Role of Sensitivity Analysis in Stress Testing Power System Controllers
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Abstract
Real-time Hardware-in-the-Loop (HIL) simulation has been a major step in design, development, and implementation of new technologies in the field of power systems. Due to their real-time characteristics, these simulations cannot be accelerated by using more powerful hardware. This makes the comprehensive evaluation of a given device under test (DUT) more challenging. Usually, the conditions and circumstances of the simulation (known as the simulation scenario) are dictated by experts to observe the behavior of the defined performance metrics when the DUT is put under stress. Although this approach is effective in establishing whether a DUT satisfies the requirements of the design, it cannot push the DUT to its absolute limit. Doing so requires a systematic approach to determine and manipulate a usually vast number of model parameters to check all the possible scenarios and identify the ones that push the DUT beyond its capabilities. However, not all model variables have the same influence on the performance metrics. Knowing the extent of influence that each variable has on a given metric can help analysts reduce the dimension of the search space drastically and therefore reduce the processing time needed to carry the analysis. Here, we use a Power Generation Module (PGM) model found on next generation Navy ships as a case study [1] Different sensitivity analysis approaches are tested on the model.

Introduction
The research goal is to reduce the dimension of the search space before establishing the boundaries of the performance of a power system controller in a real-time setting. This is accomplished by performing sensitivity analysis on the real-time model. We adopt a variance based approach to approximate the first order sensitivity indices of a set of model variables [2].

Model and output
- **Model**: 30 MW power generation module consisting of a Gas turbine, a dual-wound synchronous machine with two 3-phase outputs connected to a pair of thyristor rectifiers which have LC filters at their output [1].
- **PGM output**: 12kV DC voltage fed to the loads.
- **Model output function**: RMS value of the ripple voltage (as a percentage of the nominal voltage) at the output of the filters when the loads are at their maximum allowed value:
  \[
  V_{\text{RMS, ripple}} = \sqrt{\frac{1}{N} \sum_{k=1}^{N} (V_{\text{out}}(k) - V_{\text{ref}}(k))^2}
  \]
  where N is the number of samples in a moving window, \(V_{\text{out}}\) is the output voltage seen at the terminals of PGM, and \(V_{\text{ref}}\) is the DC component of the output voltage.

Variables
- **GaRBaUll**: The inductance of the LC filter.
- **GaRBaUlr**: Resistance in series with the LC inductor.
- **loadLimit**: Maximum level of power that the loads will demand from the PGM. The ripple RMS value is calculated at this point.
- **GaMaCE**: Capacitance of the LC filter.
- **GaMaAR**: Resistance in series with the LC capacitance.
- **Sentinel1**: A variable with no effect. Put in place as a check for integrity of the analysis.

First Order Sensitivity Index
We use a Monte-Carlo method to approximate this value for ith variable:

\[
S_i = \frac{V_i(E_{X_i}(Y|X_i))}{V(Y)}
\]

Method:
- Uniformly sample all the variables within their range of variation and form a sample of size N for each.
- Form input vectors from the randomized samples for each variables.
- Run the model for the sets of input vectors.
- For each variable, divide the sample into k subintervals.
- Calculate the mean of the output for the samples that fall within each subinterval.
- Calculate the variance of the mean values.

References