U.S. DEPARTMENT OF ENERGY

unifi consortium

universal interoperability for grid-forming inverters

Integration and Validation

Presented by: Abraham Ellis and Jack Flicker, Sandia National Laboratories

Organization

unifi consortium

Leadership

Establish management & governance structure to support sustained US leadership in GFM tech

Develop/Update Interoperability Guidelines and Functional Requirements

Advisory Board

SETO + WETO + OE
Industry + Academia
ESIG + GPST

Thrusts

Research & Development

- Advance R&D for GFM technologies
- Ensure a coherent & comprehensive portfolio of solution sets
- Integrate & evaluate new capabilities, products, & processes

Demos & Commercialization

- Provide guidance & transition R&D to commercial products and applications
- Demonstrate solutions that showcase multi-vendor interoperability
- Bring together public+private entities

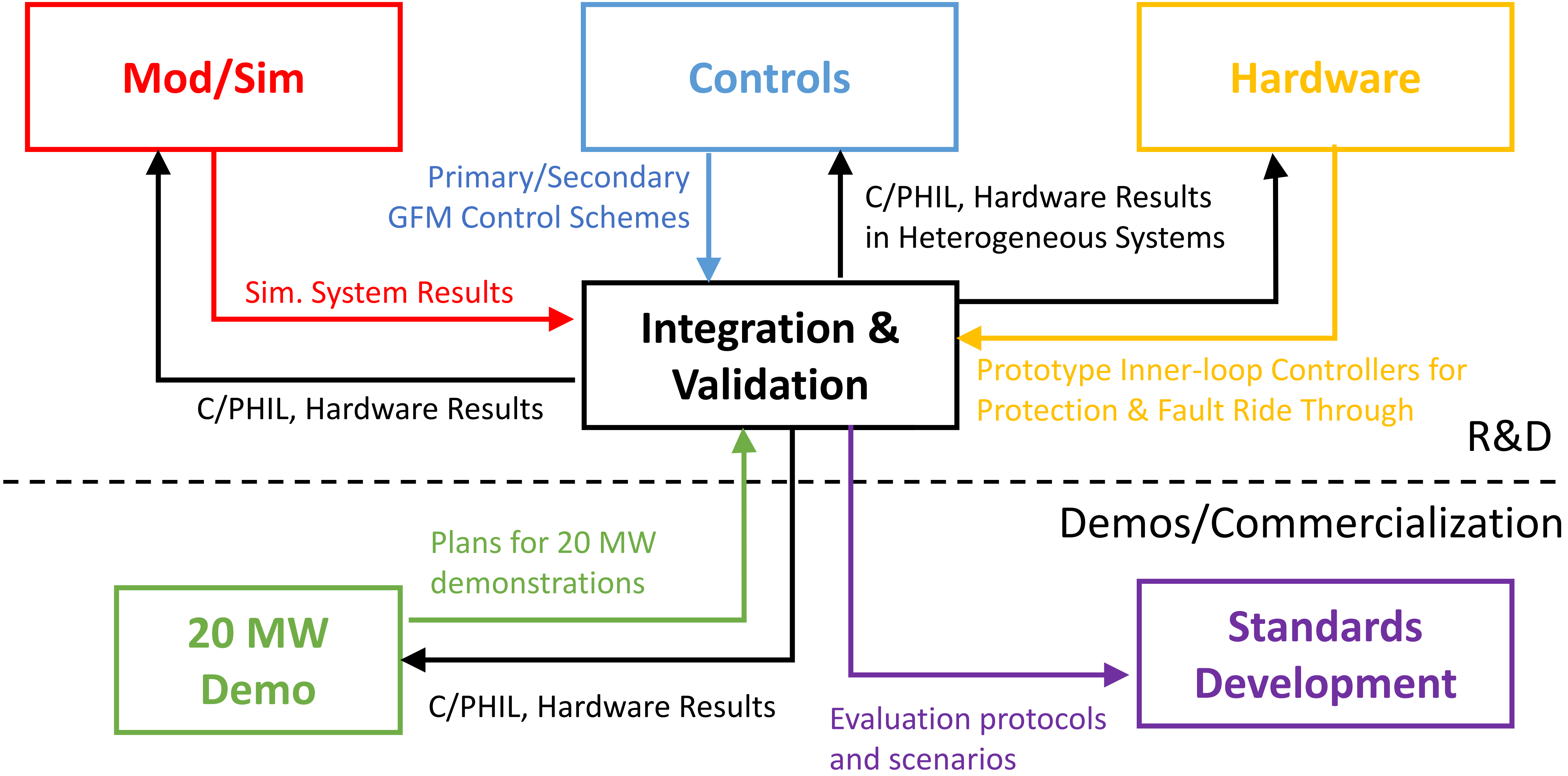
Outreach & Training

- Develop expertise, networks, & training
- Communication & dissemination strategies
- Engage community at all levels of supply chain
- Build awareness of issues, & create alignment amongst stakeholders

Areas

Research & Development		Demos & Commercialization		Outreach & Training	
Modeling & Simulation	Hardware	IP management	Domestic Products	Education	Workforce Development
Controls	Integration & Validation	Standards	Field Demonstration	Communication	Events

Integration and Validation -- Focus

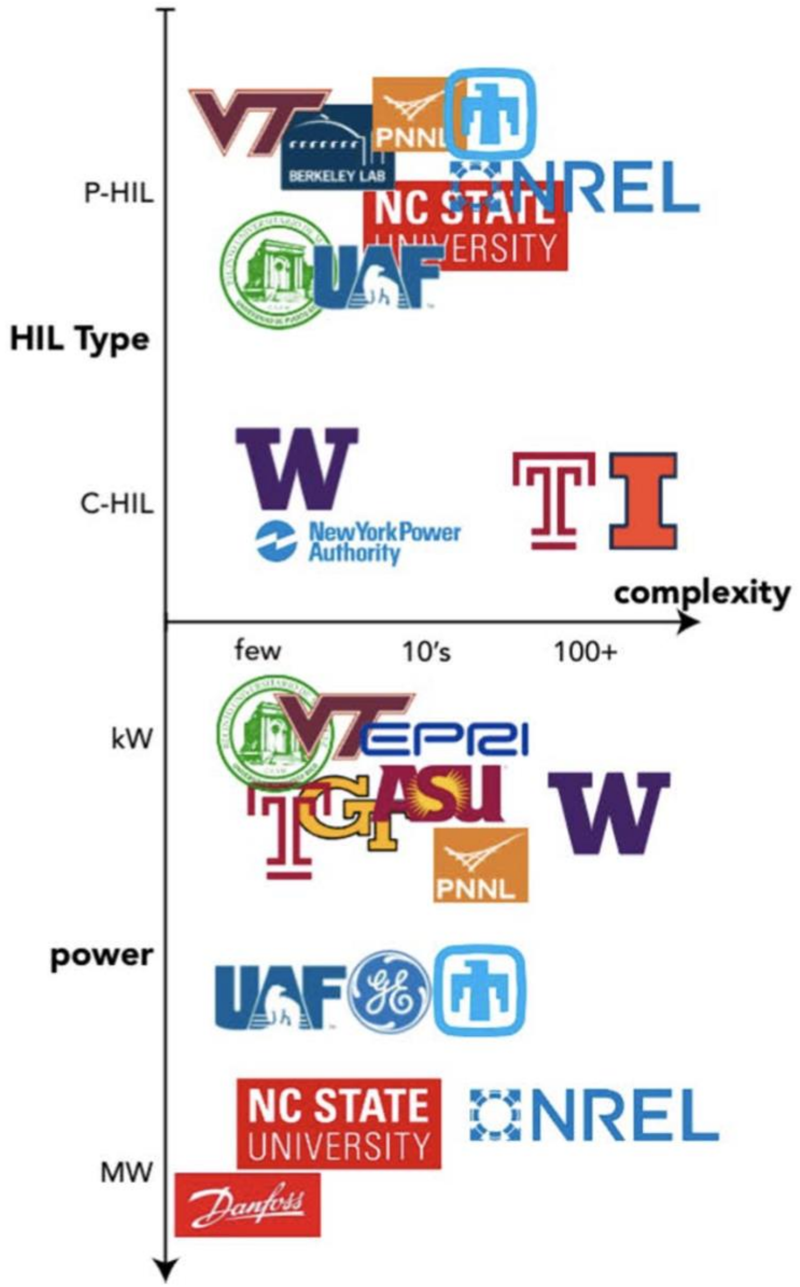


Integration and Validation – Scope

1. **Testing infrastructure and IBR baseline characterization**
   - Develop and document experimental capabilities for unit and systems-level characterization GFM
   - Baseline capabilities of current GFM devices – complement modeling, controls and hardware areas

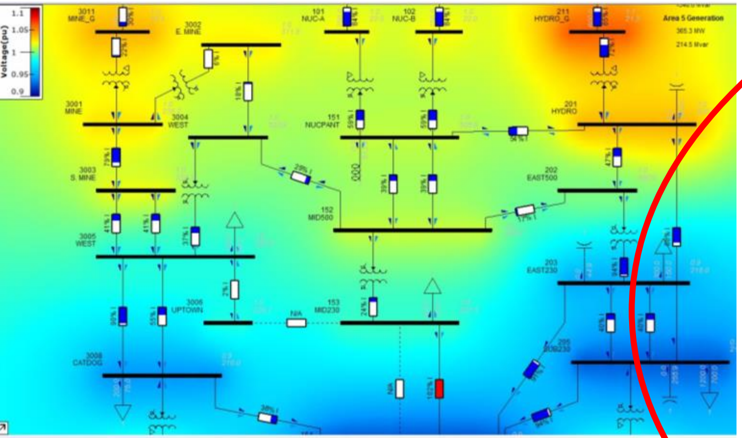
2. **GFM IBRs in representative power systems**
   - Evaluating R&D work product and quantifying improvements over baseline

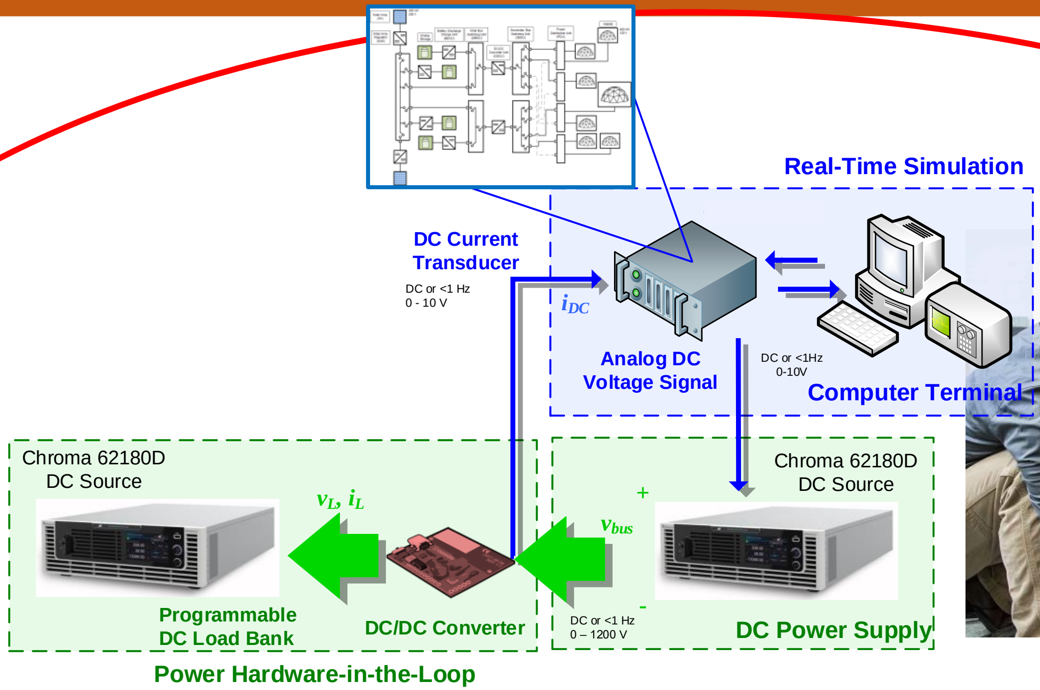
3. 1**+MW scale multi-vendor experiments**
   - Hardware demonstration for heterogeneous systems



I. Testing Infrastructure and IBR baseline characterization

Flexibility & Scalability





Pure Simulation

Extended system representation

Controller HIL

High fidelity control systems

Power HIL

High fidelity Unit Response

Pure Hardware

Nonlinear interactions

CHIL, PHIL, and Hardware evaluation of GFM in systems:

- Mixtures of GFM, GFL, rotating machines
- Normal operating conditions
- Contingency conditions (fault, blackstart)

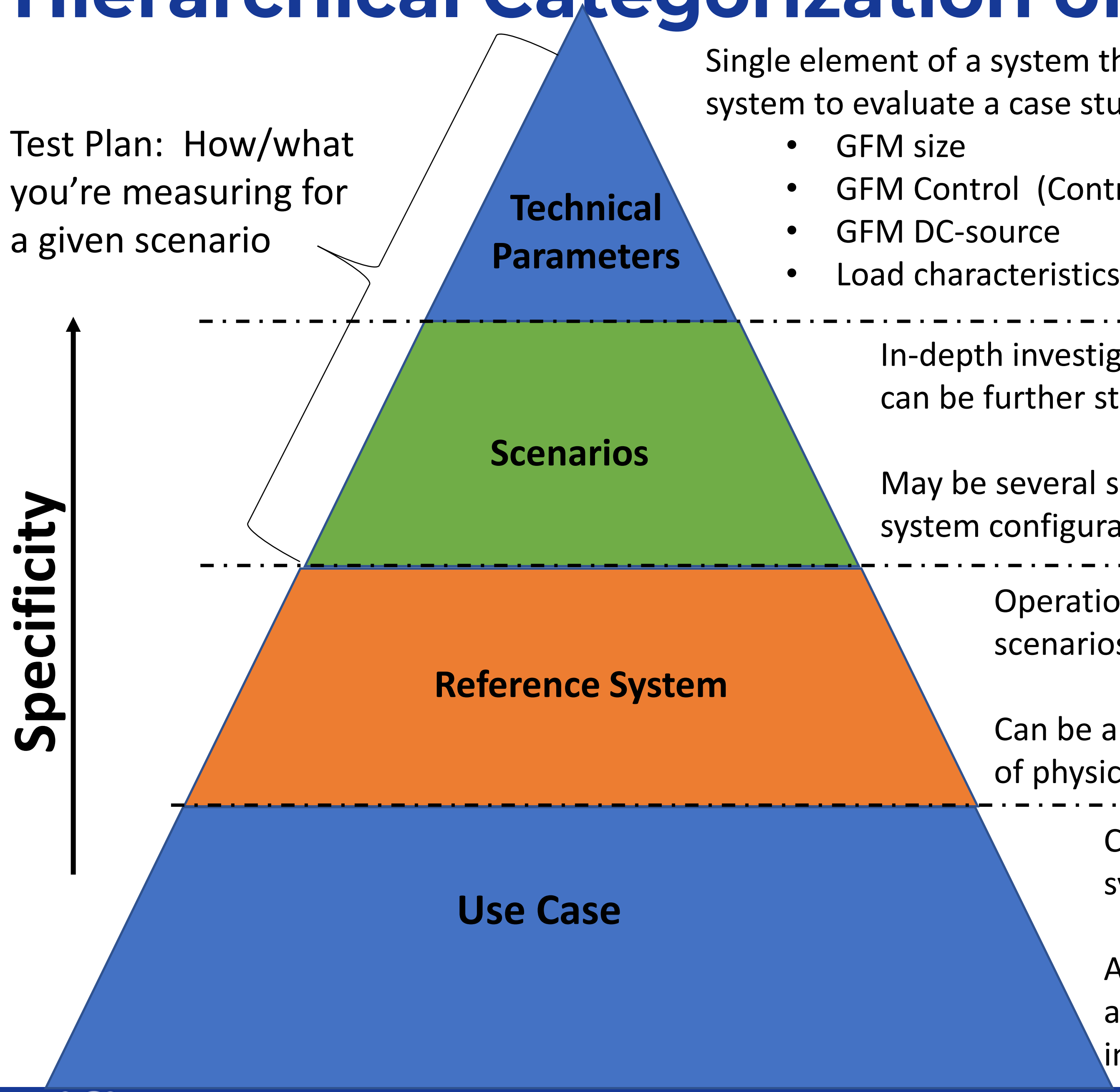
Fidelity

2. Integration of GFM into Power Systems

- **Develop testing protocols and scenarios for UNIFI Interoperability Guidelines and Functional Requirements**
  - Criteria for evaluating single units, aggregations of units, and heterogeneous systems
  - Specifications necessary for GFM IBRs to ensure seamless interoperability with the power system

- **Apply testing protocols to evaluate models and hardware/control prototypes produced by the other R&D Areas, or provided by industry partners**
  - Quantify the impact of GFM behavior in heterogenous systems
  - Consider both normal and contingency conditions over all time-scales
  - Evaluate Consortium proposed interoperability behaviors
  - Evaluate R&D products from across the Consortium

Hierarchical Categorization of GFM Use



Single element of a system that can be measured, varied, or incorporated into a reference system to evaluate a case study.

- GFM size
- GFM Control (Control type, droop offset/slope, etc)
- GFM DC-source
- Load characteristics (power factor, THD, machine/resistive/electronic composition)

In-depth investigation of specific phenomena or capability a reference system that can be further studied

May be several specific case studies for each use case, demonstrating the varying system configurations, challenges, and benefits.

Operational systems (real or simulated) that can be evaluated for different scenarios/operation modes/asset mixes, etc.

Can be analyzed entirely simulated environment, in the lab with combination of physical hardware and simulation, or in a deployed system

Concept in system analysis to broadly identify, clarify, and organize system requirements

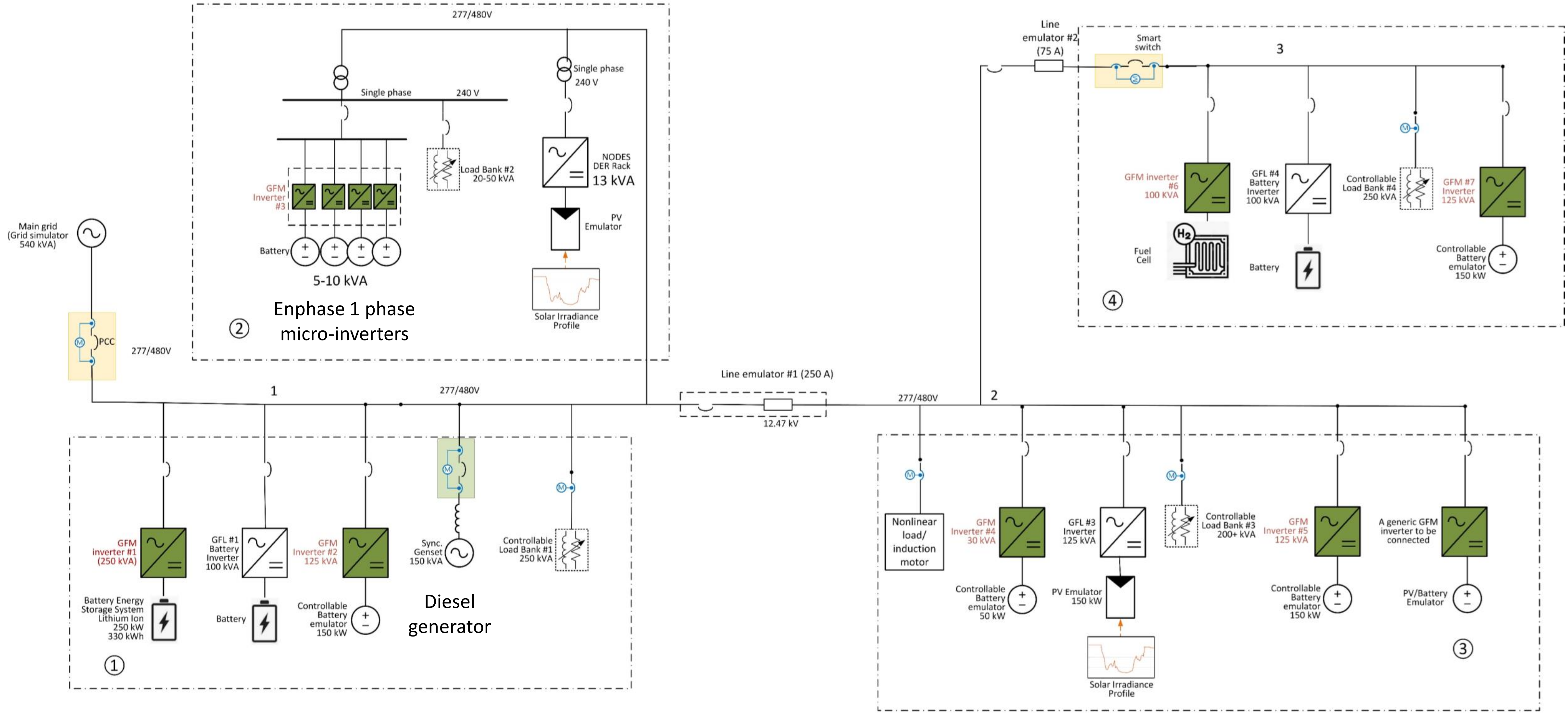
Apply innovations developed through the project to such systems to assess their value or to demonstrate their readiness for use by industry in commercially deployed systems.

3: 1MW Hardware Demo

1 MW Experiment – at NREL in Year 3

- Includes various physical sizes (250W-1MW)
- Three-phase, single-phase generation & loads
  - GFM, GFL, & synchronous machines
  - Comms interfaces (2030.5, SunSpec)
- Multiple source-side resources (PV, energy storage, wind (if possible))
- Coupled to PHIL to evaluate scales: 1MW microgrid to larger grids
- 50%, 75%, 90%, and 100% power contribution from GFM IBRs
- Network connections (LV and MV, overhead and conductors)
- Explore options to distribute demonstration amongst capabilities in multiple partner labs (ex. Via Real Time Simulation)
- Illustrate the *Interoperability Guidelines* at work with multiple vendors and wide variety of functionalities

1MW Demonstration



LEGEND

Metering capability point – includes both voltage and current measurements

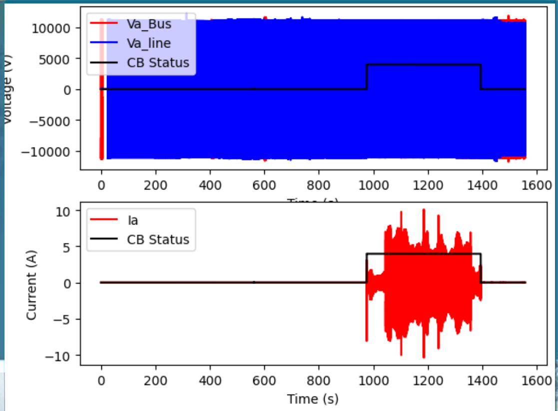
GFM inverter

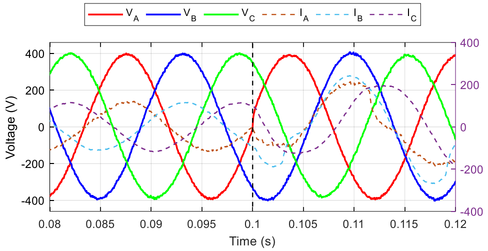
7 GFM inverters 760 kVA
4 GFL inverters 340 kVA
1 synchronous Machine 150kW
5 controllable loads

Preliminary Testing Capability for 1 MW demo

- Black start
- Loss of generation
- Phase unbalance
- Fault ride through
- Islanding (plan/unplanned) and reconnection
- Large inductive load
- GFL + GFM + rotating machine at various penetration
- Mix of three-phase and single-phase load
- Frequency regulation (secondary control)
- Voltage regulation (secondary control)
- Overload (individual GFM inverter)

Grid Forming Inverter Hardware in Loop Evaluation





Jack Flicker, Rachid Darbali, Javier Hernandez, Matt Reno, Felipe Palacios, Nick Gurule

UNIFI Seminar

May 02, 2022

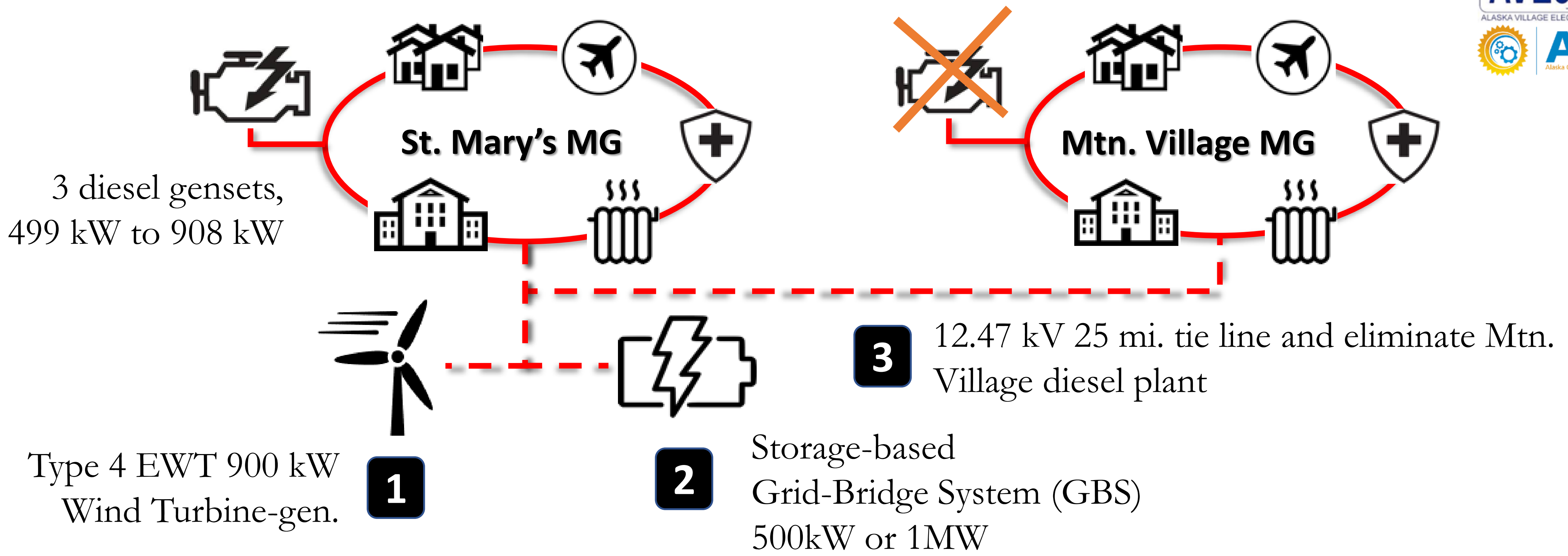
Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Case Study: GFM for Alaska Villages

GFM HIL Case Study: GFM for spinning reserve



Goal:

1. Evaluate ability of GBS to reduce spinning reserve need of diesel
2. Compare 500 kW and 1MW sizes
3. Quantify power quality differences between diesel bank and diesel + GFM during contingencies

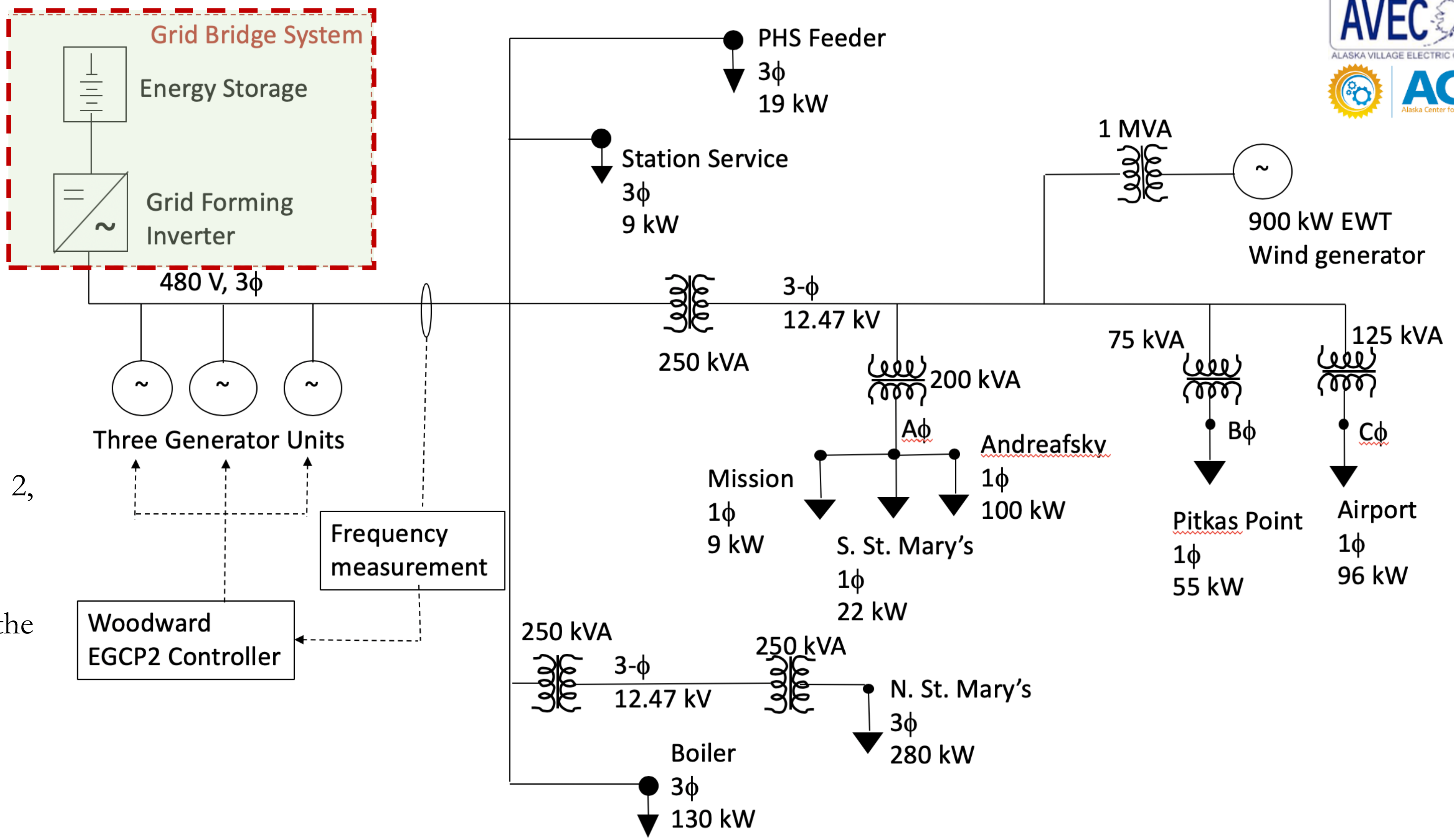
GFM HIL Case Study: GFM for spinning reserve

Lab Hardware

- 100 kW GFM
- NHR Battery Emulator
- 180 kW grid simulator
- Scaled to emulate 1 MW GBS

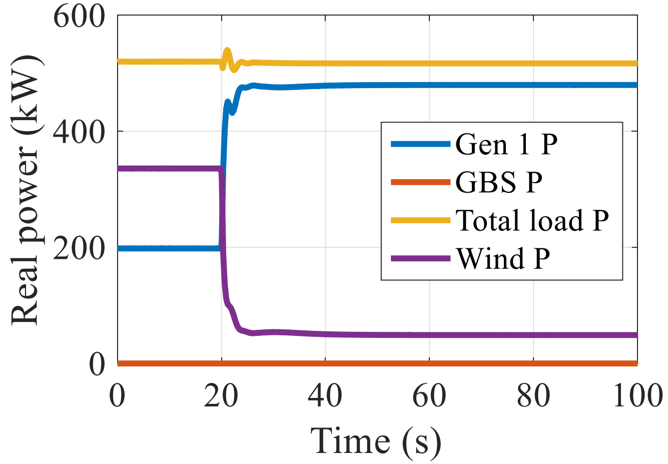
- Loss-of wind scenario with 1, 2, and 3, generators online

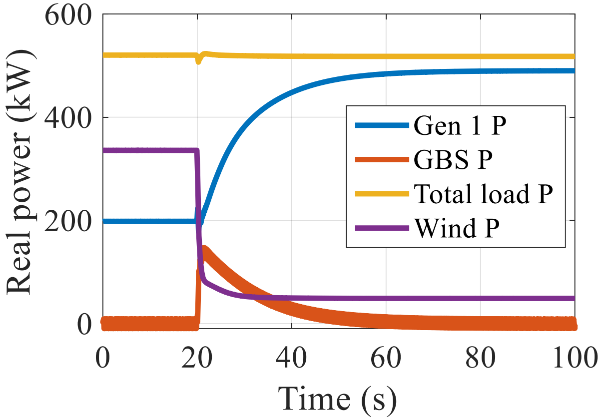
- Evaluating power quality in the system (Δf, ΔV, gov. response)

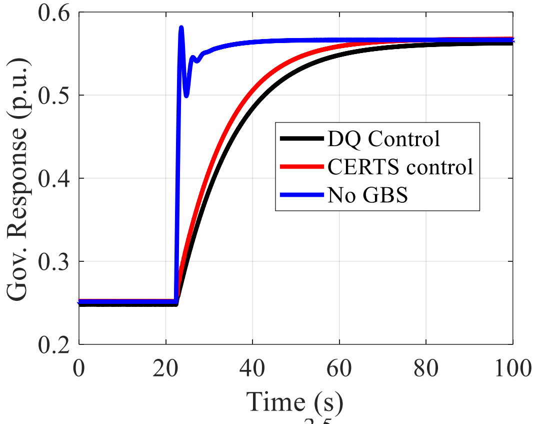


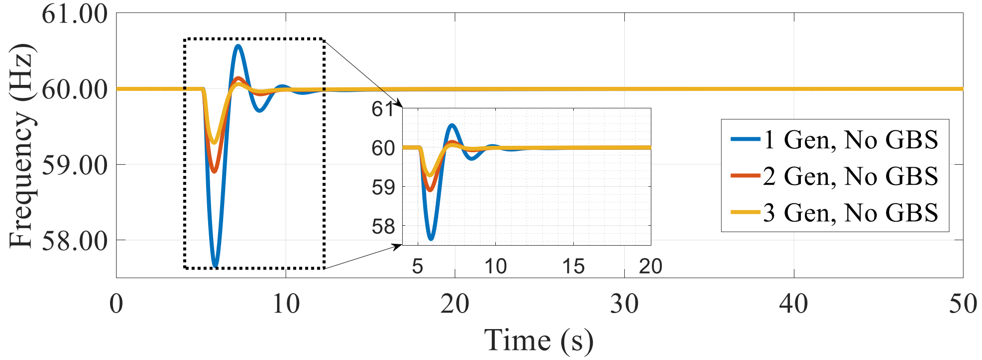
Flicker, Jack, Javier Hernandez-Alvidrez, Mariko Shirazi, Jeremy Vandermeer, and William Thomson. "Grid Forming Inverters for Spinning Reserve in Hybrid Diesel Microgrids." In *2020 IEEE Power & Energy Society General Meeting (PESGM)*, pp. 1-5. IEEE, 2020.

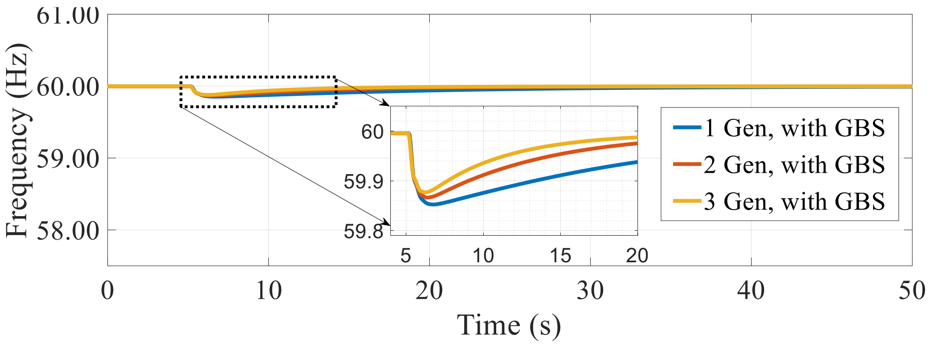
GFM HIL Case Study: GFM for spinning reserve

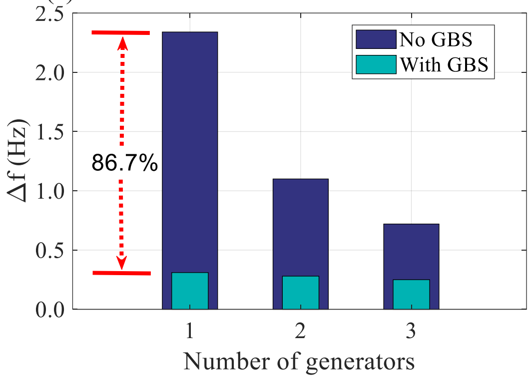


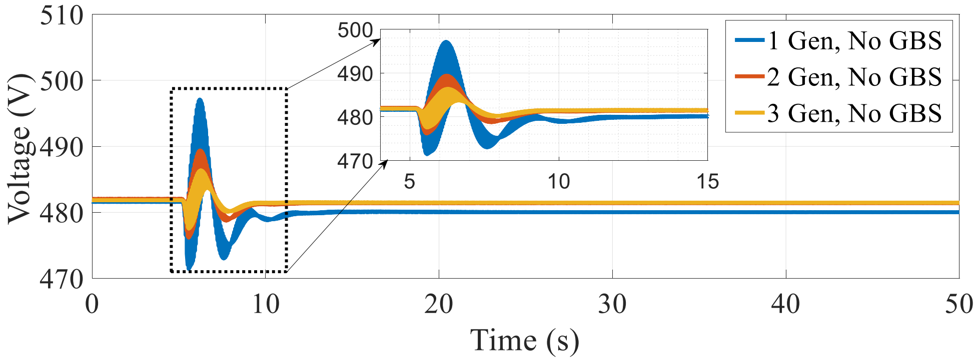


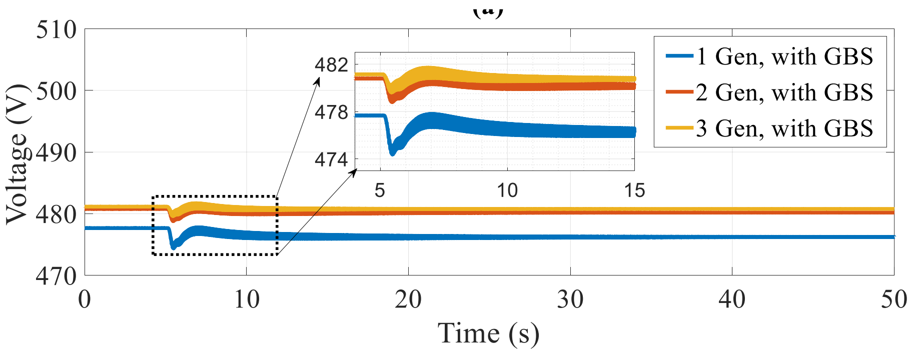


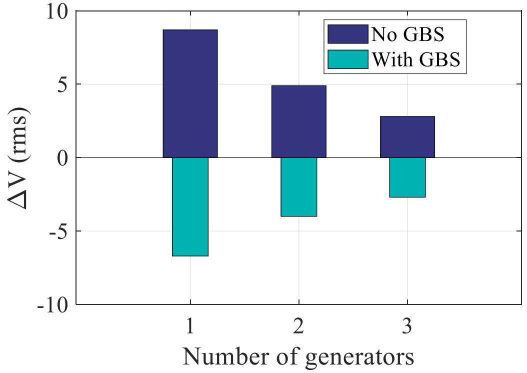






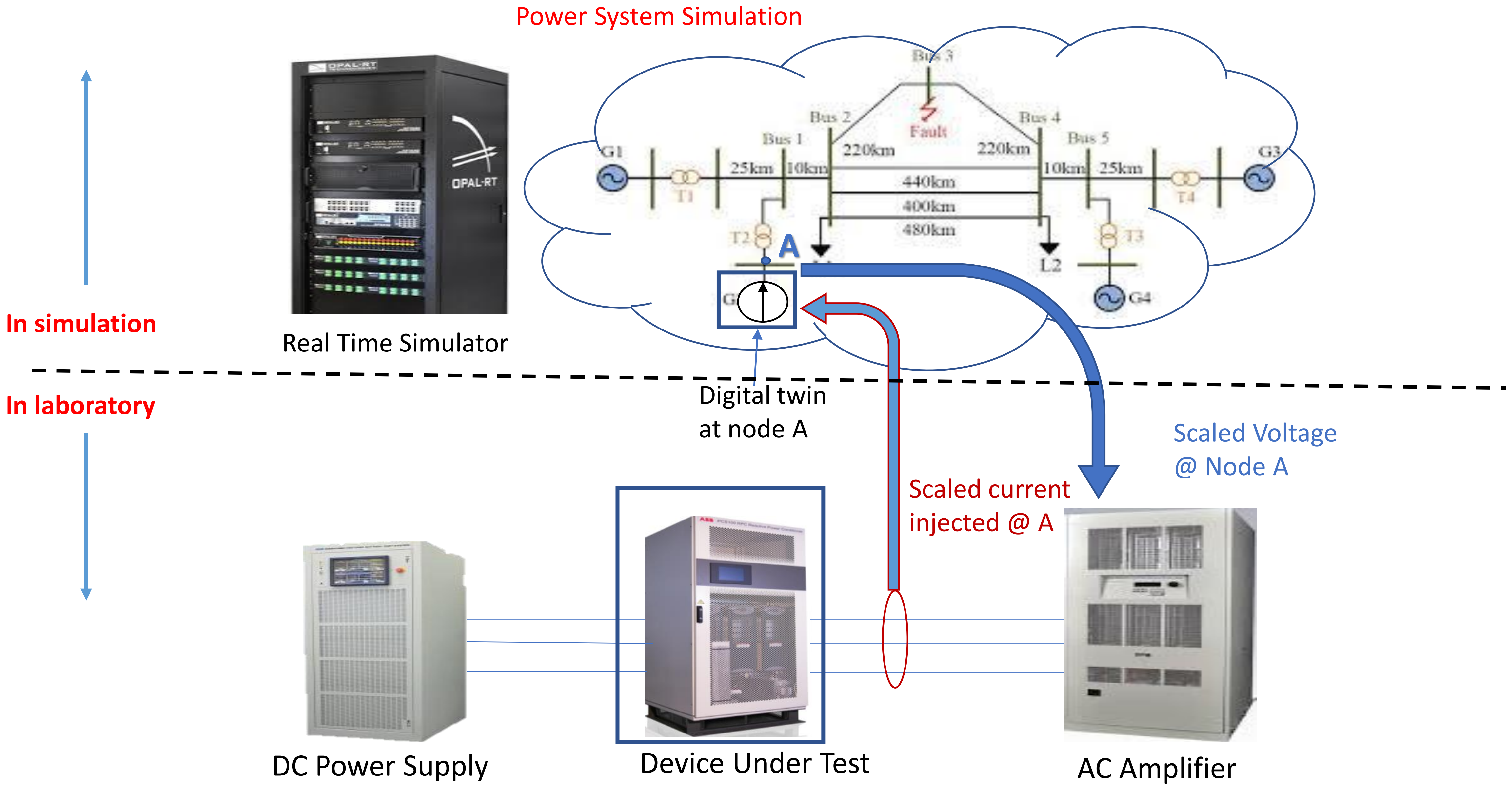




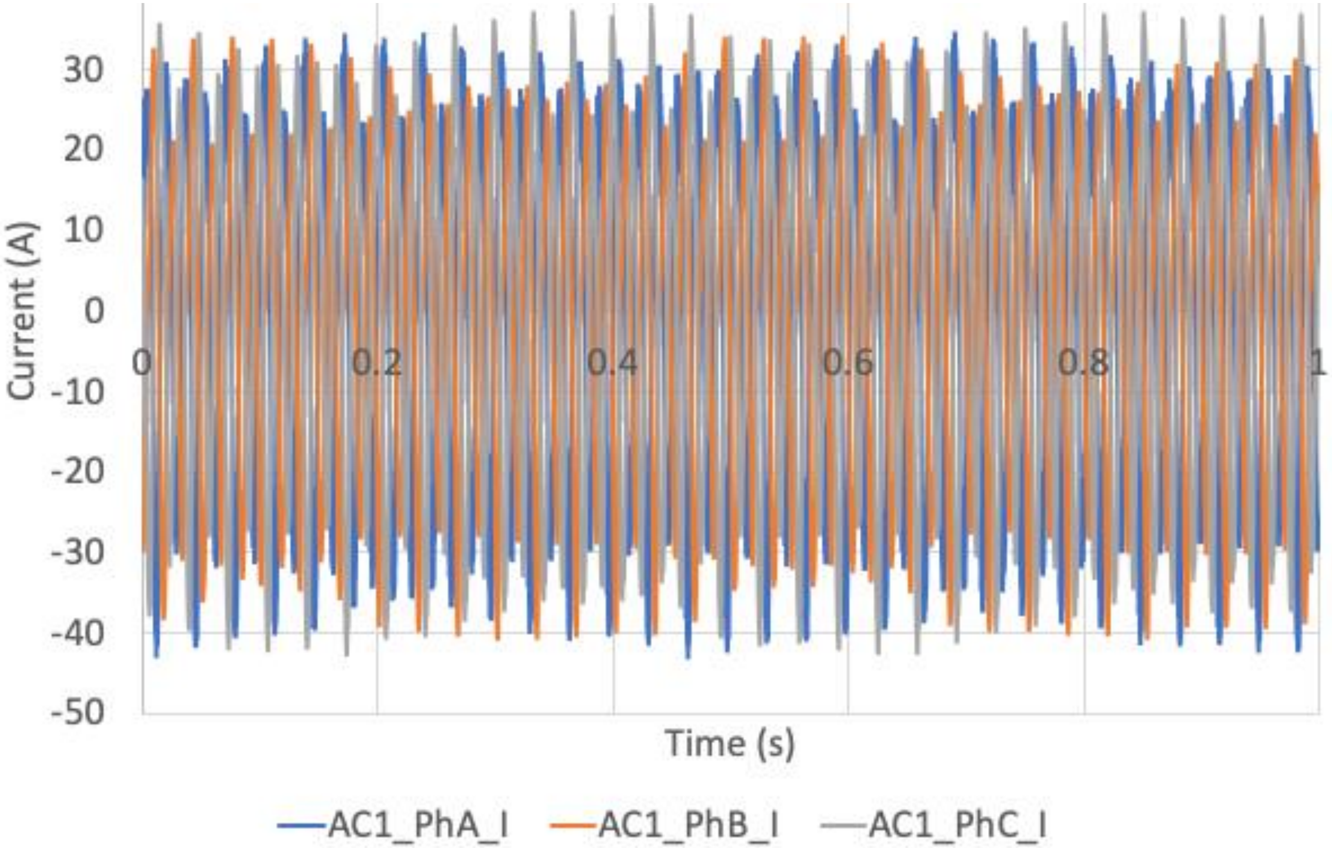


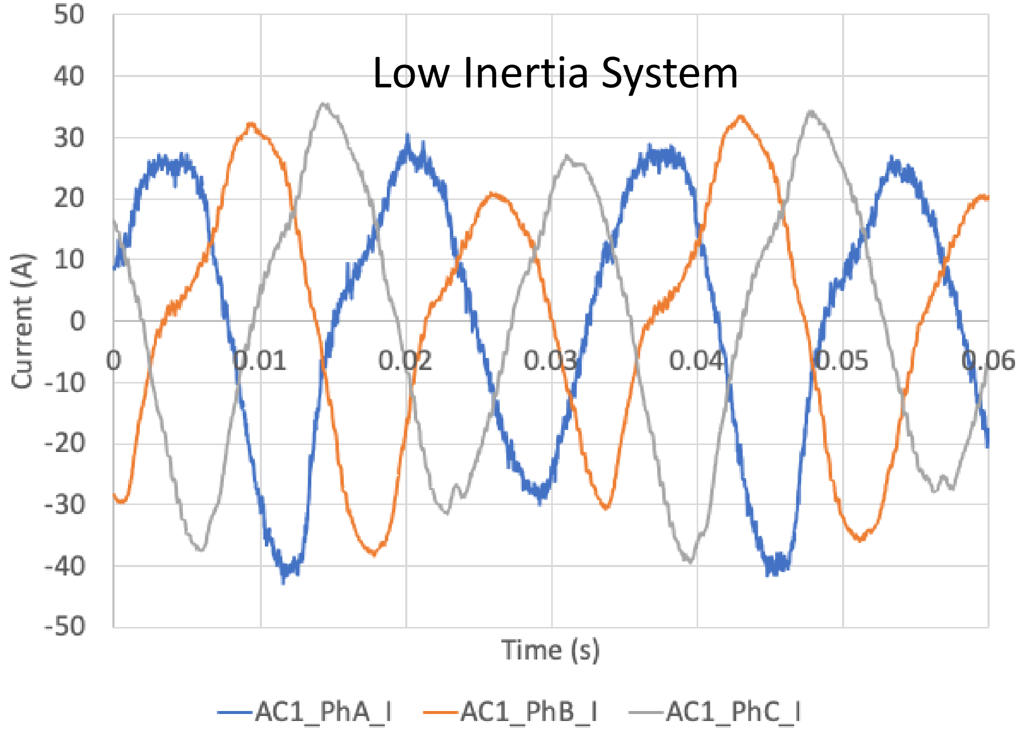
J. Hernandez-Alvidrez, R. Darbali-Zamora, J. D. Flicker, M. Shirazi and W. Thompson; "Using Energy Storage-Based Grid Forming Inverters for Operational Reserve in Hybrid Diesel Microgrids", MDPI-Energies, Special Issue: Smart Grids and Microgrids, pp 1-20, April 19, 2022.

Power Hardware in Loop of GFM



P-HIL testing of GFM can result in instability

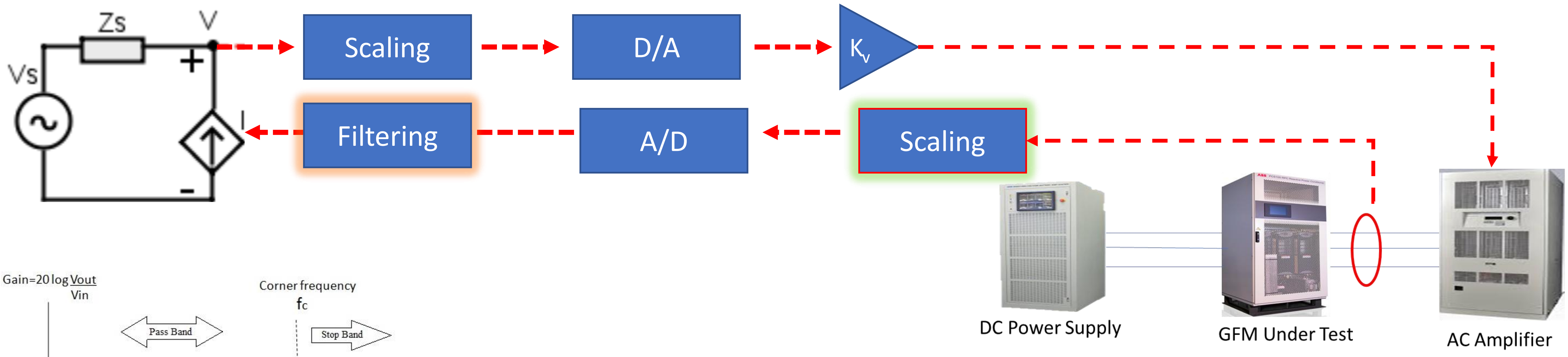


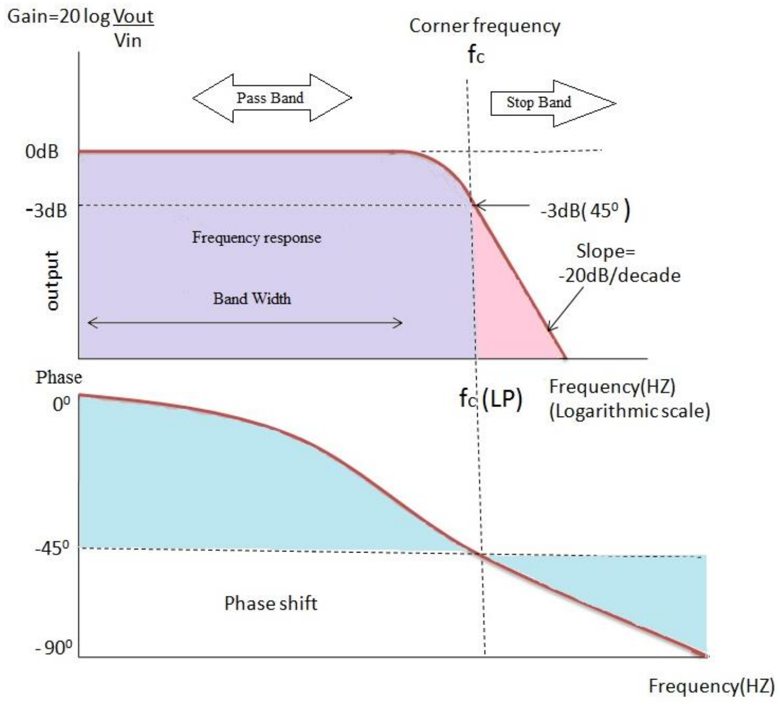


- Highly distorted waveform in low inertia systems
  - Noise Amplification
    - electromagnetic coupling of the devices
    - physical wiring
    - measurement sensors
  - Quantification Error
  - Magnetization current from internal transformer
  - Calibration

Filtering is needed to maintain stability

Real Time Simulation

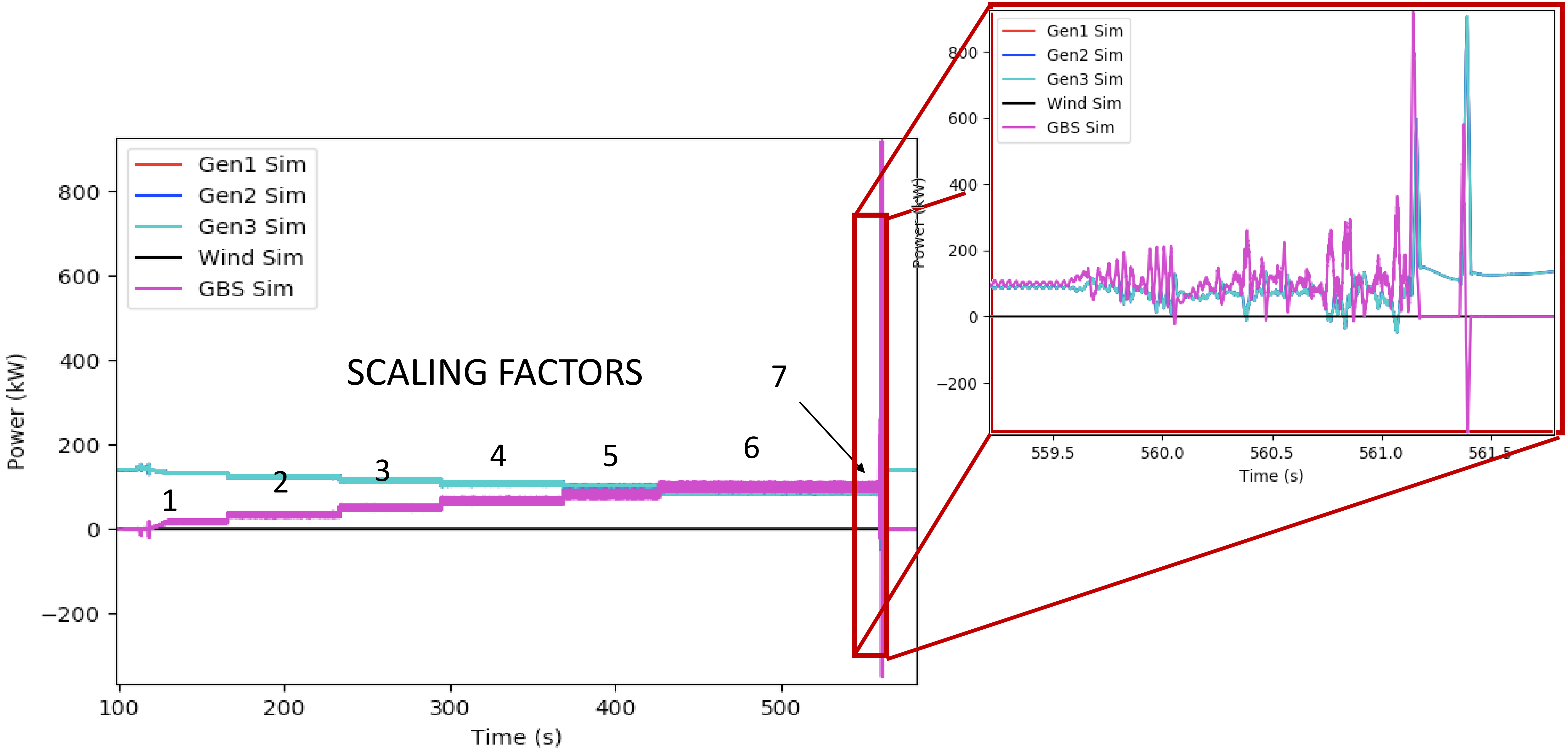




- Typical in HIL to use 1st order Low Pass Filter (LPF)
  - Simple, reliable, low computational overhead
  - Introduces ***phase shift*** and reactive power injection into the RT-simulation, can lead to instability
  - Requires **Lead Compensator**
  - Works well in **GFL** HIL testing

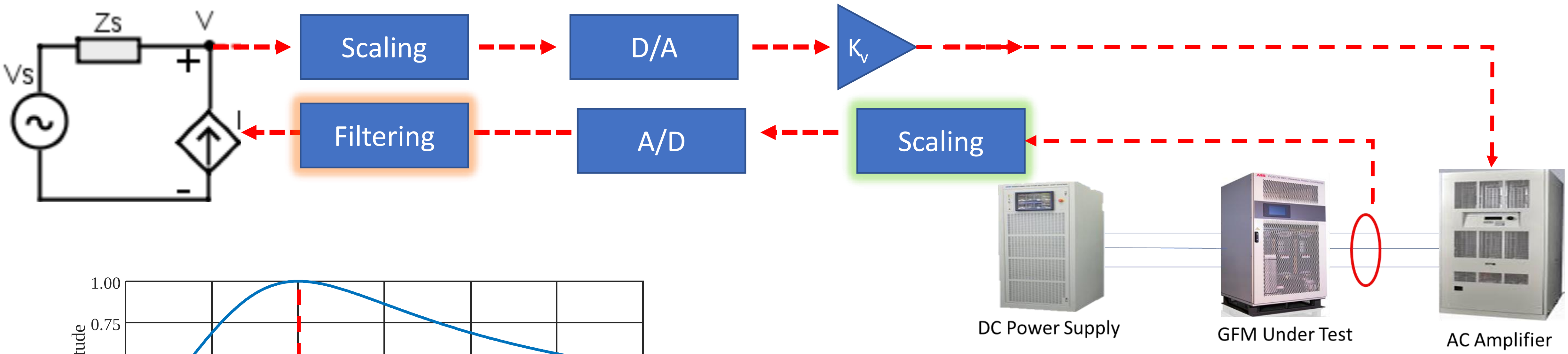
A. Summers, J. Hernandez-Alvidrez, R. Darbali-Zamora, M. Reno, J. Johnson, and N. Gurule, *Comparison of Ideal Transformer Method and Damping Impedance Method for PV Power-Hardware-In-The-Loop Experiments*. 2019.

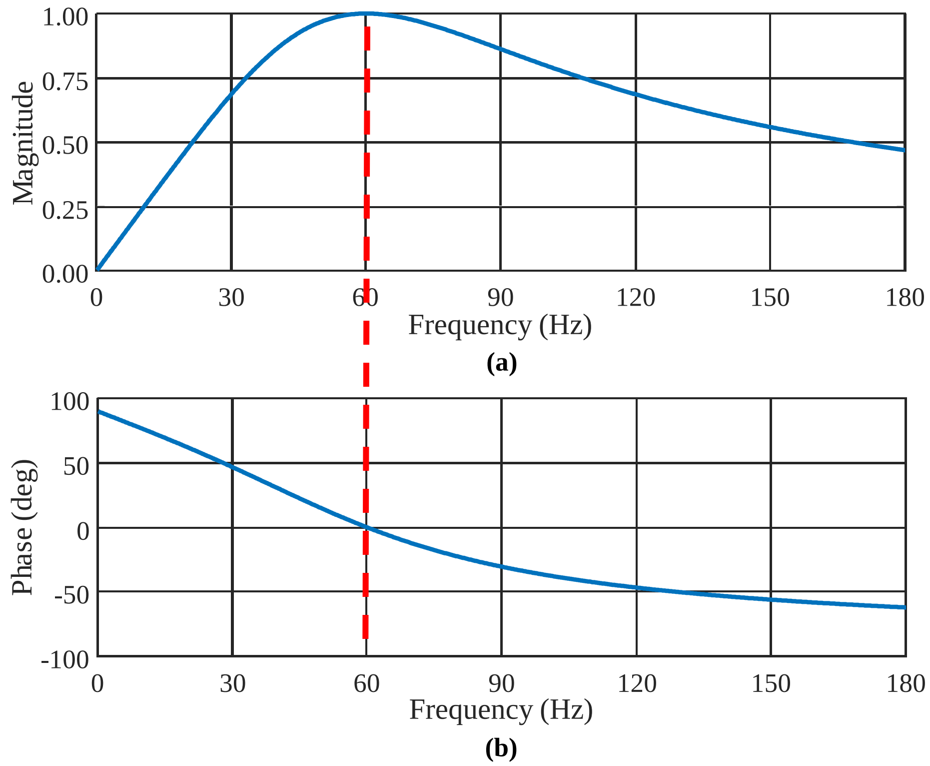
P-HIL testing of GFM can result in instability



Filtering is needed to maintain stability

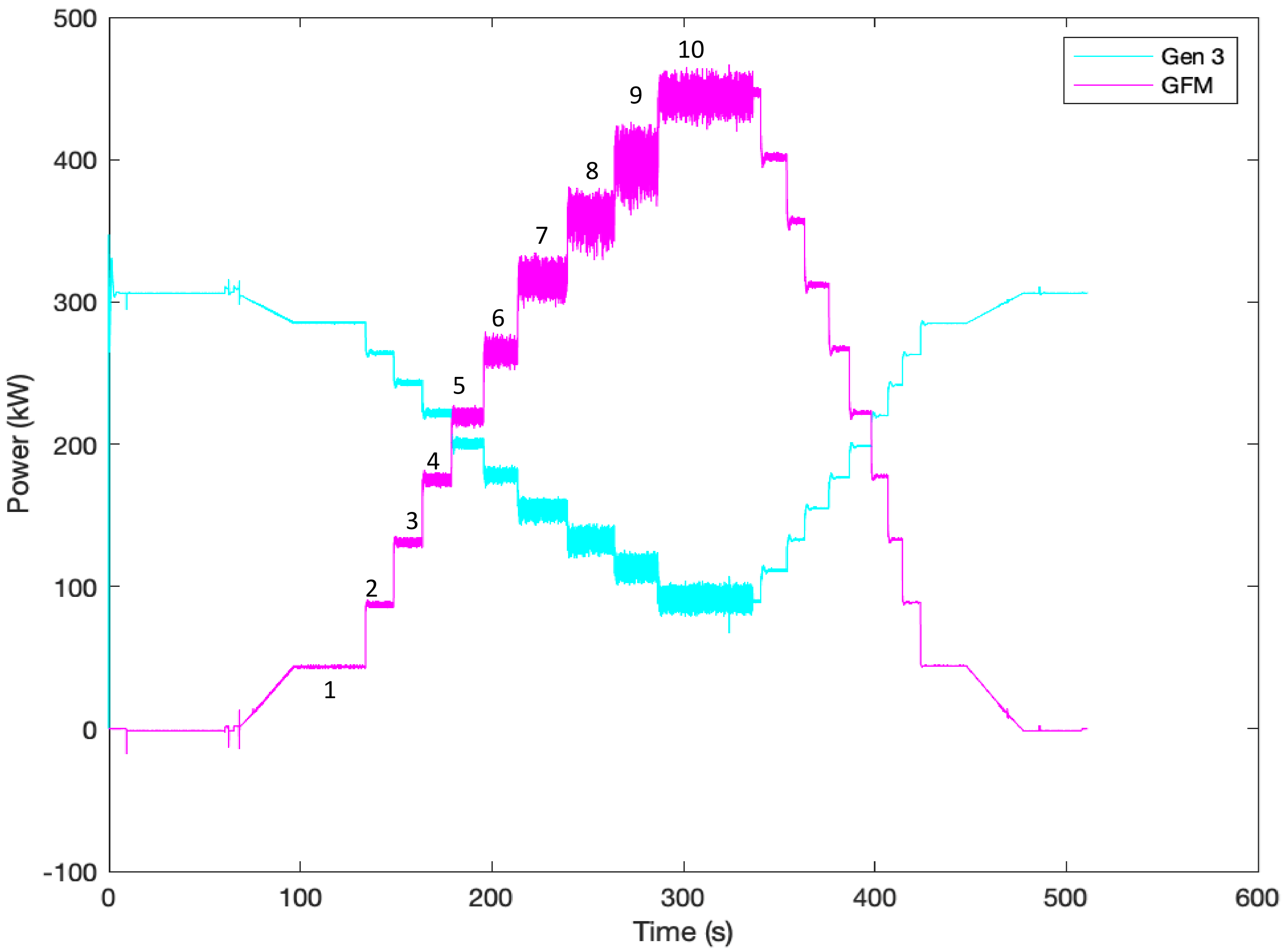
Real Time Simulation





- Using 2nd order bandpass filter for GFM
  - Centered around 60 Hz
  - No phase delay at center frequency, No lead compensator required

Filtering is needed to maintain stability



Thank you