NREL Transforming ENERGY
The 49th Annual Conference of the IEEE Industrial Electronics Society (IES)
OCTOBER 16-19, 2023, MARINA BAY SANDS EXPO AND CONVENTION CENTRE, SINGAPORE
unifi consortium
universal interoperability for grid-forming inverters

Droop Control-Based Dispatch of an Islanded Microgrid With Multiple Grid-Forming Sources

Subhankar Ganguly[1], Jing Wang[1], Mariko Shirazi[2], Benjamin Kroposki[1]
[1]National Renewable Energy Laboratory
[2]University of Alaska Fairbanks
Benjamin.Kroposki@nrel.gov

Paper No: IECON23-000319

IEEE PES Power & Energy Society
IEEE

Background & Objectives

- Grid-forming (GFM) inverters are expected to parallel synchronous generators (SGs) before rotating, fossil fuel-based SGs are phased out.
- Primary droop control allows GFM inverters to share power without communications; however, it is necessary to dispatch GFM inverters and/or SGs with the desired output power for better energy management.
- **Goal of this work**: Develop an analytic approach to dispatching GFM inverters and SGs with the desired output power.
  - Shift the droop intercept up/down while maintaining the same frequency operating point to improve transient stability.

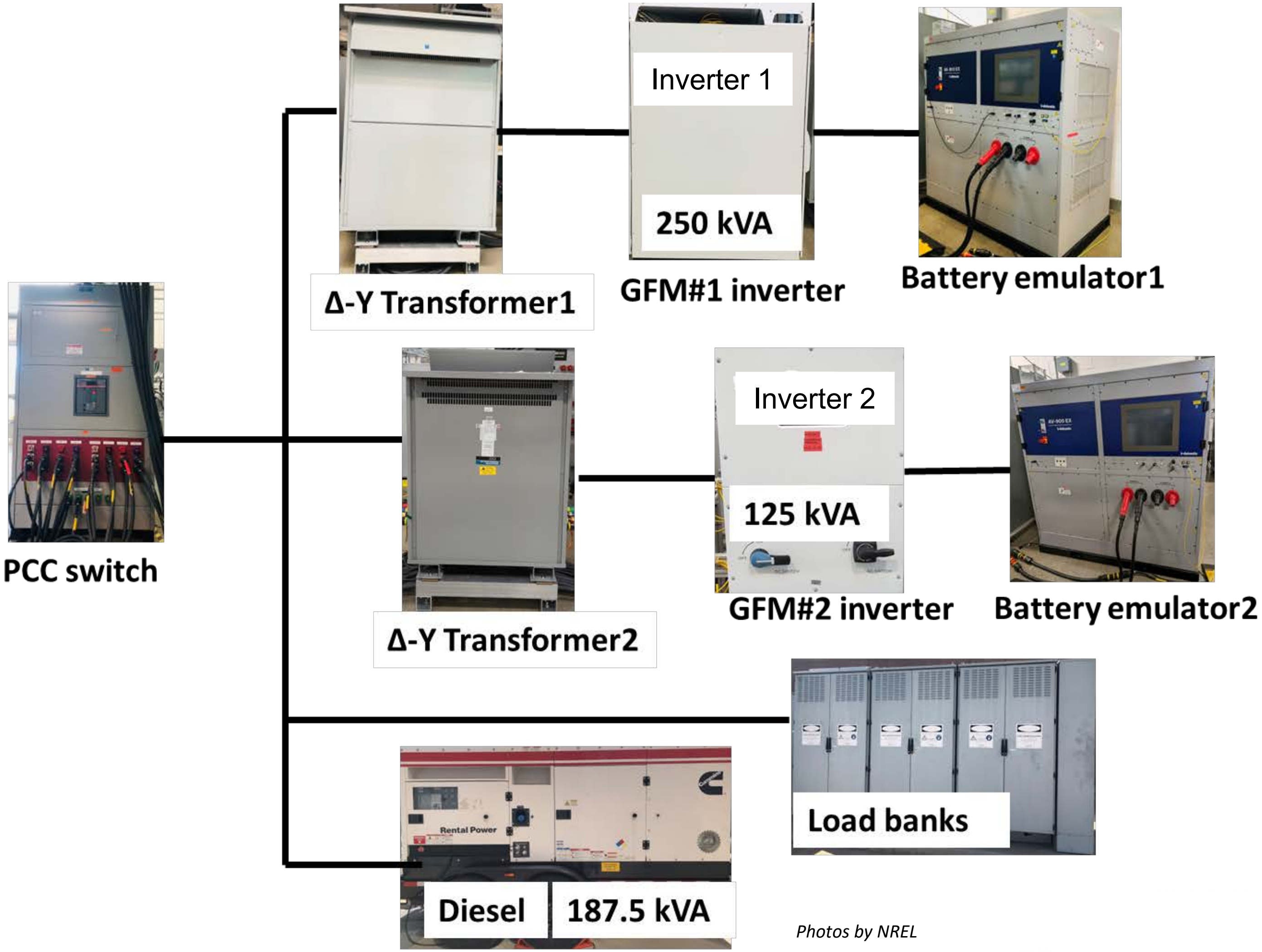
This concept is demonstrated through a pure hardware setup with two commercial inverters and one diesel generator.

Microgrid System Under Study

– Universal Interoperability for Grid-forming Inverters (UNIFI) Consortium is conducting multi-vendor testing to ensure that GFM inverters work together

– UNIFI 1-MW multi-vendor GFM inverter test bed:

- A microgrid system to demonstrate the concept
- PCC switch
- Two commercial GFM inverters and one diesel generator
- Each GFM inverter connected to a Δ-Y transformer
- Load banks (RLC load).

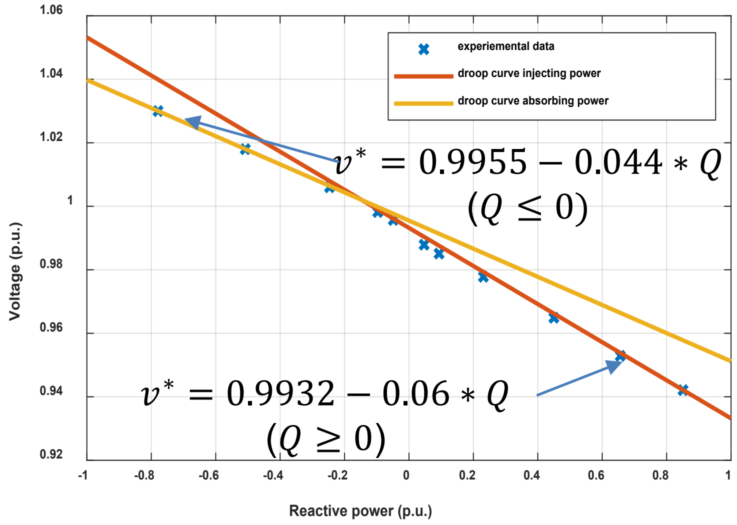


Photos by NREL

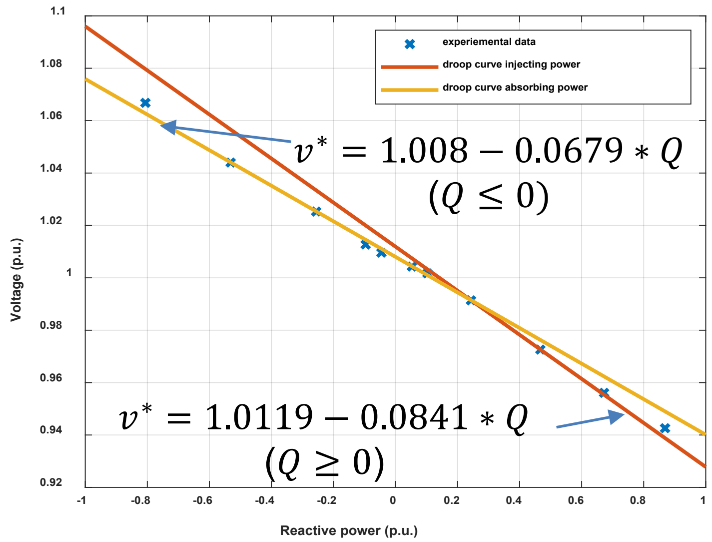
Droop Characterization of the GFM Sources

- The frequency droop matched the settings without adjustments.
- The voltage droop was off and needed to be characterized.
  - Steady-state test: 5%, 10%, 25%, 50%, 75%, 100%, PF=1, 0.8 lagging and leading, pure inductive and capacitive loads of the inverter capacity.

GFM#1 voltage droop characterization



GFM#2 voltage droop characterization



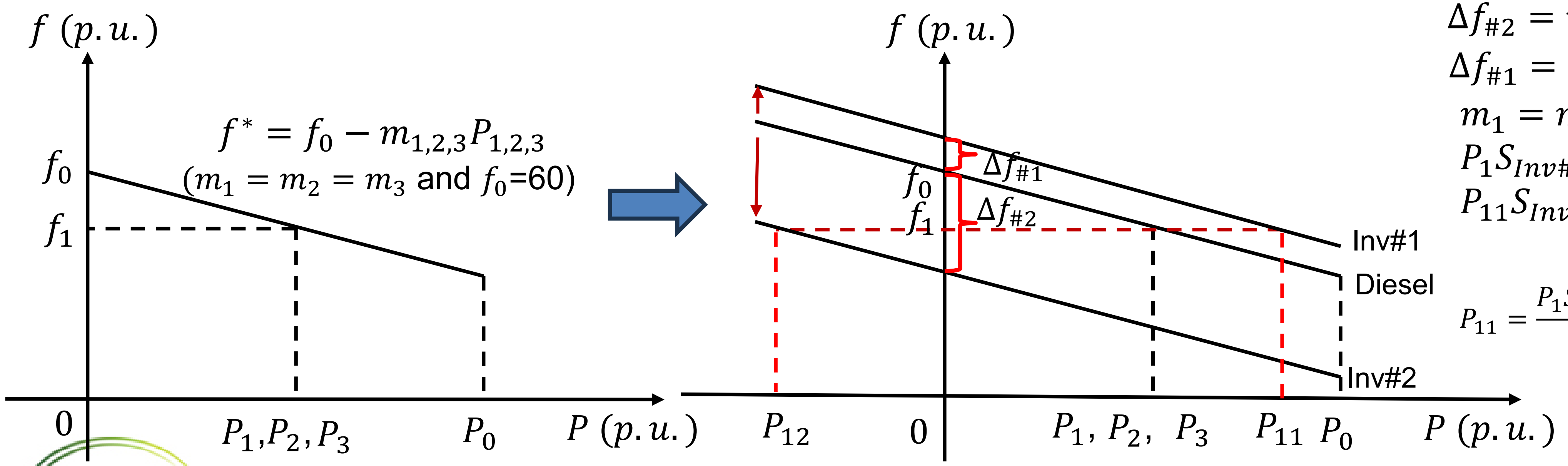
Diesel generator droop characteristics

- The frequency droop is 0.6% with a bias of -0.36 Hz representing the droop intercept of 60 Hz.
- The voltage droop is 3.7% with a zero bias representing the droop intercept of “1” p.u. voltage.

Droop-Based Real-Time Dispatch—Scenario #1

– Charge one GFM inverter with other GFM sources supplying the loads:

- Start from equal power sharing (left figure).
- Dispatch GFM#2 to charge the battery due to low SOC with the target power (right figure).
- Strategy: Shift the frequency droop intercept of GFM#2↓ and GFM#1↑, and keep the diesel at the same operating point for better stability.



$\Delta f_{\#2} = m_2(P_2 - P_{12})$ √

$\Delta f_{\#1} = m_1(P_{11} - P_1)$

$m_1 = m_2, P_1 = P_2$ and

$P_1 S_{Inv\#1} + P_2 S_{Inv\#2} = P_{11} S_{Inv\#1} + P_{12} S_{Inv\#2}$ √

⬇

$$P_{11} = \frac{P_1 S_{Inv\#1} + P_2 S_{Inv\#2} - P_{12} S_{Inv\#2}}{S_{Inv\#1}}$$

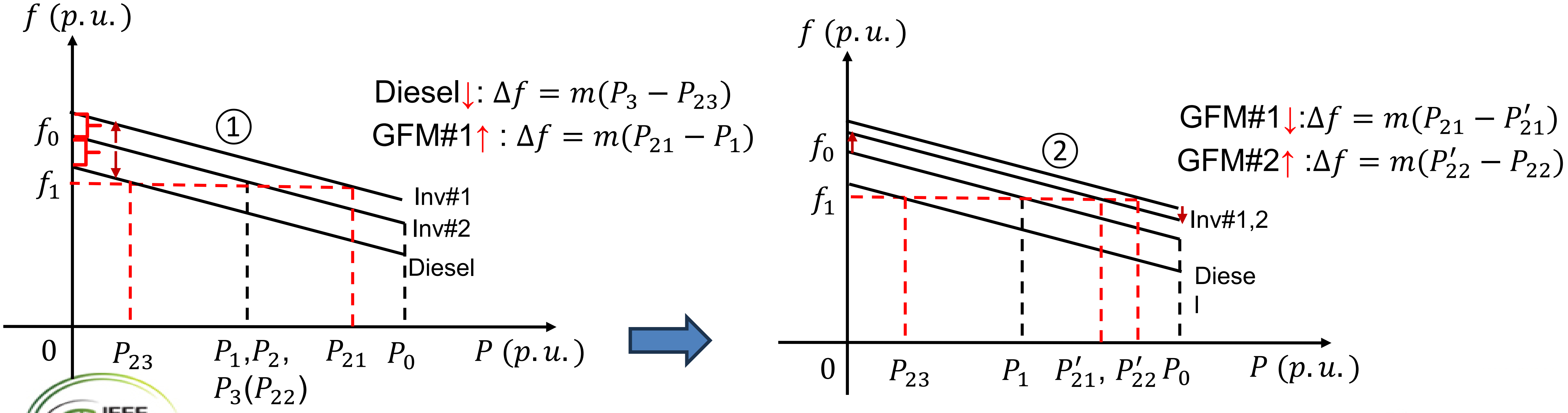
⬇

$\Delta f_{\#1}$

Droop-Based Real-Time Dispatch—Scenario #2

– Reduce the diesel output and let the two GFMs equally share power (start from equal power sharing):

- Step 1: Shift the frequency droop intercept of diesel↓ and GFM#1↑, and keep GFM#2 at the same operating point for better stability.
- Step 2: Shift the frequency droop intercept of GFM#1↓ and GFM#2↑ for equal power sharing, and keep the diesel at the same operating point for better stability.



Experiment Setup

System Configuration

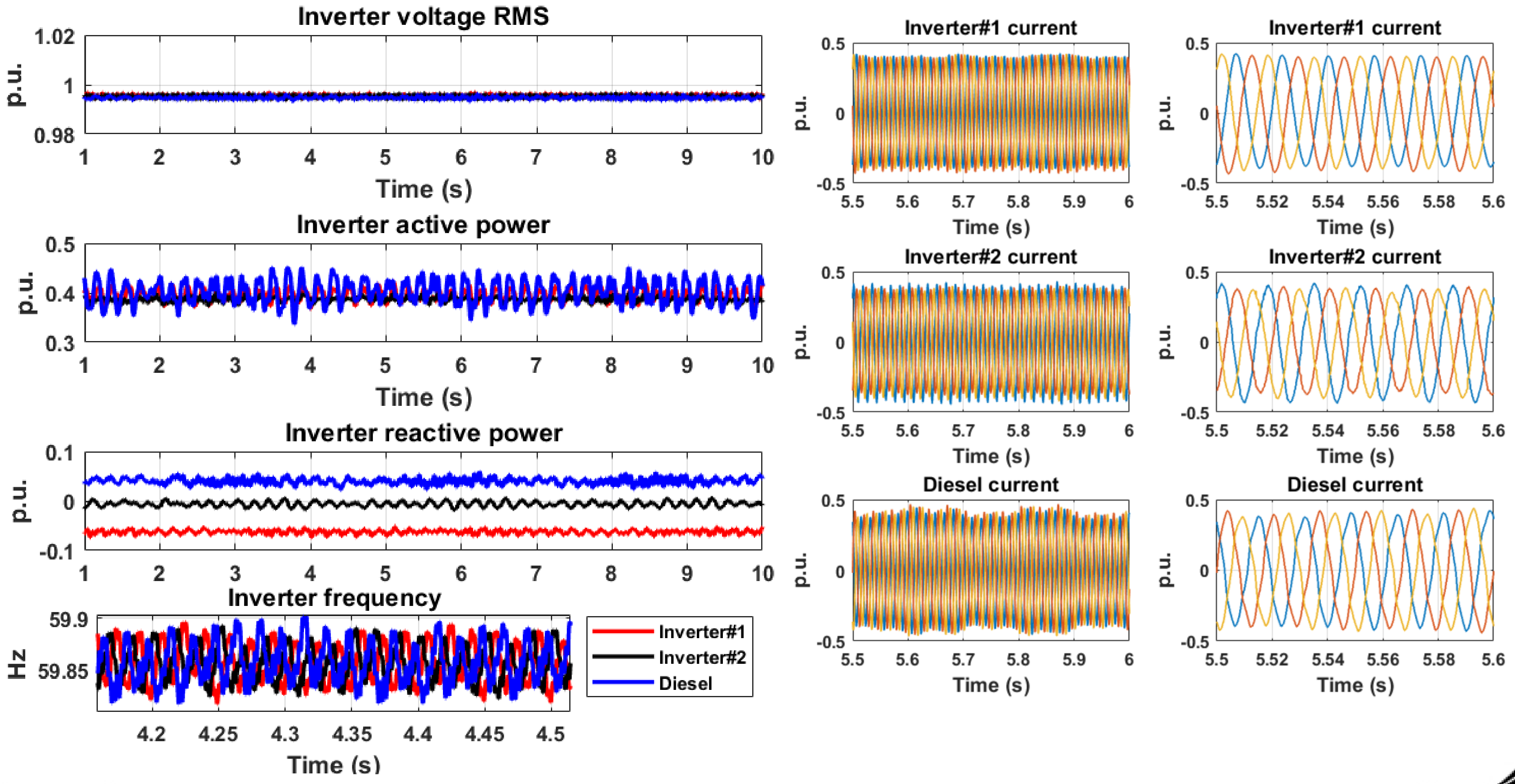
- Use the same frequency droop for all three GFM sources (0.6%).
- The voltage droop ($n * Q * 480$) needs to be compensated to avoid unnecessary reactive power flow.
- For the real-time dispatch, a controller is developed to simultaneously dispatch the three GFM sources through Modbus TCP/IP.

Element	Capacity	Configuration/Feature
Inverter 1	250 kVA	Droop: 0.6% (f-P) and 6% (v-Q). Change f^* directly to shift the droop intercept.
Inverter 2	125 kVA	Droop: 0.6% (f-P) and 5.68% (v-Q). Change the bias (default is zero) to shift the droop intercept.
Diesel generator	187.5 kVA	0.8 PF, 0.6% (f-P), and 6% (v-Q). Change the bias (default is -0.36 Hz) to shift the droop intercept.
Battery emulator 1	±660 kW	DC voltage: 900 V; current: 306 A; power: 275 kW
Battery emulator 2	±250 kW	DC voltage: 850 V; current: 162 A; power: 137.5 kW
Transformer 1	500 kVA	Delta: 480 V; wye: 480/277 V; current: 601 A, Z: 6%
PCC switch	1600 A	1600-A 4-pole circuit breaker
Transformer 2	250 kVA	Delta: 480 V, wye: 480/277 V; current: 300A, Z: 4.4%
Load banks	2*250 kVA	2 units in parallel 480 V, 3 phase

Experiment Results

– Baseline: GFM sources **equally share power** on a per-unit basis.

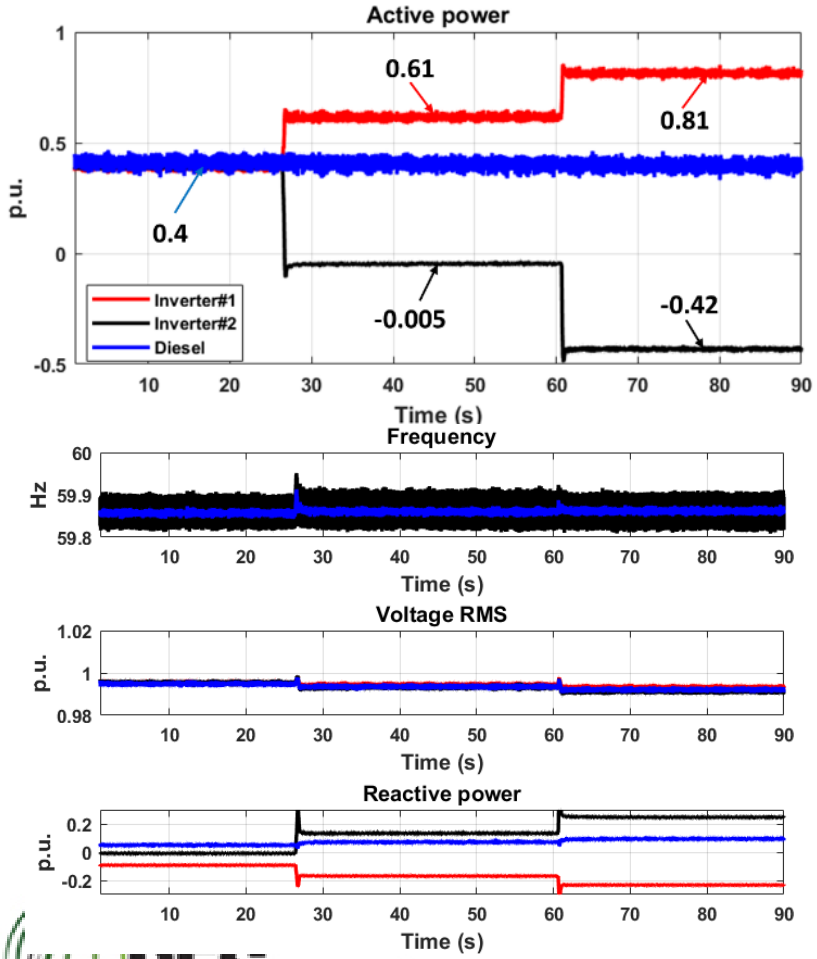
- Total load is equal to 40% of the total capacity of the three GFM sources.

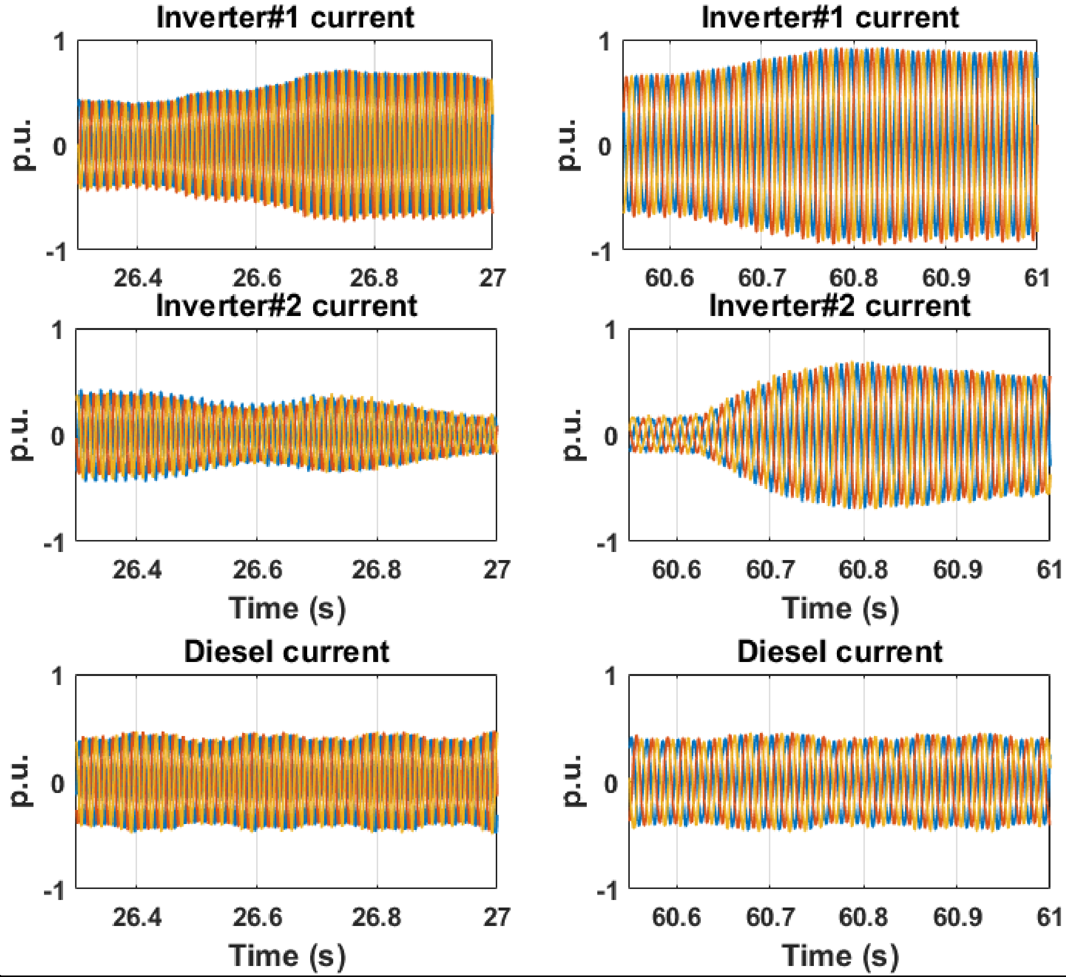


Experiment Results

– Scenario #1: Dispatch GFM#2 Absorbing Desired Power

- Step 1: GFM#2 injects zero power; Step 2: GFM#2 absorbs 0.4 p.u. active power.





Conclusion:

Two steps are taken because there might be instability with such a big frequency intercept shift:

- The overall dispatch target is achieved.
- The tracking error is due to the round-up of the frequency droop intercept

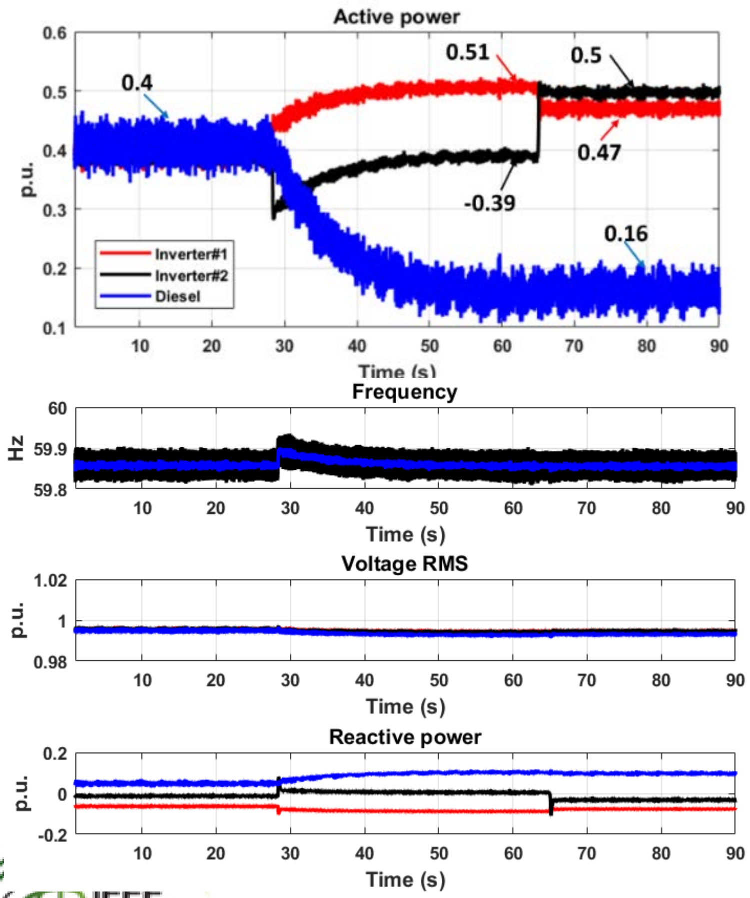
$$GFM1:\ \Delta f = 0.006 * (0.4 - (-0.4)) * 60 = 0.288 \approx 0.29\ Hz$$

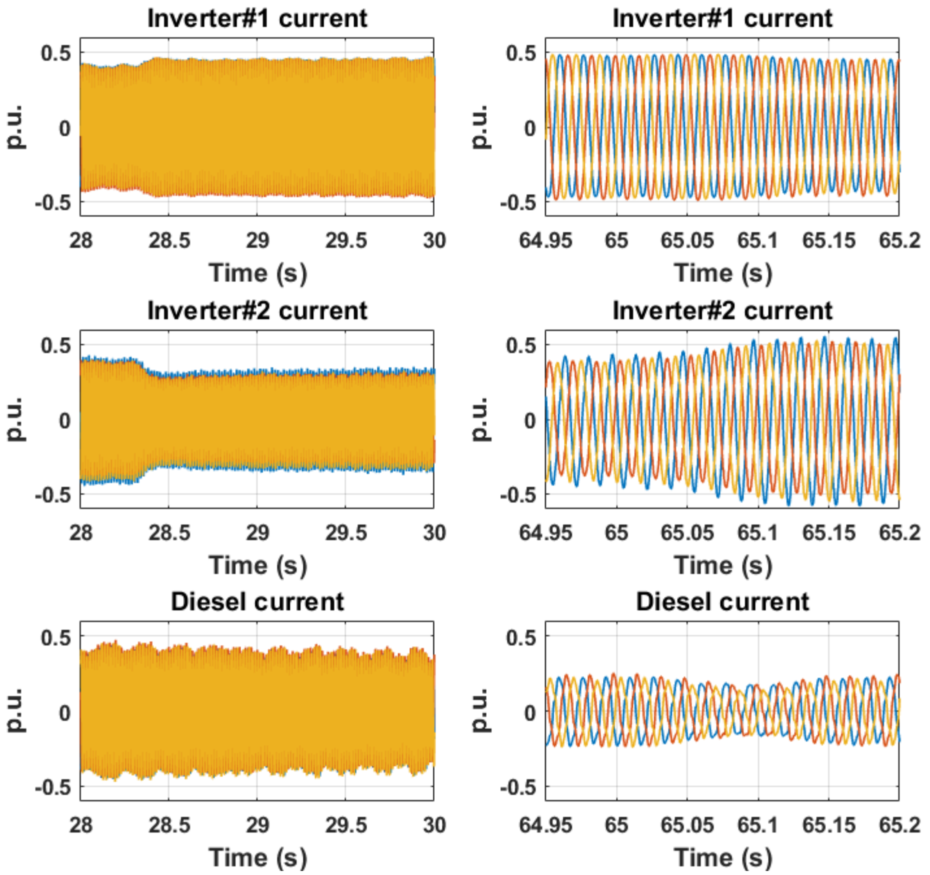
All GFM sources can only take two decimals.

Experiment Results

– Scenario #2: Reduce power in the diesel and let the GFM inverters equally share power.

- Step 1: Diesel outputs 0.15 p.u. (minimal loading), GFM#1 takes over the power from the diesel.
- Step 2: GFM#1 and GFM#2 equally share power.





Conclusion:

- The overall dispatch target is achieved.
- The tracking error is due to the round-up of the frequency droop intercept.
- Demonstrates the concept of dispatching GFM sources' power through dispatching the frequency droop intercept.

Conclusions

- The experimental results show that the dispatched GFM sources respond to the changed droop intercept to output the desired active power, and it is important to maintain the same frequency.
- It is important to compensate for the voltage drop across the transformers in the voltage droop equations to achieve the expected reactive power sharing.
- Even though the concept is demonstrated in an islanded microgrid, the concept is applicable to grid-connected operation.
- This dispatch algorithm can be included in energy management systems to dispatch a system with both GFM and grid-following (GFL) inverters.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office Agreement Number 38637. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.