48th ANNUAL CONFERENCE OF THE INDUSTRIAL ELECTRONICS SOCIETY
IECON' 2022 | 17-20 October

Study of Inverter Control Strategies on the Stability of Low-Inertia Microgrid Systems

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Paper No: IECON22-000149

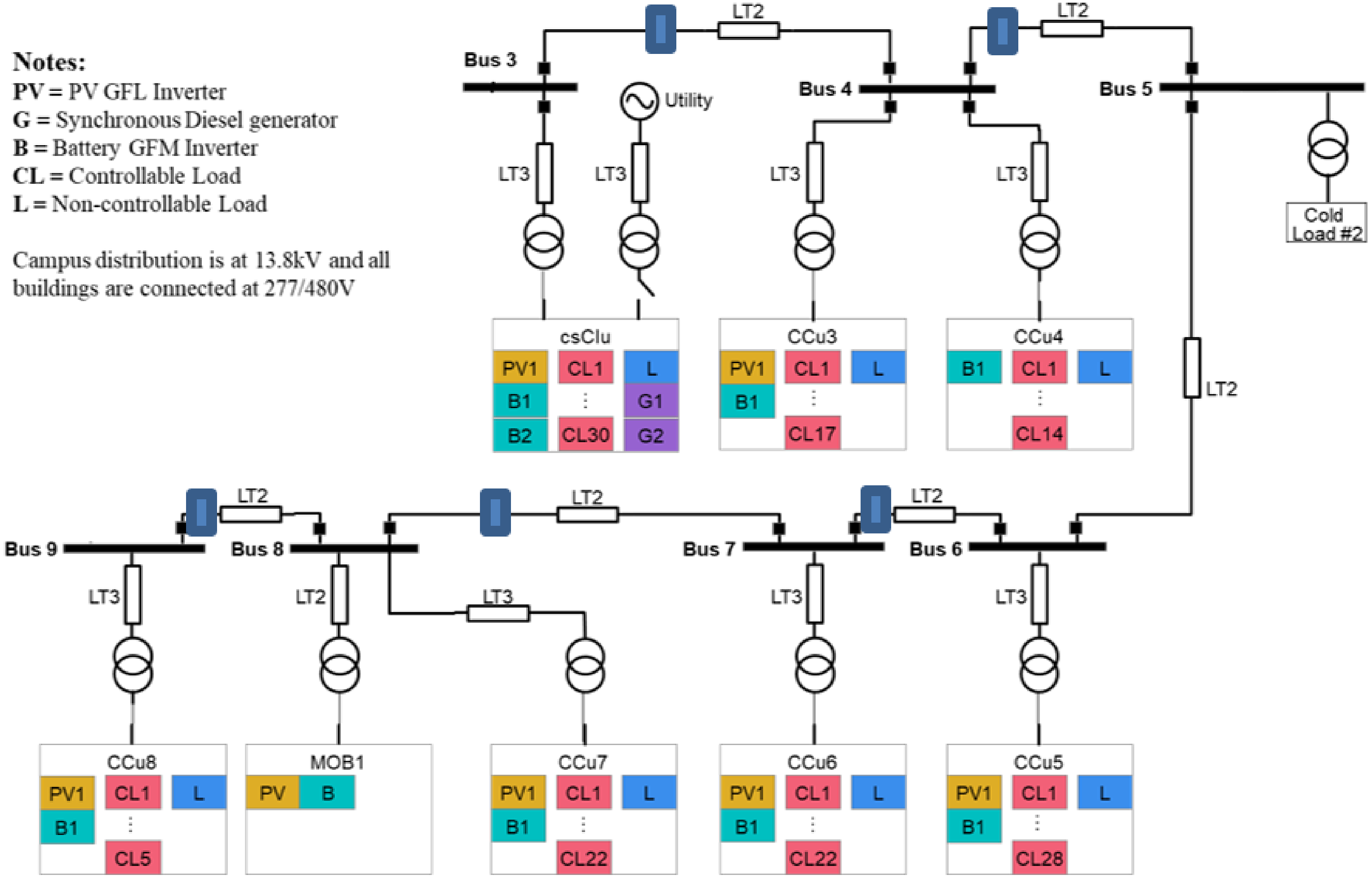
Background & Objectives

- An islanded campus-based microgrid powered by grid-forming (GFM) and grid-following (GFL) inverters and diesel generators
- Need to compare two types of control strategies:
  - Strategy I: All battery inverters work in GFM mode with power sharing by droop control (50% GFM inverters).
  - Strategy II: Only two battery inverters work as GFM sources (10% GFM inverters).

Based on the study, select the more appropriate control strategy for the microgrid.

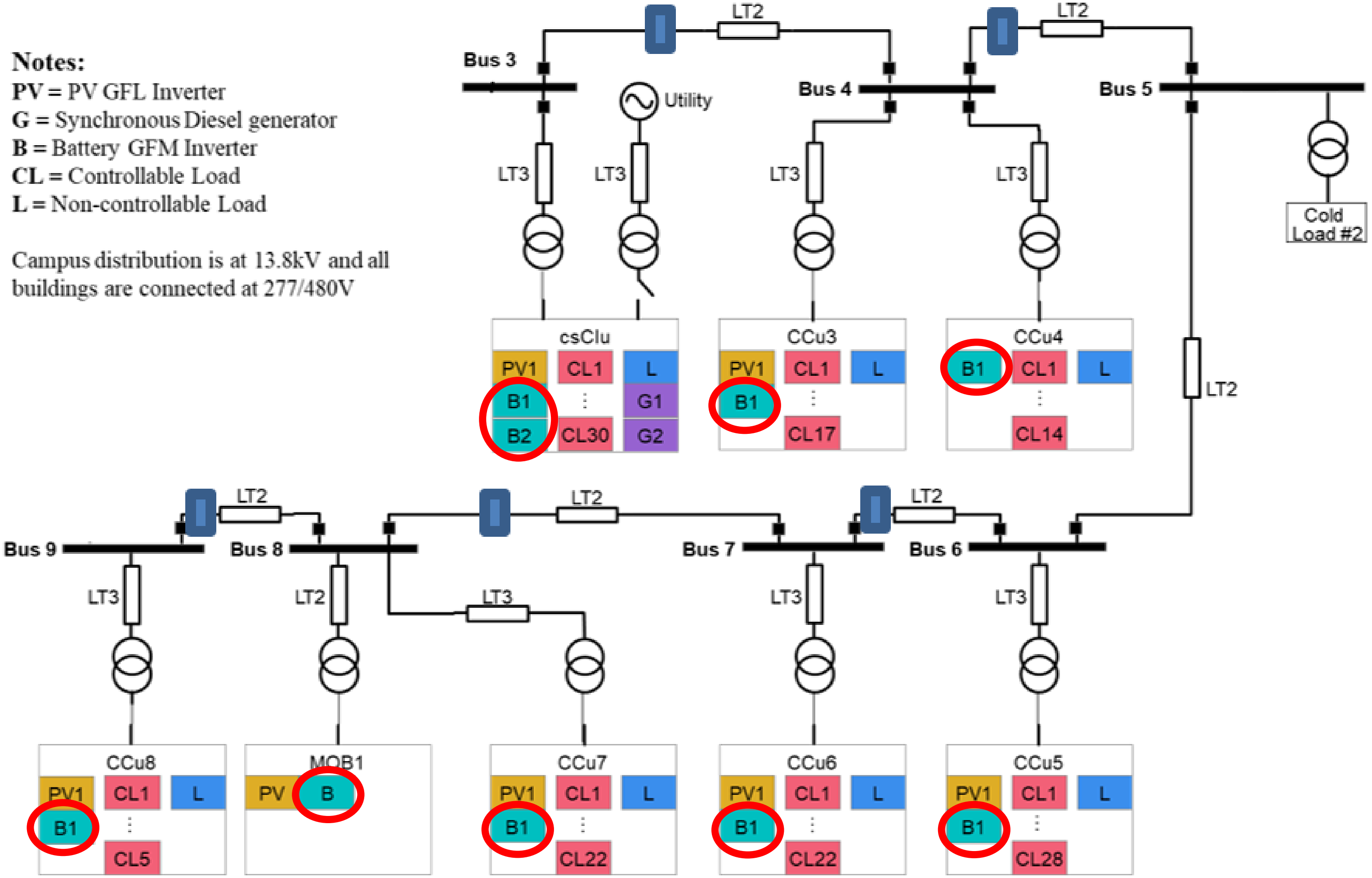
Microgrid System Under Study

- University of Minnesota campus microgrid:
  - Islanded mode
  - 9 battery inverters (GFM/GFL mode)
  - 7 GFL PV inverters
  - 2 diesel generators in GFL PQ mode
  - Building loads.
- EMT real-time simulation:
  - OPAL-RT eMEGASIM (100 us)
  - ARTEMiS-SSN
  - V-type interface for partitioning
  - Changing load and PV profiles.



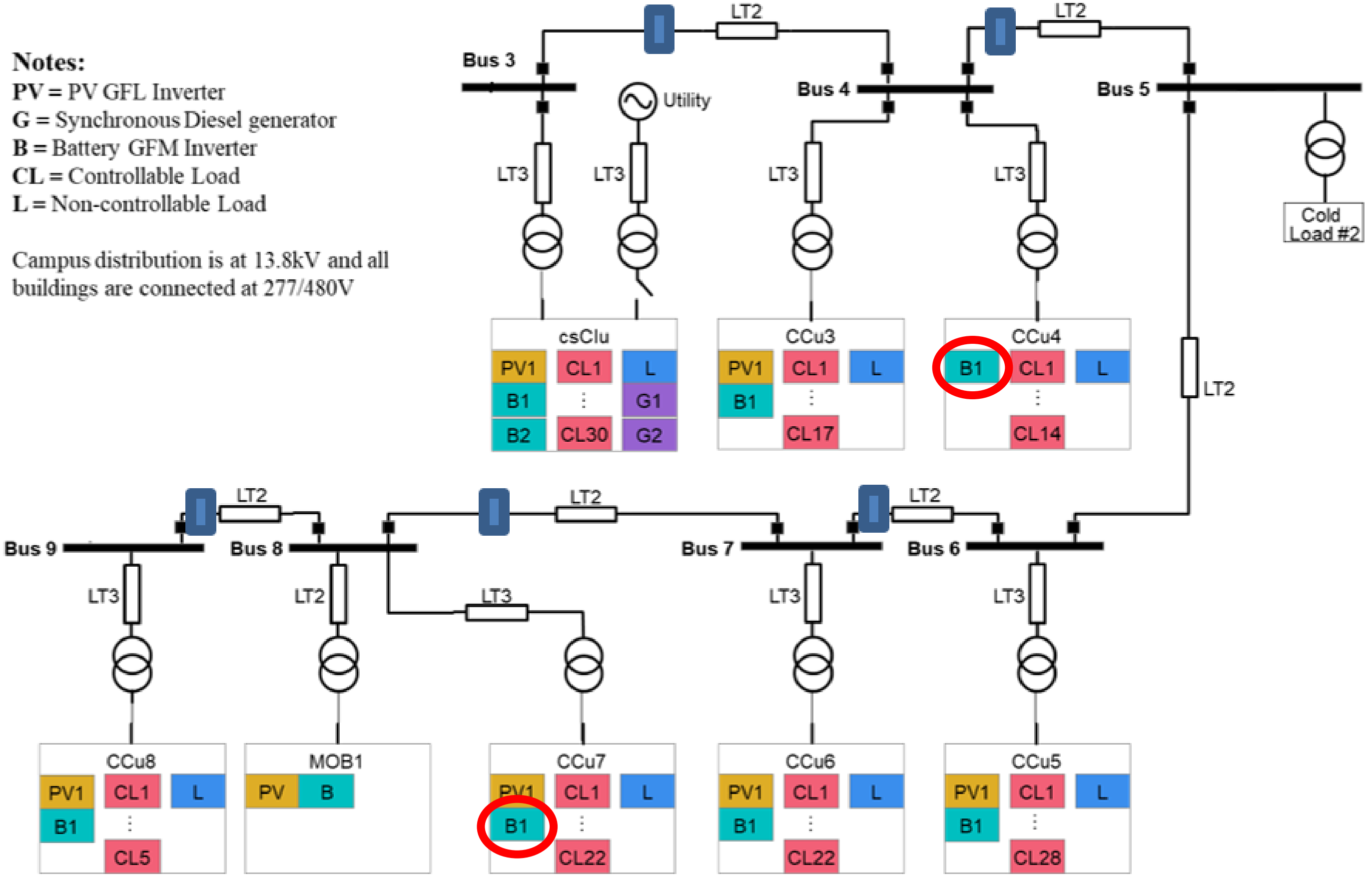
Strategy I: 50% GFM Inverters

- 9 GFM battery inverters:
  - Power sharing with droop control
  - Droop coefficients (mp and nq) calculated based on inverter capacities
  - Changing system voltage and frequency
  - Bias $\Delta\omega$ and Δv are added in the primary control.
- 2 diesel GFL mode
- 7 GFL PV inverters.



Strategy II: 10% GFM Inverters (Original)

- **2 GFM battery inverters:**
  - Power sharing with droop control
  - Droop coefficients (mp and nq) calculated based on inverter capacities
  - Changing system voltage and frequency
  - Bias $\Delta\omega$ and Δv are added in the primary control.
- 2 diesel GFL mode
- 7 GFL PV inverters and **7 GFL battery inverters.**



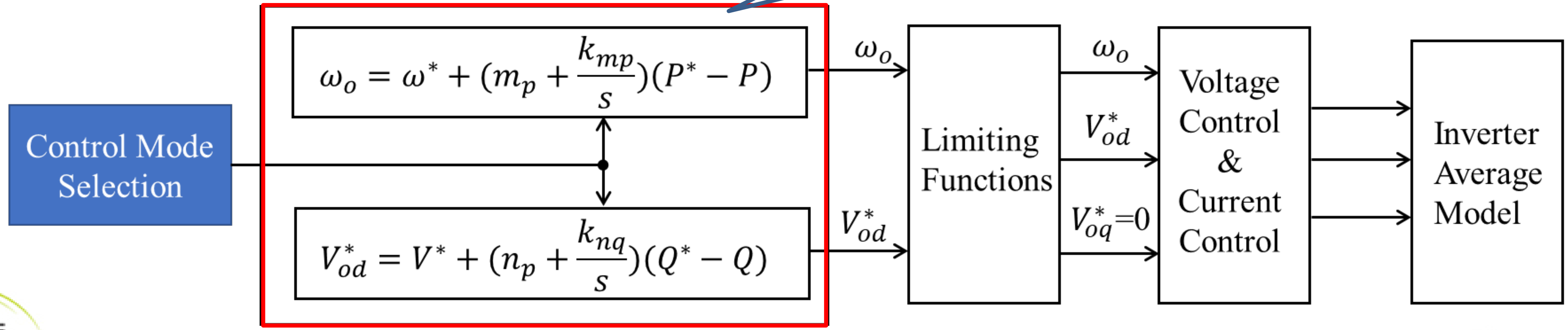
The system is unstable when loads change, and two GFM inverters struggle to reach new operating points of voltage and frequency.

The islanded microgrid does not have enough GFM capability.

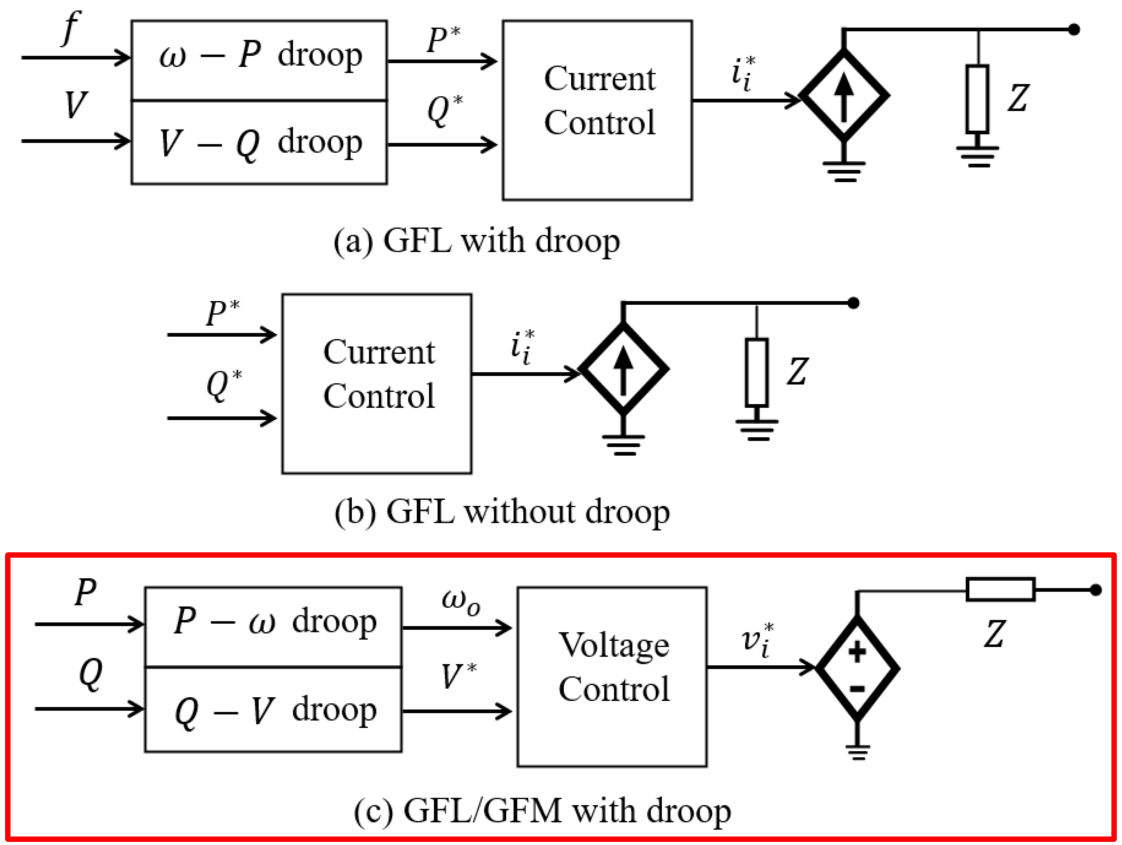
Strategy II: 10% GFM Inverters (Improved)

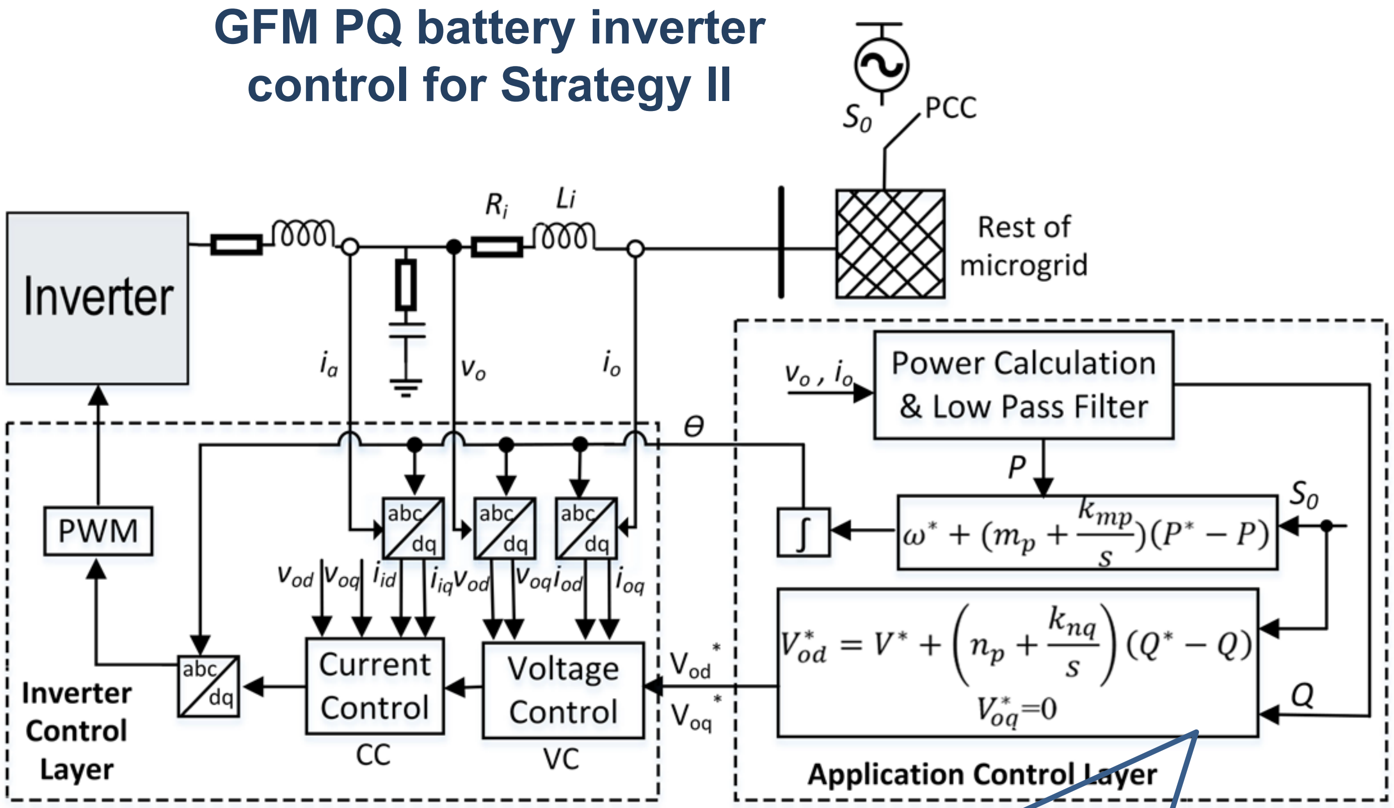
- **2 GFM battery inverters:**
  - No power sharing
  - Isochronous control with fixed voltage and frequency.
- 2 diesel GFL mode
- 7 GFL PV inverters
- **7 GFL battery inverters:**
  - **Change from GFL PQ control to GFM PQ control**
  - **Inverter-level control uses VF control.**

- Power tracking needs to enable the integrator.
- This only works well with fixed frequency.
- GFM inverters need to work in isochronous mode.



Inverter Modeling and Control



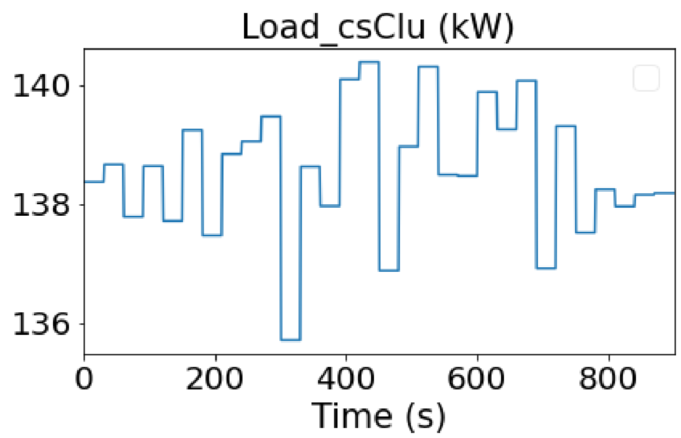


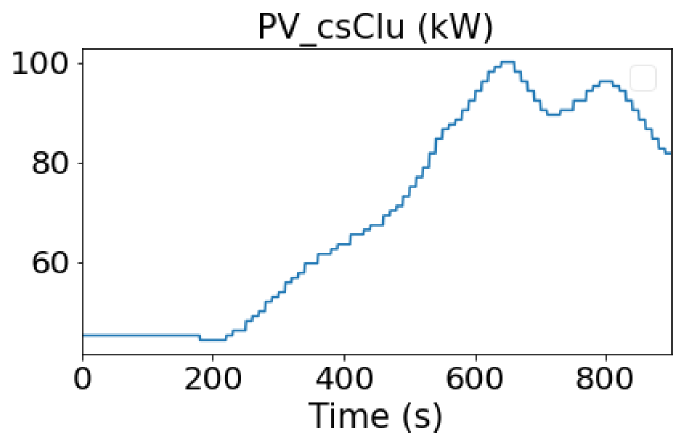
- Kmp and Knq are very small (1×10^{-4}).

Simulation Results

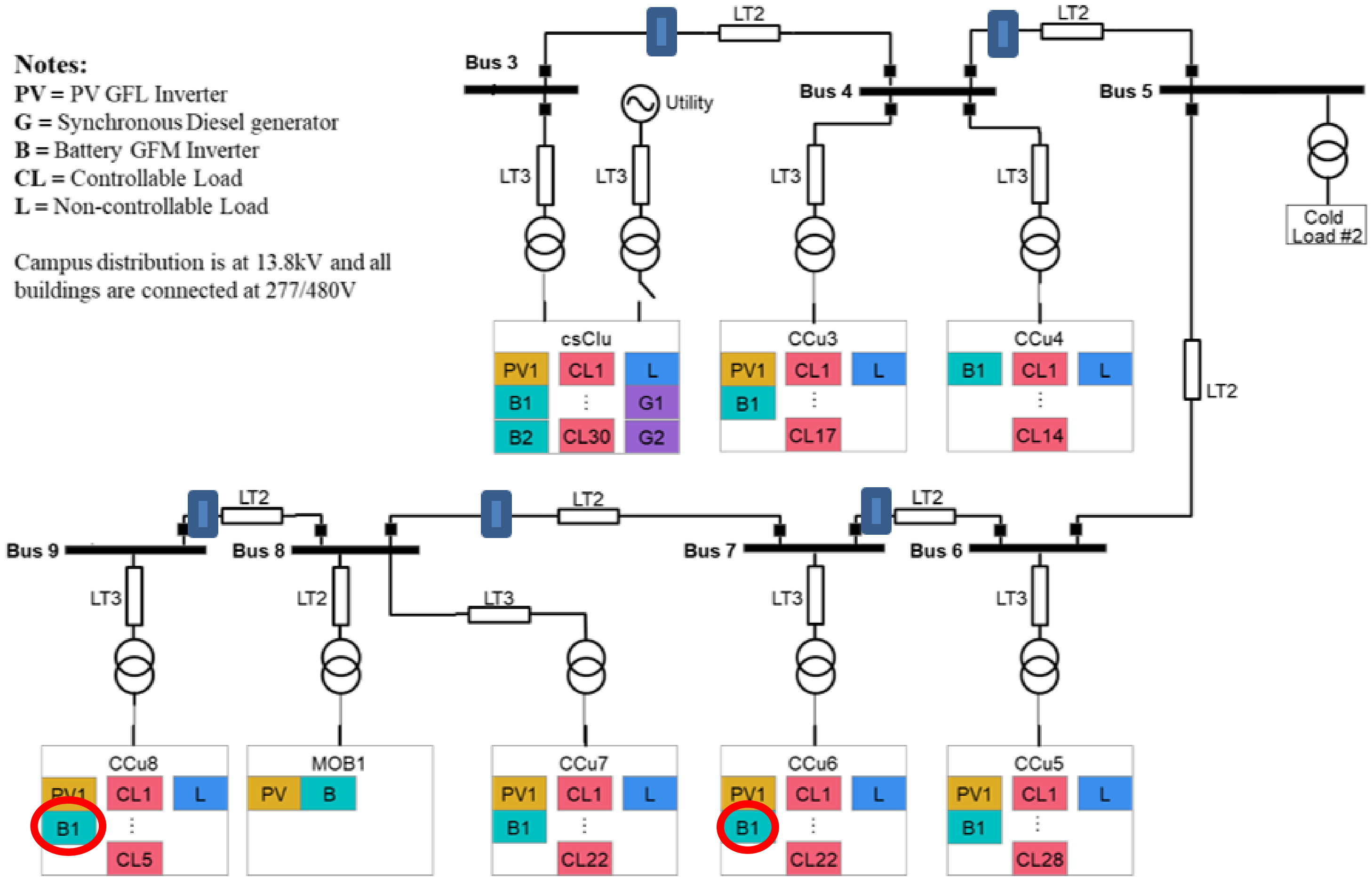
Simulation Setup

- Configuration for a 15-minute test:
  - Load profiles are from the metering system with a resolution of 30 seconds.
  - PV profiles are from NREL's solar Measurement and Instrumentation Data Center with a resolution of 10 seconds.
  - Changing load and PV generations provide good testing conditions to evaluate the stability of the microgrid.





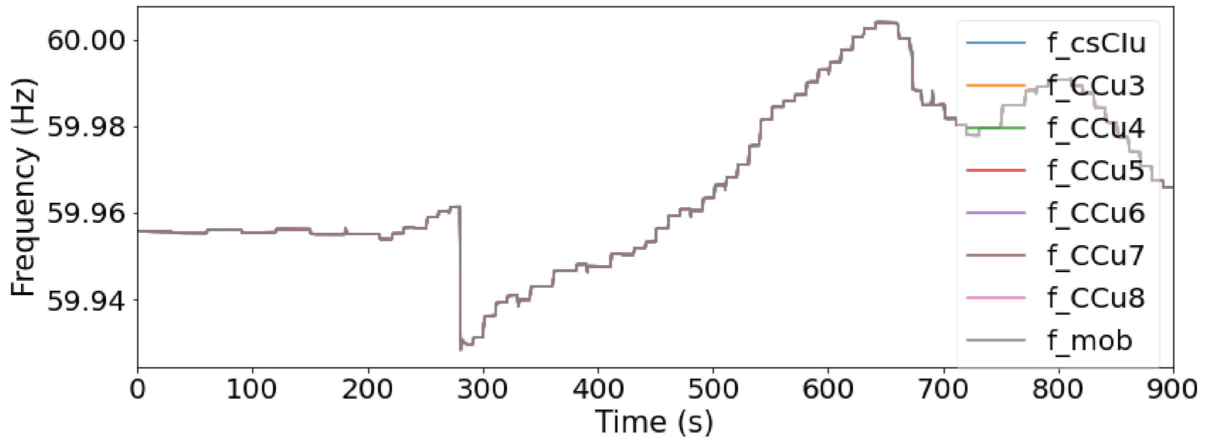
Simulation Results



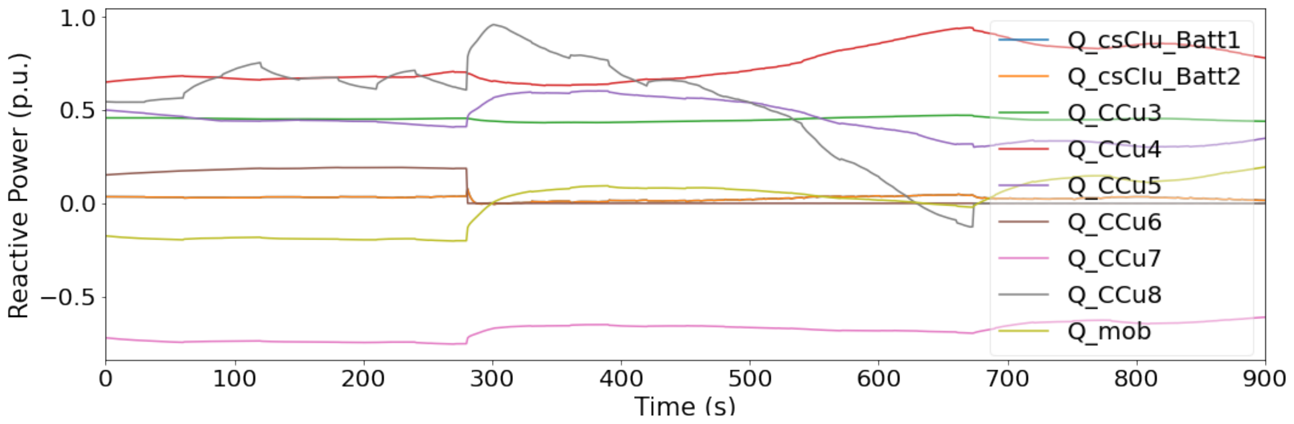
- Two contingency events are applied to see the transient stability of the microgrid under two strategies:
  - 1st: A 200-kVA battery inverter is disconnected at 5 minutes at CCu6.
  - 2nd: A 50-kVA battery inverter is disconnected at 11.5 minutes at CCu8.

Simulation Results for Strategy I

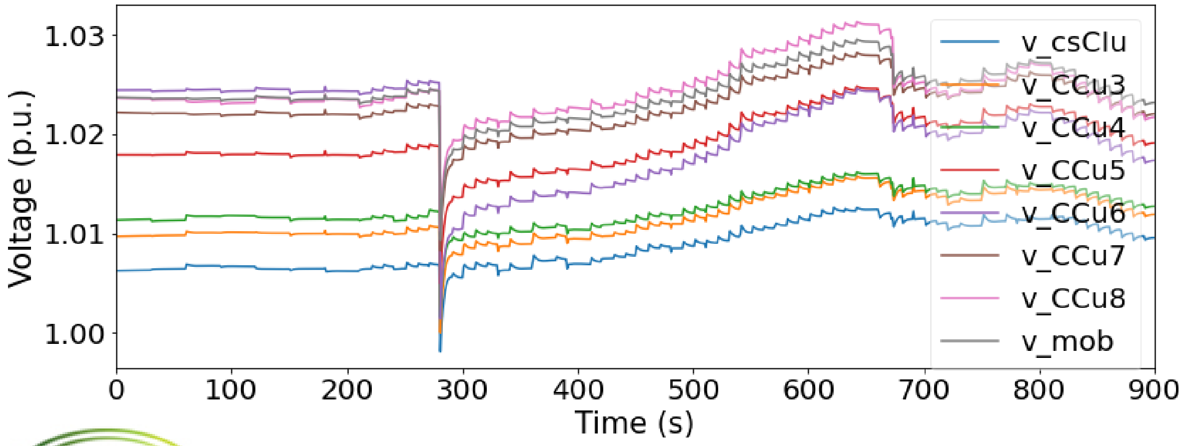
— All battery inverters are in GFM mode.



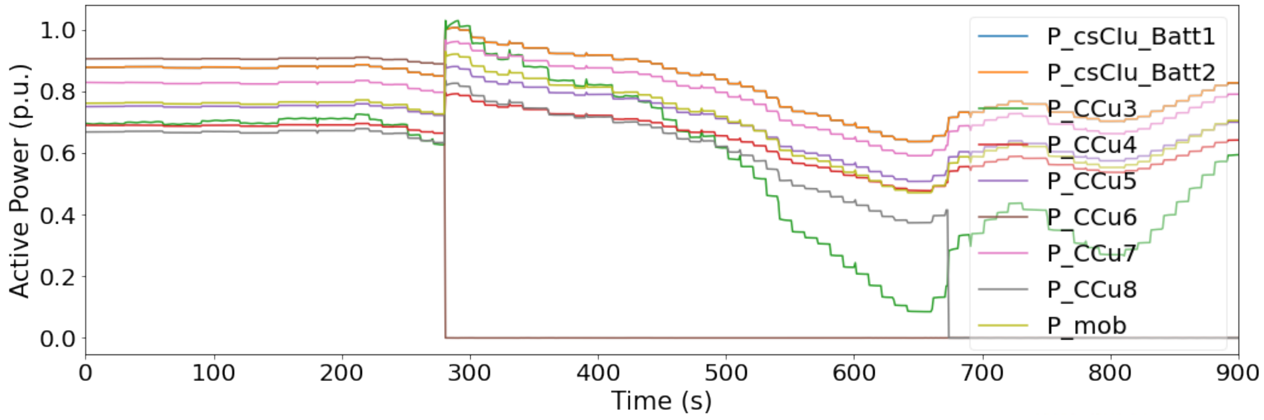
Frequency of all the buildings



Active power output of all GFM inverters



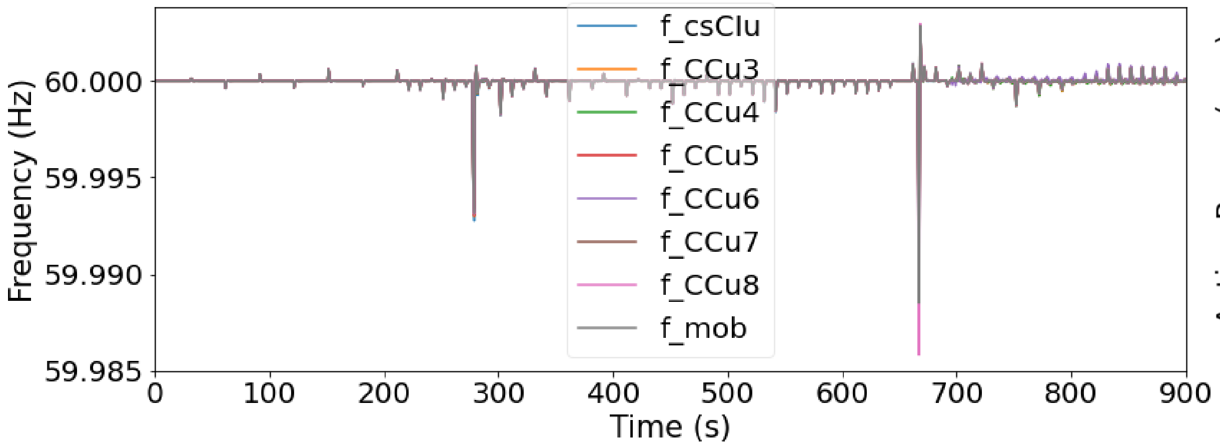
Voltage RMS of all the buildings



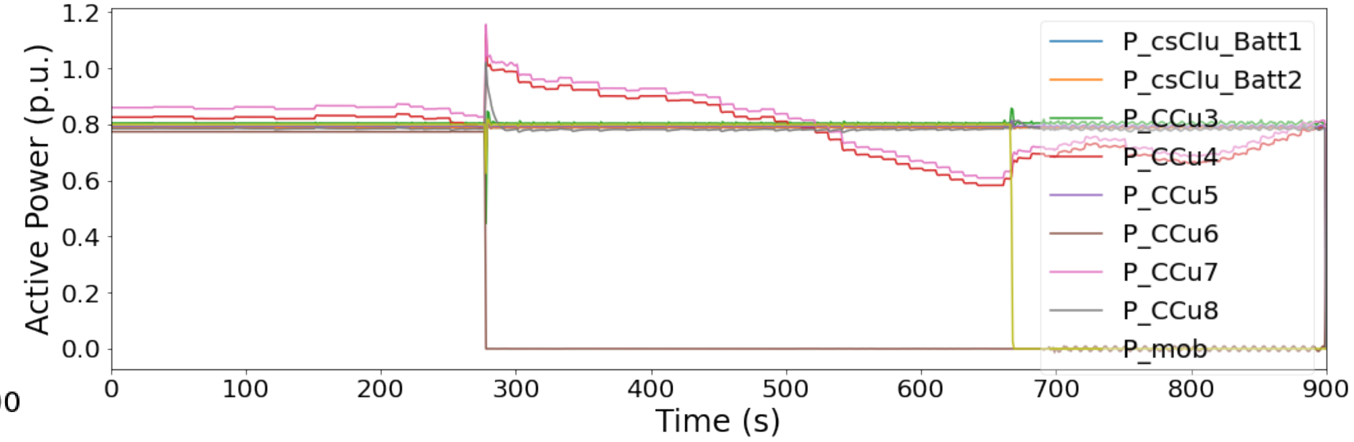
Reactive power output of all GFM inverters

Simulation Results for Strategy II

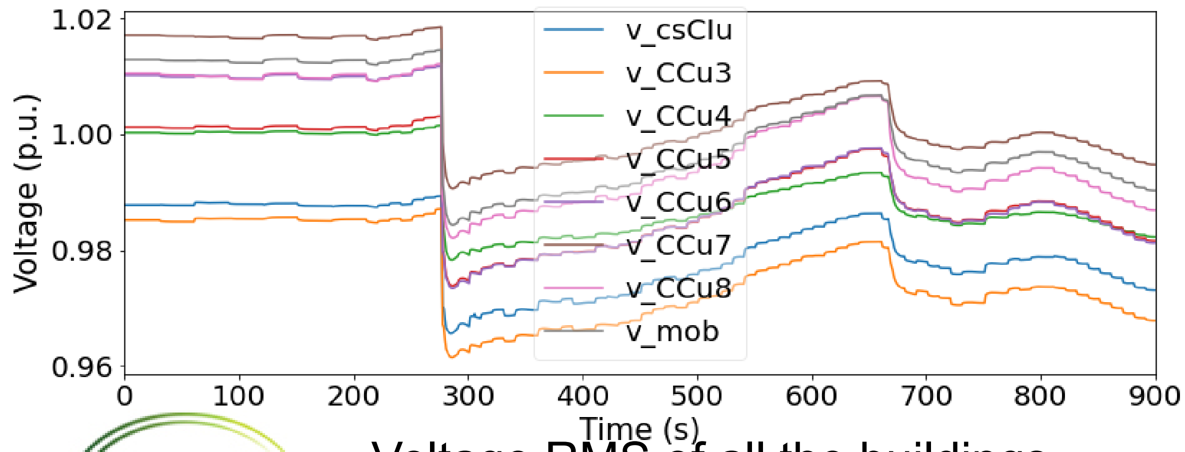
— Only two battery inverters are in GFM mode.



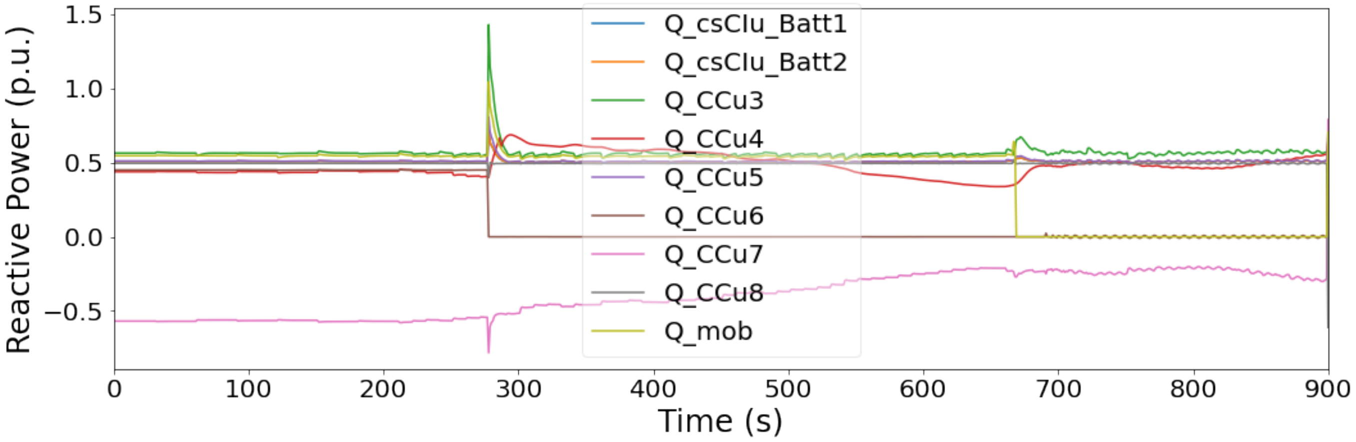
Frequency of all the buildings



Active power output of all GFM inverters



Voltage RMS of all the buildings



Reactive power output of all GFM inverters

Conclusions

- Both strategies can maintain system voltage and frequency stability. Strategy I has better voltage transient stability, and Strategy II has better frequency transient stability.
- The GFM inverters maintain better stability than the GFL inverters, and a microgrid system with a higher percentage of GFM inverters has better stability.
- A microgrid with a lower percentage of GFM inverters can have poor stability, but improved control strategies in inverters can improve system stability.

This work was authored 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 This material is based upon work supported by the U.S Department of Energy, Advanced Research Projects Agency – Energy under grant DE-AR0001016. 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.