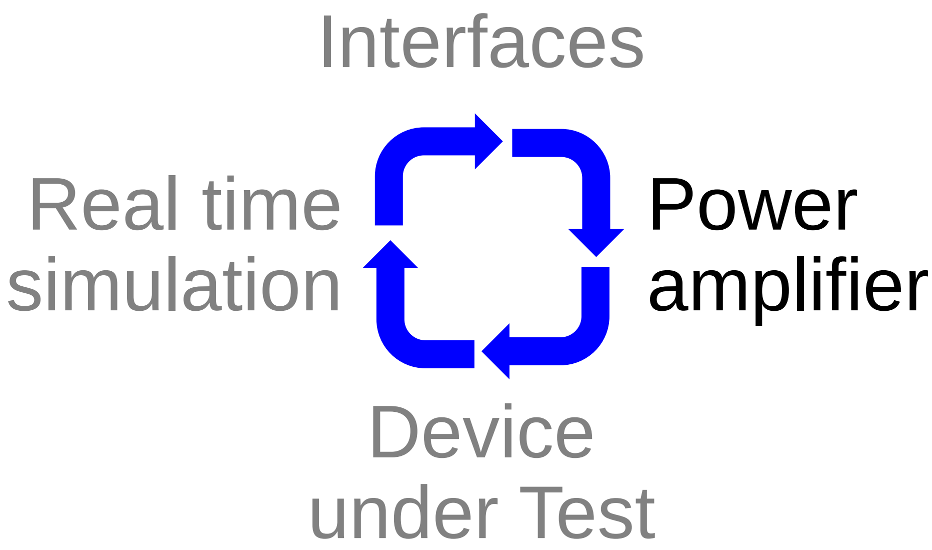
Modeling and Characterizing a Power Hardware-in-the-Loop Amplifier

NREL Technical Monitor
Mariko Shirazi

CAPS @ FSU
M. Steurer, J. Langston, K. Schoder,
J. Hauer, F. Bogdan

AMETEK Programmable Power, Inc.
Ron Brown

Motivation



Power Hardware-in-the-Loop Testing

Amplifier interfaces with device under test

Experiment design

Predict stability and accuracy

Need to know response characteristics

Project objective

System identification

Model building and validation

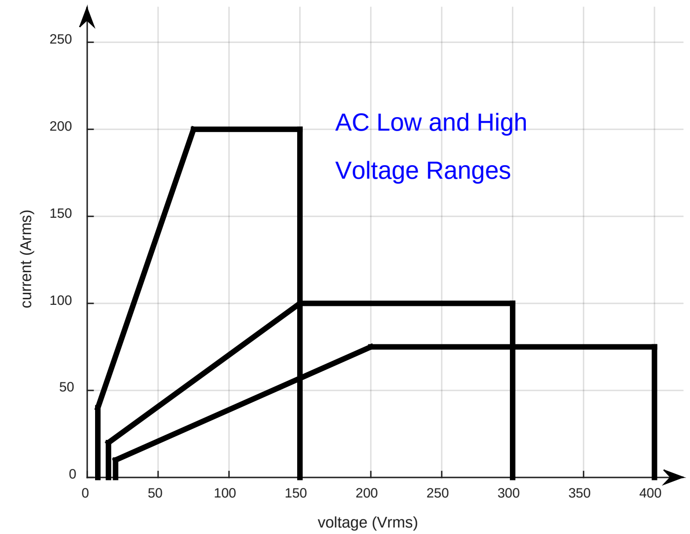
Operating modes

AC (90kVA) and DC (60kW) voltage source

With and w/o transformer coupling

Choice of voltage levels

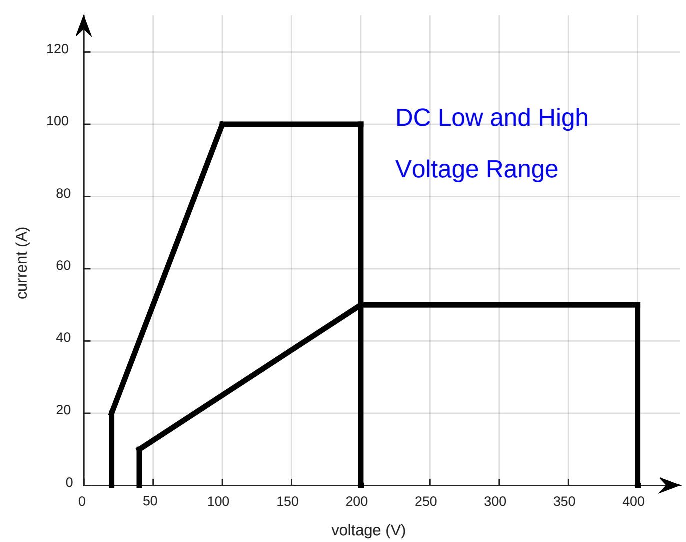
4-quadrant



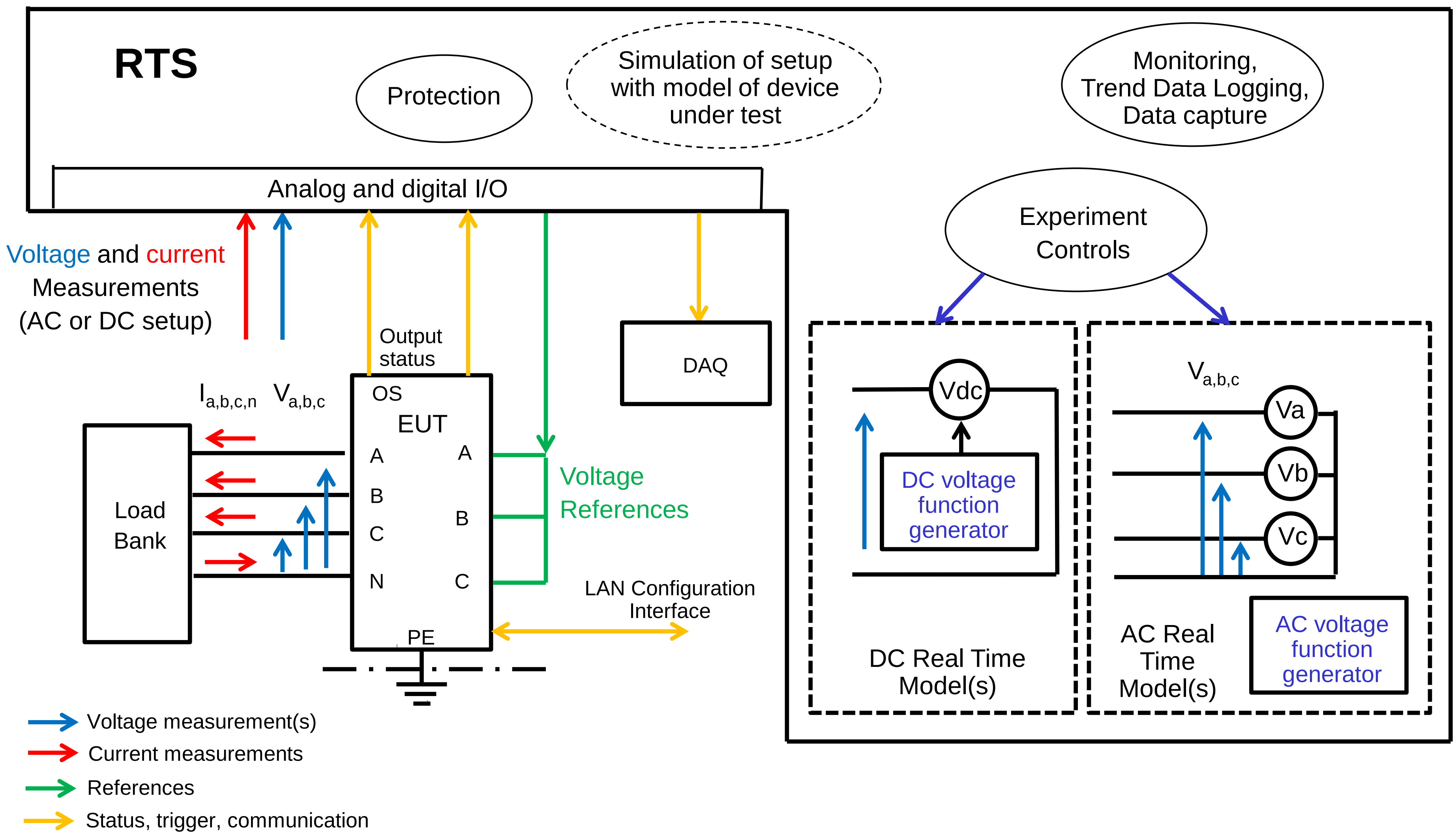
Three independent amplifier stages

One amplifier per phase

To be characterized



Example Test Setup



Project Tasks

Testing →

Select operating conditions

Test sets

- Voltage oscillations
- Voltage ramps (steps)
- Load steps
- Regeneration mode

Modeling →

Circuit models

- Switching
- Average value

Transfer functions

- Instantaneous
- Envelop

Simulating

Selected operating conditions and test sets

↓

Validating

(current project phase)

Experiments

Response quantities/Metrics

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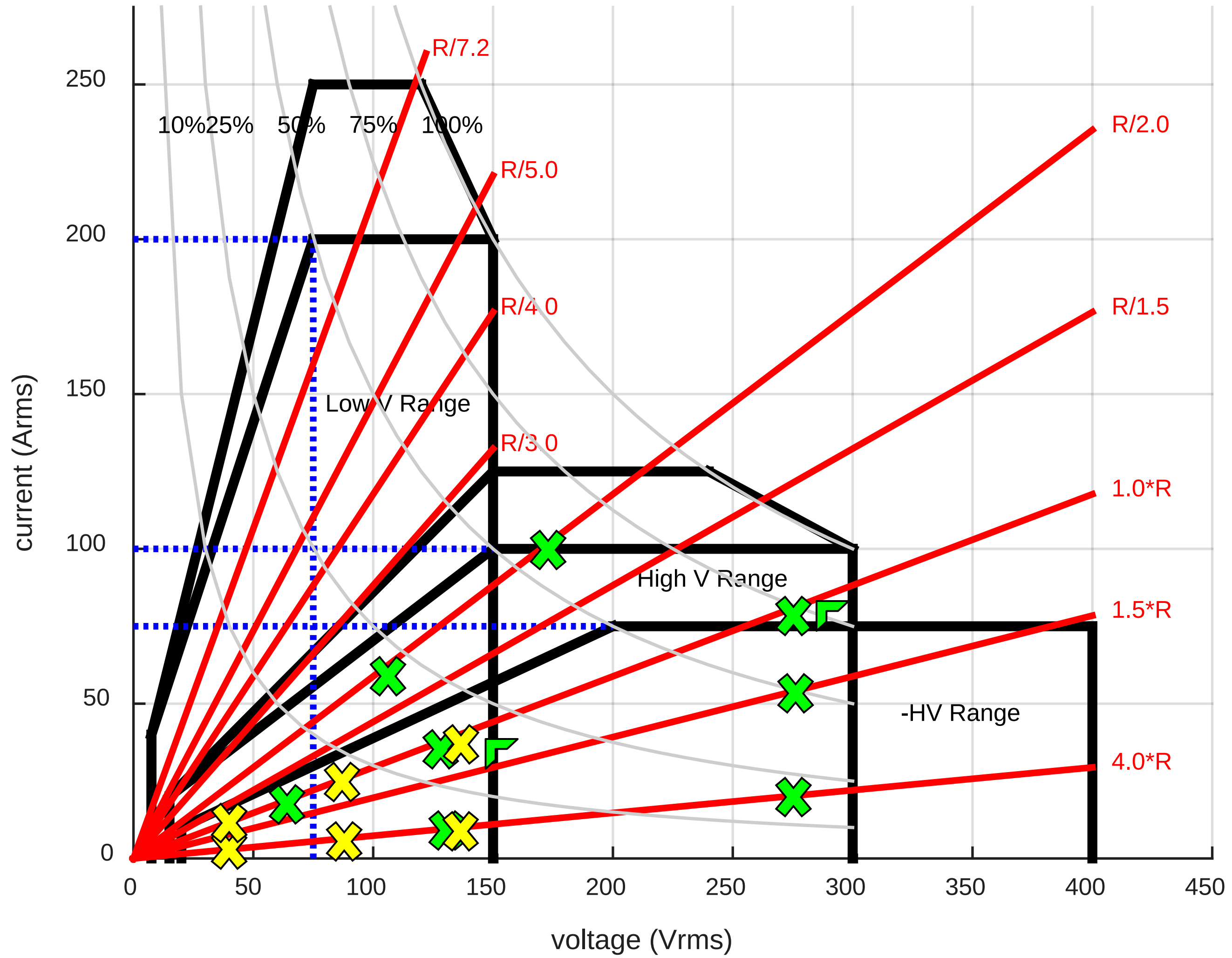
PHIL Design

Apply model and determine stability

←

PHIL example

Example Test Sets with Resistive Loads



Disturbance type:

oscillations

step response

Operating mode:

AC 150 V

AC 300 V

R … base resistor component, 3.4 ohm, 80 A, twelve available

Modeling and Simulation

Model structure → **Model implementation**

Core power components with information from AMETEK

Sub-power stages and connections

Filter

Controls
- Outer voltage loop
- Inner current loop

Model implementation

Offline and real time parameterized models
- Physics based
- Transfer function

Simulating

Selected operating conditions and test sets

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Validating
(current project phase)

Evaluate metrics that allow compare measured and simulated

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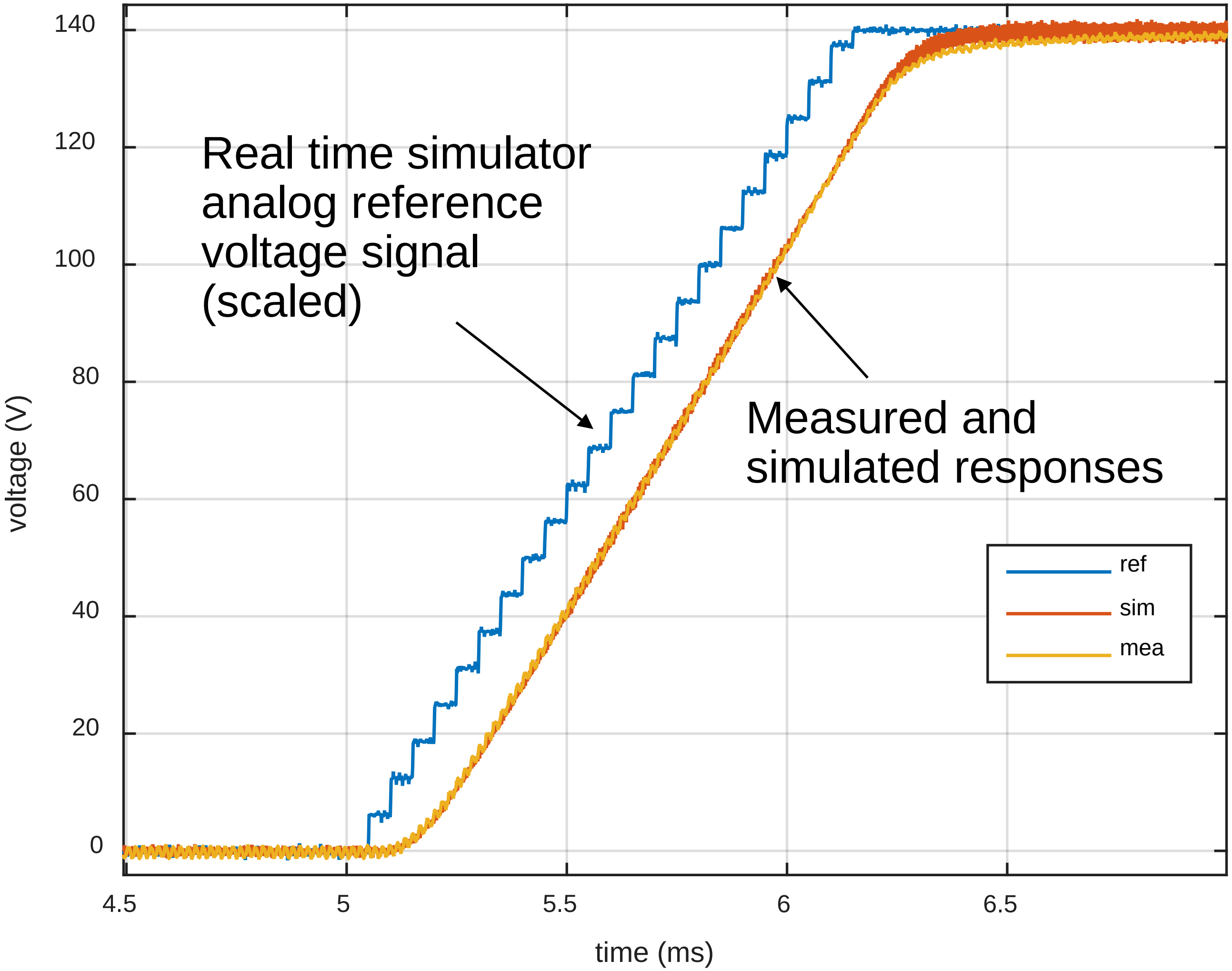
PHIL Design

Experiment: Apply model and determine stability

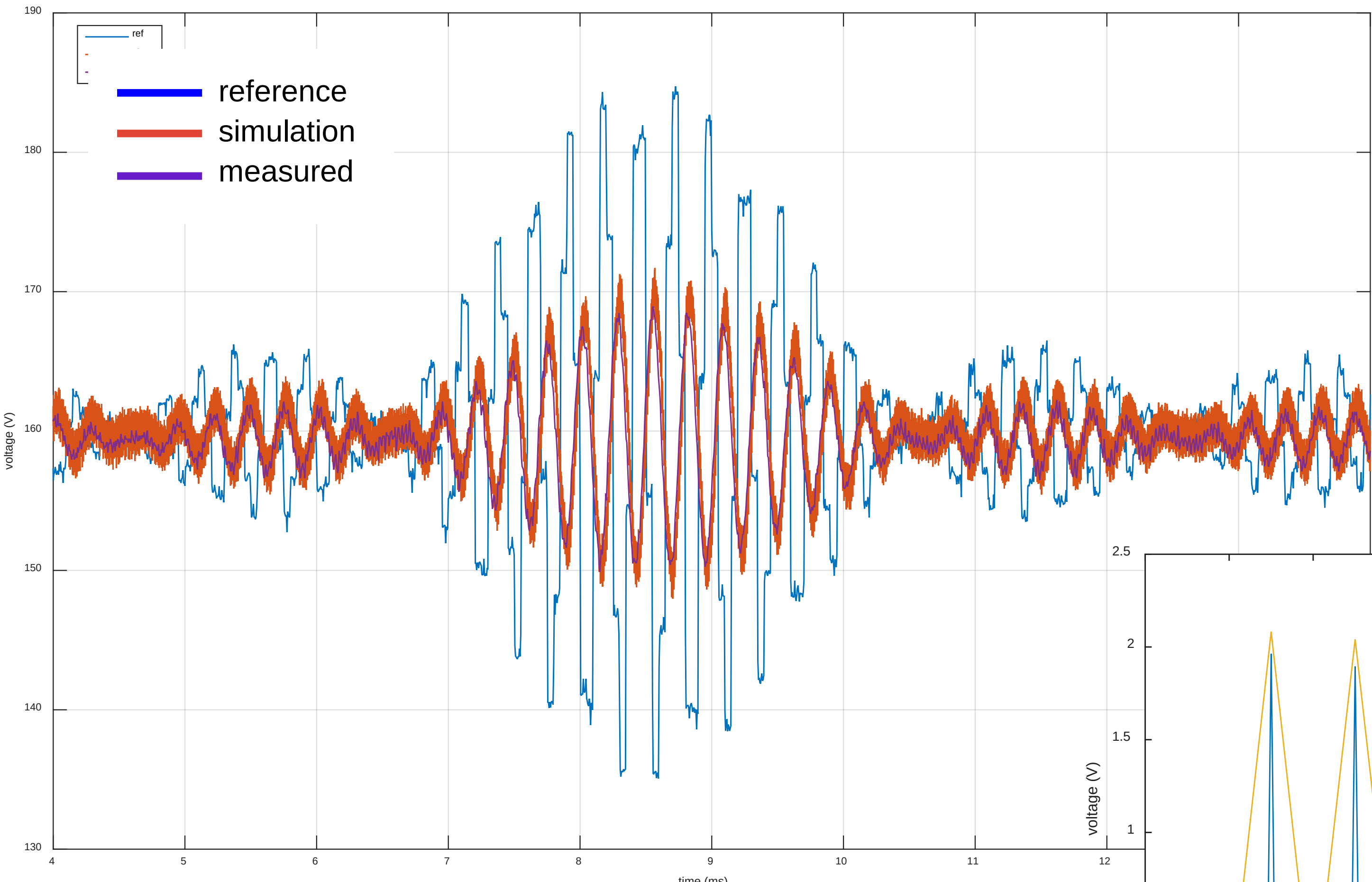
Example Response: DC Ramp



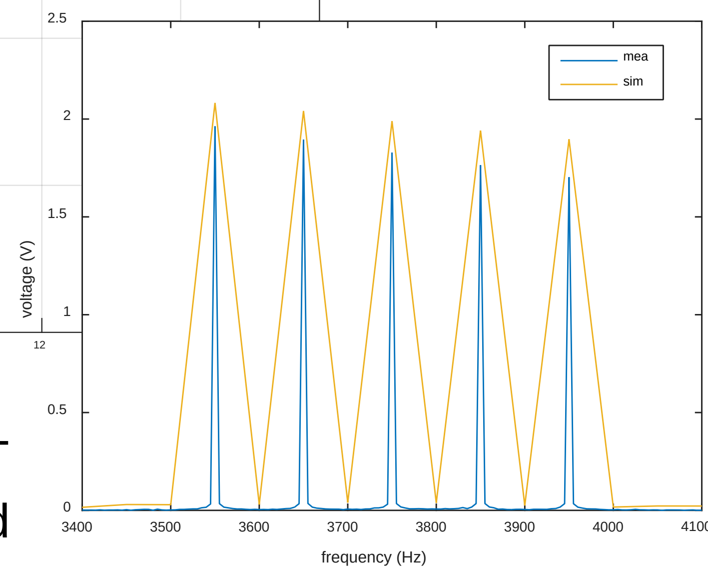
DC ramps

Same voltage reference for laboratory testing and simulation

Example Response: DC with Oscillations

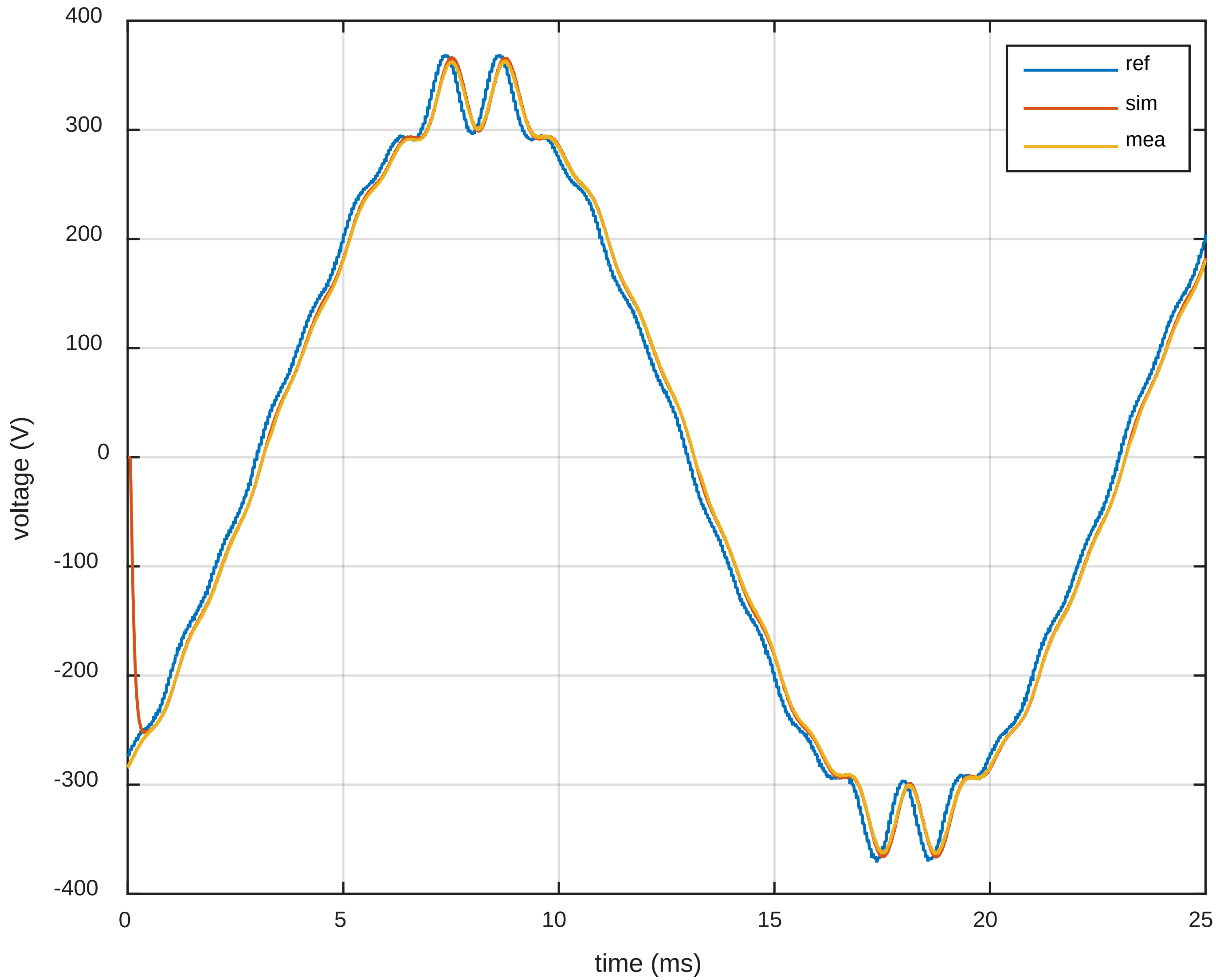


Added oscillations to DC offset



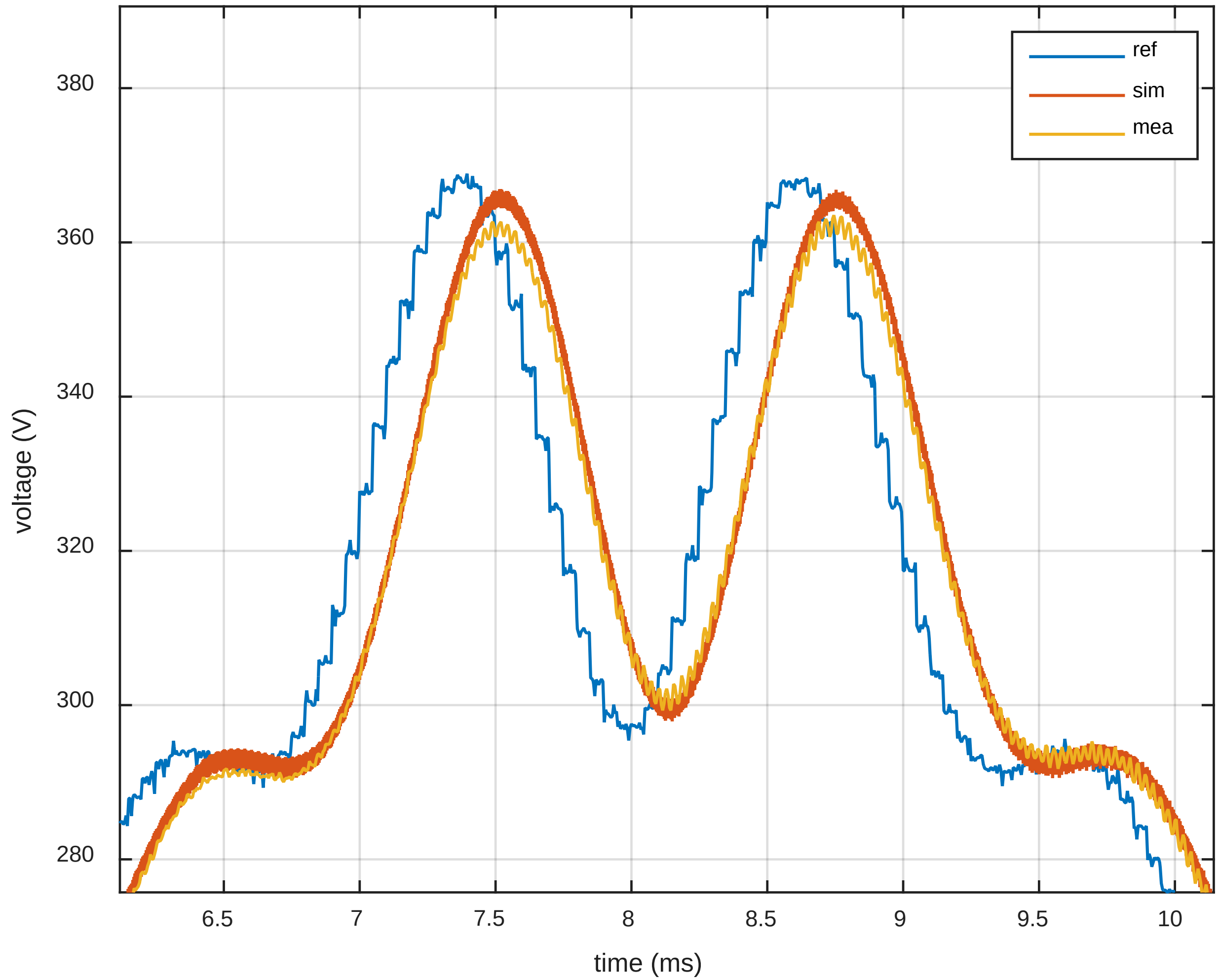
Comparing measured FFT with simulated

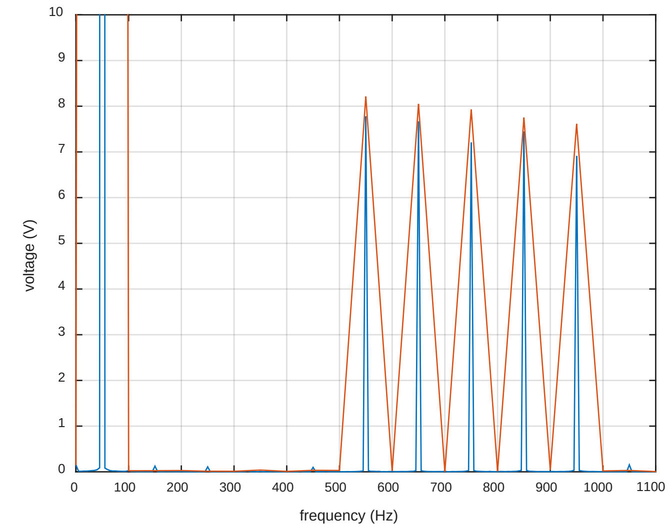
Example Response AC

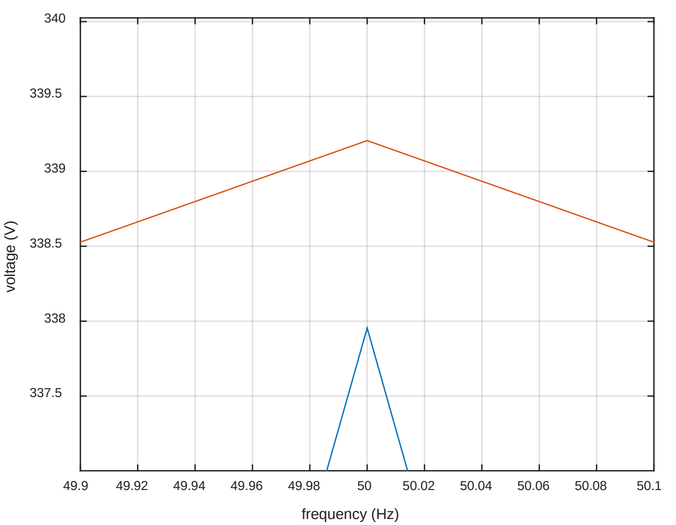


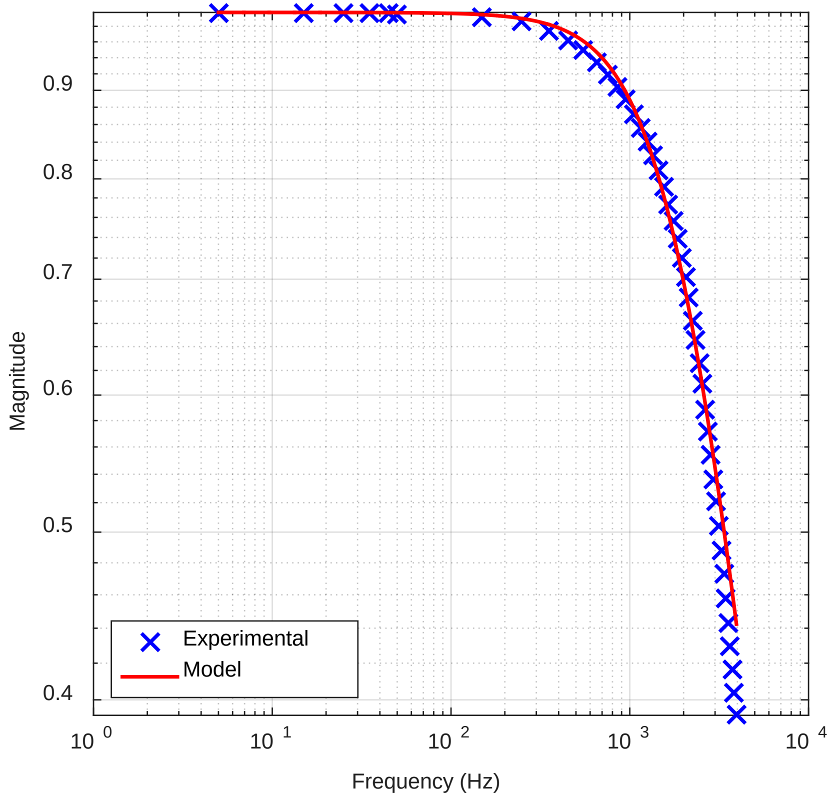
AC fundamental + harmonics

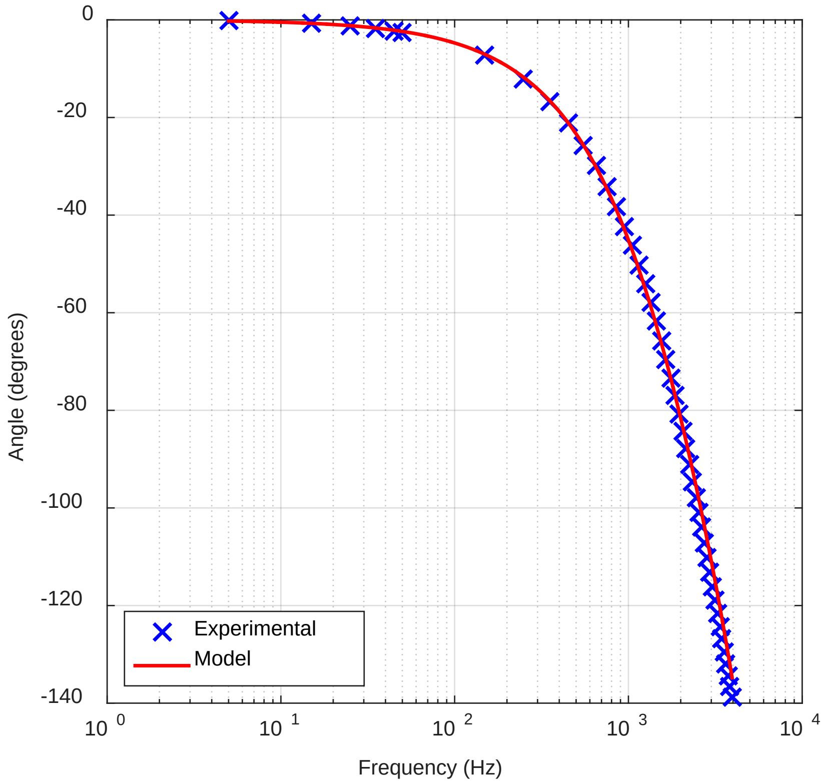
Example Response AC









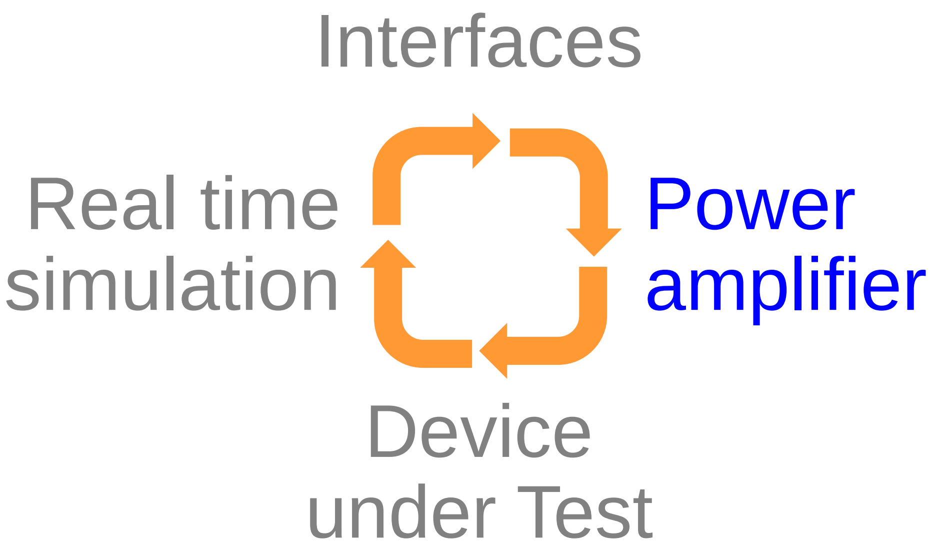


DC 200 V Mode
5.1 Ohm, Y-connected Load
0.8 pu Voltage Magnitude
(Group 22)

$$\frac{V_{out}}{V_{ref}} = \frac{G}{\frac{s}{2\pi f_p} + 1} e^{-sT_{del}}$$

G = 0.998
f_p = 1950 Hz
T_{del} = 50 us

Summary



This project:

Characterizes amplifier

Model building and validation

Future application:

Power Hardware-in-the-Loop Testing

Experiment design: predict stability and accuracy

NREL Energy System Integration Facility

Amplifier is base building block of grid simulator based testing