Grid Forming Inverters in Microgrid Systems

PRESENTED BY

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Collaborators

St. Mary's, Alaska GFI Microgrid

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Grid Forming Inverters Modeling

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Grid Forming Inverters in Interconnected Systems

Brian Johnson, University of Washington

Robert Lasseter, University of Wisconsin

Yashen Lin, National Renewable Energy Laboratory

Ryan Elliott, Brian Pierre, Sandia National Laboratories

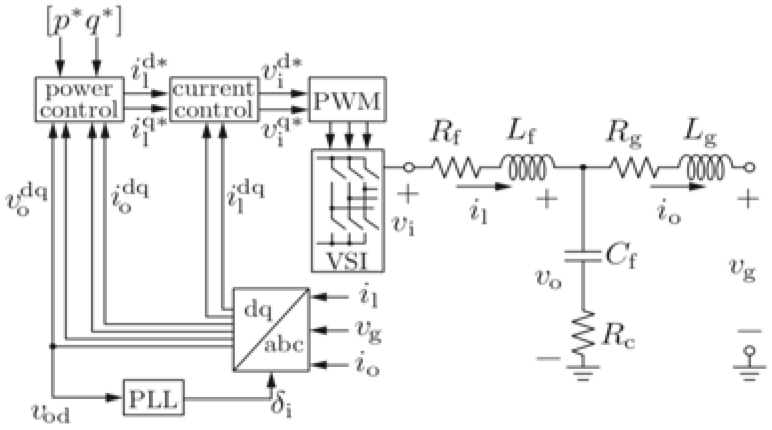
Joseph Eto, Lawrence Berkeley National Lab

Grid Forming Inverters (GFM) Introduction

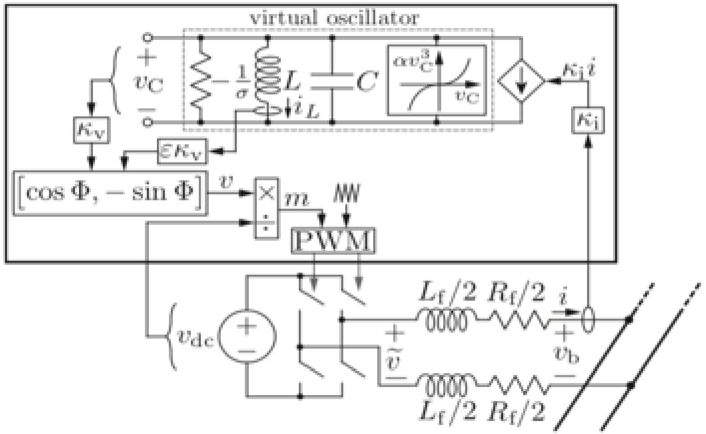
Two fundamental types of **voltage sourced** inverter controls

Grid Following Control (GFL)	Grid Forming Control (GFM)
Controls current and phase angle	Controls voltage magnitude and frequency
Controls active & reactive power as well as fault currents	Instantaneously balances loads without coordination controls
Cannot operate standalone	Can operate standalone
Cannot achieve 100% penetration	Can achieve 100% penetration

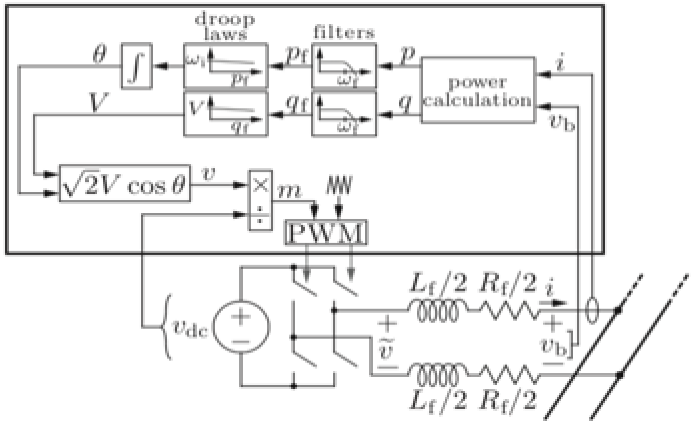
Courtesy Brian Johnson, Univ. Wash.



Grid-following:
Current control with PLL



Grid-forming:
Virtual oscillator control



Grid-forming:
Droop control

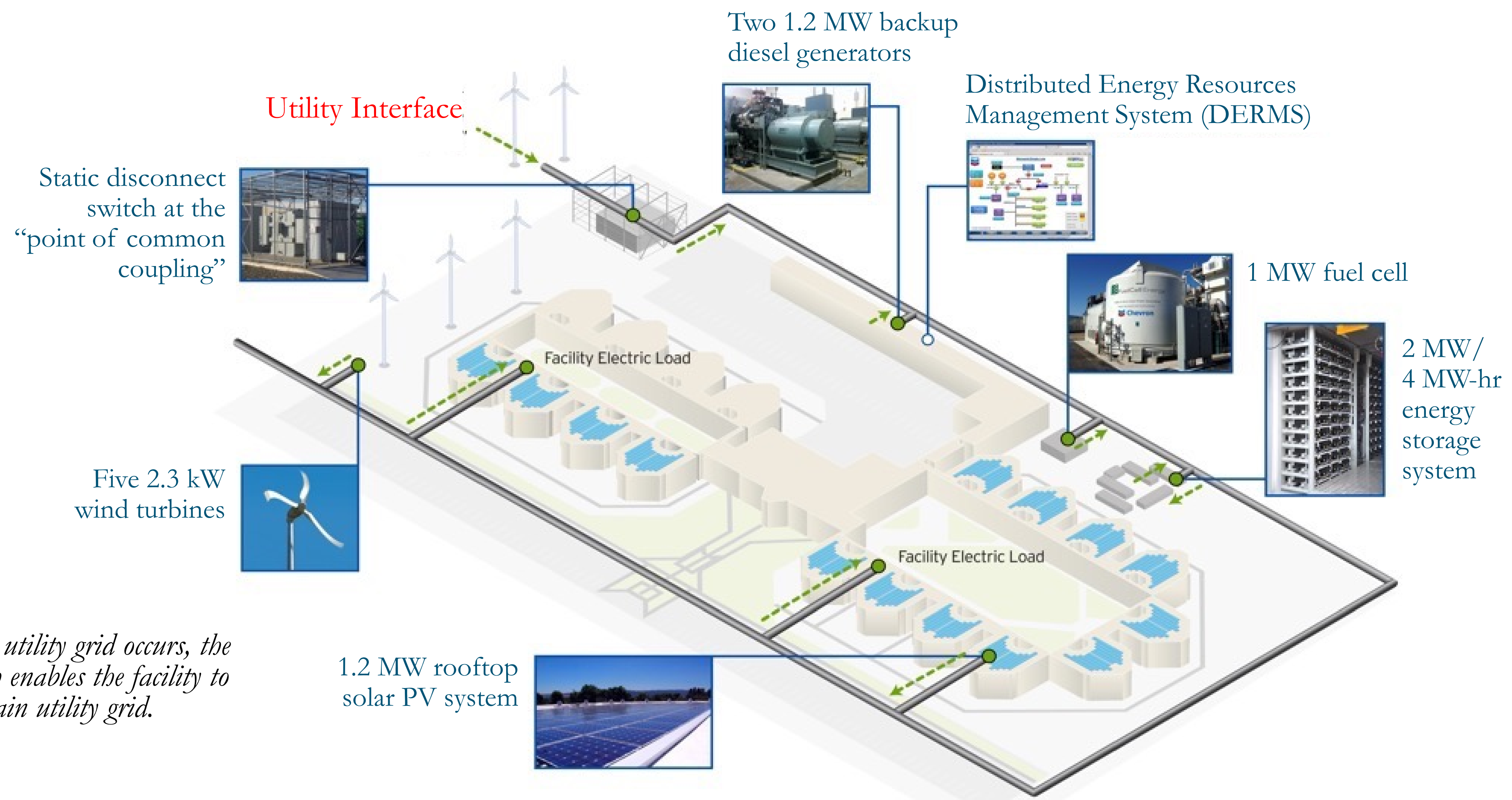
GFI inverters were studied and deployed in DOE/CERTS microgrids

- Consortium for Electric Reliability Technology Solutions (CERTS) formed in 1999

CERTS Microgrid Concept

- Testing at a full-scale microgrid demonstration test bed operated by American Electric Power (AEP)
- Peer-to-peer
    - Droop control to allow flexible hybrid microgrids
    - αβ reference (not DQ)
    - Continue operating with loss of an individual component or generator
    - No single component (e.g. master controller or a central storage unit) required for operation of the microgrid
- Plug-and-play
    - unit can be placed at any point within the microgrid
    - No need to re-engineering controls
    - Similar to the flexibility one has with home appliances.

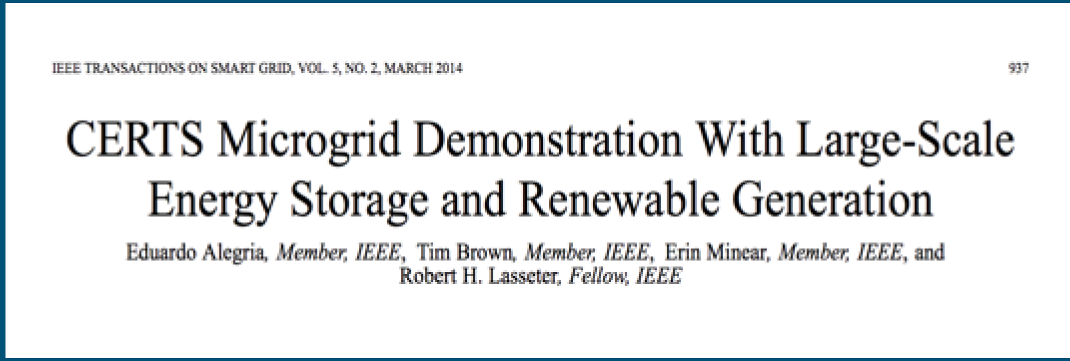
GFI inverters were studied and deployed in DOE/CERTS microgrids



When a disturbance to the utility grid occurs, the automatic disconnect switch enables the facility to "island" itself from the main utility grid.

GFM inverters were studied and deployed in DOE/CERTS microgrids

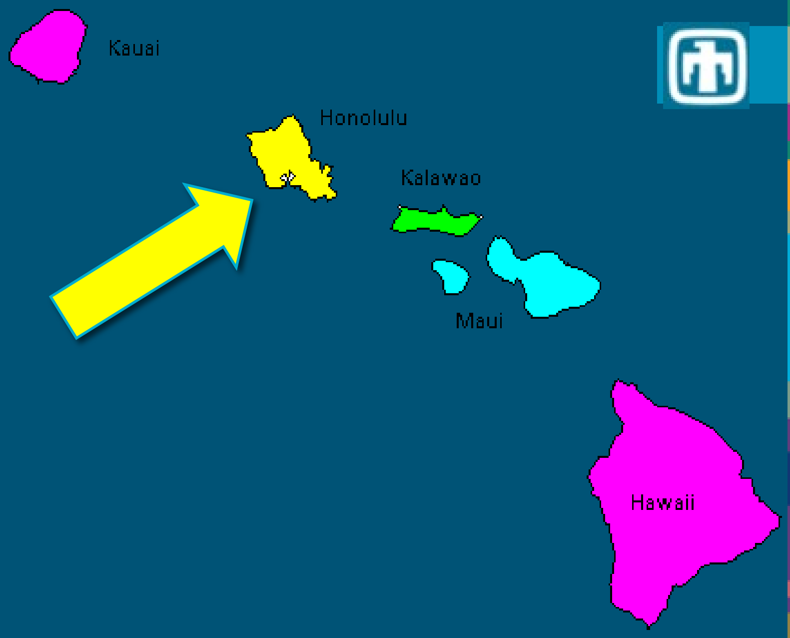
- Seamlessly switches between grid and island operation and back
- Stable without communications
- Sources are plug-and-play
- Proven in microgrid applications


IEEE TRANSACTIONS ON SMART GRID, VOL. 5, NO. 2, MARCH 2014 937

CERTS Microgrid Demonstration With Large-Scale Energy Storage and Renewable Generation

Eduardo Alegria, *Member, IEEE*, Tim Brown, *Member, IEEE*, Erin Minear, *Member, IEEE*, and Robert H. Lasseter, *Fellow, IEEE*

GFM Inverters can ensure stability in larger grids



- GFM **required** for 100% renewable grid
  - Historically have been used for high penetration microgrids
  - But can be used in larger grids
  - Now seeing integration onto island grids
    - High renewable portfolio standards, high cost of generation

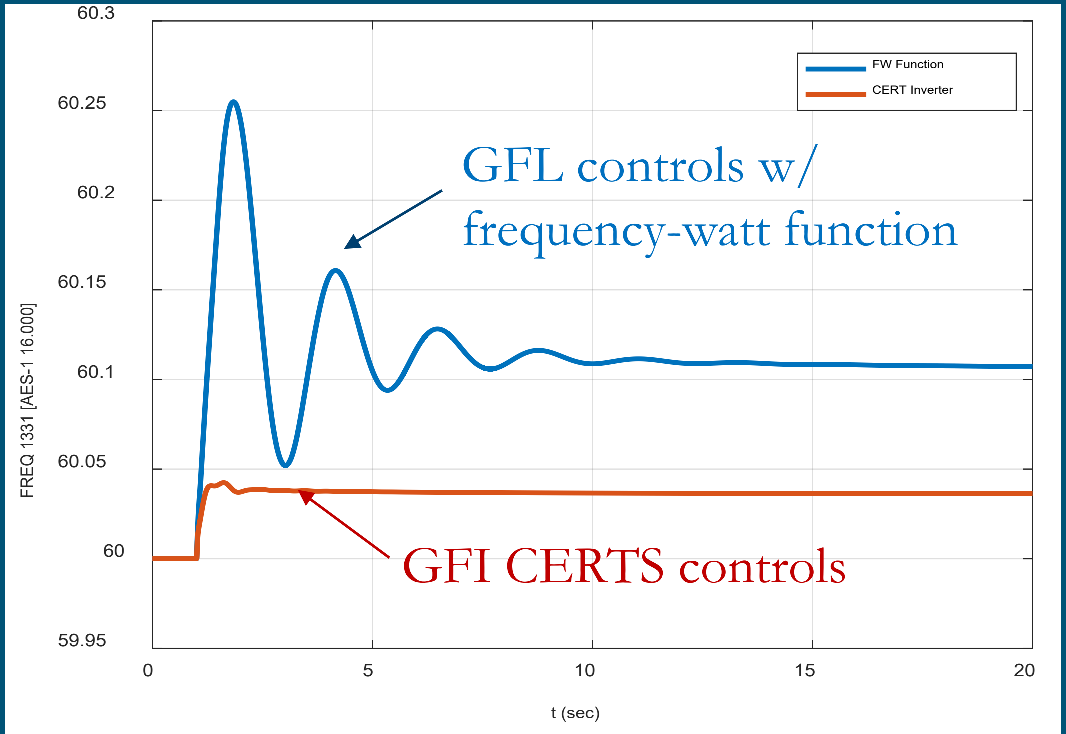
- High penetration of inverter-based generation decreases system inertia
  - Can result in reliability issues during contingencies
  - GFL inverters have advanced inverter functions to respond to contingencies

- GFMs will increase or decrease their output power **instantaneously** to balance loads and maintain local voltage and frequency
  - **no significantly delay** in change of output
  - GFM sources can respond much faster to any contingencies than a GFL
    - (for GFM that do not utilize DQ controls)

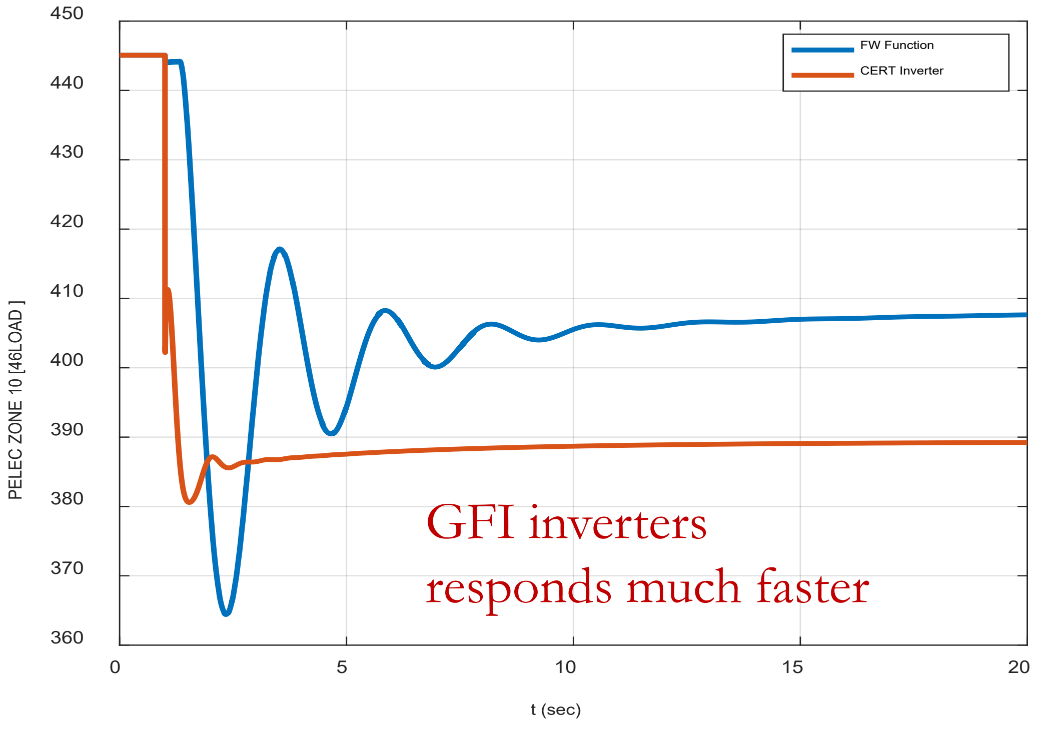
Case study – O'ahu, Hawai'i, 50% distributed PV

System at **920** MW load, **466** MW PV

Event is loss of **62** MW **load**



Frequency



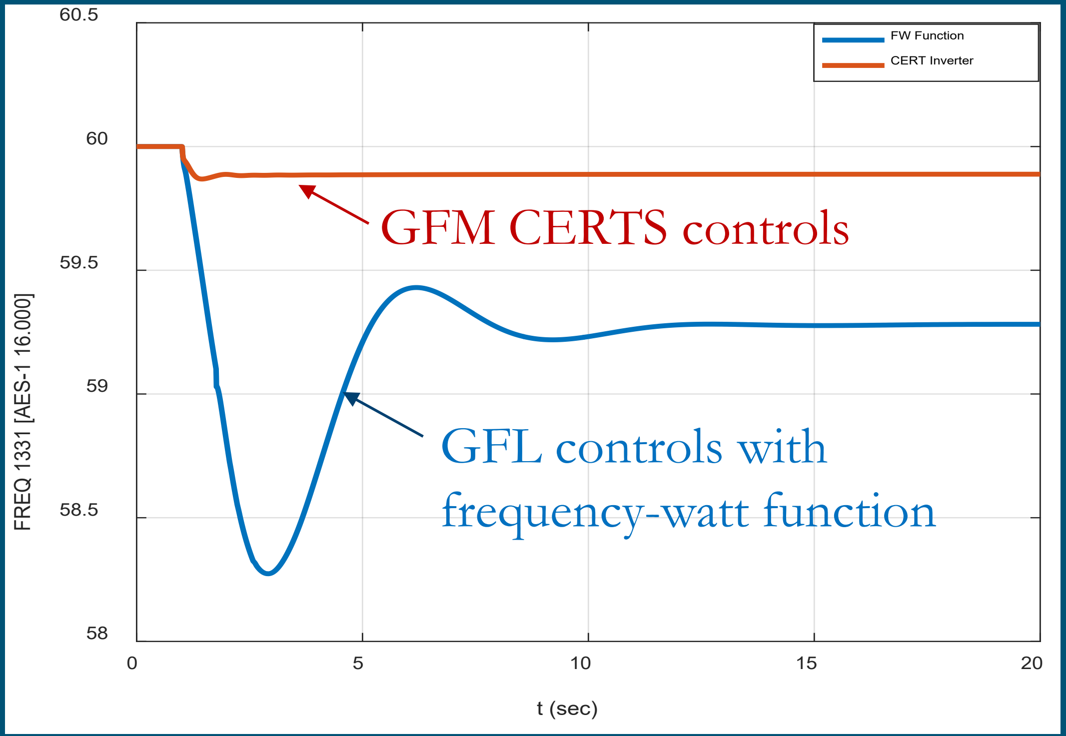
Aggregated PV output

Case study – O'ahu, Hawai'i, 50% distributed PV

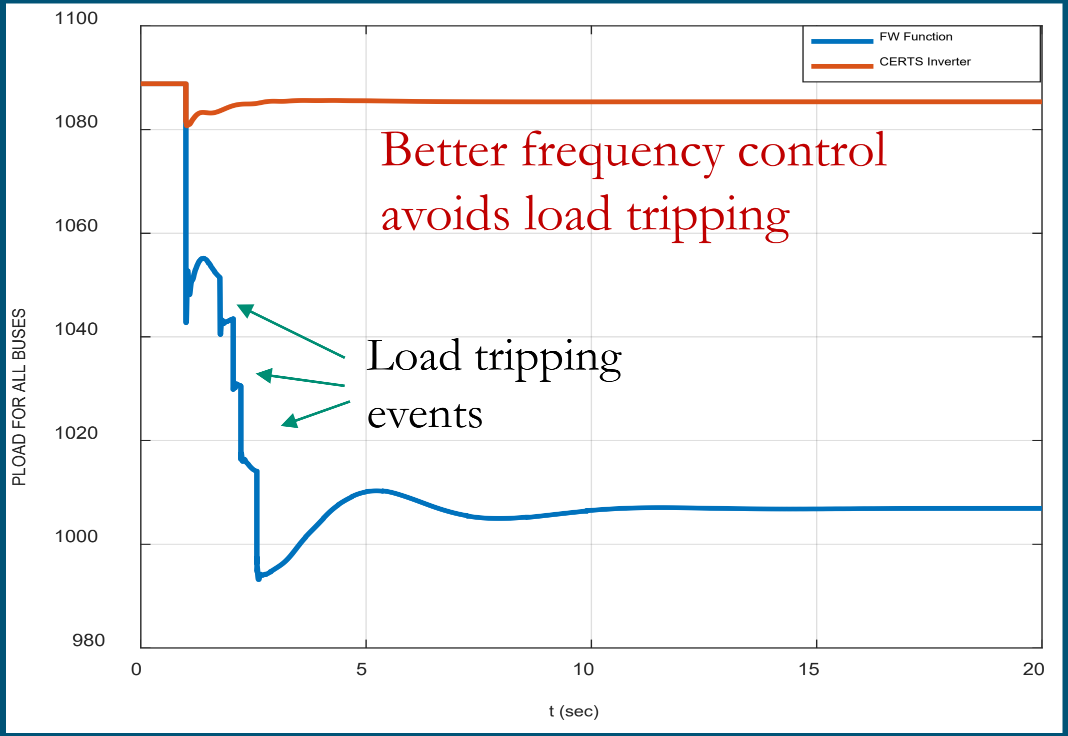
System at **1,080** MW load, **540** MW PV

Event is loss of **200** MW **generator**

M. E. Khatib, W. Du, R. Lasseter, "Evaluation of Inverter-based Grid Frequency Support using Frequency-Watt and Grid Forming PV Inverters", SAND ID #659600



Frequency

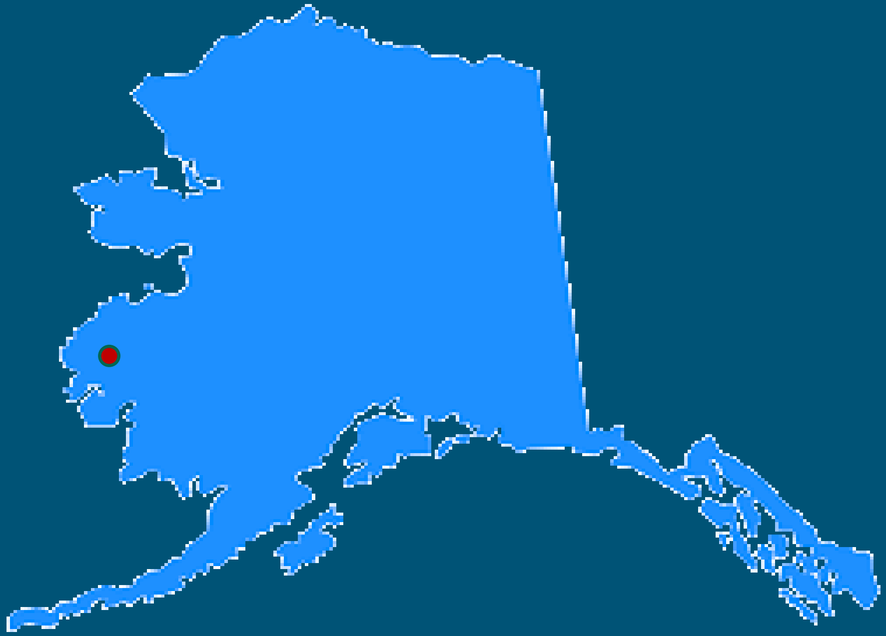


Total System Load

St. Mary's and Mountain Village, AK

St. Mary's, AK. Pop. 550
Peak load: 600 kW (winter)
Min load: 150 kW

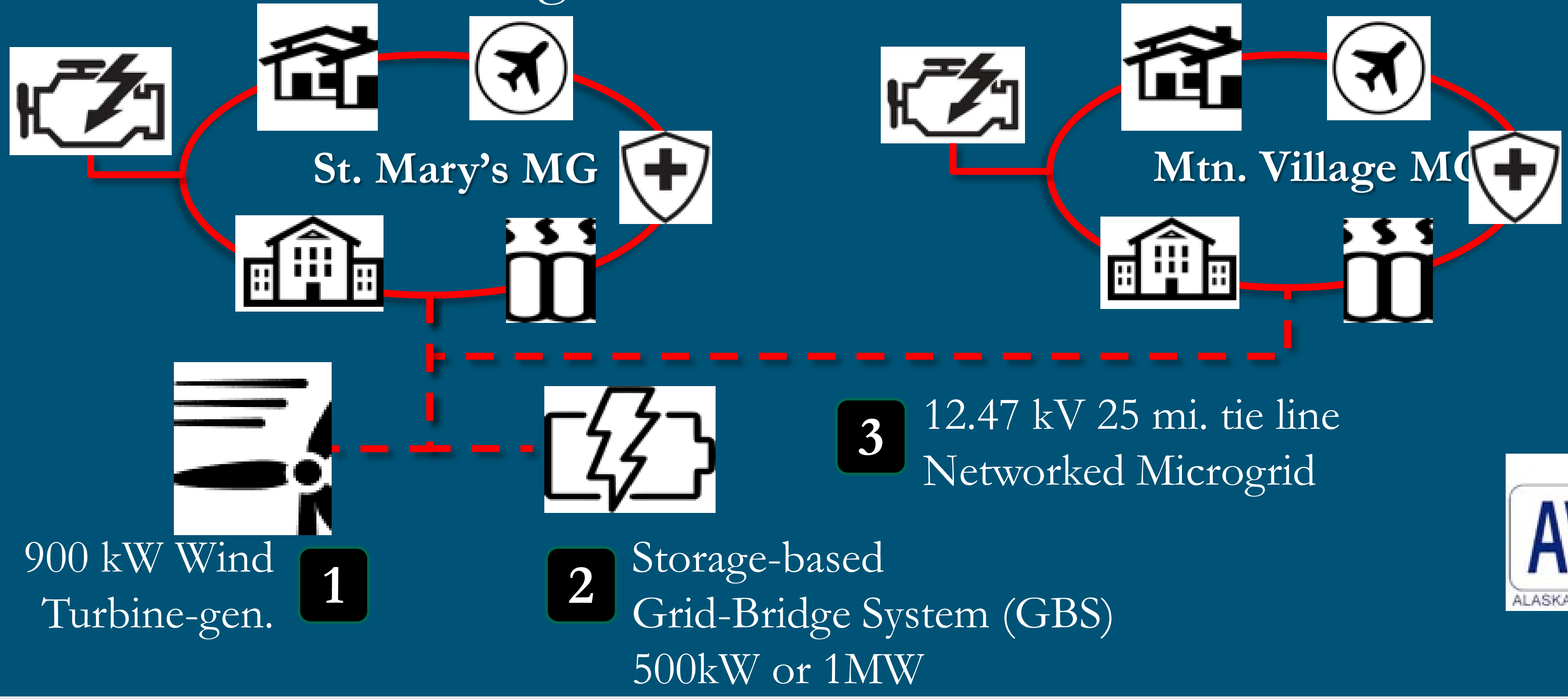
Mountain Village, AK. Pop. 820
Peak load: 500 kW (winter)
Min load: 150 kW



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

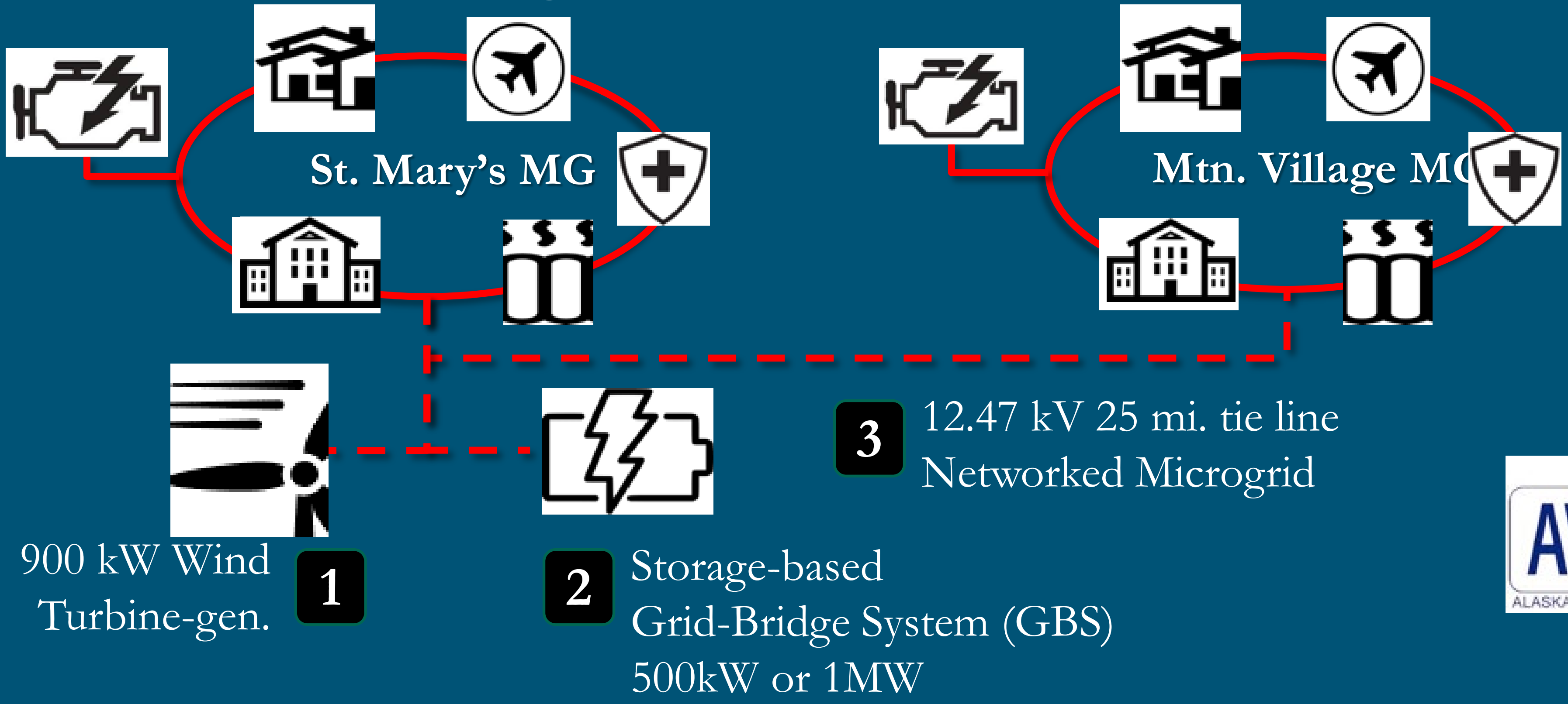
St. Mary's and Mountain Village, AK



- 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 Commissioning**
    - EWT 900 kW Type IV pitch-controlled wind turbine generator
2. Storage-based grid bridge system (GBS) for spinning reserve (DOE/OE + DOD/ONR) — **RFP Drafted, est. Fall 2019**
3. Network St. Mary's MG with Mountain Village MG via 12.47 kV tie-line — **Winter 2019/2020**

St. Mary’s and Mountain Village, AK



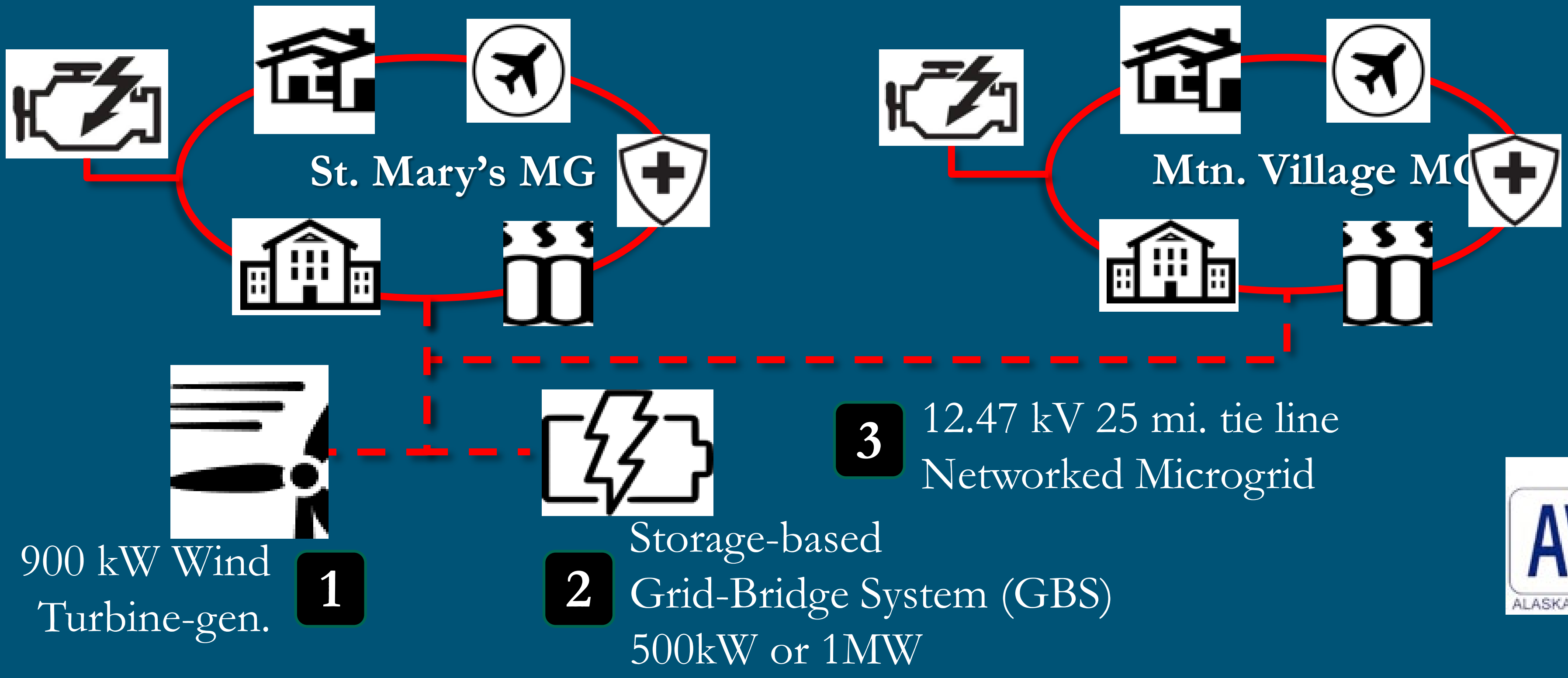
AVEC
ALASKA VILLAGE ELECTRIC COOPERATIVE

<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

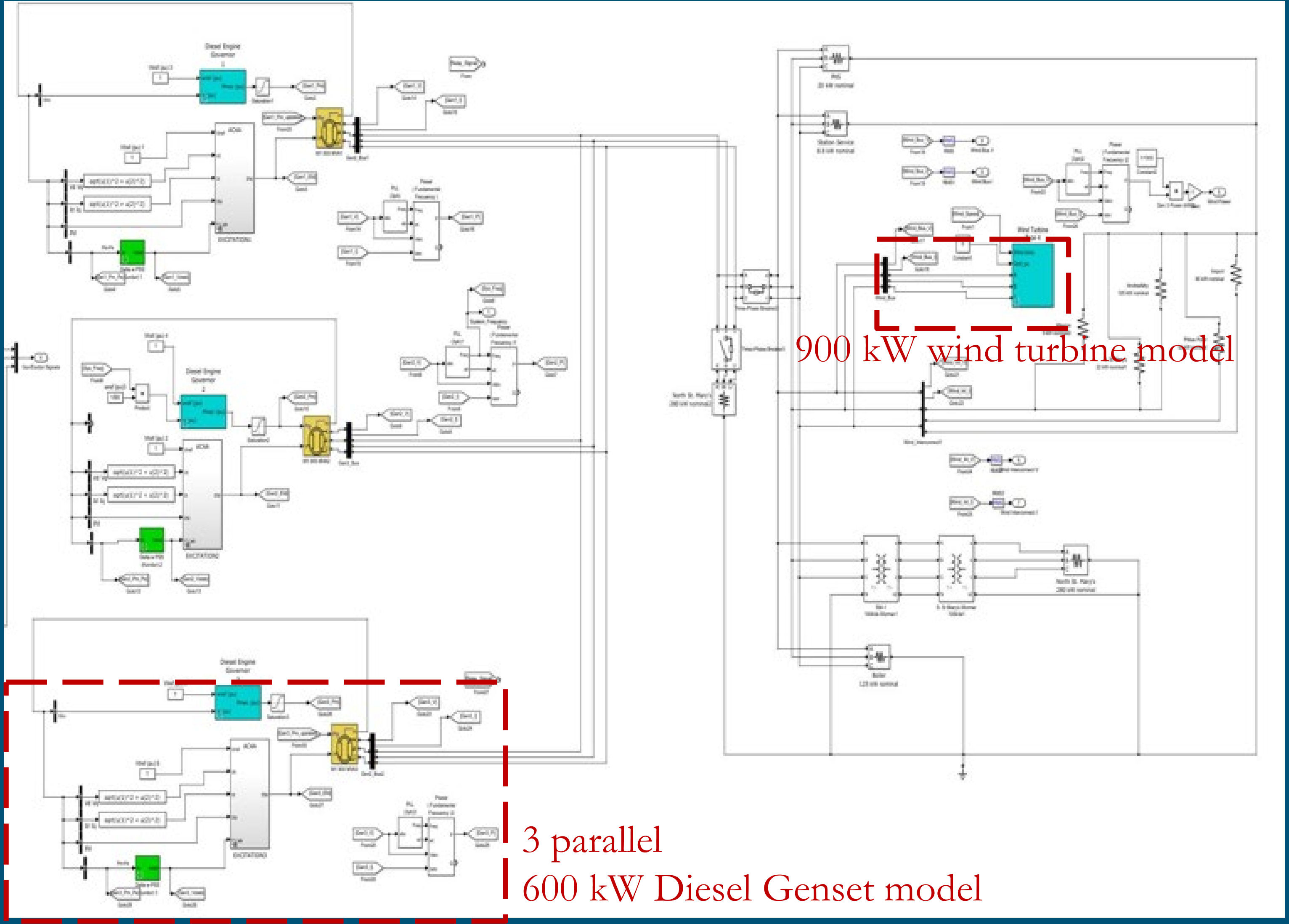
  - Significant operational cost savings from shifting spinning reserves to ‘synthetic’ reserves
  - Grid forming inverter backed by high power, low energy capacity storage system

St. Mary's and Mountain Village, AK



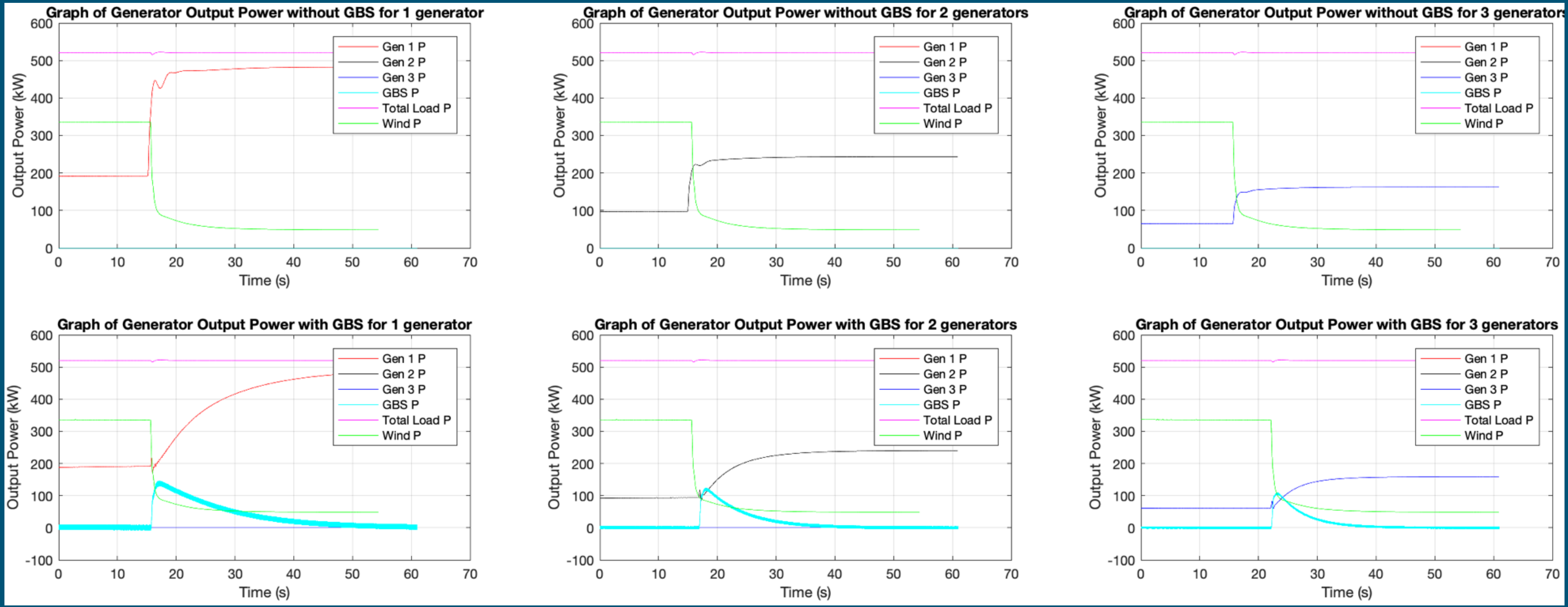
- Primary use as spinning reserve and associated step-load capabilities
  - Fast frequency and voltage support whenever active (~200kW, 3 seconds, ~100,000 cycles/year)
  - Inherently stiff (low impedance) voltage source that will provide good transient support during events
  - Adjustable droop response 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

Open-source models for RE-based networked MG



- Developed full Matlab Simulink model for the St. Mary's microgrid
  - includes developed models for diesel gensets (installed)
  - wind turbine (being commissioned) at St. Mary's
- 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

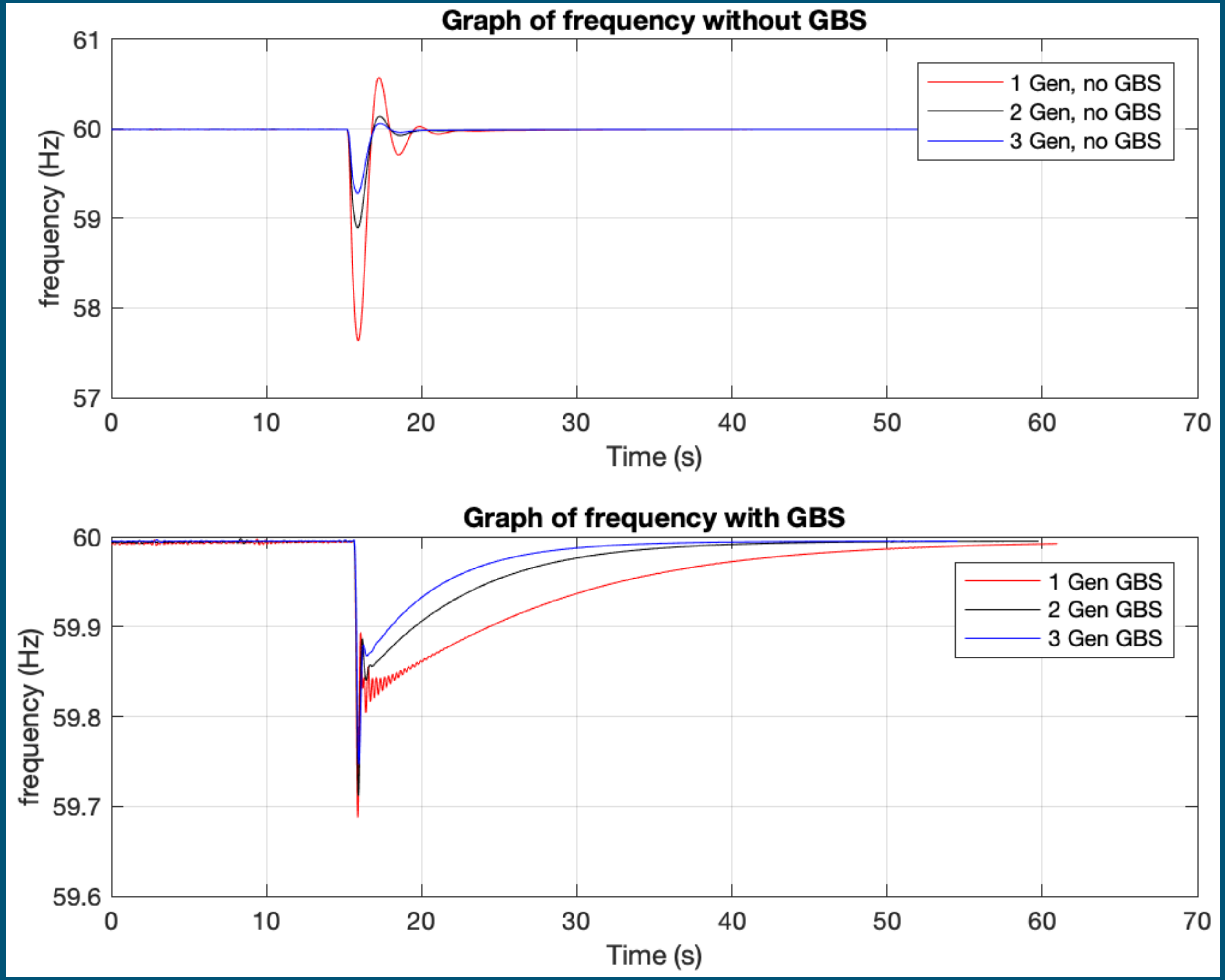
GFM can be used to provide spinning reserve

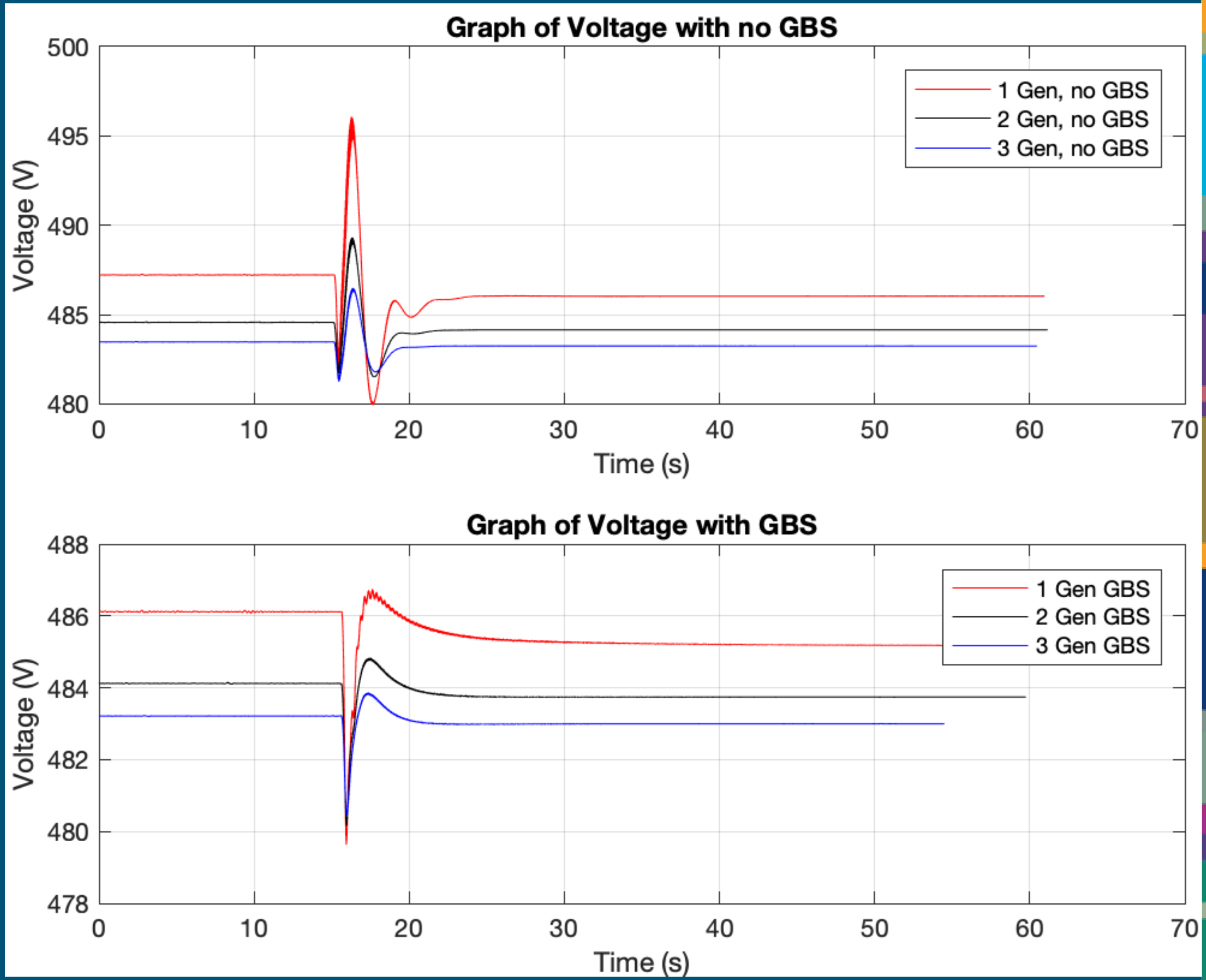


Contingency event:

Wind penetration 85% → 15% in 2s

GFM can be used to provide spinning reserve





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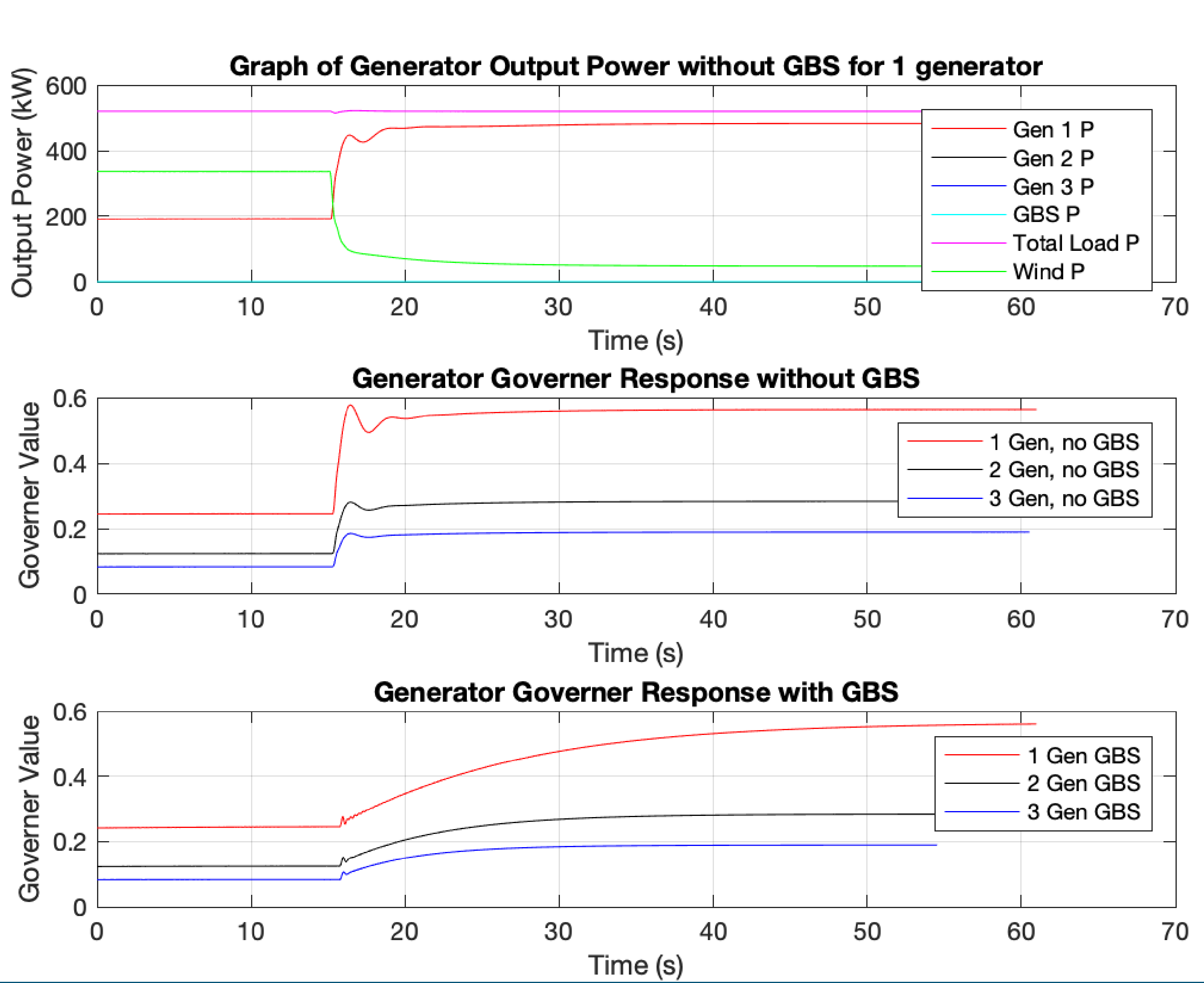


GFM as spinning reserve:

1. Can stabilize voltage and frequency in a contingency
2. Shift reserve from diesel to GFM
3. Allow for more effective loading of generators
4. Slows system dynamics
   → slower gov. response
   → fuel savings

- GFM being procured by AVEC and commissioned by ACEP
- Commissioning data to be use to validate simulations

Sandia's Distributed Energy Technology Laboratory GFMs

DER technology Development and Validation

Power Electronics Devices and Systems

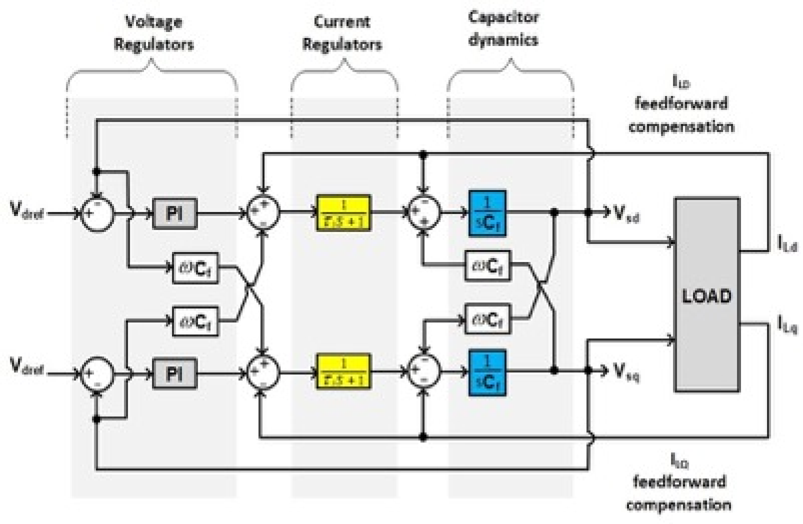
- Sandia premier facility since
- Specialize on DER systems integration: inverters, energy storage, gensets, microgrids, controllers
  - AC and DC System performance characterization/optimization
    - DER assets
    - Microgrids (DC and AC)
    - Grid integration
  - Advanced Inverter R&D and grid compatibility assessment

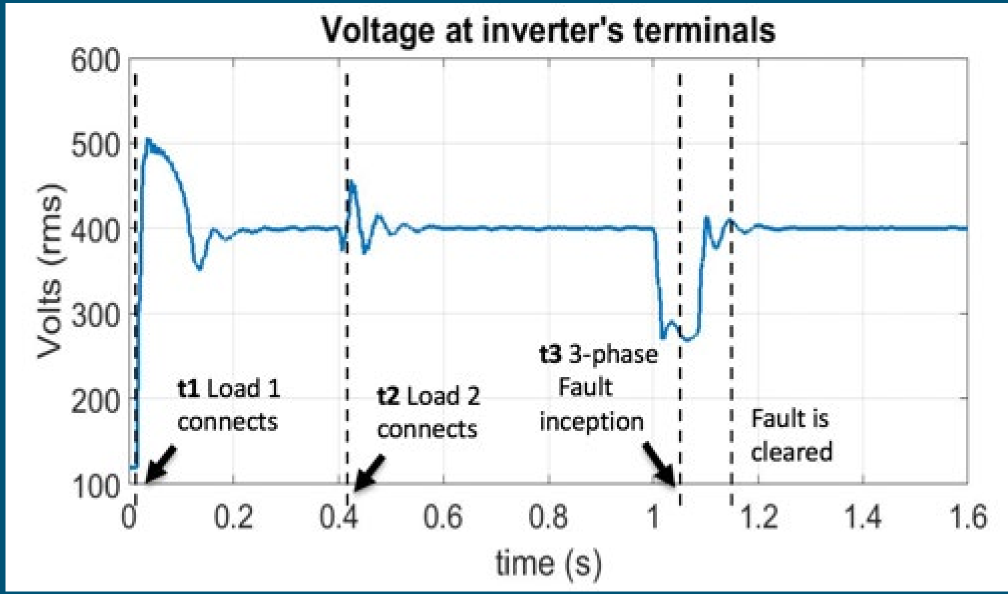
- Focused on developing GFM transient models
  - Open source
  - Validated
  - Generic

- Valuable for use by system and protection designers to understand transient GFM behavior during faults

Sandia's Distributed Energy Technology Laboratory GFIs

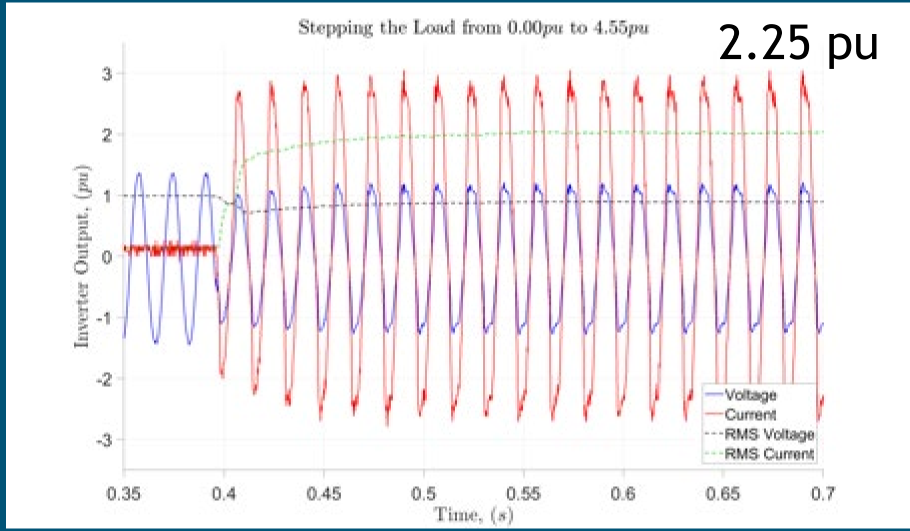
Currently developing models

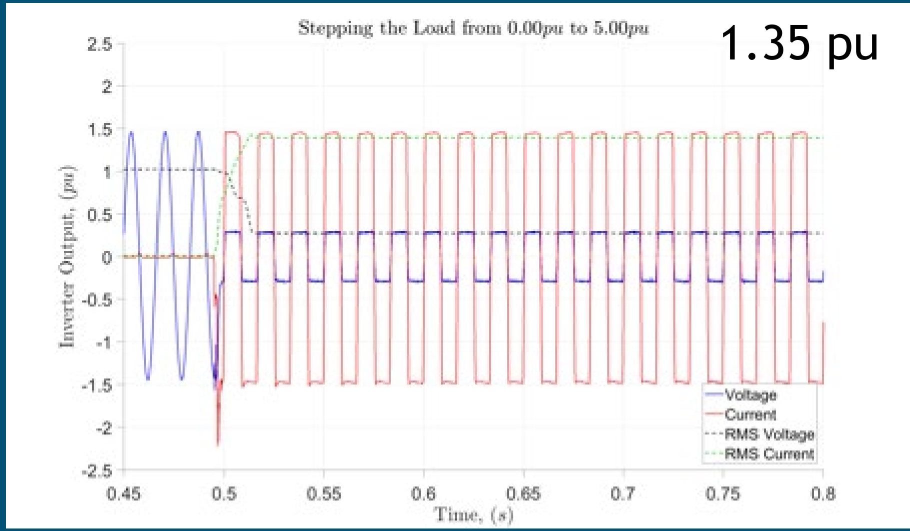




Testing transient response for validation:

- Single-phase
- ”Three-phase”
- Three-phase



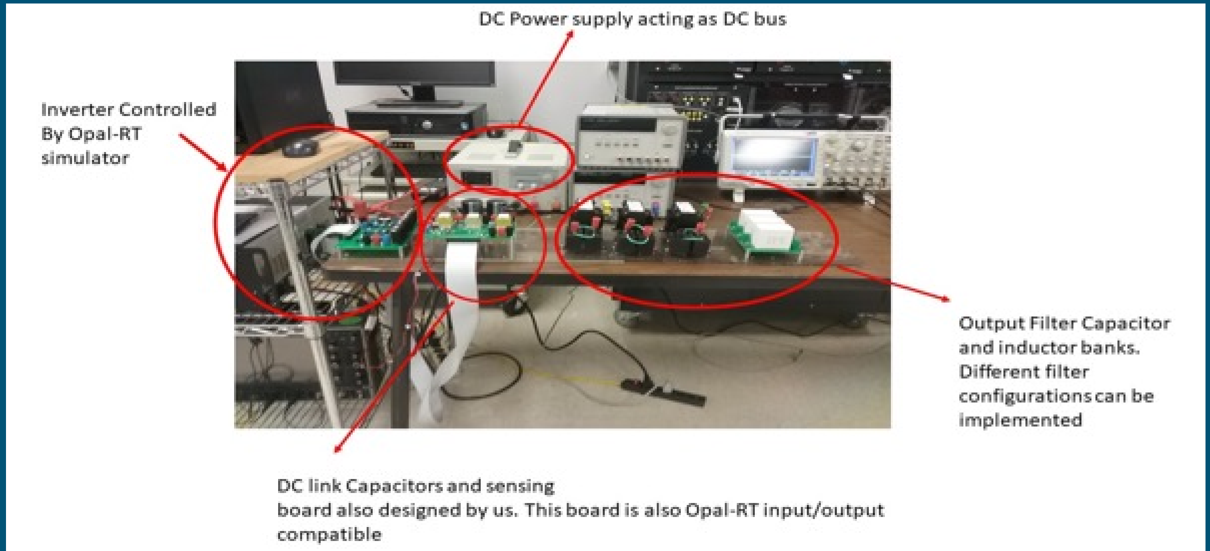


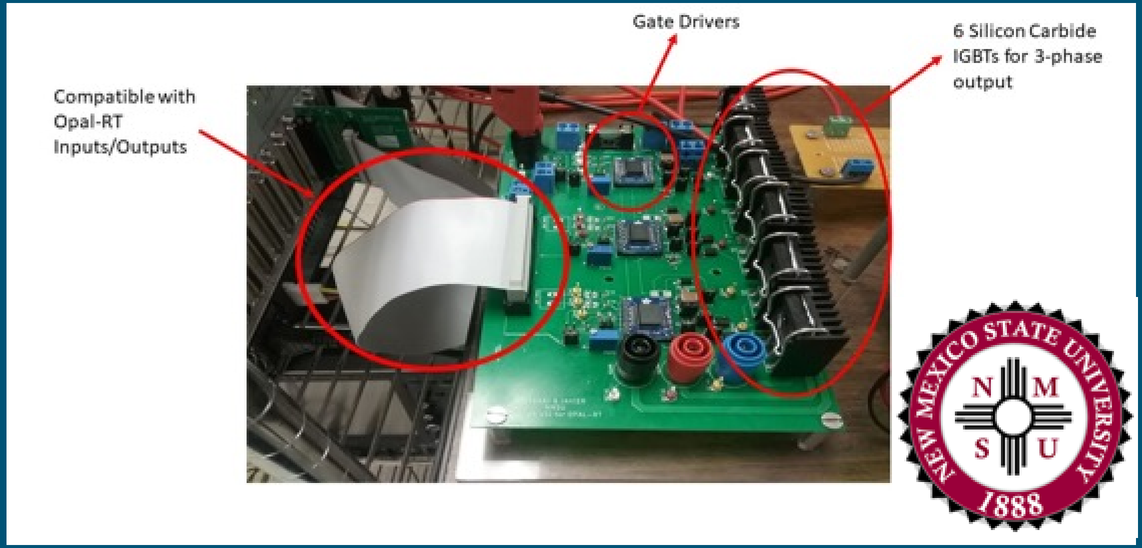
Sandia's Distributed Energy Technology Laboratory GFIs

Custom Hardware-in-Loop (HIL) GFM testbed being developed

- Testing of commercial units
    - Evaluation of behavior to large number of microgrid conditions (esp. fault behavior)

- Testbed to implement flexible control schemes in hardware
    - Evaluate dynamics of the internal signals of the inverter under unbalanced or fault conditions
    - Current work is ongoing to fabricate and commission the hardware testbed above





Design/Performance Challenges for Microgrids

- **Transition from GFL to GFM mode**
  - Grid Following must have anti-islanding protection (UL1741)
  - Grid Forming must initiate an island
  - How do we reconcile these disparate requirements in a **seemless transition**?
    - Technically being done
    - Significant standards issues

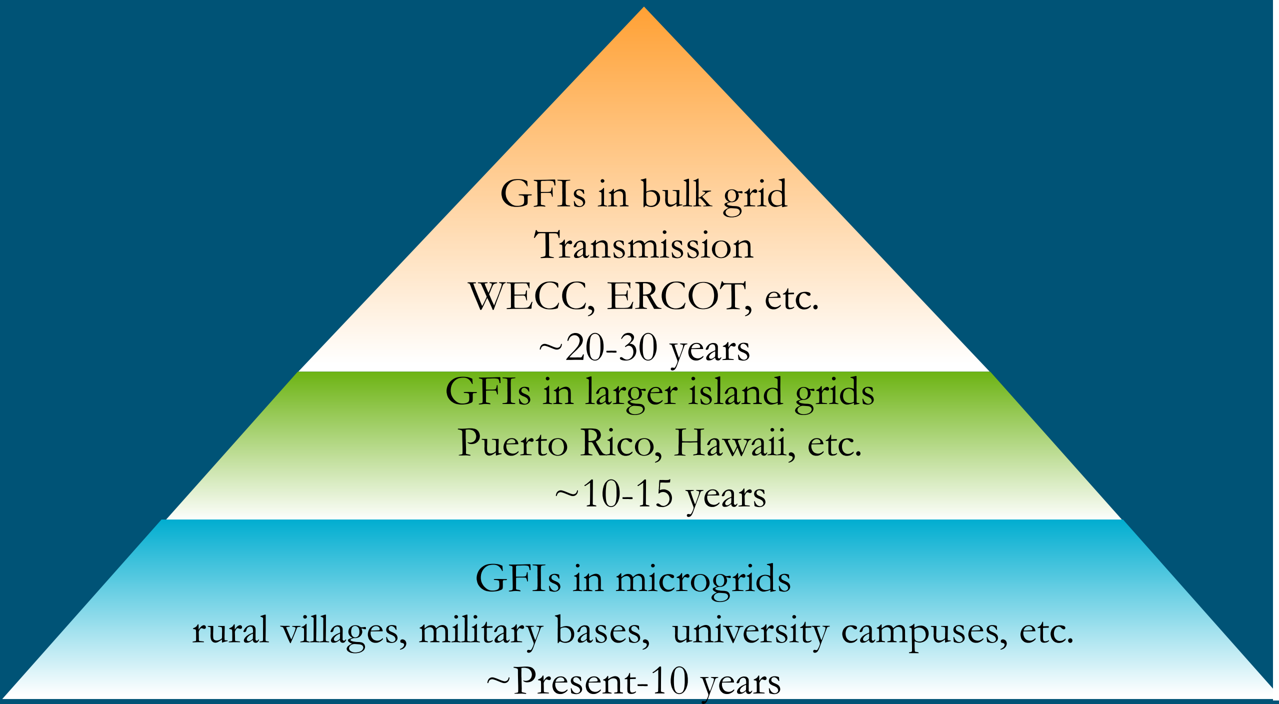
- **GFIs and protection**
  - Current protection designed for synchronous machines (short circuit ~10 pu)
  - Majority of GFI provide <2.5 pu (steady-state, 4-6 pu possible at <10 cycles)
  - How do we adapt protection for GFIs (or other inverter-based resources)
    - Increase short-circuit (requires control/hardware upgrades)?
    - Utilize synchronous condensers?
    - Do we need to totally **rethink protection paradigm** for power electronics?

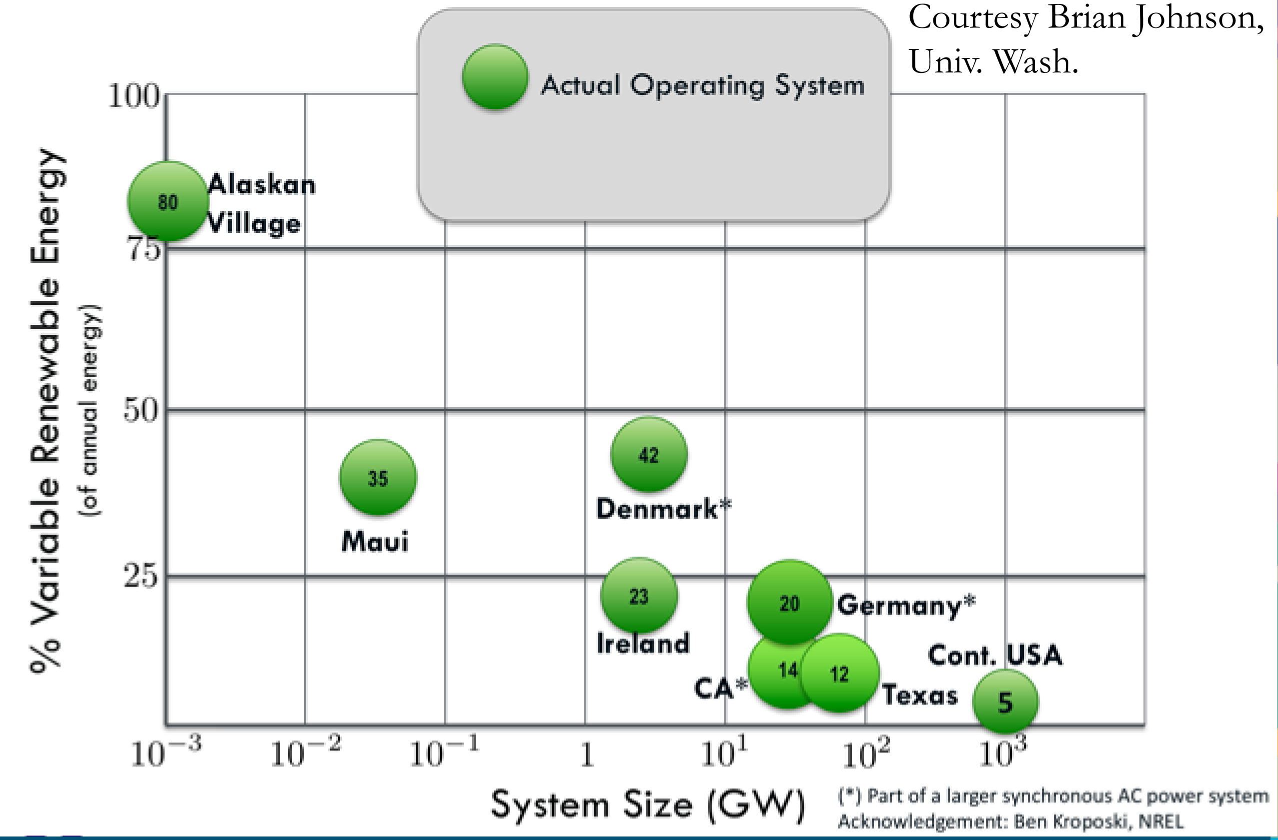
  - In general, synchronous generation is well defined
    - Need **standardized models** to understand impacts of GFM on protection schemes
    - Need **standardized behavior** for variety of control schemes

- **GFMs and unbalanced loads**
  - GFMs (and GFL) could be able to source negative and zero-sequence current
  - Most do not
    - Due to control schemes (PQ) and grounding (3- vs. 4-wire)
    - Significant implications to protection and response time

GFIs must transition from Microgrid to Bulk Grid

- GFI most likely occur through phased implementations
  - starting with smaller, more constrained microgrids
  - moving towards larger grids

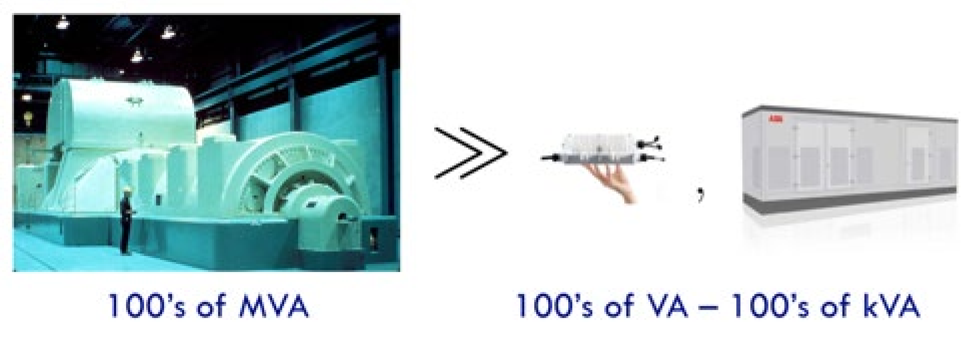




Courtesy Brian Johnson, Univ. Wash.

Challenges of moving from Microgrid to Bulk Power Space

- **Protection issues**
  - Protection becomes more complicated in bulk system
  - Bidirectional power flow for DERs on distribution system
  - Need for zero and negative-sequence currents
  - Inconsistent behavior inverter to inverter
- **Black start capabilities**
  - GFMs could be a major black start resource
  - Saturation behavior important due to inductive motor start
  - Black start/reserve by PV/wind → curtailment
- **Aggregation of DERs**
  - Current system is composed of centralized plants **~100 MVA**
  - Future system will be distributed resources of **0.1-100 kVA**
  - How do we accurate represent aggregations of small units?
  - Especially when connected on distribution system?



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