 100$$



Variability Variation by Location

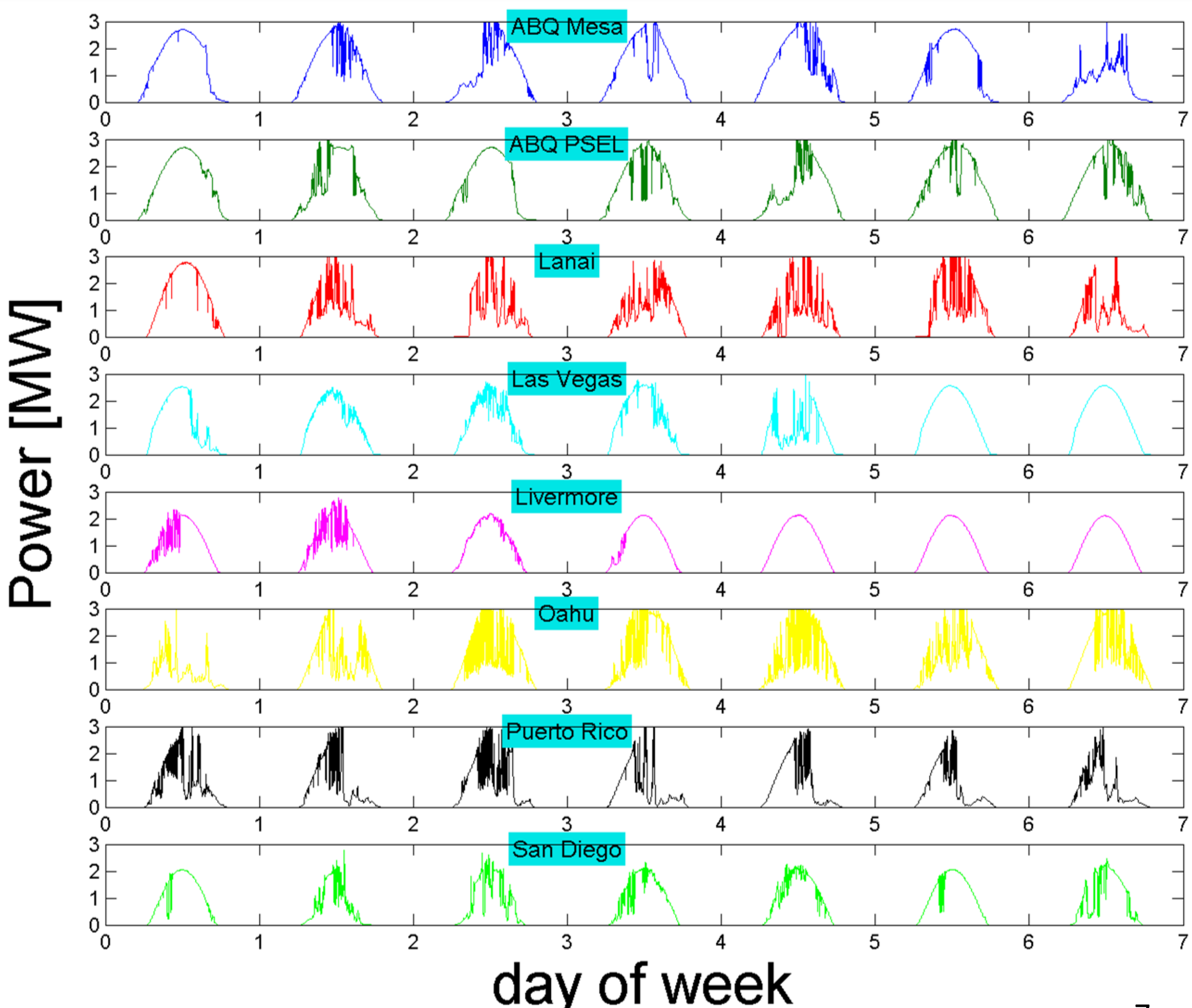
- Cumulative distributions of ramp rates show differences between locations.
  - In Oahu, 5%/30-sec ramps occur ~20% of the time
  - In Las Vegas, 5%/30-secc ramps occur less than 5% of the time
- VS_{cdf} quantifies these differences.
  - Oahu: $VS_{cdf} = 17.1$
  - Las Vegas: $VS_{cdf} = 6.2$





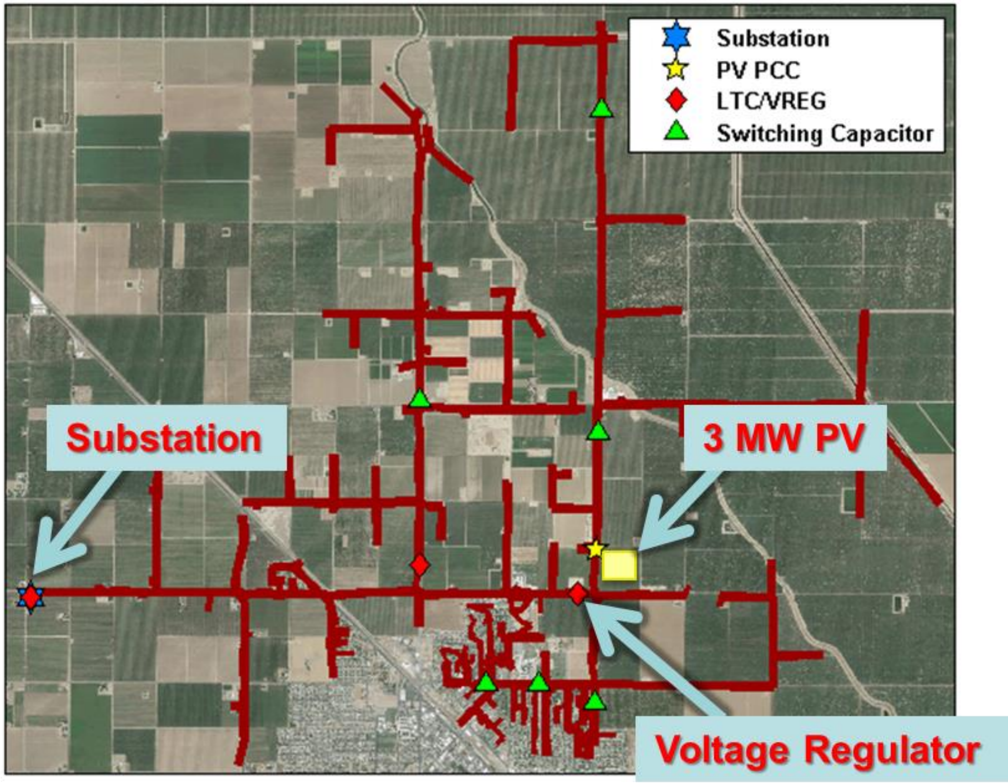
Weekly Samples for Feeder Analysis

- 1-week samples found by selecting the 7-day period with the VS_{cdf} value closest to the annual VS_{cdf} value.
- Irradiance samples were scaled to represent the output of a 3MW PV plant using the WVM (wavelet variability model).



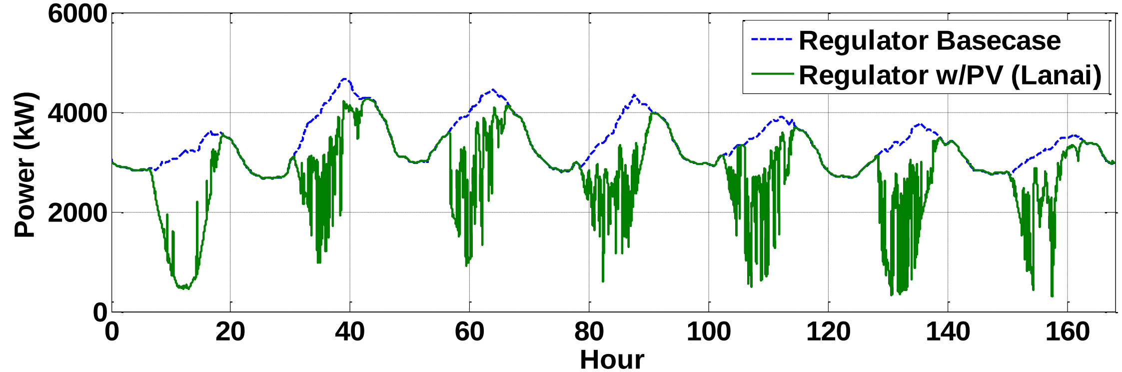
Distribution System Impact Analysis

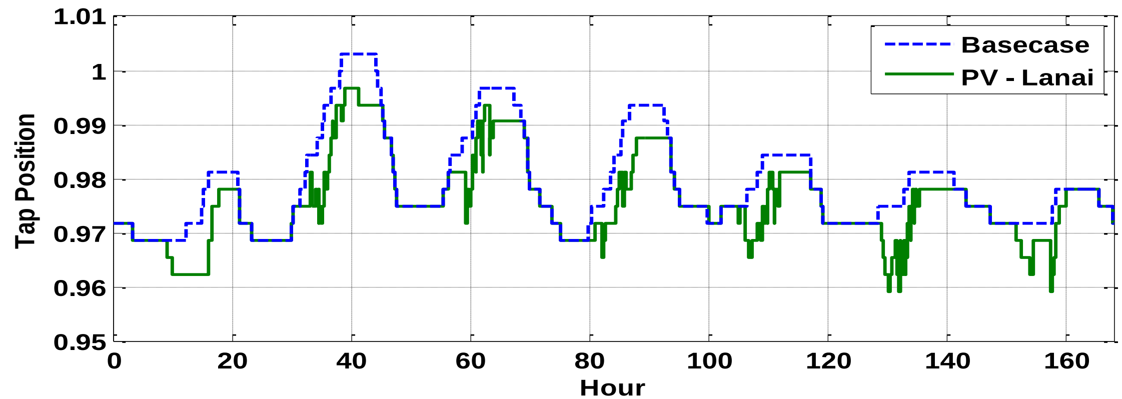
- Study Feeder
  - agricultural 12kV feeder in California
  - Voltage regulator with 45-second time constant just before PV PCC
- One week simulation
  - Quasi-static time-series (QSTS) power flow analysis at 1-second resolution for peak load week Sunday 8/18/13 to Saturday 8/24/13
  - Ran QSTS simulation 9 times (basecase, 8 PV variability profiles) to analyze the impact on the line voltage regulator

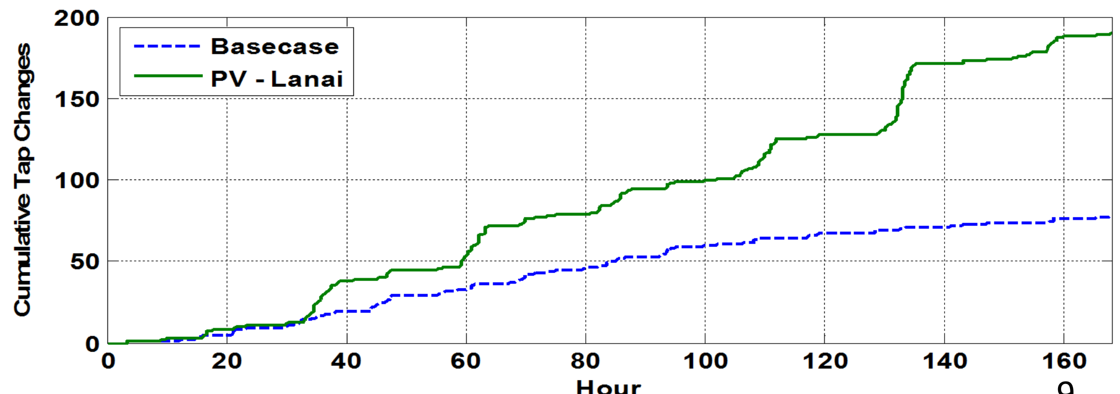


Simulation Results

- For the week simulation
  - No voltage issues from the PV because it is so close to the voltage regulator
  - No reverse power through the voltage regulator (separate study necessary to study regulator reverse settings)
- Tap changes at some locations (e.g., Lanai) greatly exceeded the base case.



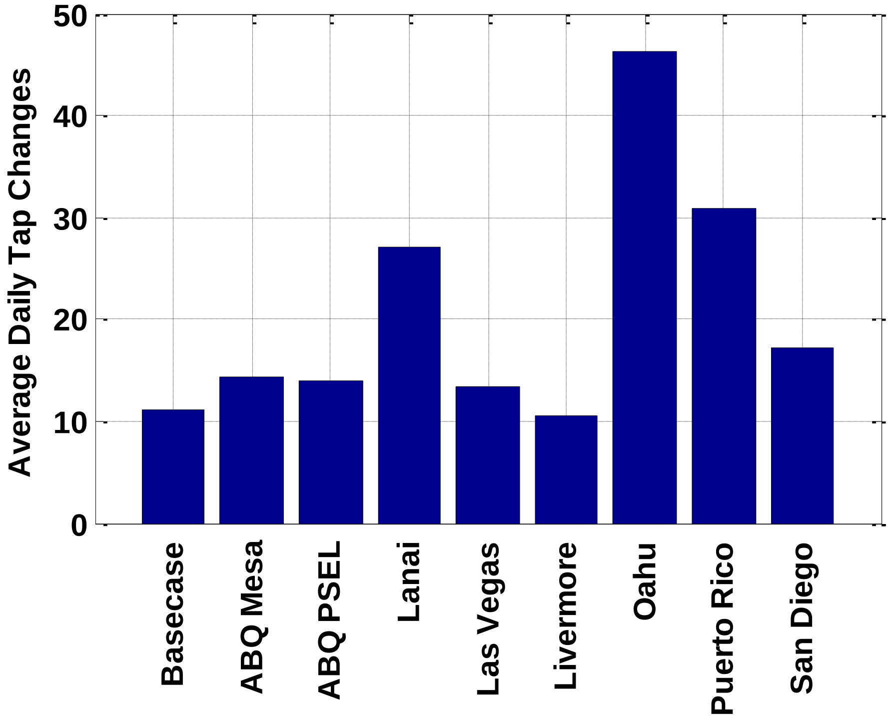


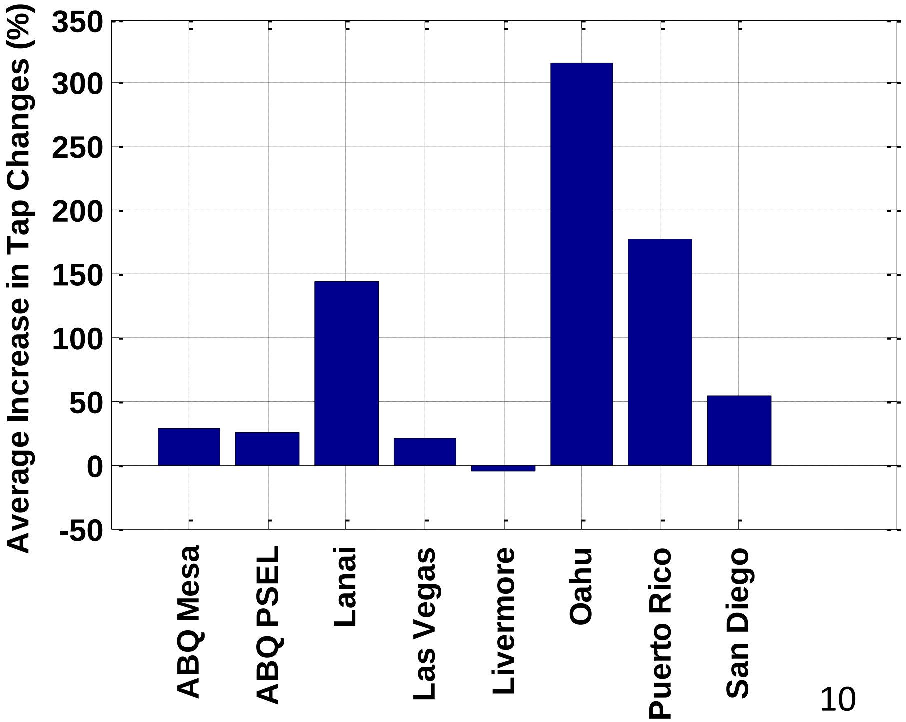


Tap Changes for each Location

Shows the importance of using accurate solar variability:

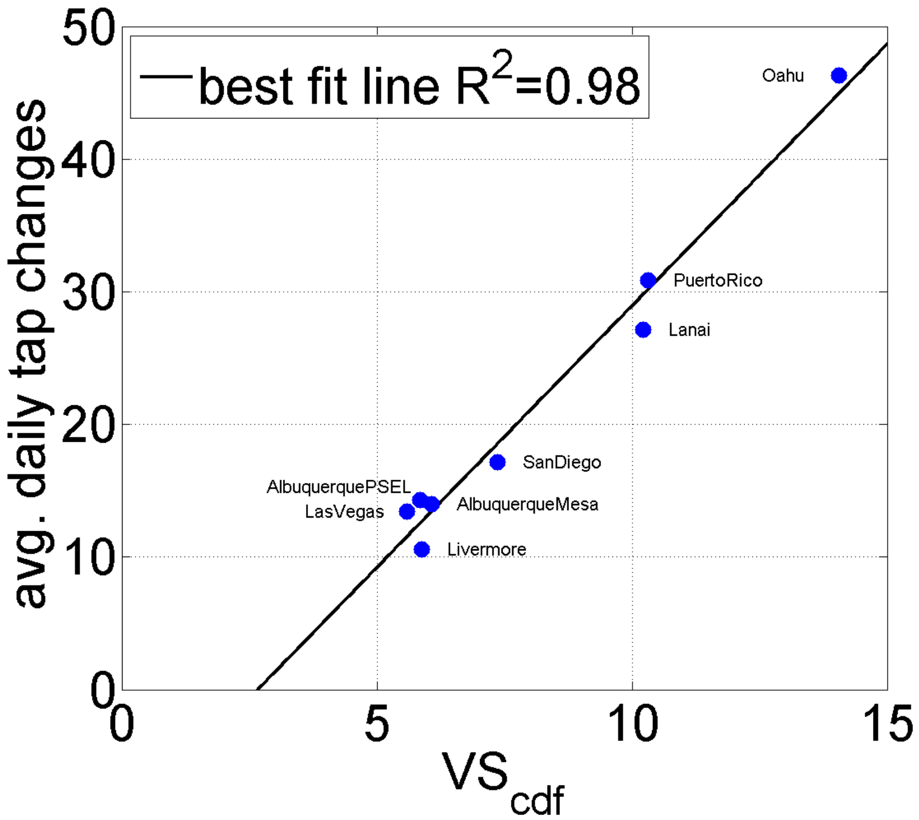
- For Lanai, Oahu, and Puerto Rico profiles, tap changes increased over the base case by more than 100%.
- Over 50% increase for San Diego profile.
- Albuquerque, Las Vegas, and Livermore had more modest changes (Livermore profile actually decreased tap operations).





VS_{cdf} vs. Number of Tap Changes

- VS_{cdf} highly correlated to the number of tap operations caused, so is a good metric for quantifying solar variability impact to distribution feeders.
- Shows that irradiance variability has a big impact on tap operations.



Summary

- High-frequency PV variability can vary significantly by location.
- These different PV variability profiles cause different numbers of tap changes.
  - **For distribution studies, it is important to use climatologically-representative solar variability.**
- Locations with similar VS_{cdf} values have similar number of tap changes.
  - Can reasonably use proxy data from a location with a similar VS_{cdf}.

Future Work:

- Classify zones of like variability (similar VS_{cdf} values)
  - Will lead to a tool to generate representative solar samples for distribution studies at locations without high frequency measurements by using a high-frequency sample from a different location with a similar VS_{cdf}.

Thanks to Data Partners

- Thanks to data partners:
  - UC San Diego
  - SunPower
  - NREL Oahu Solar Measurement Grid

Questions?

- Contact: mlave@sandia.gov