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Intelligent Sampling of Periods for Reduced Computational Time of Time Series Analysis of PV Impacts on the Distribution System

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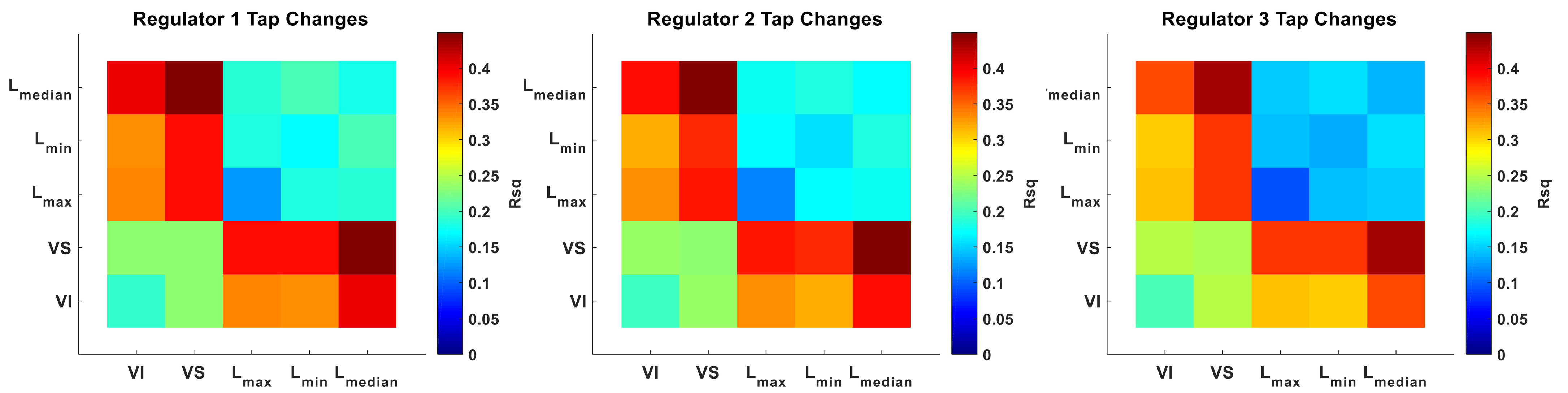
Motivation

High resolution quasi-static time series (QSTS) simulations are needed to analyze any seasonal grid impact of PV installations. These types of QSTS simulations are computationally intensive and can take days to perform for large distribution system models. The computational burden limits the practicality of QSTS for parametric analysis or for the hundreds of PV interconnection requests that a utility receives.

Method

- Break year into 6-hour intervals (1460 in 365 days)
- Categorize intervals according to input irradiance and load timeseries metrics
  - Irradiance: Variability Index [1], Variability Score[2]
  - Load: Max, Min, Median
- Bin and sample time intervals based on input metrics
- Estimate annual tap changes for *k* regulators ($TC_1,\ldots,TC_k$)

Least squares 2-parameter regression – shows correlation to tap changes, but low R^2



Binning Approach

- Bin with load median and variability index (VI)
  - n_i samples ($s_1,\ldots,s_{n_i}$) in *i*th bin
  - $\bar{B}_{i,1}$ average taps changes (reg 1) in *i*th bin
- Exact Solutions

$$TC_1 = \sum n_i\,\bar{B}_{i,1}, \quad \bar{B}_{i,1} = \frac{s_1 + \cdots + s_{n_i}}{n_i}$$

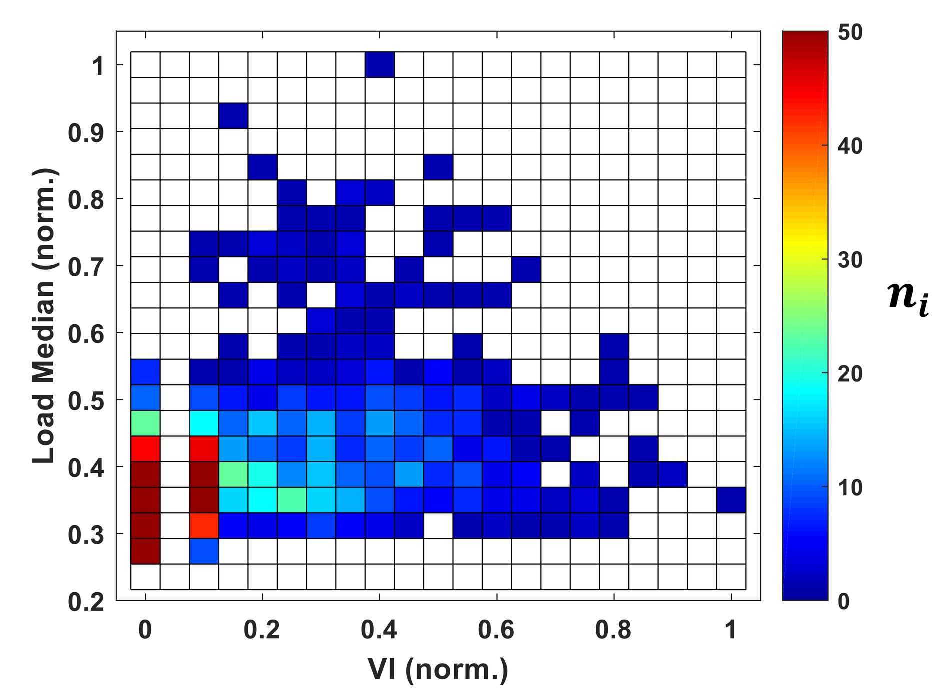
- Estimated Sampled Solutions

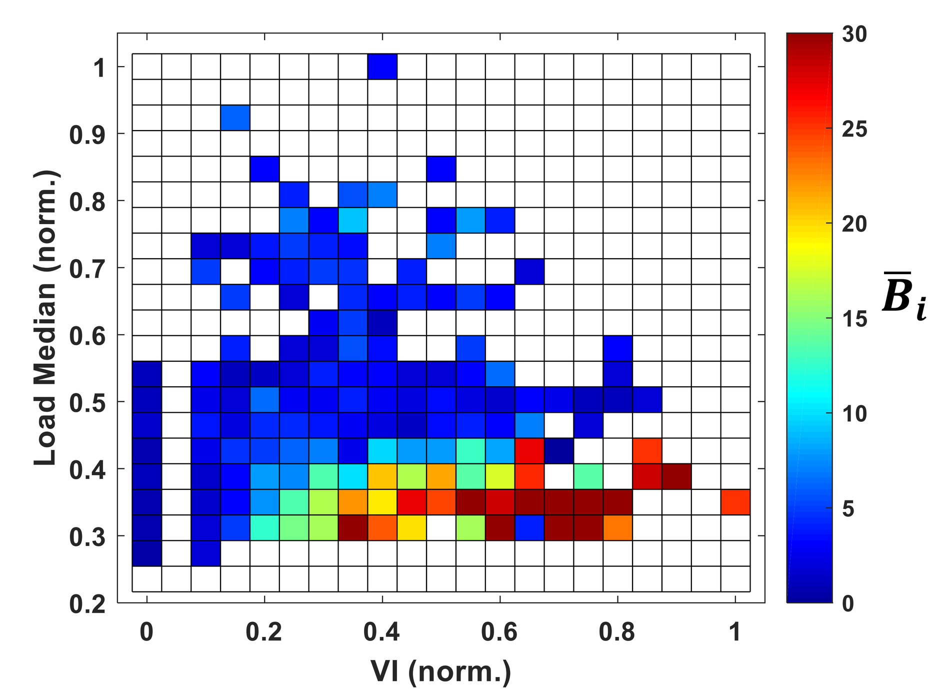
$$\widehat{TC}_1 = \sum n_i\,\hat{B}_{i,1}, \quad \hat{B}_{i,1} = \frac{s_1 + \cdots + s_{v_i}}{v_i}$$

v_i samples from *i*th bin, $0 < v_i \le n_i$

- Percent of Year Simulated

$$\%Year = 100\,\frac{\sum v_i}{1460} \le 100\%$$





Selected References
[1] J. S. Stein, C. W. Hansen, and M. J. Reno, "The variability index: A new and novel metric for quantifying irradiance and PV output variability."
[2] M. Lave, M. J. Reno, and R. J. Broderick, "Characterizing local high-frequency solar variability and its impact to distribution studies."

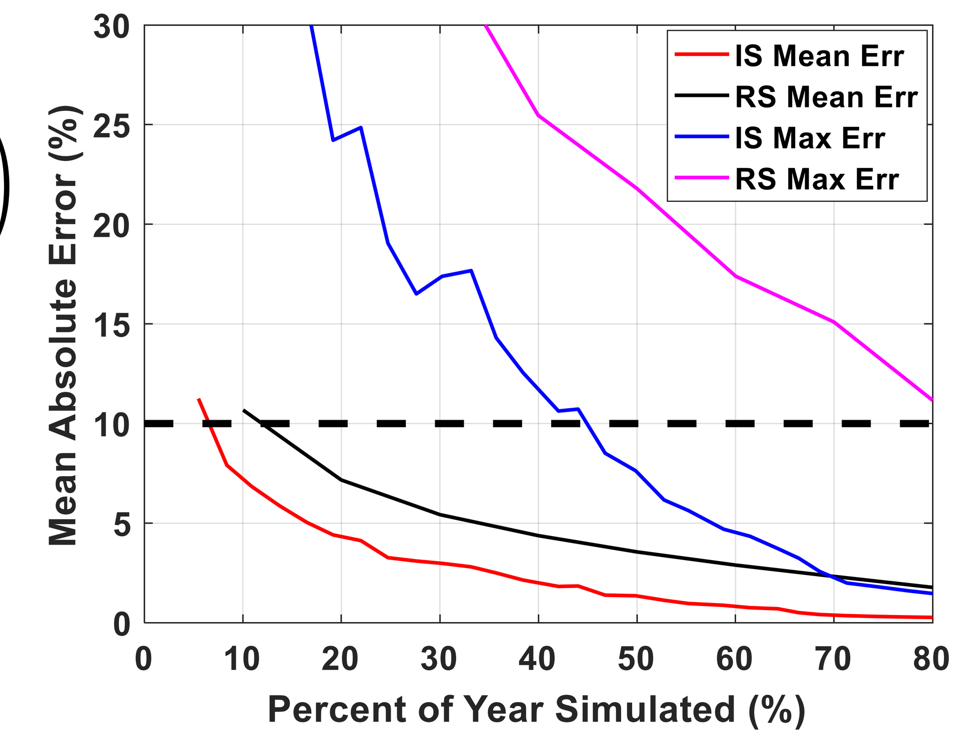
Goals

- **Reduce QSTS simulation time by simulating a subset of the year**
- **Use input irradiance and load timeseries data to choose subset**
- **Estimate annual taps changes (TC) on voltage regulators**
- **Keep estimated error <10%**
- **Compare against simple random sampling**

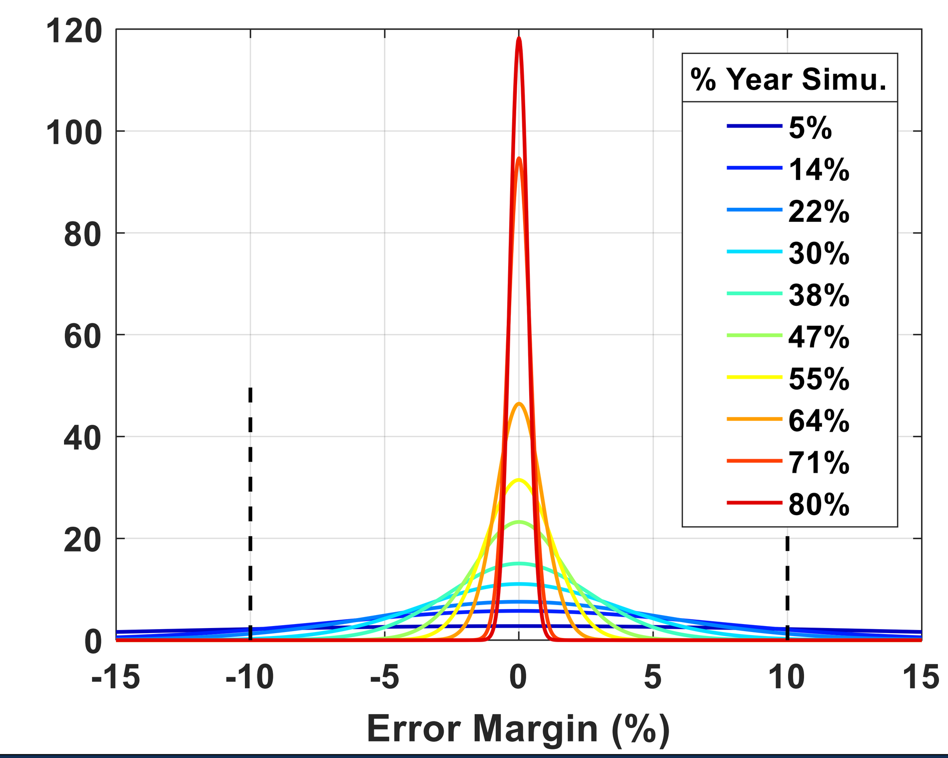
Results

Intra-bin samples are randomly selected, so the error distribution is attained using a 100,000 iteration Monte Carlo simulation for the proposed intelligent sampling (IS) and a simple random sampling (RS) algorithm. The random sampling picks randomly, without replacement, from the overall 1460 sample population. The mean absolute error (MAE), as calculated below, is used to quantify each iteration's estimation error for an IEEE 13-bus circuit with three voltage regulators.

$$MAE = \frac{1}{3}\left(\left|\widehat{TC}_1 - TC_3\right| + \left|\widehat{TC}_2 - TC_3\right| \ldots + \left|\widehat{TC}_3 - TC_3\right|\right)$$



- Mean MAE under 10% for IS and RS
- Max error bound under 10%
  - IS: 43% Year Simulated
  - RS: 85% Year Simulated
- IS ~2x faster than RS (within 10% max MAE)



- Max error is worst case scenario
- Under 43% year simulated, most estimates still bounded
- 25-43% Year Simulated
  - >97% estimates bounded
- Future work
  - Develop convergence test inside 25-43% year simulated
  - Validate IS across different circuits

Outlook

QSTS computation time can be reduced by simulating a subset of the year to estimate results. The proposed algorithm reduces simulation time by 57% compared to a simple random sampling method, which achieves only a 15% reduction. Smaller simulation sizes (20-43% of year) have "mostly bounded" simulation estimates and future work will try to implement a detection scheme to separate bounded from unbounded estimates.

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