Generation Unit Model Tuning Efforts using Synchrophasor Data

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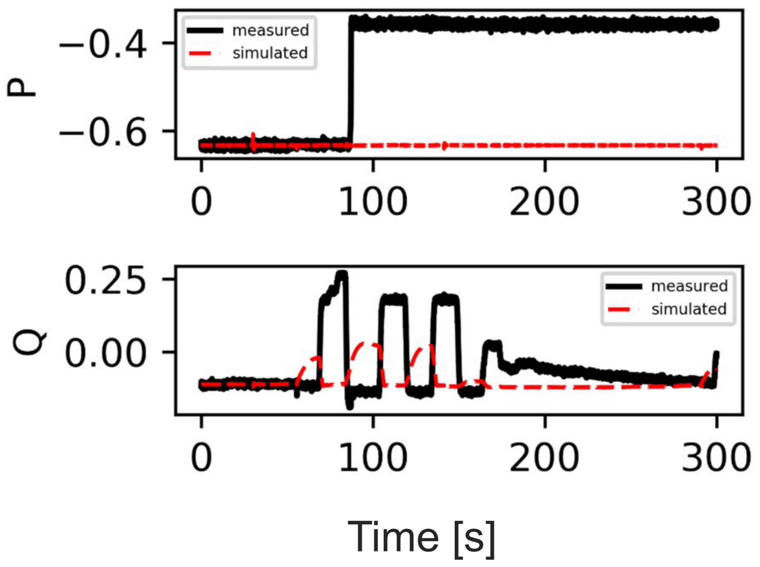
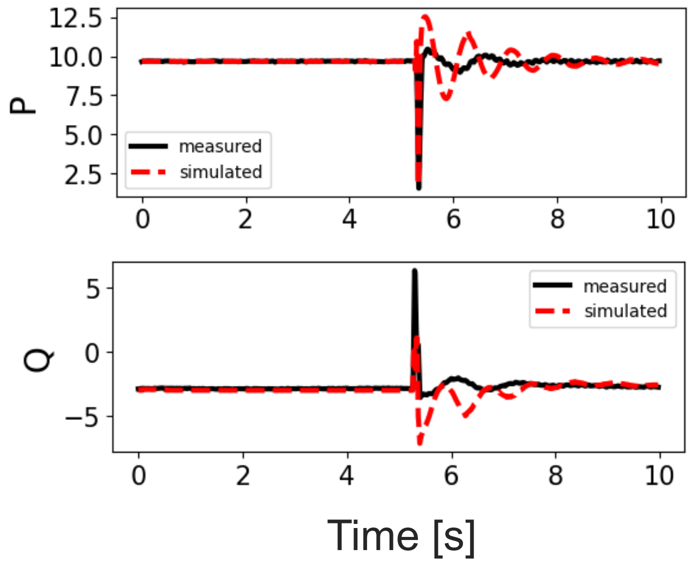
Models are only as good as what they were built for

Example of a neglected generic model



Example of a model missing the mark regarding a PPC communications delay that exists in a solar site.

Example of a model that is not well tuned



Example of a synchronous generator model that requires parameter recalibration .

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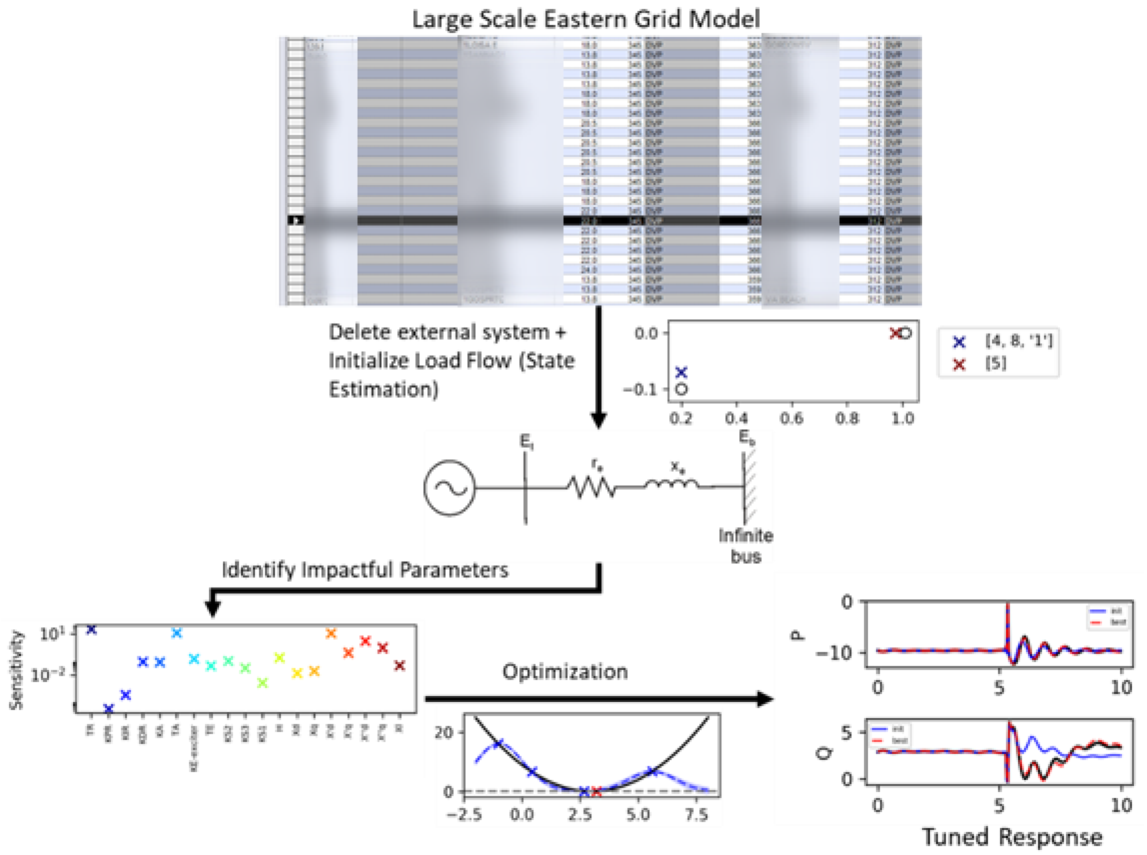
Workflow



Model Calibration Workflow Example

Step 1: Subsystem Creation
Extraction of the generation-to-playback-bus subsystem.

Step 2: Subsystem Initialization
State Estimation to match operating condition.

Step 3: Sensitivity Analysis
Estimation of model sensitivity to parameter perturbation, and reduction of tunable parameter space.

Step 4: Model Calibration
Calibration of a select subset of parameters.

Model Sensitivity: Morris Algorithm

Step 1: One-at-a-time parameter perturbation

Each parameter x_i is perturbed by Δ_i to create a trajectory through the parameter space.

Step 2: Elementary Effects (EE)

$$EE_i = \frac{f\left(x_1, \dots, x_i + \Delta_i, \dots, x_p\right) - f(x)}{\Delta_i}$$

$f(x)$ represents prior point in the trajectory.

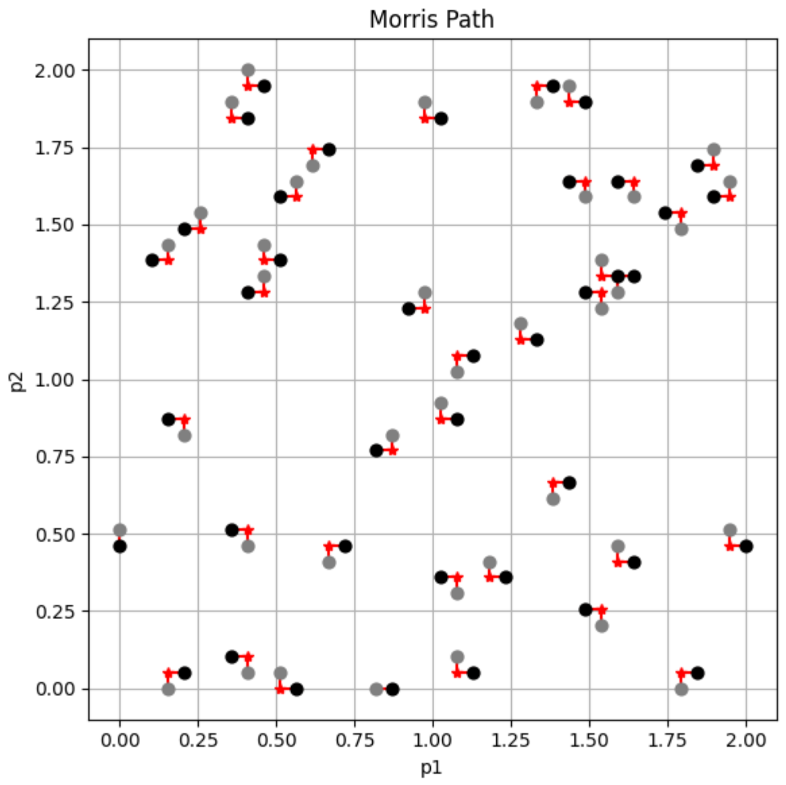
- One can calculate the elementary effects of each parameter (parameter paths) with only $p+1$ model evaluations. This task is repeated for N different starting points within the parameter space.
- Because Morris method requires single-value outputs to generate each EE_i, we convert our time-series measurement and simulation data into a normalized score $D = [0,1]$.

$$D = \sqrt{S_1 S_2}$$

S_1 is L1-distance metric (normalized amplitude mismatch), and S_2 is angular distance metric (normalized directional mismatch).

Step 3: Average and Standard Deviations of EE's

- After all trajectories are sampled, the resulting set of EE's are averaged, serving as estimate of total-order effects.
- Similarly, standard deviation is also calculated to describe the variability throughout the parameter space, and the extent to which parameter interactions are present.



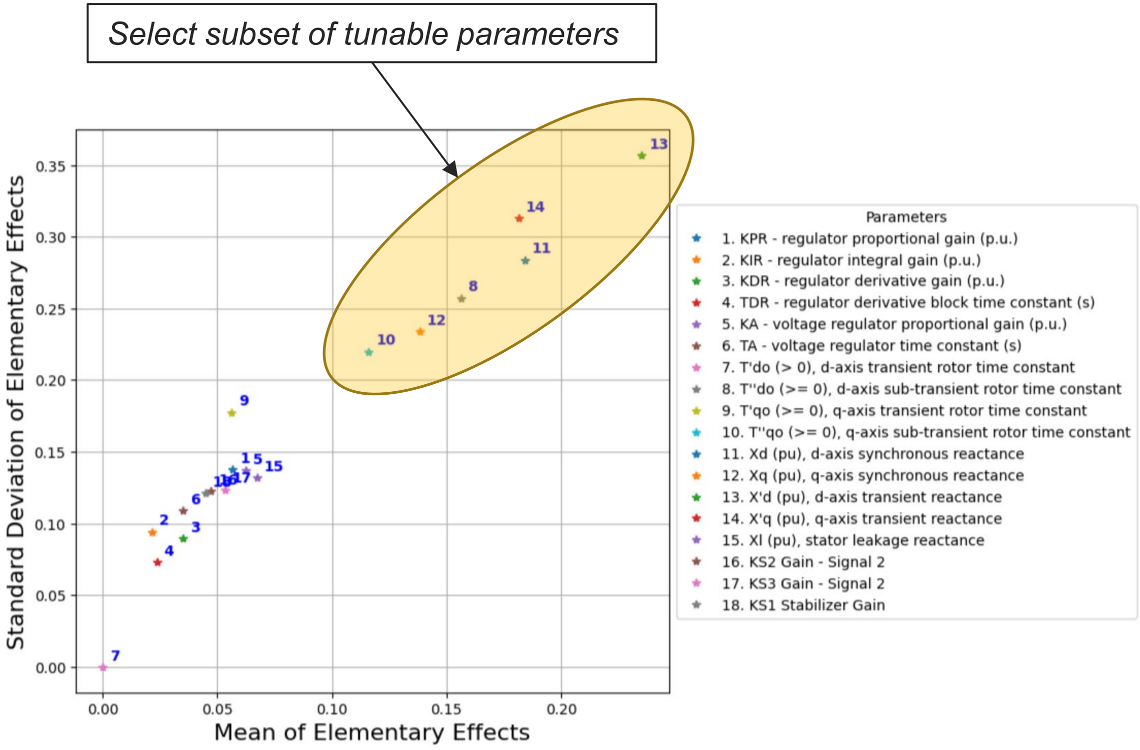
Morris's parameter paths for a 2-parameter model

Model Sensitivity: Synchronous Gen Unit Example

Step 0: Pre-filtering of total model parameters

- Careful selection of a subset of parameter. Synchronous unit model has a total of 44 + GENROE parameters.
- Pre-filter the parameter pool to only 18 candidates.

Parameters	Group
'KPR - regulator proportional gain (p.u.)', 'KIR - regulator integral gain (p.u.)', 'KDR - regulator derivative gain (p.u.)', 'TDR - regulator derivative block time constant (s)',	Excitation voltage regulator PID controller
'KA - voltage regulator proportional gain (p.u.)', 'TA - voltage regulator time constant (s)',	Voltage regulator
"T'do (> 0), d-axis transient rotor time constant", "T''do (>= 0), d-axis sub-transient rotor time constant", "T'qo (>= 0), q-axis transient rotor time constant", "T''qo (>= 0), q-axis sub-transient rotor time constant", 'Xd (pu), d-axis synchronous reactance', 'Xq (pu), q-axis synchronous reactance', "X'd (pu), d-axis transient reactance", "X'q (pu), q-axis transient reactance", 'Xl (pu), stator leakage reactance',	Generator parameters
'KS2 Gain - Signal 2', 'KS3 Gain - Signal 2', 'KS1 Stabilizer Gain'	Stabilizer gains



Follow along with Steps 1, 2, and 3.

Calibration: Bayesian Optimization (BO)

Purpose:

Method for optimizing expensive black-box models, especially useful in PSSE where component-wise perturbation experiments can't be performed to study dynamic modes or link them to measured modes.

$x^* = argmin_x\ f(x)$	$f(x)$ is the distance score obtained from running the black-box PSSE model, where x is the tunable parameter set.

Surrogate Model:

BO predicts the unknown function based on past evaluations:

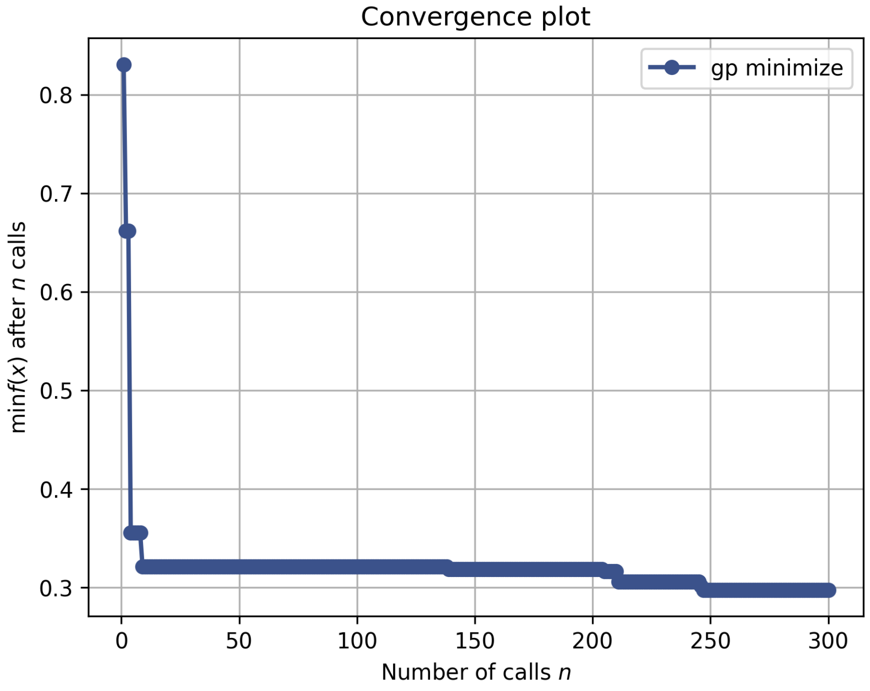
$$\mu(x), \sigma(x) = \text{GP posterior of } x$$

Acquisition Function:

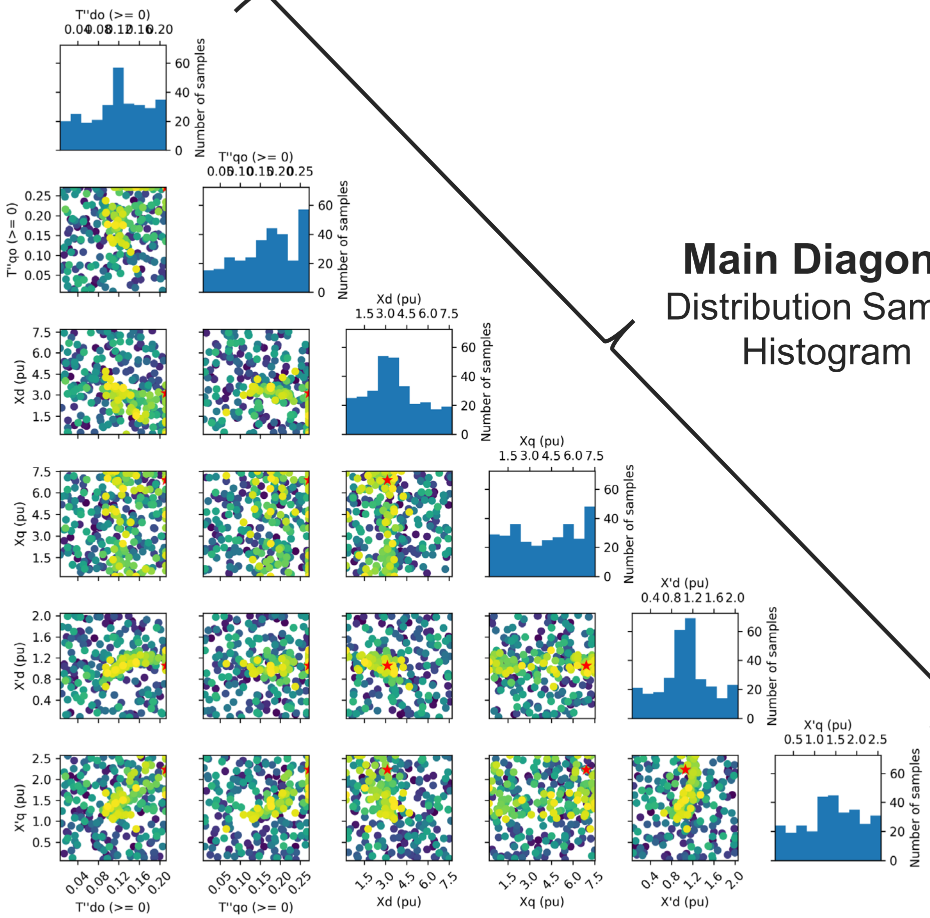
Expected Improvement (EI) ⟶ $\alpha(x) = \text{Expected Improvement at } x$

<u>How BO chooses between exploring uncertainty and exploiting predicted optima.</u>

Next point to evaluate: $x_{t+1} = argmax_x\ \alpha(x)$

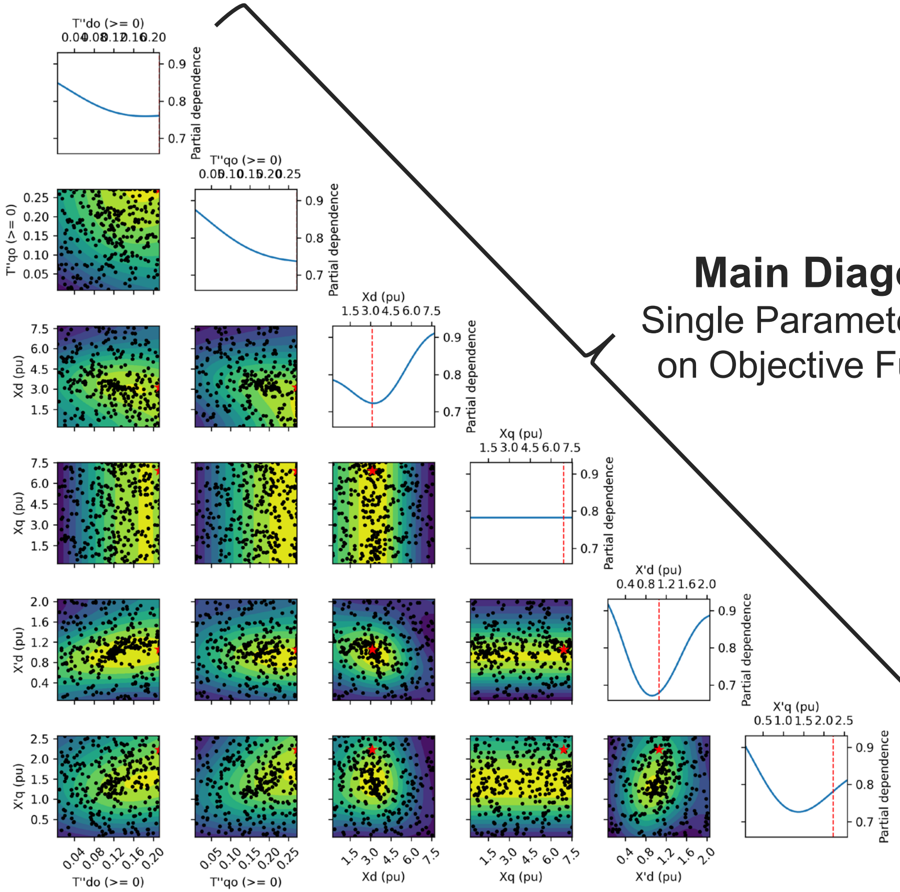


Calibration: BO Sampling/Learning



Main Diagonal
Distribution Sample Histogram

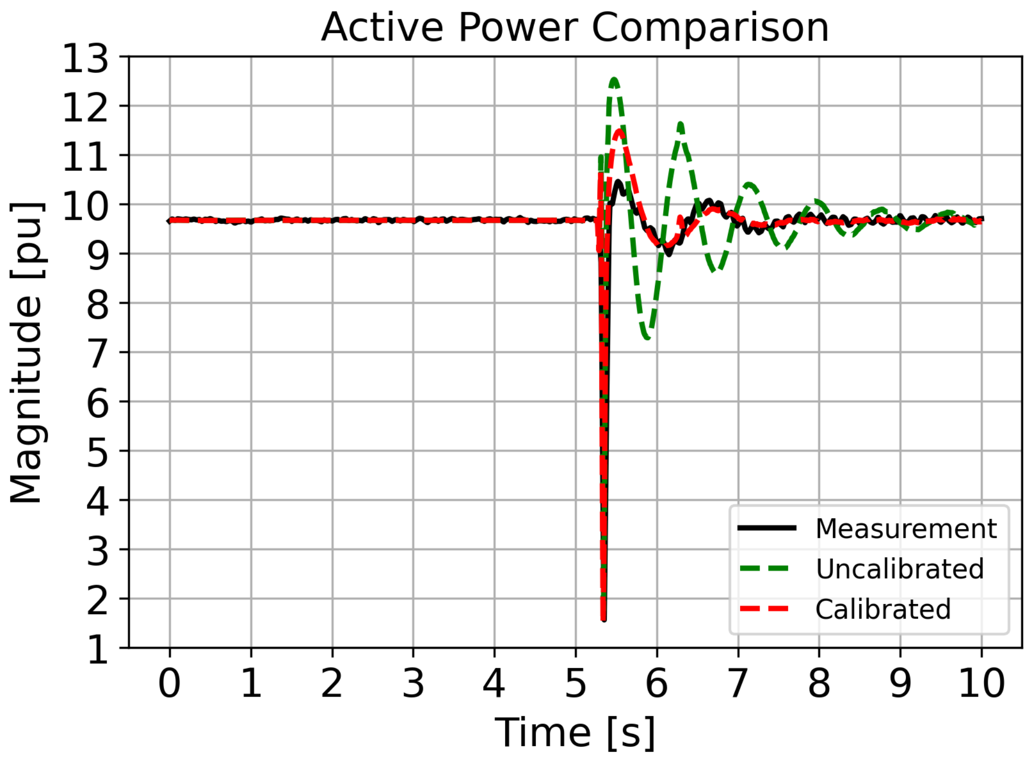
Order in which points were sampled during optimization

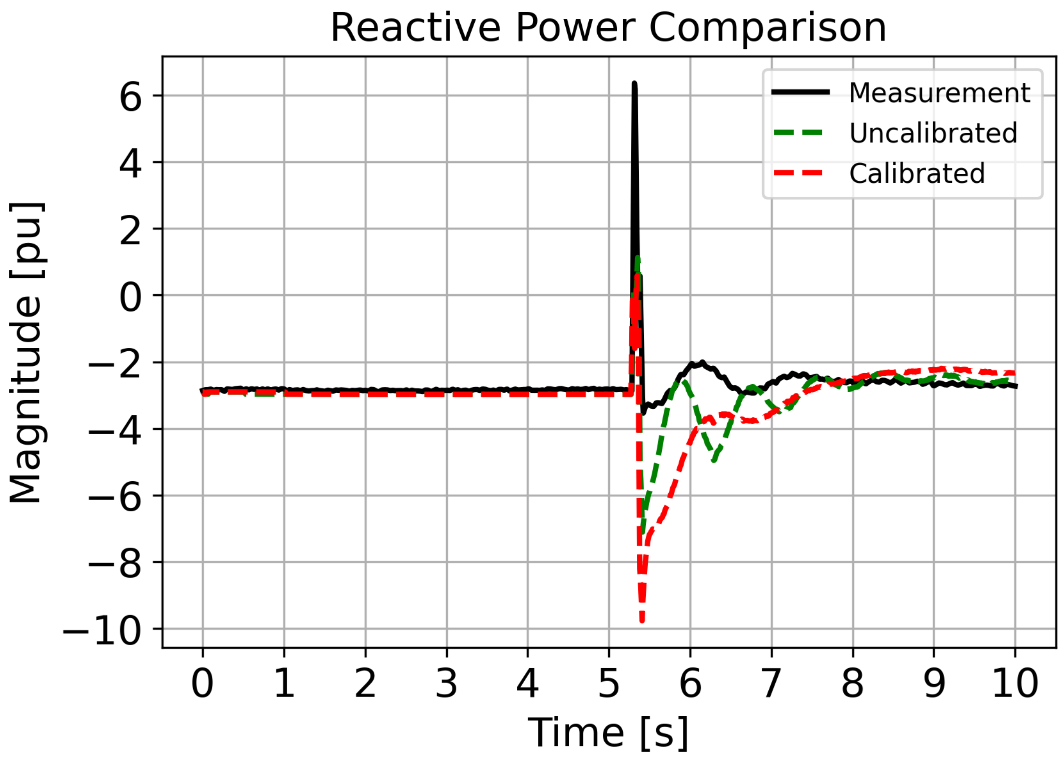


Main Diagonal
Single Parameter Effect on Objective Function

Partial Dependence plots of the objective function

Calibration: Measurement vs Calibrated Model





Next steps

- Simulation results are promising, but there is still lots to do.
- What to do when there is a lack of dynamics in models? Remove dynamics from measurement, or add dynamics to the original model?
- Should optimization rely on informative metrics during tuning? Are standard Euclidean and angular distance metrics the best approach to generating a similarity score?
- How do we work within the constraints of the software (PSS®E versus other tools)? Should we consider alternatives that provide full state visibility and allow us to design tests that isolate which model components drive the dynamics observed in measurements?
- How to ensure that we avoid overfitting a model when calibrating.
- Multi-event vs single-event calibration?
- How to expand the current framework for load calibration, specifically data center load models?

Thank you!

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