Project: Impedance Measurement Techniques in PHIL Environment

Project Completion: 2018

Output: Two technical papers [1, 2] were developed, as well as a master's thesis [3]. These documents described evaluations of techniques and configurable parameters for impedance measurements in the context of power hardware-in-the-loop (PHIL) simulation experiments.

Outcome: Several impedance measurement techniques were evaluated for their potential use in high power PHIL simulation experiments. An analysis of four different techniques and associated configuration parameters was performed, with the pros and cons for each one being discussed. Several measurement techniques were used to probe controller hardware-in-the-loop (CHIL) simulation models as well as physical hardware to validate the applicability of these techniques in this environment.

Project Motivation:

New load power requirements coming to electric ships require new distribution systems to be employed, heavily making use of power electronic converters. These power electronics have been shown to cause instabilities in some systems due to their constant power load characteristics. One approach of stability analysis is based on the impedance of the components in the system. These impedance measurements can be obtained from the actual hardware by applying voltage and/or current perturbations to the device while energized. However, in some cases, the impedance presented by a device may depend on other portions of the system (e.g. the input-side impedance of a converter may be influenced by the dynamics of the load connected to the converter). PHIL simulation provides a method whereby the effects of the surrounding system may be incorporated into the impedance measurements, by interfacing the device-under-test to emulated portions of the system. Additionally, it is possible to use the amplifiers inherent to PHIL simulations to inject the perturbations into the system. This allows for early stage testing of the device of interest as well as less hardware needed for the test. This impedance information is also of importance for analysis of the PHIL experiment, itself. An example of what is described was reported in a technical paper [1], where MW scale impedance measurements were performed in a PHIL experiment setting using PHIL amplifiers as the perturbers. In this work, four different types of perturbation signals, along with associated configuration parameters, have been considered to determine their suitability in this context. The goal of this research is to determine the best suied approaches for perturbing systems in medium voltage and high power PHIL experiments. The methods researched include the following:

Single Tone Single frequency sine wave exciting one discrete frequency at a time. Configuration parameters include the amplitude of the perturbation, the length of the capture, number of repeated captures per frequency, etc.

Multi-tone A sum of sine waves at different frequencies. This allows one injection signal to perturb many frequencies at the same time, drastically reducing measurement time. Configuration parameters include the amplitude of each tone, the number of tones per capture, the length of the capture, the method for phase shifting components, etc.

Chirp A continuous sweeping wave over a given frequency range. Excites a continuous band of frequencies rather than a discrete set of points like the single tone and multi-tone. Configuration options include the magnitude and length of the chirp signals, the number of chirp signals applied over the frequency range of interest, and how the frequency is swept for each (i.e. linearly or logarithmically).

Pseudorandom Binary Sequence (PRBS) A pseudorandom binary sequence based off of a maximum length sequence has similar properties to white noise, therefore it is able to excite all frequencies within its excitation bandwidth at once. Configuration options include the amplitude of the perturbations, the length of the sequence, the length of the capture, the number of captures, etc.

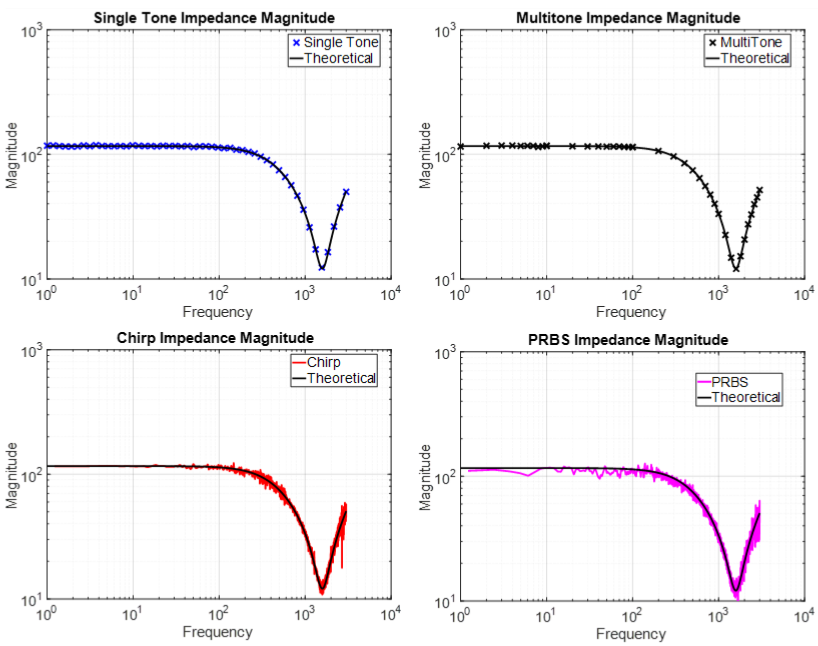


Figure 1: Example Measurements using Techniques

An example of each of the methods characterizations can be seen in figure 1. Each of these methods have been used to probe CHIL models of a Modular Multilevel Converters (MMC) used as an amplifier for PHIL experiments. The single tone and chirp methods were also used to characterize the actual hardware MMCs. In each of these scenarios, the devices were operating at 3 kV and 100 A. This shows that using the PHIL amplifiers with superimposed perturbations can accurately characterize systems in the medium voltage megawatt power range up to the low kHz frequencies. The chirp and multi-tone methods were able to get accurate characterizations of the systems while using drastically less time than the single tone method.

Project Extent: This project involved multiple researchers from one ESRDC institution and is documented in two technical papers [1] and [2].

Technical Point of Contact: Mischa Steurer (steurer@caps.fsu.edu)

References:

[1] J. Langston, K. Schoder, M. Steurer, F. Fleming, and M. Kmiecik. Medium voltage impedance measurement on a mw scale power conversion module using phil simulation. In *2018 ASNE Advanced Machinery Technology Symposium*, March 2018.

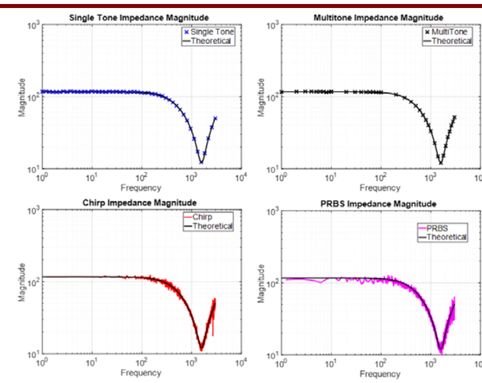
[2] G. Chauncey, J. Langston, K. Schoder, T. Szymanski, and M. Steurer. Impedance measurement techniques for phil simulation experiments in noisy environments. In *2018 ASNE Technology Systems and Ships*, June 2018.

[3] Gunnar Chauncey. Impedance measurement techniques in noisy medium voltage phil environments. Master's thesis, Florida State University, August 2018.

Impedance Measurement Techniques in PHIL Environment

Motivation

- Impedance measurements of components are important for
  - Analysis of components within systems
  - Analysis of accuracy, sensitivity, and stability of PHIL simulation experiments
- Evaluate techniques and configuration options for impedance measurements in PHIL experiments with the following considerations
  - Leverage amplifier of PHIL interfaces for impedance measurements
  - Techniques must be compatible with limited bandwidth of PHIL amplifiers
  - Techniques must cope with sensor noise and switching noise from high power amplifiers
  - Techniques must simultaneously maintain small perturbations in voltage and current



Approach

- Considered techniques and configuration parameters include
  - Single tone – amplitude of perturbation, length of capture, number of repeated captures per frequency
  - Multi-tone – amplitude of each tone, number of tones per capture, length of captures, method for phase shifting components
  - Chirp – amplitude and lgneth of chirp signals, number of chirp signals applied over frequency range of interest, how frequency is swept (i.e. linearly or logarithmically)
  - Pseudorandom Binary Sequency – amplitude of perturbations, length of the sequence, length of the capture, number of captures
- Consider known impedance characteristics and compare methods based on
  - Mean and maximum error in magnitude and phase angle
  - Total time and total energy expended in measurements

Outcomes

- Strengths and weaknesses of techniques and configuration options evaluated through application to several simulated impedance characteristics
- Used simulated noise injections to include sensitivity to noise in analyses
- Applied techniques to measurement of impedances for controller hardware-in-the-loop (CHIL) simulation of existing 5 MW modular multilevel converter (MMC) amplifier used for PHIL simulation
- Applied techniques to measurement of impedances for actual MMC amplifier