Theoretical Hardware-in-the-Loop Framework | Thrust 1

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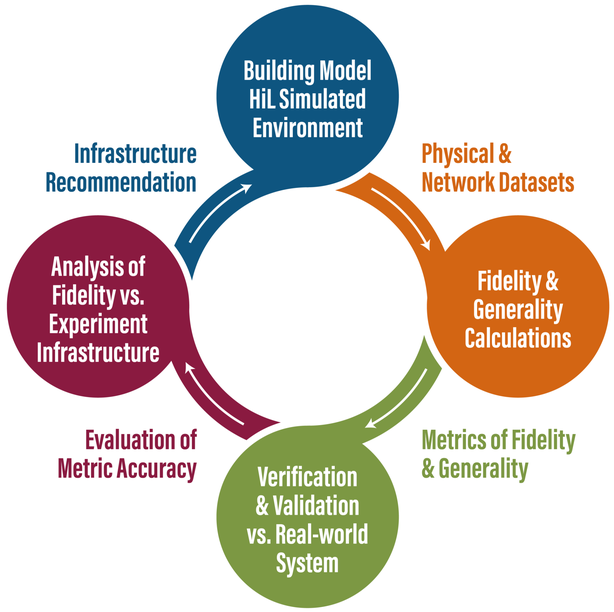


Cycle of experimentation, evaluation, and recommendations

OBJECTIVE

The project aims to provide users with a method to measure the fidelity of a testbed and resulting datasets.

In support of evaluating the generality of an experiment, the project performs uncertainty quantification. It provides a systematic experimental approach to evaluate factor effects and the effect of variability on responses and fidelity metrics.

ACHIEVEMENTS

- Proof-of-concept demonstration of transfer function approach using the Microgrid Model Instantiation and Validation project datasets
- Pipeline for parsing of large high-volume datasets and metric calculations
- Cross-project collaboration:
  - Cyber-Physical Subsystem Studies under Adverse Conditions Project—provide input on experimental design and dataset evaluation. Identified gaps in sensor data and object identifiers
  - Microgrid Model Instantiation and Validation Project—provide feedback on data needs, format, and availability

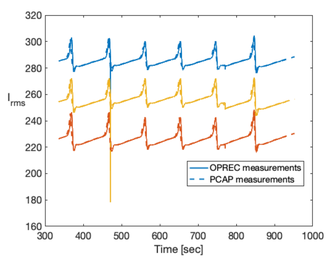
APPROACH

Fidelity

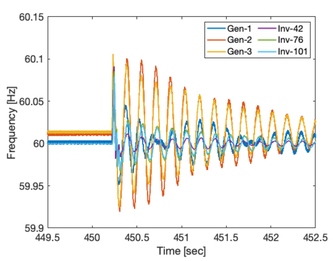
We define fidelity as the *transparency* of the data transfer between the hardware and software part of the simulation. Transfer functions are used to estimate the two necessary polynomial functions. Transparency is then defined as the Euclidean distance between these functions. In a fully transparent system, this distance will equal zero.

Fidelity is then defined as follows: $F = \frac{1}{1+T}$

By this definition, the value of F will always fall in the range $(0,1]$. A value of 1 indicates perfect fidelity, while values close to 0 indicate a low level of fidelity. This metric is computed at multiple states for a given system.



Phase measurement comparison data



Sample data for variance calculations

Generality

In comparison to the fidelity metric, generality assesses experimental results over a wide range of inputs and provides an estimate of use case coverage for a given experiment and resulting dataset.

Generality is a function of typical operating variance as well as experimental design and testbed architecture. We use full-factorial and fractional-factorial experiments on simulated processes to assess response. This provides an accurate description of the process and precise quantification of variance.

SEL Devices (Hardware) [PCAP Data] | Interface (or) Coupling | OPAL-RT Simulation (OPREC Data)

$$G_{HS}(s) = \frac{\hat{y}_h(s)}{y_h(s)} \approx 1 \qquad G_{SH}(s) = \frac{y_s(s)}{\hat{y}_s(s)} \approx 1$$

Definition of transparency and data flow

RESULTS/IMPACT

We demonstrate proof of concept using the Load 31 dataset from Scenario 1A provided by the Microgrid Model Instantiation and Validation project. Initial calculations consider the three phase current measurements I_{rms} between busses 149 and 1. These measurements support calculation of the transparency from the OPAL-RT simulation to SEL devices. Resulting values are listed below:

Phase 1	F = 0.4575
Phase 2	F = 0.2203
Phase 3	F = 0.0455

These values imply a system with relatively low fidelity. This is due to several factors, such as the time granularity available on devices. Further testing will provide insight.

Path Forward

Initial testing shows that this approach is achievable with the data provided by the experimental testbed. The next steps cover further testing for robustness of the approach.

- Complete calculations for remaining measurements and scenarios
- Perform experiments to evaluate degree of transfer functions
- Perform calculations at higher levels of time granularity for comparison

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