# Controller-Hardware-in-the-Loop Evaluation of a Microgrid Controller for a Microgrid System With Multiple Grid-Forming Inverters

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## Abstract

This paper presents the laboratory evaluation of a commercial microgrid management system (MGMS) implemented in the real-world Bronzeville Microgrid that features a futuristic scenario with high renewable energy integration and the use of multiple grid-forming (GFM) inverters. The laboratory controller-hardware-in-the-loop (CHIL) provides realistic testing environment through detailed electromagnetic transient modeling of the microgrid system, hardware MGMS, and standard communication protocols (DNP3).

- The primary objective of the performance evaluation for the MGMS is **to assess the MGMS's capability to dispatch GFM units, including a GFM photovoltaic (PV) unit and two GFM battery units**, to maintain the system stability and ensure economic operation.
- This CHIL evaluation shows how the MGMS effectively manages the GFM inverters, **highlighting its performance in maintaining stability, reliability, and survivability in a microgrid environment with a high penetration of renewable energy sources.**

## System Configuration of Bronzeville Microgrid

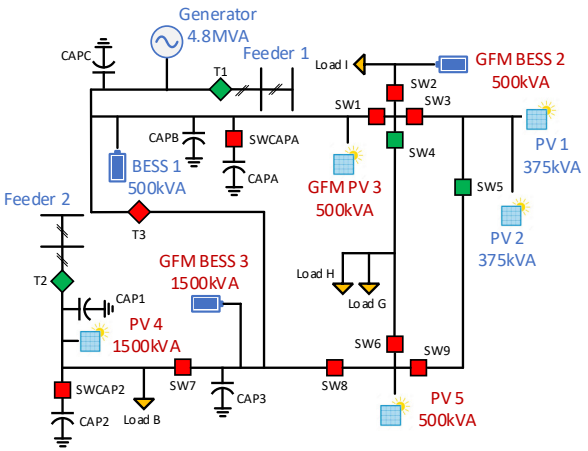
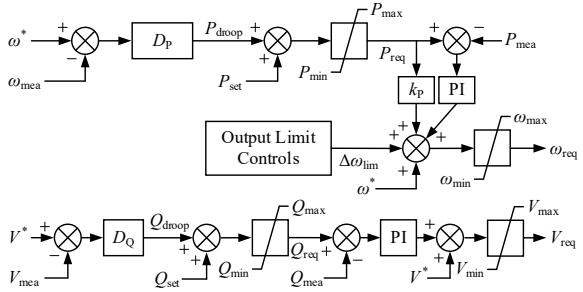



Fig. 1: The system diagram of the microgrid under testing

## Conclusion

- PV inverters can operate in GFM mode in parallel with traditional battery GFM inverters. **Power sharing is achieved among GFM battery energy storage system (BESS) and PV inverters** by dispatching voltage and frequency setpoints from distribution management system with GFM PV set with dynamic and vertical droop for low solar irradiance conditions.
- **Both GFM PV and battery inverters can be dispatched through frequency and voltage set points to output the target power**, which is aligned with UNIFI 1-MW demo testing approach.
- The CHIL evaluation of the microgrid controller demonstrates that the target performances are achieved, **including islanded energy management for 24 hours, secondary control, constraint management (voltage), autonomous islanding operation, and black-start and autonomous synchronization operation**.

## GFM PV Controls for Parallel Inverter Operations




## Secondary Controls for GFM PV and Battery Inverters

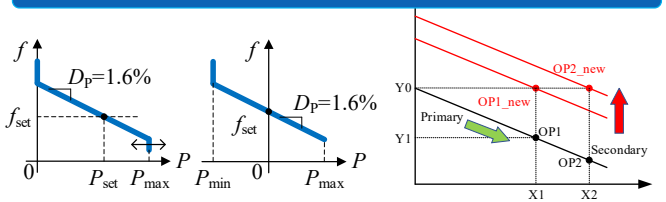
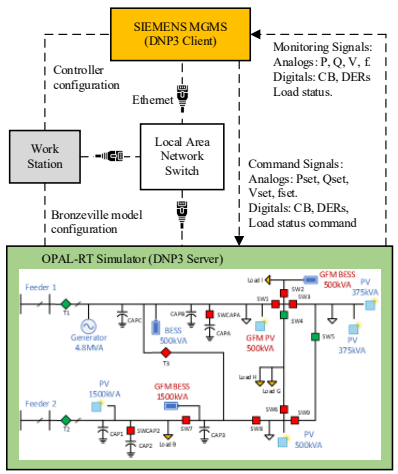



Fig. 2. Droop for GFM PV (left) and BESS (right). Fig. 3: MGMS secondary controls.

## Laboratory Controller-Hardware-in-the-Loop Validation

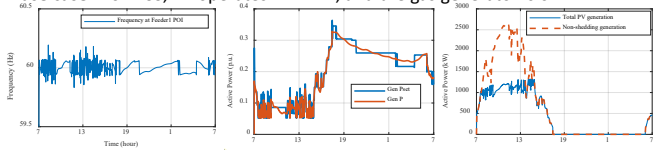



## Case Studies

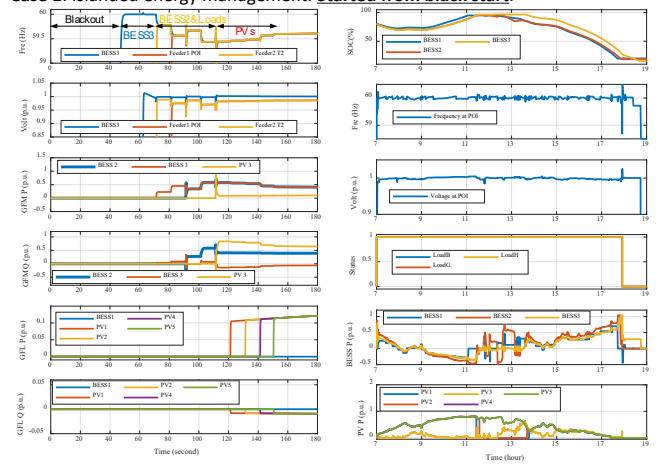
**Case settings**:

| | | | |
|---|---|---|---|
| Base ase | 24 hours. Generation and load balance | Case 1 | Up to 24 hours. Coordinate the generation and consumption during island operation. |
| Case 2 | 30 min. Regulate the system frequency to nominal during the dynamic changes. | Case 3 | 30 min. Coordinate the microgrid assets (DERs, capacitor banks) to relieve high-voltage constraints. |
| Case 4 | 5 min. The system goes into unplanned islanding and survives. | Case 5 | 5 min. The microgrid will send control signals to the POI relay to synchronize to the grid. |

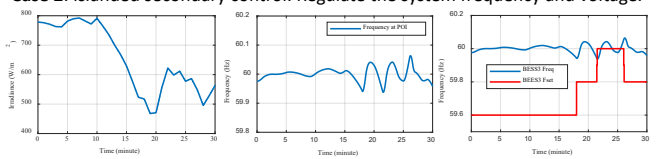
**Base case**: No BESS, PV operates in MPPT, and the gas generator is on.



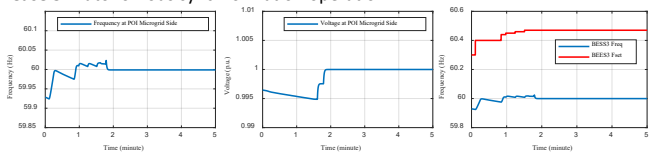
**Case 1**: Islanded energy management. **Started from black start**.




**Case 2**: Islanded secondary control. Regulate the system frequency and voltage.



**Case 5**: Autonomous synchronization operation.



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