SAND2019-15353PE

Grid-bridging Inverter Application at St. Mary’s/Mountain Village Microgrid Systems

COLLABORATORS

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Project Partners

Project Start: Feb 2018
Continued through FY19

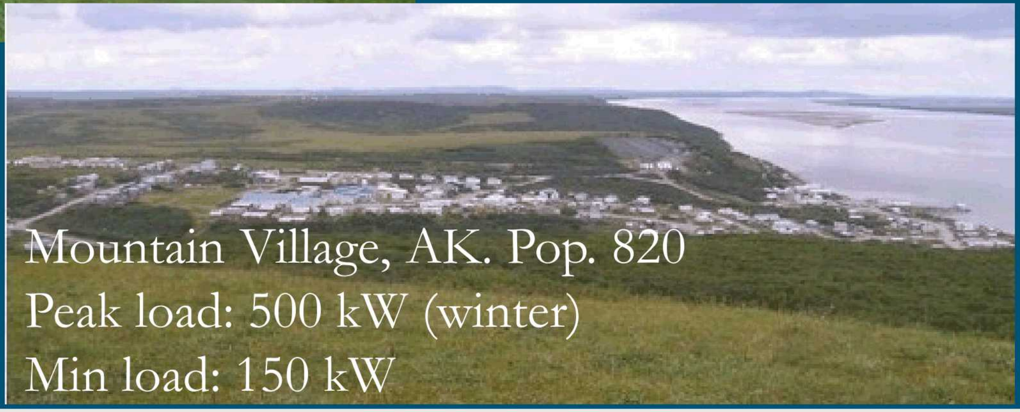
Alaska Village Electric Cooperative (AVEC)

- Provides electricity to members in 58 communities
  - >40% of Alaska village population
  - Village sizes from ~100 to ~1,000 customers (100 kW to 3 MW)
- None connected to a transmission grid
  - Power generated locally utilizing diesel electric generators
  - Wind (11) and solar power in a subset of communities
- Interested in replicating successful approaches microgrid systems
  - Reducing fuel consumption while increasing resiliency

Alaska Center for Energy and Power (Univ. of Alaska-Fairbanks)

- Power Systems Integration Lab
- On the same scale as a village power system
  - Emulates isolated hybrid-diesel grid at up to 500 kW
  - 480 VAC three-phase, up to 600A
  - Wind, diesel, and grid-forming emulators
  - Fault/contingency scenarios

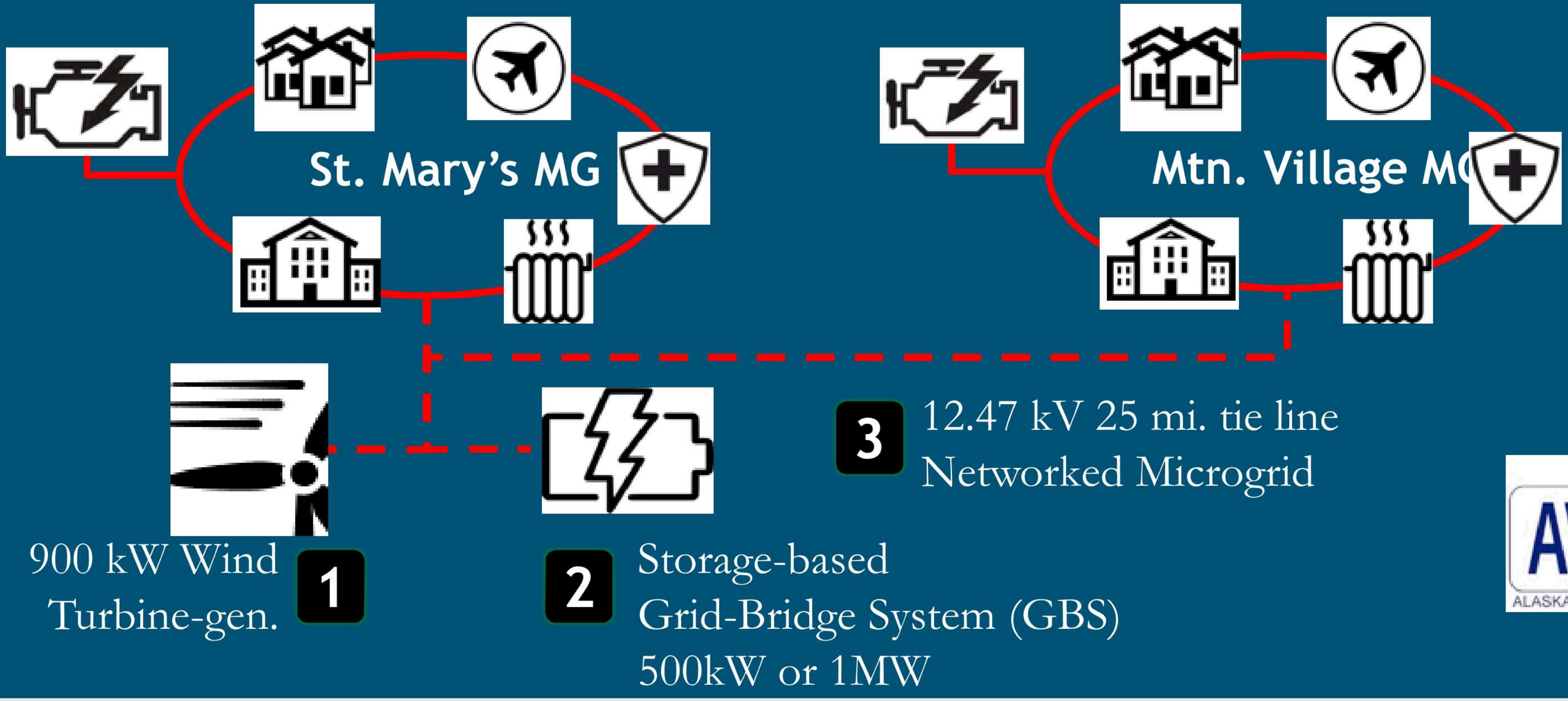
St. Mary's and Mountain Village, AK



Energy Resilience Challenge:

- Both villages are rural microgrids supplied by diesel gensets
- Diesel fuel shipped up Yukon River, impassable August-April
- Life threatening issues if diesel runs out during winter
  - Necessity for high reliability, low maintenance components
- High energy cost, >25% of average household income

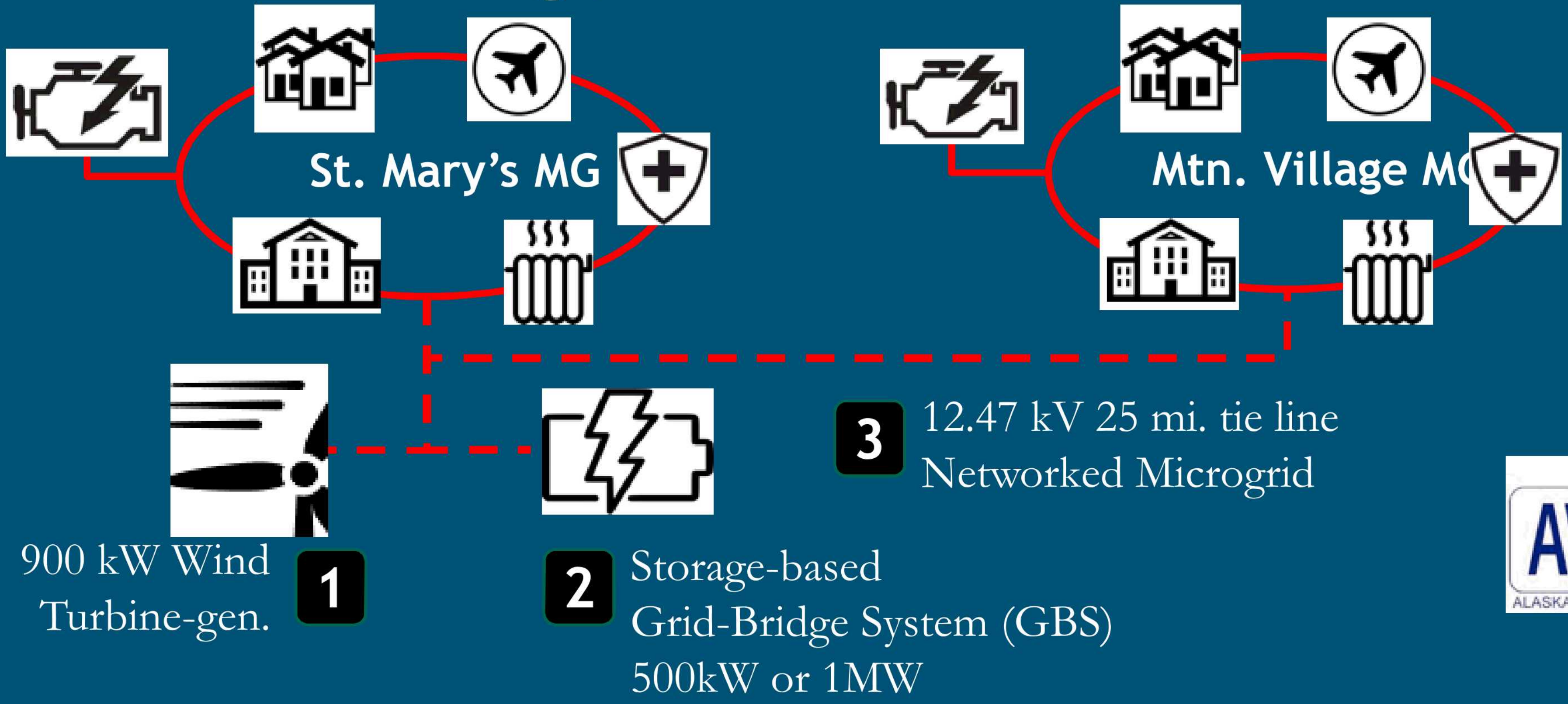
St. Mary’s and Mountain Village, AK



- Currently three diesel gensets (499 kW to 908 kW)
- Three-stage plan to lower costs and increase reliability and resilience

1. Wind turbine-generator to reduce fuel use (DOE/IA) — **Currently Operational**
    - EWT 900 kW Type IV pitch-controlled wind turbine generator
2. Storage-based grid bridge system (GBS) for spinning reserve (DOE/OE + DOD/ONR) — **Procurement Underway, est. Sept 2019**
3. Network St. Mary’s MG with Mountain Village MG via 12.47 kV tie-line — **Currently Commissioning**

St. Mary's and Mountain Village, AK



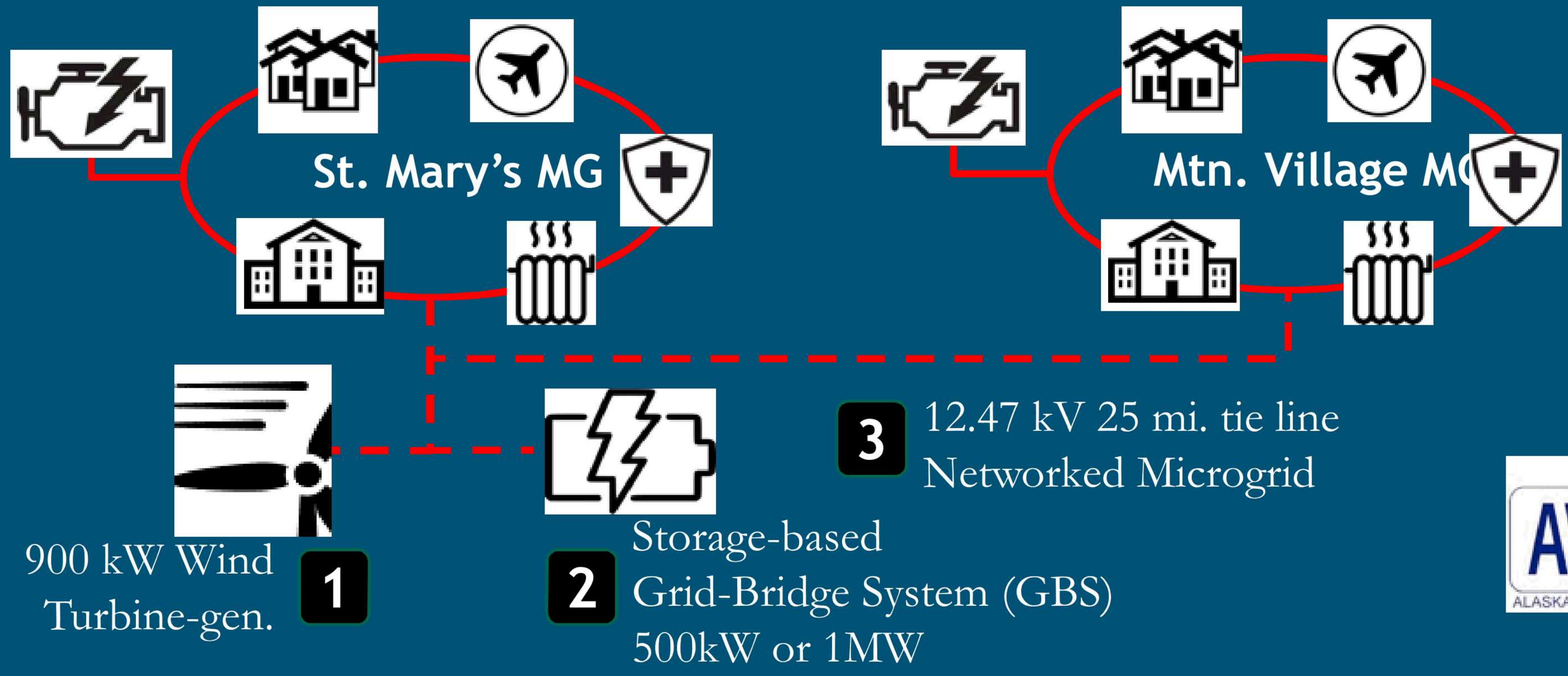
AVEC ALASKA VILLAGE ELECTRIC COOPERATIVE

<u>Grid Bridge System (GBS)</u>

- For high stochastic distributed generation
  - potential loss of power quality due to constant shifting between generation sources
  - less efficient to provide operational (spinning) reserves from diesel generators

- In previous work, ACEP showed
  - significant operational cost savings from shifting spinning reserves to 'synthetic' reserves
  - Grid forming inverter backed by high power, low energy capacity storage system

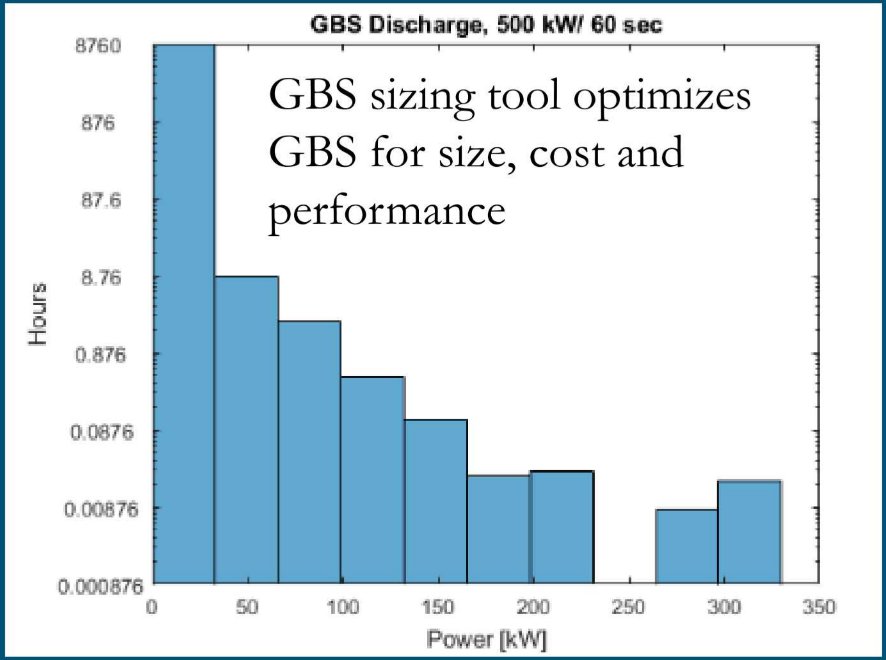
St. Mary's and Mountain Village, AK



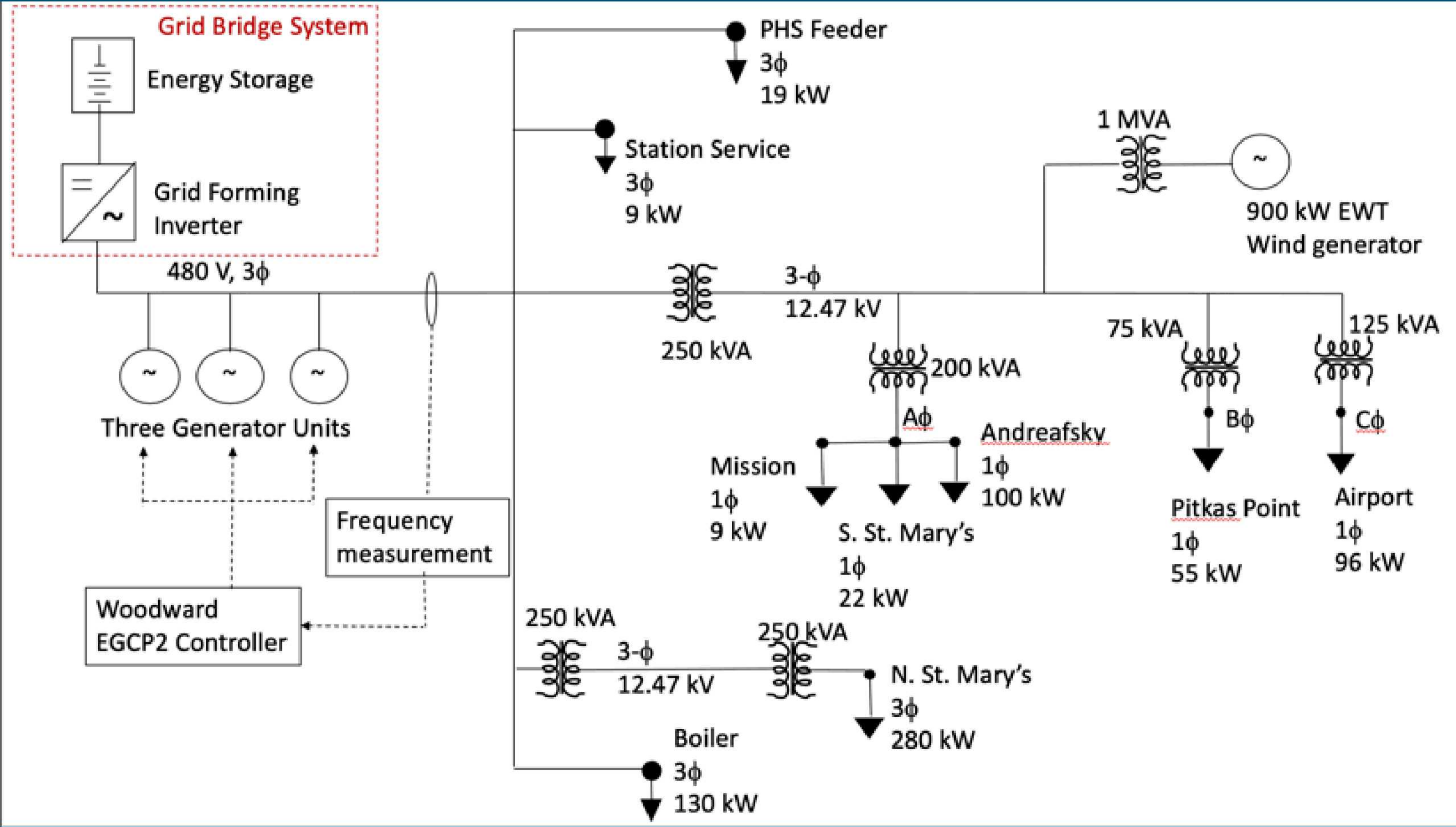
- Primary use as spinning reserve and associated step-load capabilities
  - Fast frequency and voltage support whenever active (~200kW, 3 seconds, ~100,000 cycles/year)
  - Inherently stiff (low impedance) voltage source that will provide good transient support during events
  - Adjustable droop response for both frequency and voltage deviations
- Eventual goal to run in diesels-off mode
- Desire to replicate successful approach across other their hybrid-diesel microgrid systems
  - Applicable for any similarly sized microgrid faced with increasing penetration of renewables

St. Mary's and Mountain Village, AK

- Sandia National Labs Alaska, Village Electric Coop (AVEC), and Alaska Center for Energy and Power (ACEP), partnering to study and demonstrate advanced renewable-based microgrids
- Planned outcomes:
  1. Validated open-source models for RE-based networked MG, including grid-forming inverters
  2. Demonstration of replicable and sustainable energy resilience solution for AK & beyond
     - 6 potential AK locations identified
  3. Identification of technology, standards and workforce gaps relevant to the deployment of islanded and grid-connected networked microgrids
  4. Open-source GBS optimal sizing tool for microgrid implementation



Open-source models for RE-based networked MG



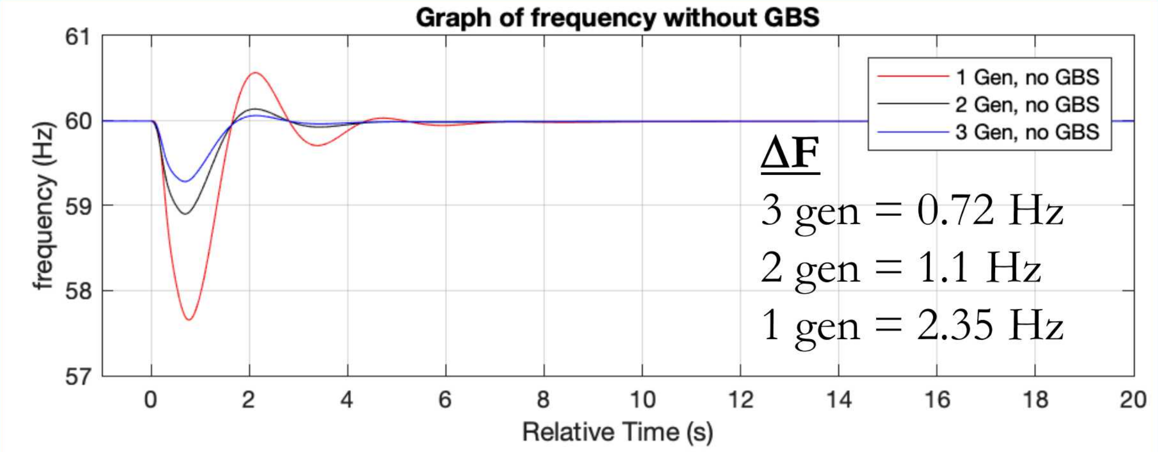
- Developed full Matlab Simulink model for the St. Mary's microgrid
  - includes developed models for diesel
  - wind turbine
  - Grid Bridge System
- System size based on average winter high consumption, provided by AVEC
- System has voltage imbalance of ~5%
- Implemented on Real Time simulator (Opal RT)
  - Allows for Hardware-in-loop testing

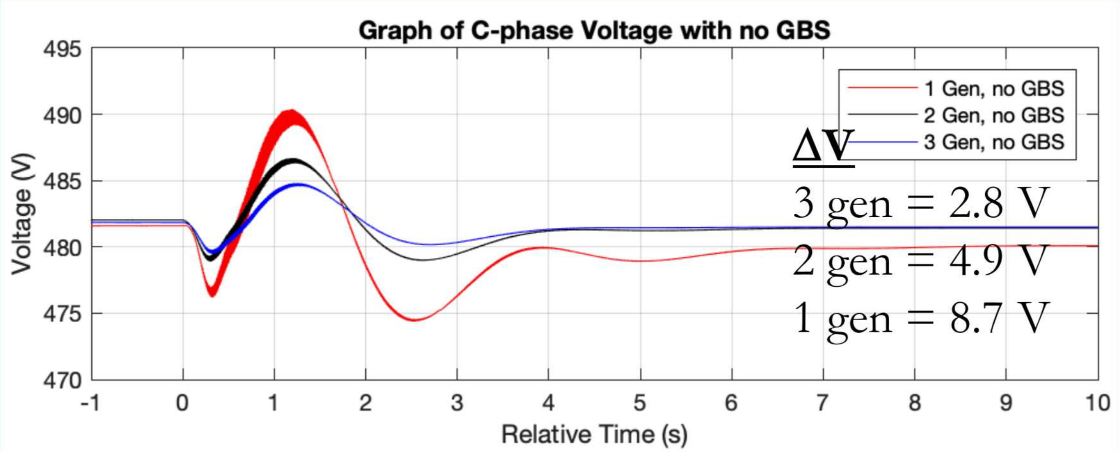
GFM can be used to provide spinning reserve

Evaluated GBS ability to provide spinning reserve for loss-of-wind scenario

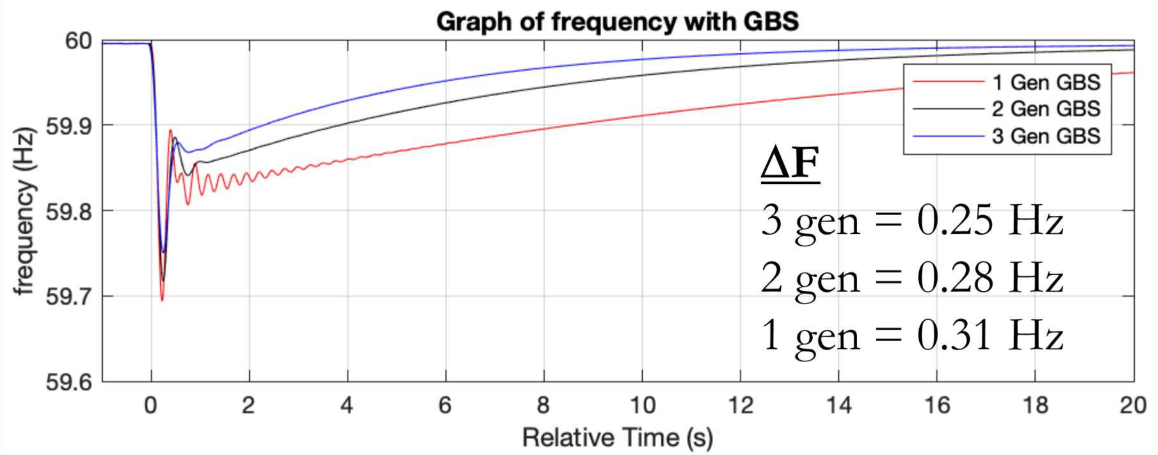
Frequency | Voltage

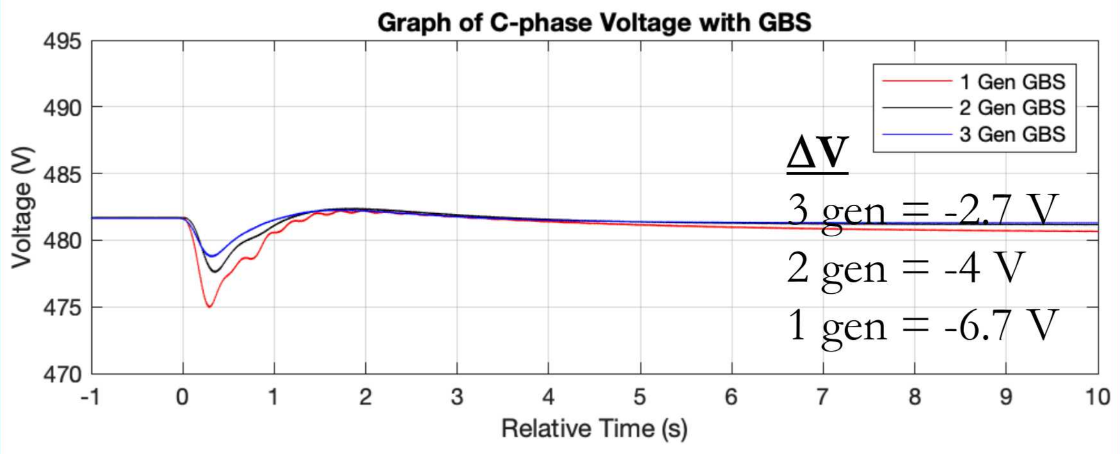
No GBS





With GBS

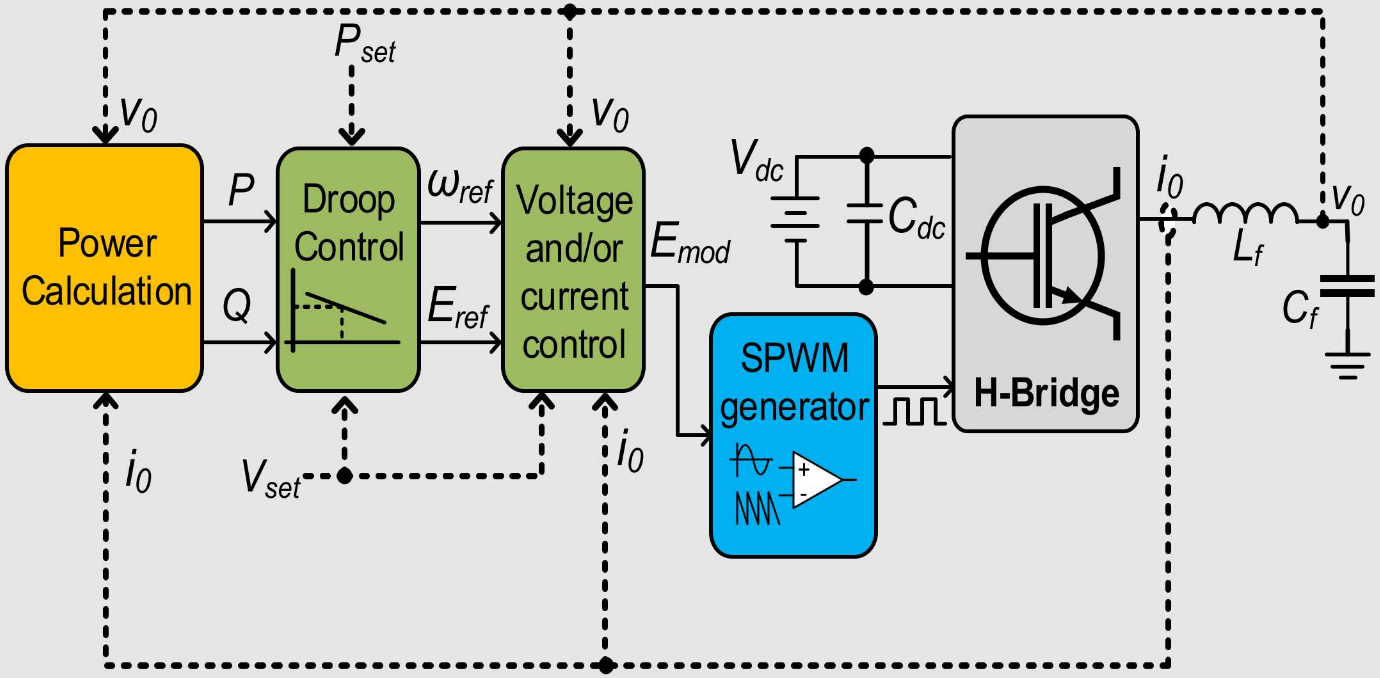




Contingency event:
Wind penetration 85% → 15% in 2s

GFM can be used to provide spinning reserve

Evaluating different control schemes and differences in providing spinning reserve



- Both share the same generic control scheme
- After the power calculation block, notice that droop control is a fundamental part of the control scheme

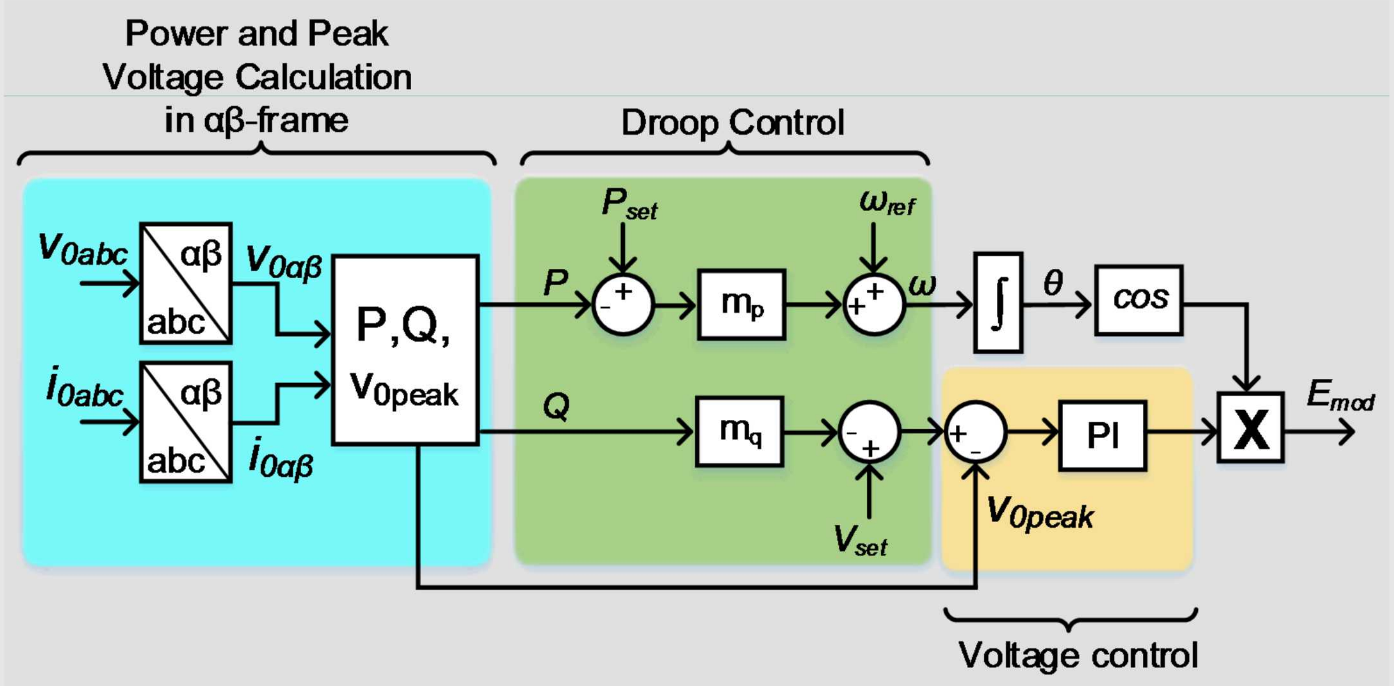
- Need some more info about "generic" GFM

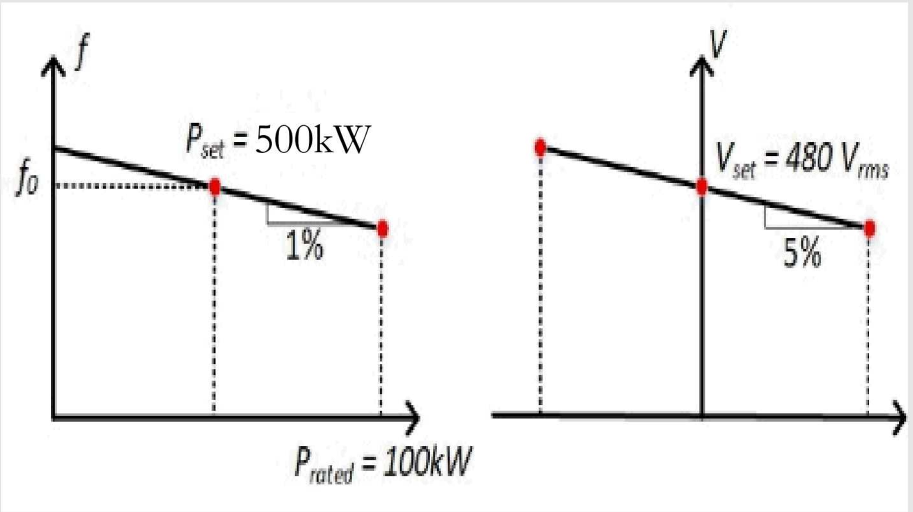
Open-source models for RE-based networked MG

GBS model based on CERTS control

- Consortium for Electric Reliability Technology Solutions (CERTS) formed in 1999
- Droop control (freq. and voltage) to allow flexible hybrid microgrids (Plug-and-play)
  - No single component (e.g. master controller) required for operation of the microgrid
- Output variables i_0 and v_o are mapped into the αβ-frame
- PI controller is used to regulate the voltage reference provided by the voltage droop stage

S_{base}	500 kVA	KP_{vol}	6.1
V_{base}	480 Vrms	KI_{vol}	0.001
m_p	0.01	L_f	0.8 mH
m_q	0.05	C_f	1500 μF
C_{dc}	10000 μF	V_{dc}	900 V





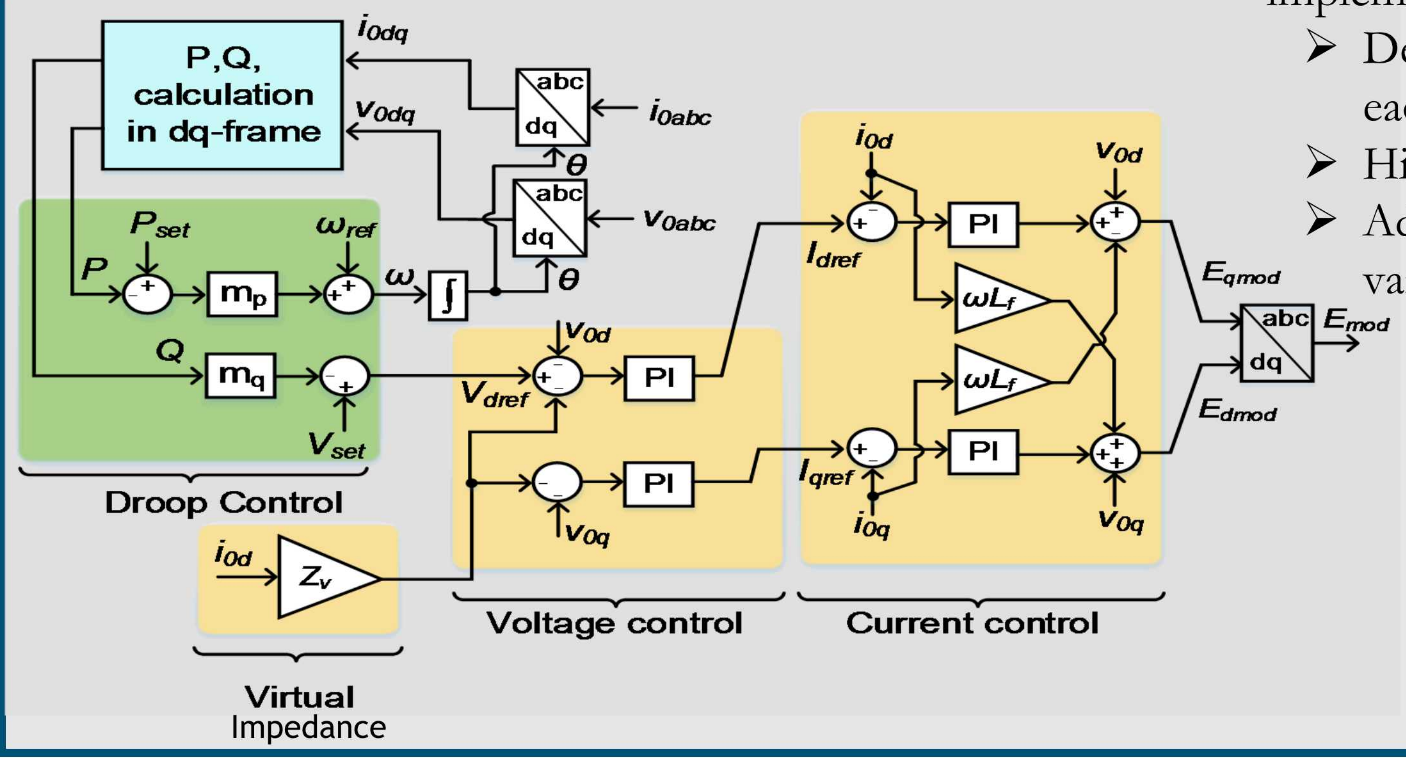
Javier Hernandez-Alvidrez, Adam Summers, Matthew J. Reno, Jack Flicker, Nataraj Pragallapati. Simulation of Grid-Forming Inverters Dynamic Models using a Power Hardware-in-the-Loop Testbed. PVSC. 2019. *In press*

Open-source models for RE-based networked MG

GBS model based on DQ control with virtual impedance

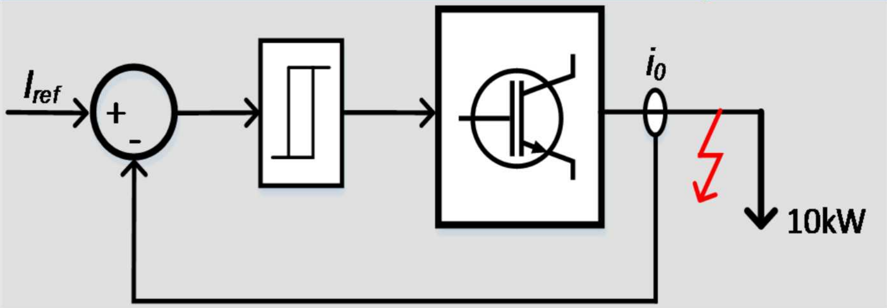
- Same generic control scheme as CERTS, but different voltage regulation scheme
  - Frequency-droop scheme dictates the frequency according to load demand
  - *dq*-frame transformation
    - used to calculate the real and reactive power in real time
    - *q*-component reference (V_{qref}) is normally set to zero (lack of negative sequence)

- Compensation of the cross-coupling ωL_f terms must be implemented
  - Decouple the dynamics of each current control loop from each other
  - Highly dependent on system impedance → stability issues
  - Addition of virtual impedance (Z_v) stabilizes model for variety of system impedances



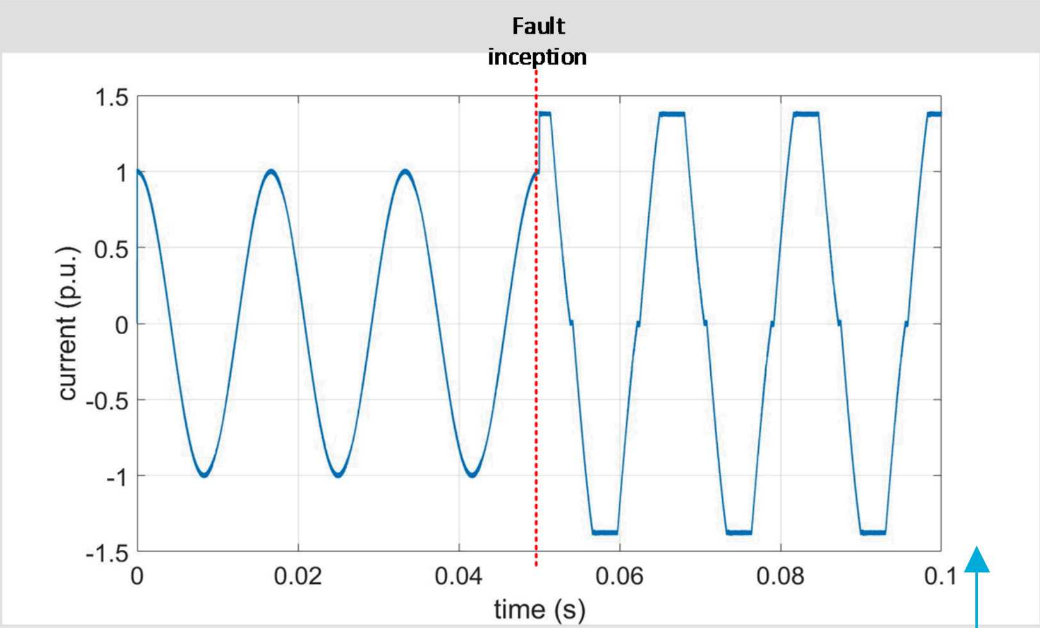
S_{base}	**500 kVA**	KP_{vol}	**1.0**
V_{base}	480 Vrms	KI_{vol}	10.0
m_p	0.01	L_f	3.0 mH
m_q	0.05	C_f	100 μF
C_{dc}	10000 μF	V_{dc}	900 V
KP_{curr}	5.663	KI_{curr}	1700

Open-source models for RE-based networked MG
GBS model based on Hysteresis control



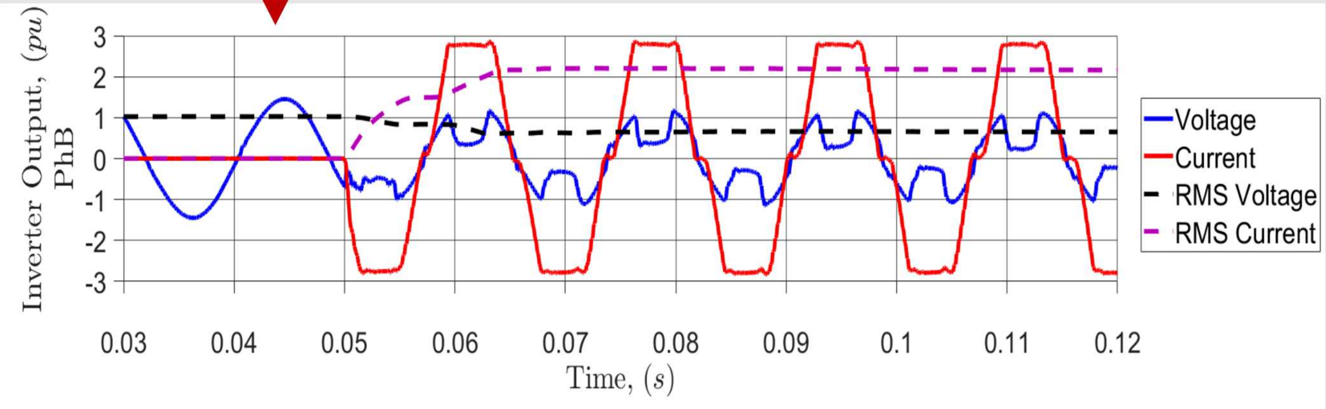
- Control switching scheme based on hysteresis
  - facilitates the four-quadrant operation of the inverter as an AC current source into a grid regulated for voltage and frequency
  - hysteresis comparison implemented by using output current of the inverter

- Validated against real GFM
  - fault applied at the terminals of the inverter supplying rated power (10 kW) at a time of 0.05 s
- Fault behavior shows a good qualitative match to the experimental fault behavior
  - inverter current saturates in a near square wave behavior
  - characteristic shoulder at a current of 0 p.u
- Further work is ongoing to implement full closed loop control



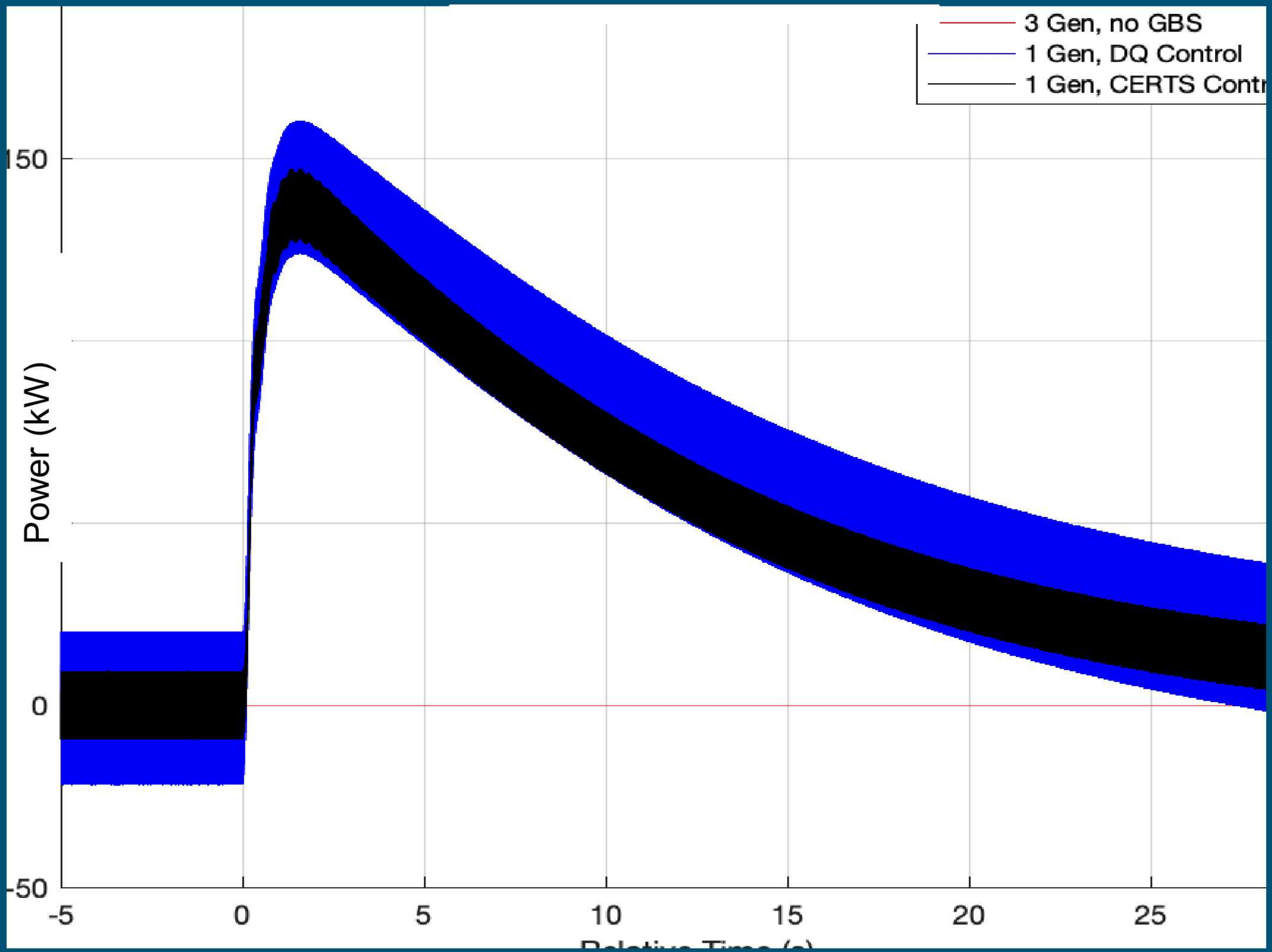
Simulated

Experimental



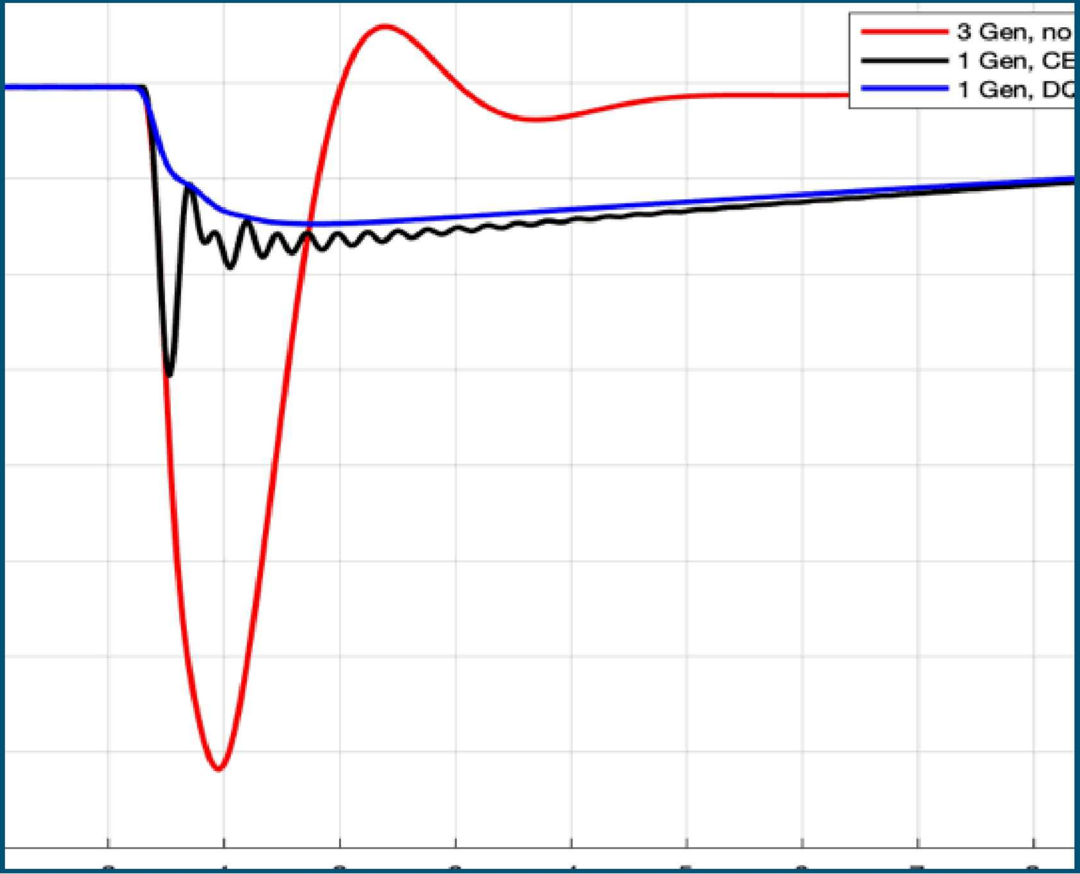
Open-source models for RE-based networked MG

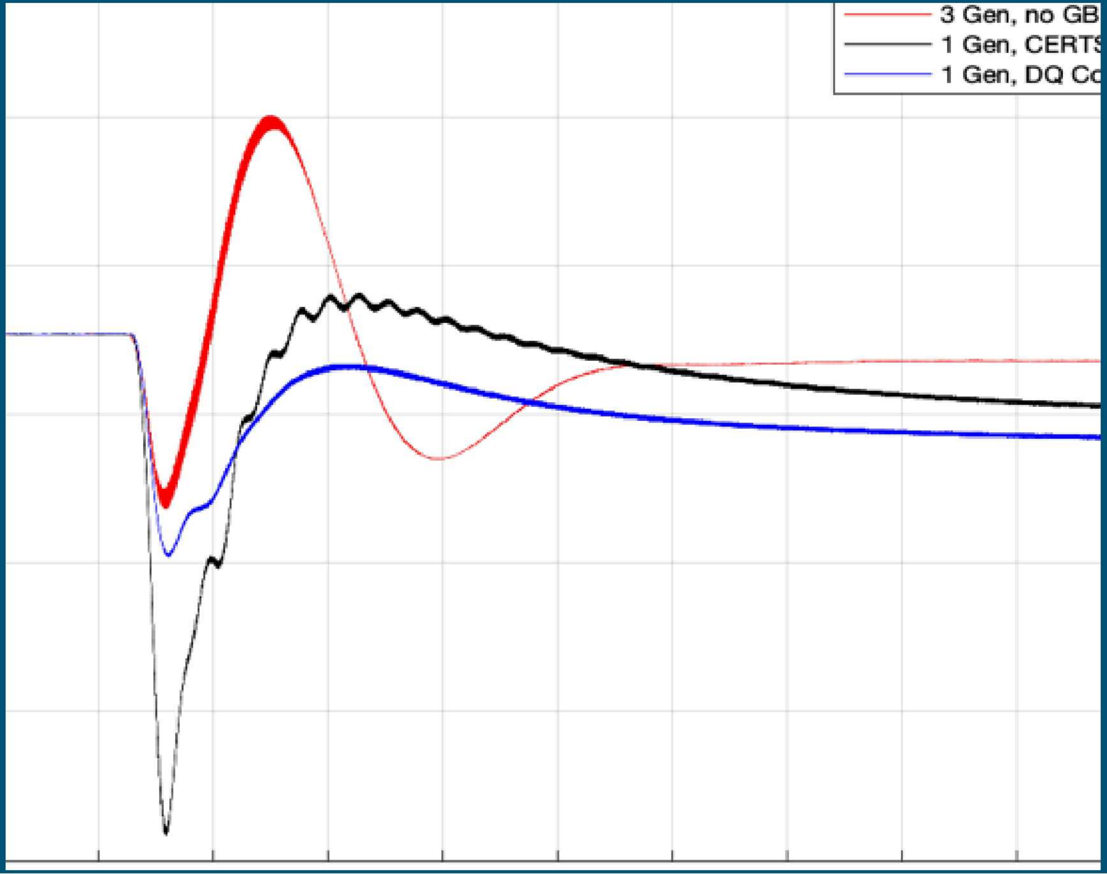
- Both DQ and CERTS droop control can provide spinning reserve
  - Have not compared Hysteresis control yet
- Respond to frequency injection within ~1s
  - Tail off gradually to 30s
  - Allows time for generation to spin-up



Open-source models for RE-based networked MG

- GFM results in better frequency and voltage response than splitting spinning reserve among 3 generators
- DQ control demonstrates better response to voltage and frequency
  - Smooth frequency nadir and response
  - Faster voltage arresting
  - CERTS control suffers from some oscillatory behavior





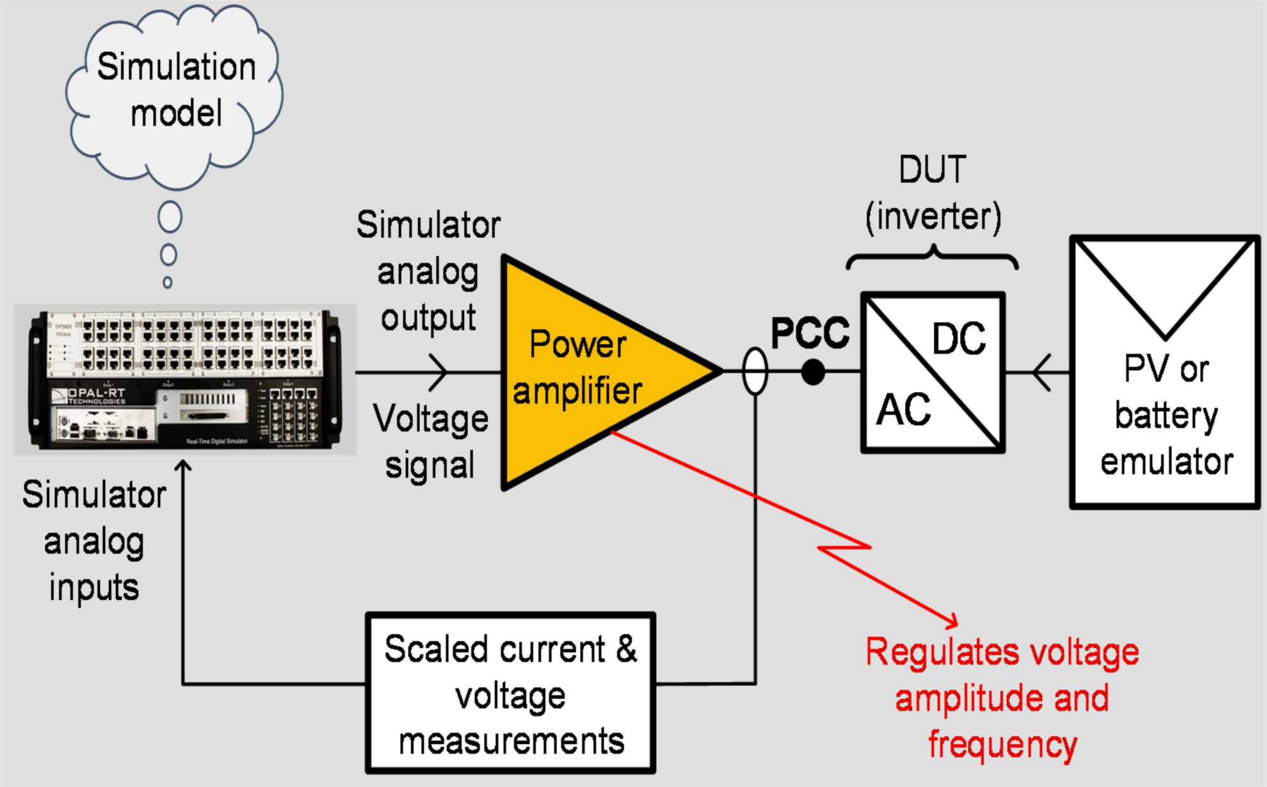
Power Hardware in Loop Validation of GFM for spinning Reserve

- Next step is to move from pure simulation to evaluating commercial hardware
- Utilizing Power Hardware-in-Loop (PHIL) setup to characterize real devices in St. Mary's environment

- PHIL simulation setups for traditional Grid Following Inverters (GFLIs) are well documented

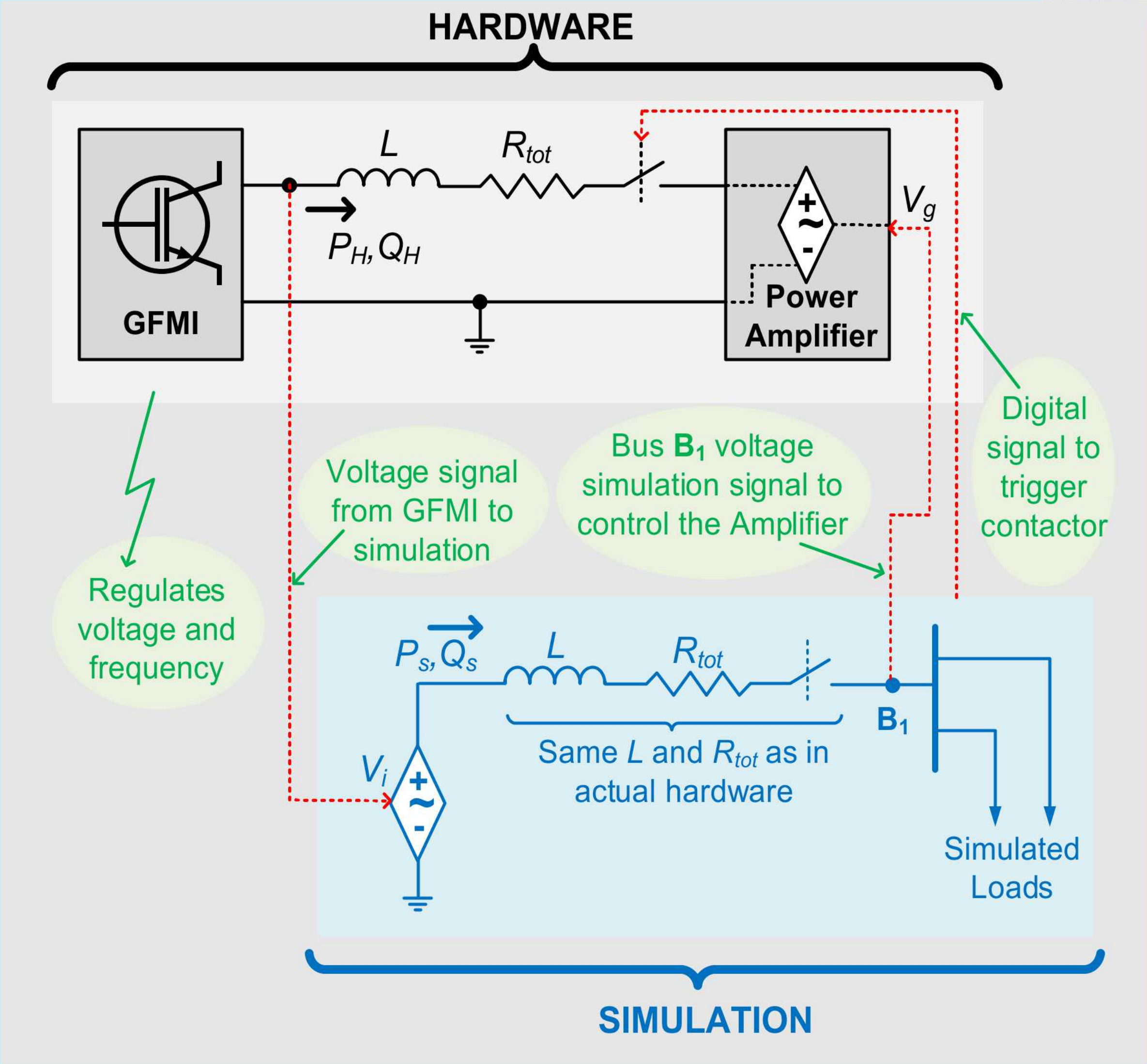
- However, the interfacing of GFMs into closed-loop PHIL simulation setups is lightly documented
  - If DUT is a GFM, then direct connection with power amplifier can lead to instability → catastrophic damage
    - Both devices inherently try to regulate the voltage and frequency at their own settings
    - Lack of angle synchronization between the two devices

  - We are developing method to interface GFM with simulation in PHIL



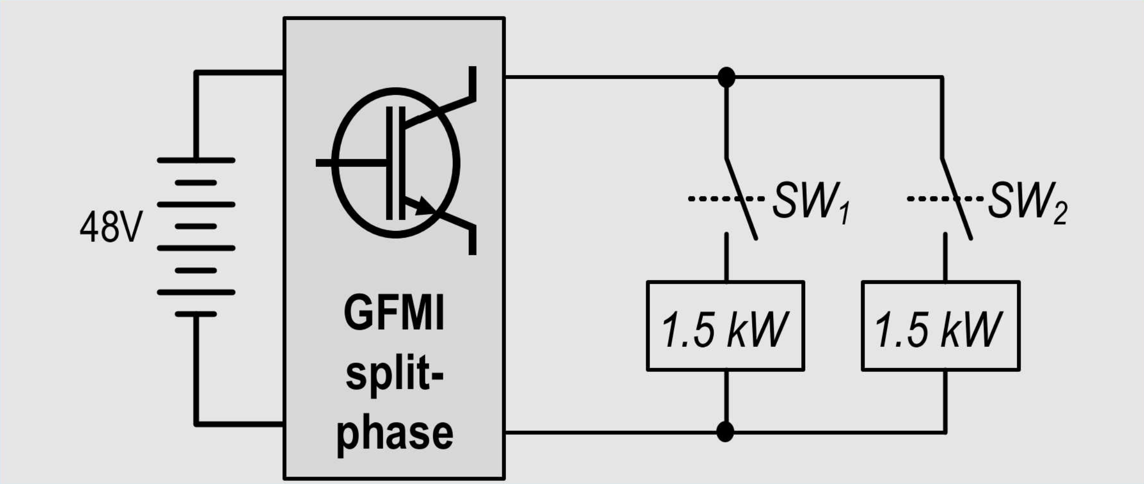
Power Hardware in Loop Validation of GFM for spinning Reserve

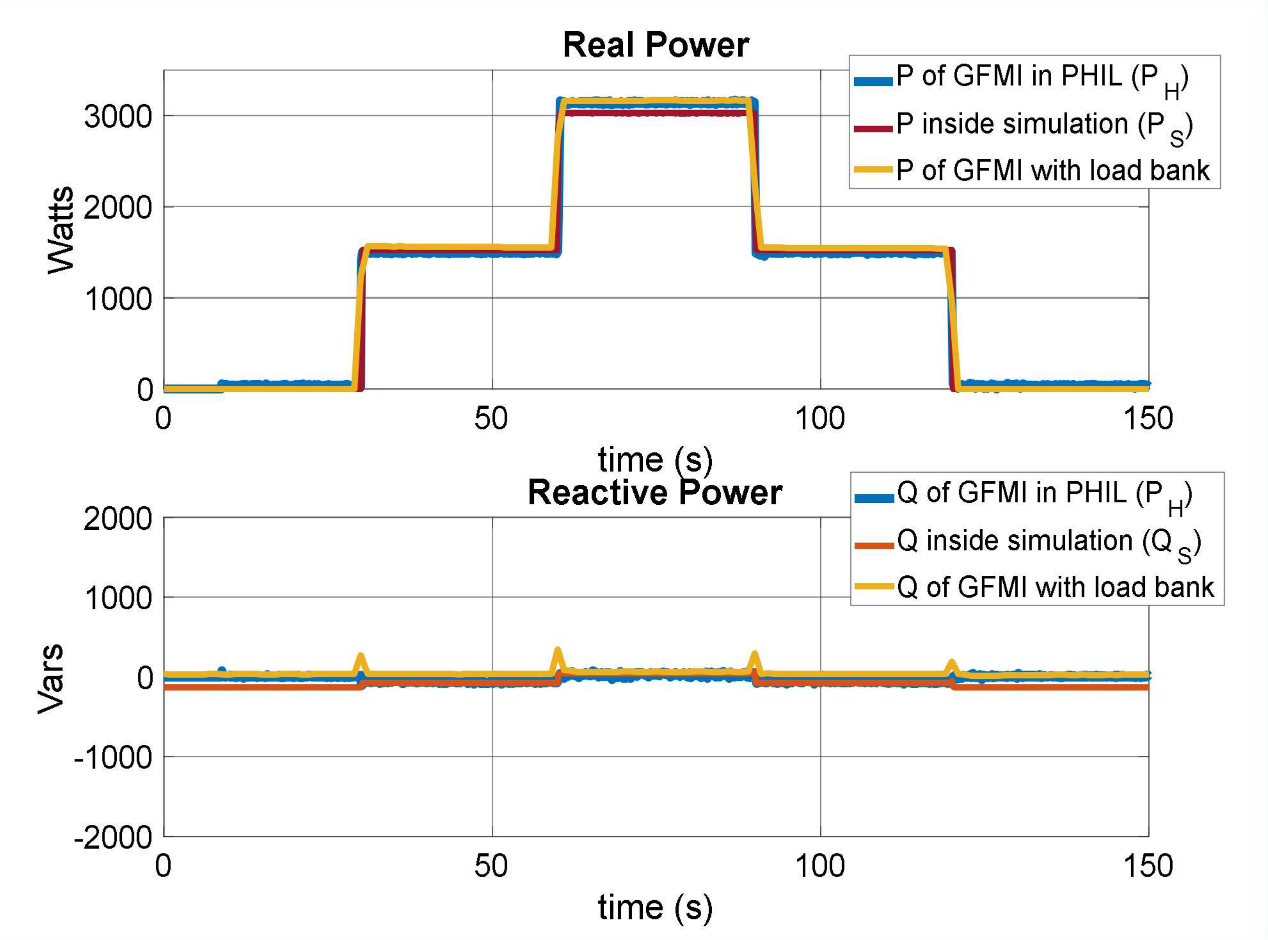
- Proposed method:
  - Inductor placed between GFM and power amplifier
    - Avoids instability issues previously mentioned
  - Contactor controls interconnection devices and
    - triggered by a digital signal from real time simulator.
  - In simulation voltage measured at GFM replicated in controlled voltage source V_i
  - Inductor and total resistance of hardware replicated inside the simulation
  - Power amplifier emulates voltage at bus B1



Power Hardware in Loop Validation of GFM for spinning Reserve

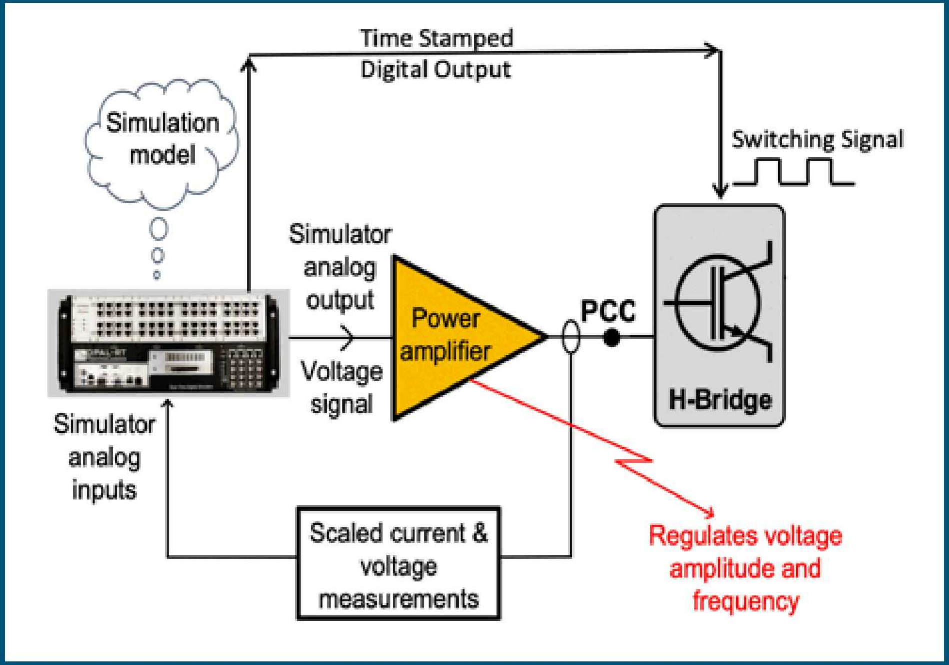
- To verify accuracy of method compared GFM with a staircase load pattern
  - Compare simulation only, PHIL, and hardware only
- Good agreement between all three methods
  - Agreement between methods of ≤5%
  - PHIL method fully stable under abrupt load change

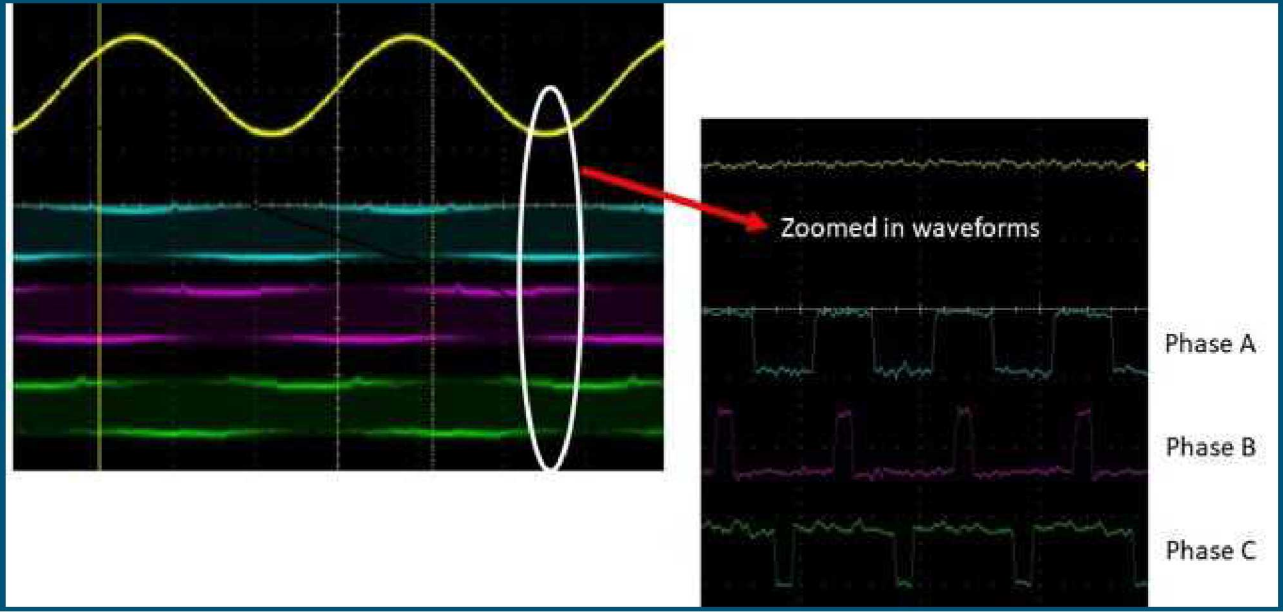




Power Hardware in Loop Validation of GFM for spinning Reserve

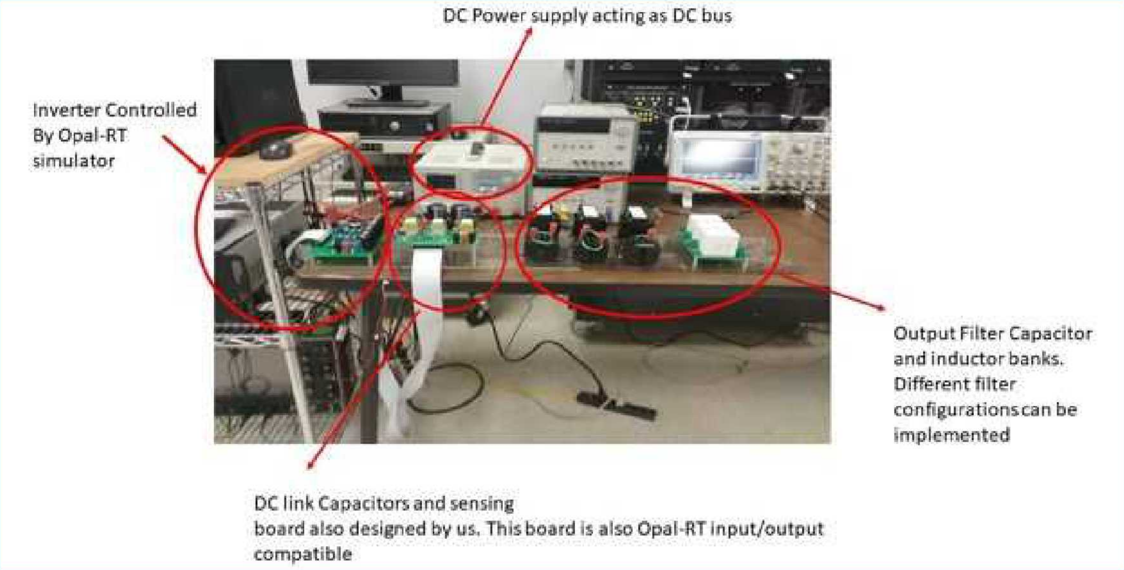
- PHIL evaluation of commercial hardware is valuable, but does not allow us to compare control schemes
- Need hardware testbed for GFM that has complete flexibility for changing/adapting control schemes
  - Not just parameters in a particular mode
  - But comparing different control modes with similar hardware
- Utilizing Opal RT system to supply gate drive signals to hardware
  - Time Stamped Digital Outputs allow for ~ 300kHz switching within 40 μs timestep

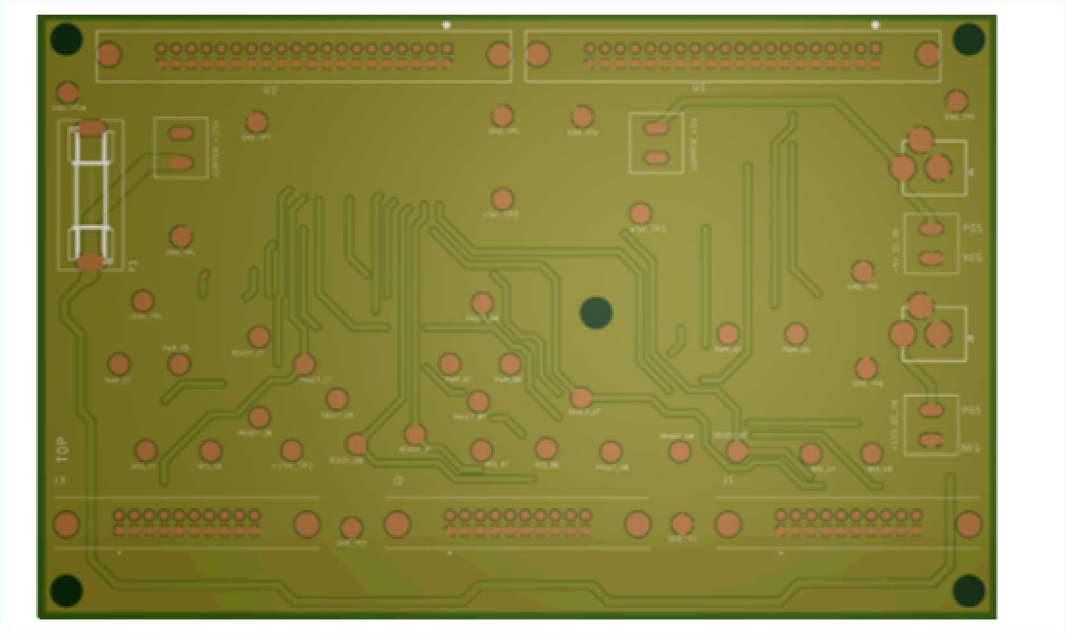


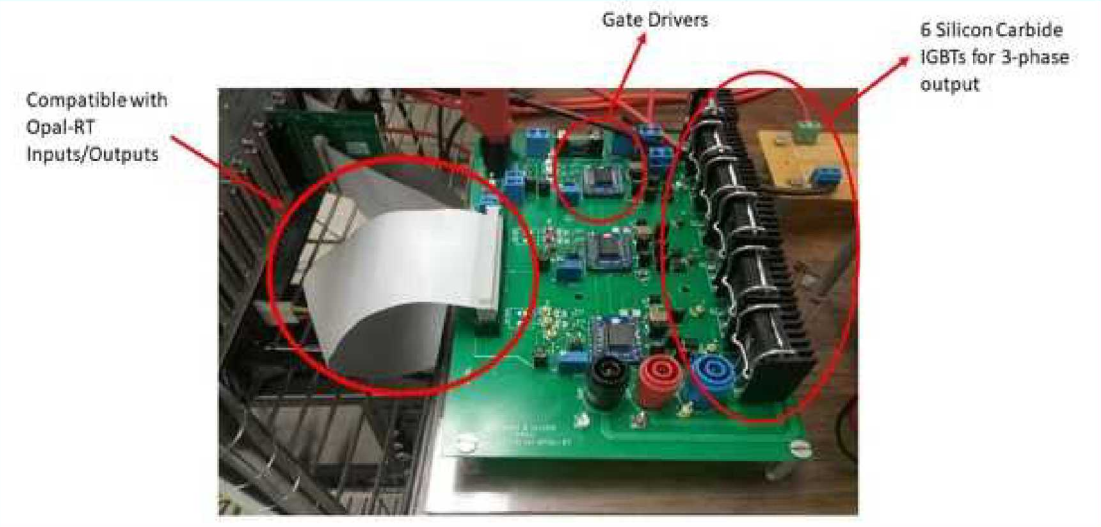


Power Hardware in Loop Validation of GFM for spinning Reserve

- Initial prototype replicates work of collaborator, NMSU
- Current work focuses on design 7 kW (10 A
  - Working on sizing of components and developing heatsink capabilities
  - Layout of PCB boards for higher power version







Next Steps in FY20

- Finish PHIL implementation of 3ϕ GFM and evaluate commercial devices to contingencies in St. Mary's

- Complete flexible testbed construction to test PHIL of different control schemes

- Assist AVEC with procurement of GBS system for St Mary's
  - Target installation Sept 2020

- Work with ACEP to evaluate real system behavior before final installation at St. Mary's
  - Laboratory Acceptance Testing
  - Final validated model for St. Mary's with real GBS system