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Role of Sensitivity Analysis in Stress Testing Power System Controllers

B. Mohebali* , K. Schoder, M. Stanovich**, M. Steurer**, G. Erlebacher***

* Department of Scientific Computing
** Center for Advanced Power Systems

Contact Information:
Florida State University
Department of Scientific Computing
Tallahasee, Florida

Email: `bmohebali@fsu.edu`

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 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 metrics beyond their acceptable range. 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 percentag of the nominal voltage) at the output of the filters when the loads are at their maximum allowed value:

$$V_{ripple}^{RMS} \sqrt{\frac{1}{N}\sum_{k=1}^{N}(V_{out}(k) - V_{dc}(k))^2} \qquad (1)$$

where N is the number of samples in a moving window, V_{out} is the output voltage seen at the terminals of PGM, and V_{dc} 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.
- **GaMaCf**: Capacitance of the LC filter
- **GaMaRf**: Resistance in series with the LC capacitance.
- **Sentinel1**: A variable with no effect. Put in place as a check for integrity of the analysis.

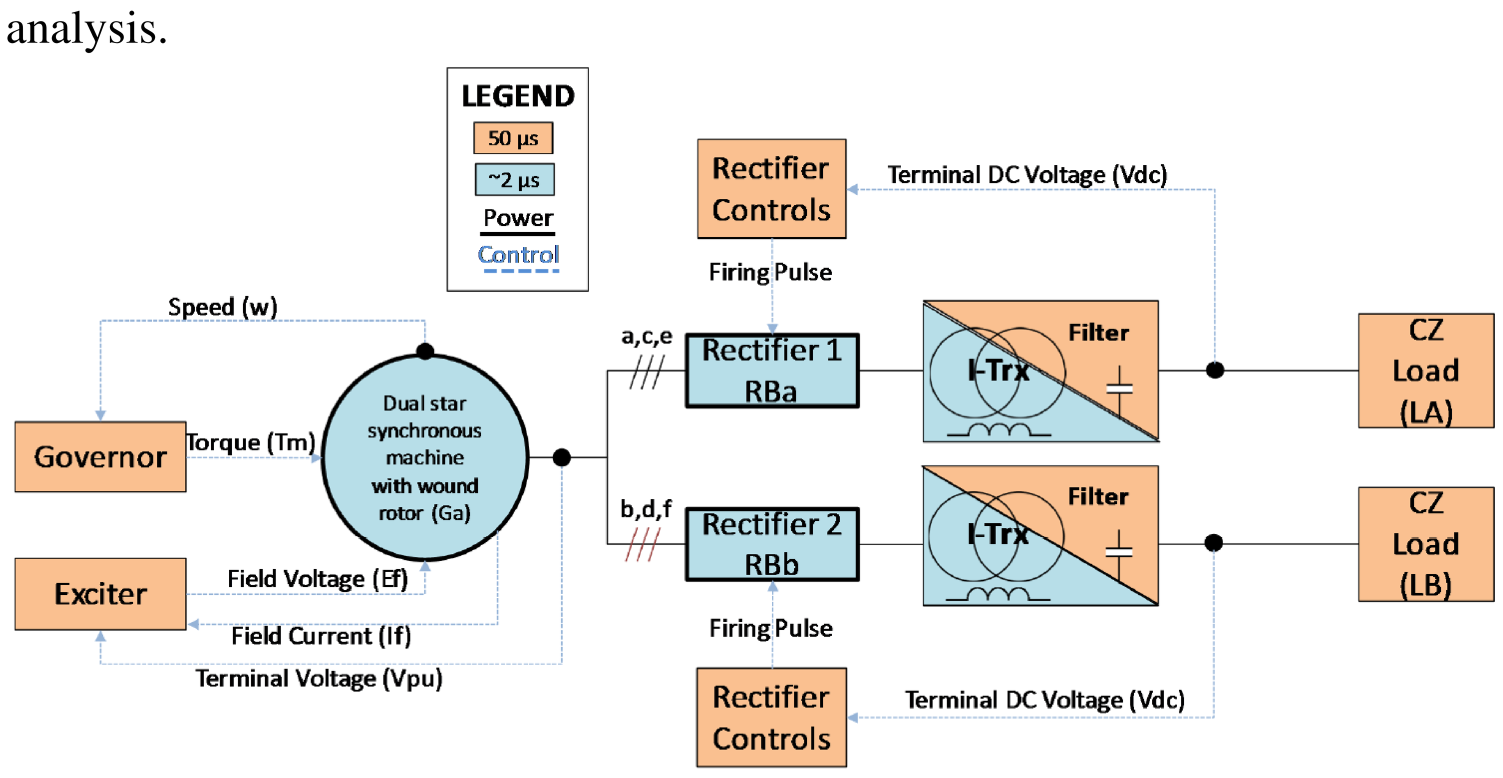

Figure 1: PGM model under investigation. The different colored components are simulated by different time steps.

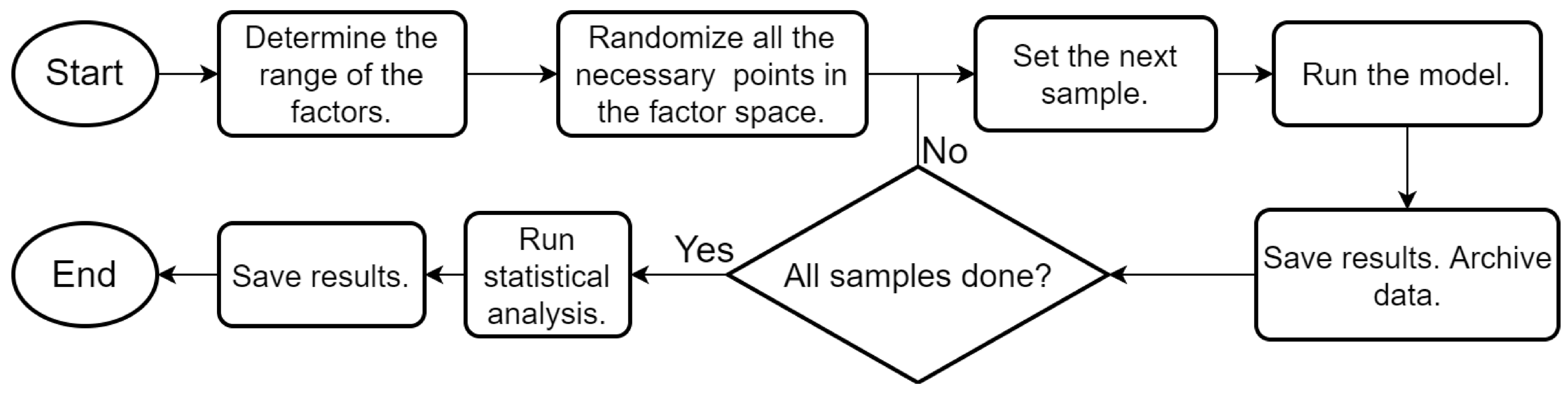

Figure 2: The automated process of gathering the samples for First order sensitivity index calculations.

First Order Sensitivity Index

We use a Monte-Carlo method to approximate this value for *ith* variable:

$$S_i = \frac{V_{X_i}(E_{X_{\sim i}}(Y|X_i))}{V(Y)} \qquad (2)$$

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.

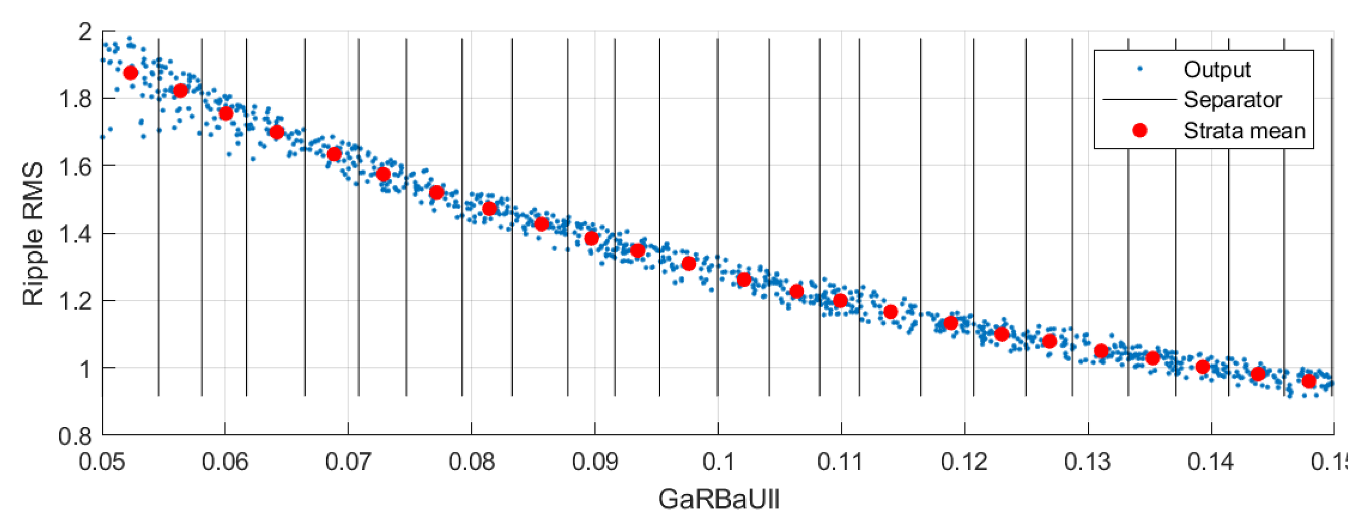

Figure 3: The scatter plot of the output values of the samples when the sample is divided into subintervals w.r.t. one variables (GaRBaUll).

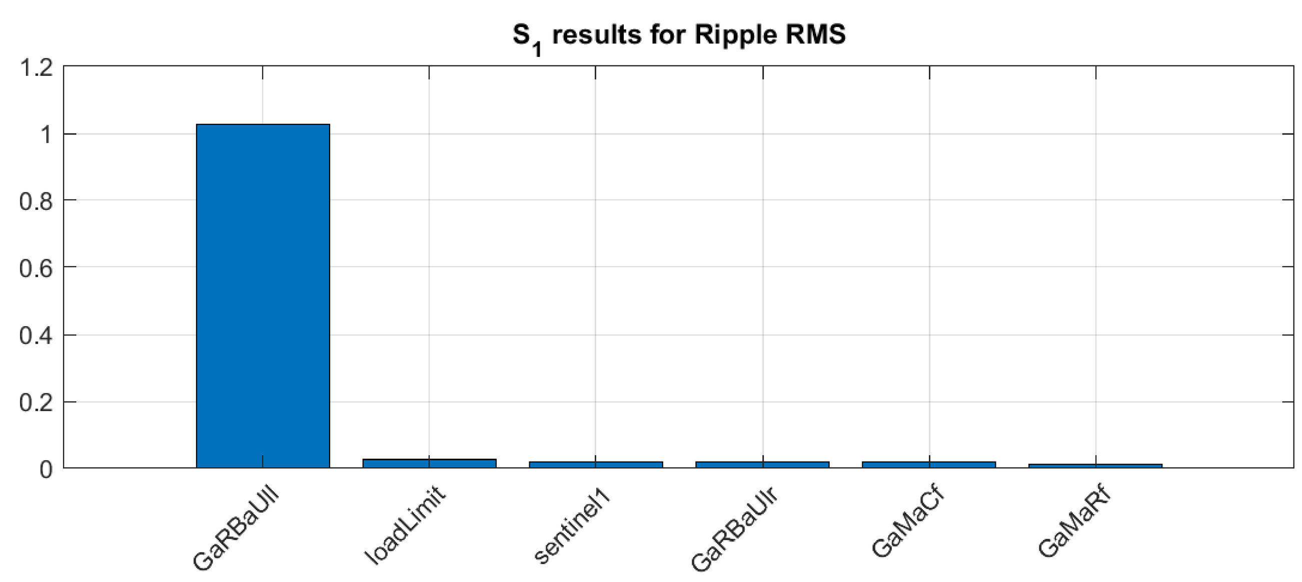

Figure 4: Final results of the first order sensitivity indices for all the considered variables. The filter inductance has a dominant influence on the voltage ripple RMS value. There is some intrinsic randomness in the approximated values. This is why the index for sentinel1 (the non-influential variable) is not zero as it should be. However, the stochastic nature of the analysis should not change the conclusions of the analysis.

Conclusions

We have shown that one variable dominates the influence on the model output (RMS ripple voltage). The whole sample took two days to execute. In general, the variance-based approaches are known for their high computational cost and therefore are not suitable when the resources are scarce.

References

[1] Harsha Ravindra, Michele Difronzo, Murilo Almeida, Edwin Fonkwe, Karl Schoder, Andrea Benigni, Matt Baker, James Langston, Mischa Steurer, and Herb Ginn. An exercise on model description document based implementation of shipboard power system modules on drts platforms. In *2019 IEEE Electric Ship Technologies Symposium (ESTS)*, pages 73–80. IEEE, 2019.

[2] Andrea Saltelli, Marco Ratto, Terry Andres, Francesca Campolongo, Jessica Cariboni, Debora Gatelli, Michaela Saisana, and Stefano Tarantola. *Global sensitivity analysis: the primer*. John Wiley & Sons, 2008.