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Study of Inverter Control Strategies on the Stability of Microgrids Toward 100% Renewable Penetration

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Background & Objectives

- Understanding the impact of different control strategies on microgrid stability and strength under certain and increasing renewable penetrations:
  - In particular, the dynamics between a synchronous generator (SG) and grid-following (GFL) inverters, between an SG and grid-forming (GFM) inverters, and among SGs, GFM inverters, and GFL inverters.
- Microgrid planners will face various options when selecting the inverter-based resources (IBRs) (GFM, GFL, or mixed) and their controls with existing synchronous generation and increasing renewable penetrations.

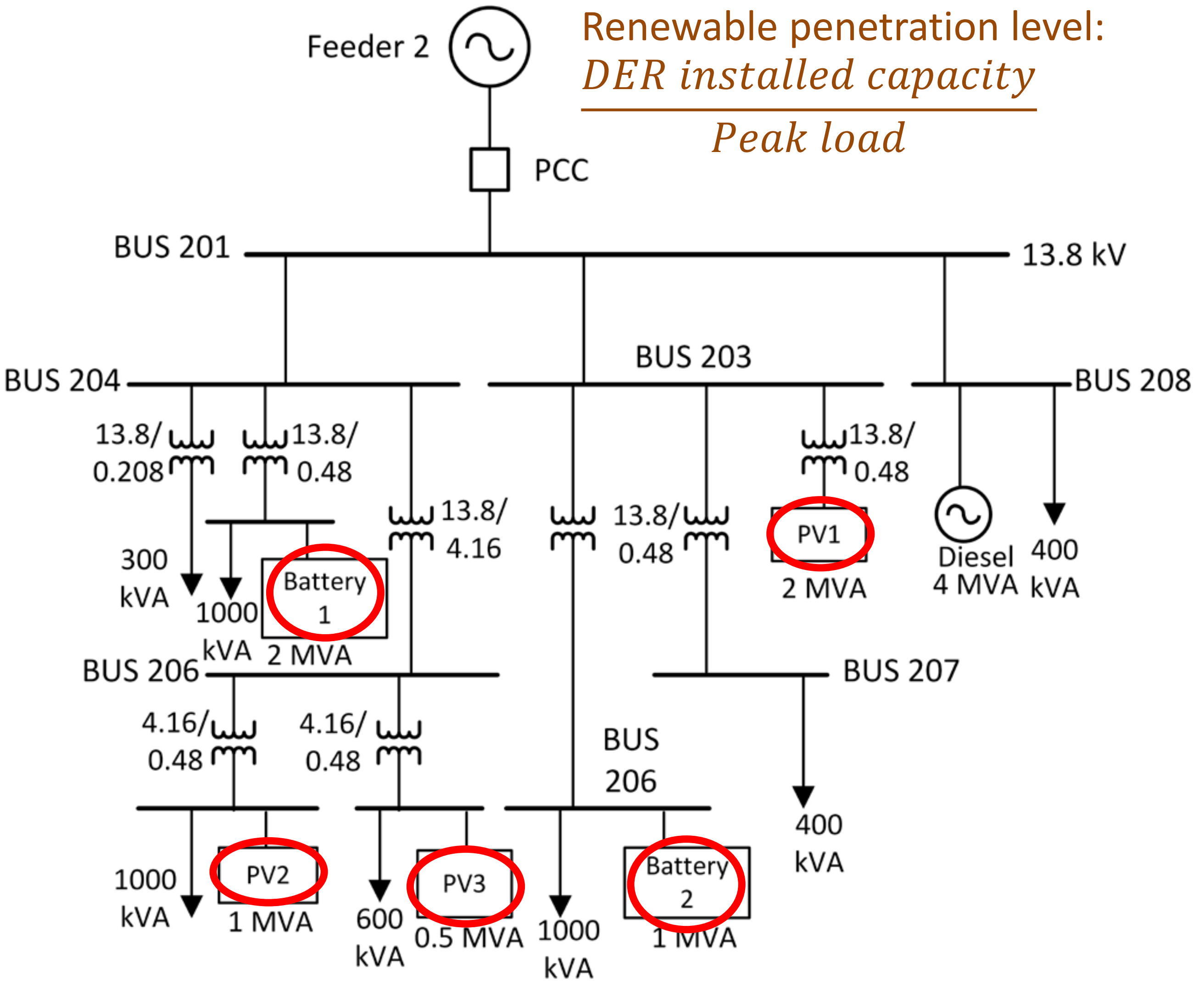
This comprehensive study provides helpful references for microgrid engineers to understand microgrid stability when facing various choices of installing IBRs (GFLs, GFMs, or mixed).

Microgrid System Under Study

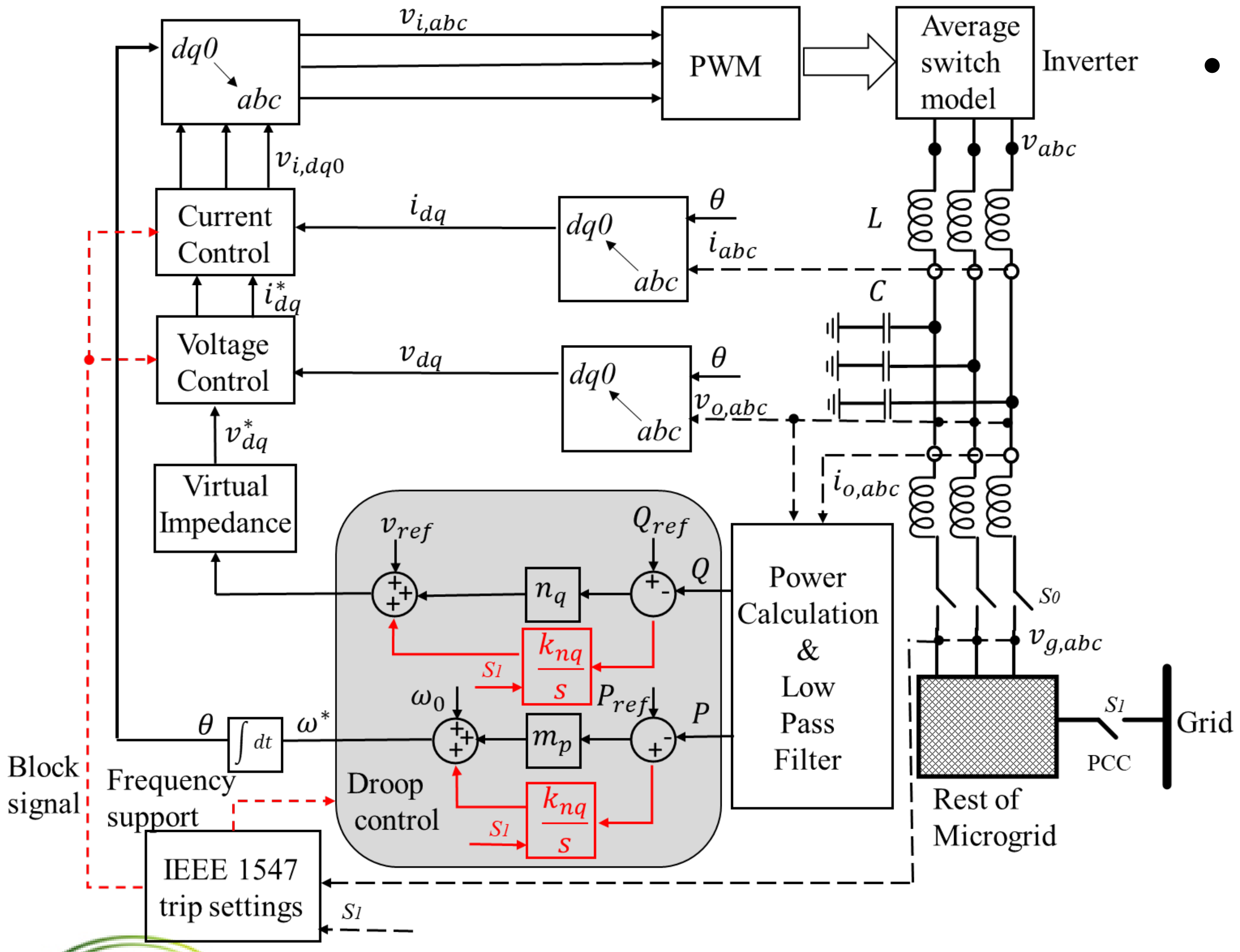
- Feeder 2 of Banshee benchmark microgrid:
  - 2 GFM battery inverters
  - 3 GFL PV inverters
  - 1 diesel generator
  - Constant impedance loads (4.7 MW).

Renewable Penetration Level	DER capacity
20%	Option 1: 1-MVA PV Option 2: 1-MVA battery
40%	Option 1: 1-MVA PV and 1-MVA battery Option 2: 2-MVA PV Option 3: 2-MVA battery
60%	Option 1: 2-MVA PV and 1-MVA battery Option 2: 1-MVA PV and 2-MVA battery Option 3: 3-MVA PV Option 4: 3-MVA battery
80%	Option 1: 3.5-MVA PV and 1-MVA battery Option 2: 1.5-MVA PV and 3-MVA battery Option 3: 2.5-MVA PV and 2-MVA battery
100%	3.5-MVA PV and 3-MVA battery

Renewable penetration level: $\frac{\textit{DER installed capacity}}{\textit{Peak load}}$



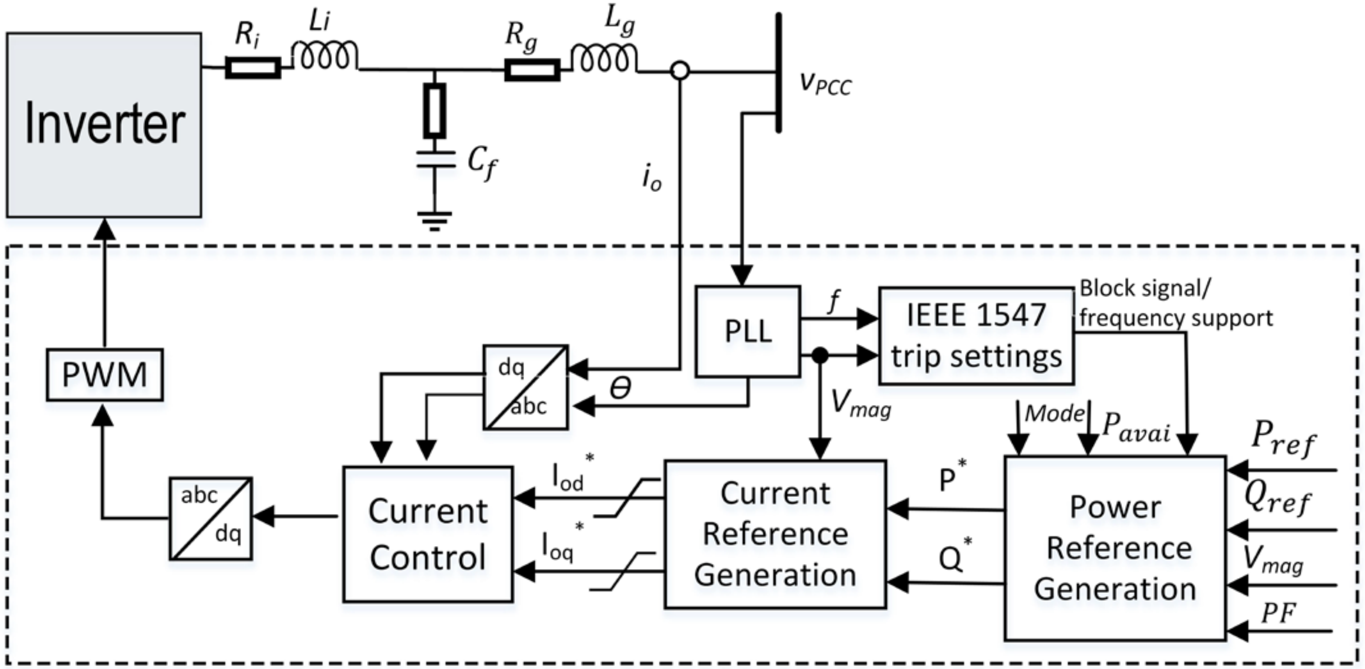
Modeling and Control of Inverters



- GFM inverter control:
  - Power tracking for grid-connected mode (integrator in droop control enabled)
  - VF power sharing control for islanded mode (integrator in droop control disabled)
  - IEEE 1547 compliant in grid-connected mode
  - Inverter control layer: virtual impedance control, voltage control, and current control
  - Average switching model.

Modeling and Control of Inverters

- GFL inverter control:
  - Fixed power factor control with 0.9 leading
  - No droop control
  - A phase-locked-loop (PLL) for synchronization
  - IEEE 1547 compliant
  - Average switching model.



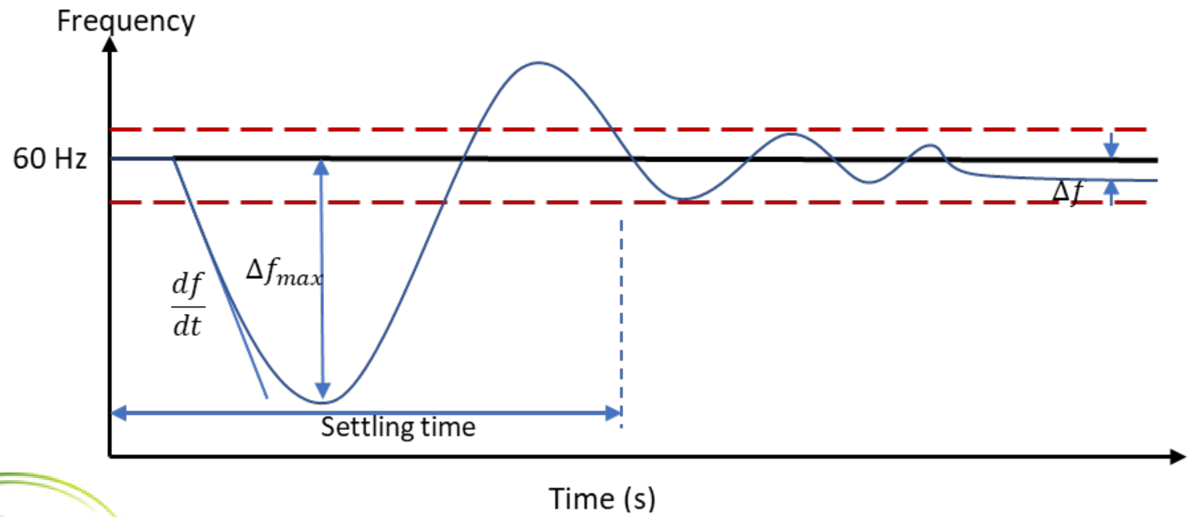
Diesel Generator Modeling and Control

- Standard synchronous generator model in Simulink/Simscape:
  - Fixed power factor control with 0.9 leading
  - No droop control
  - A PLL for synchronization
  - IEEE 1547 compliant
  - Average switching model.

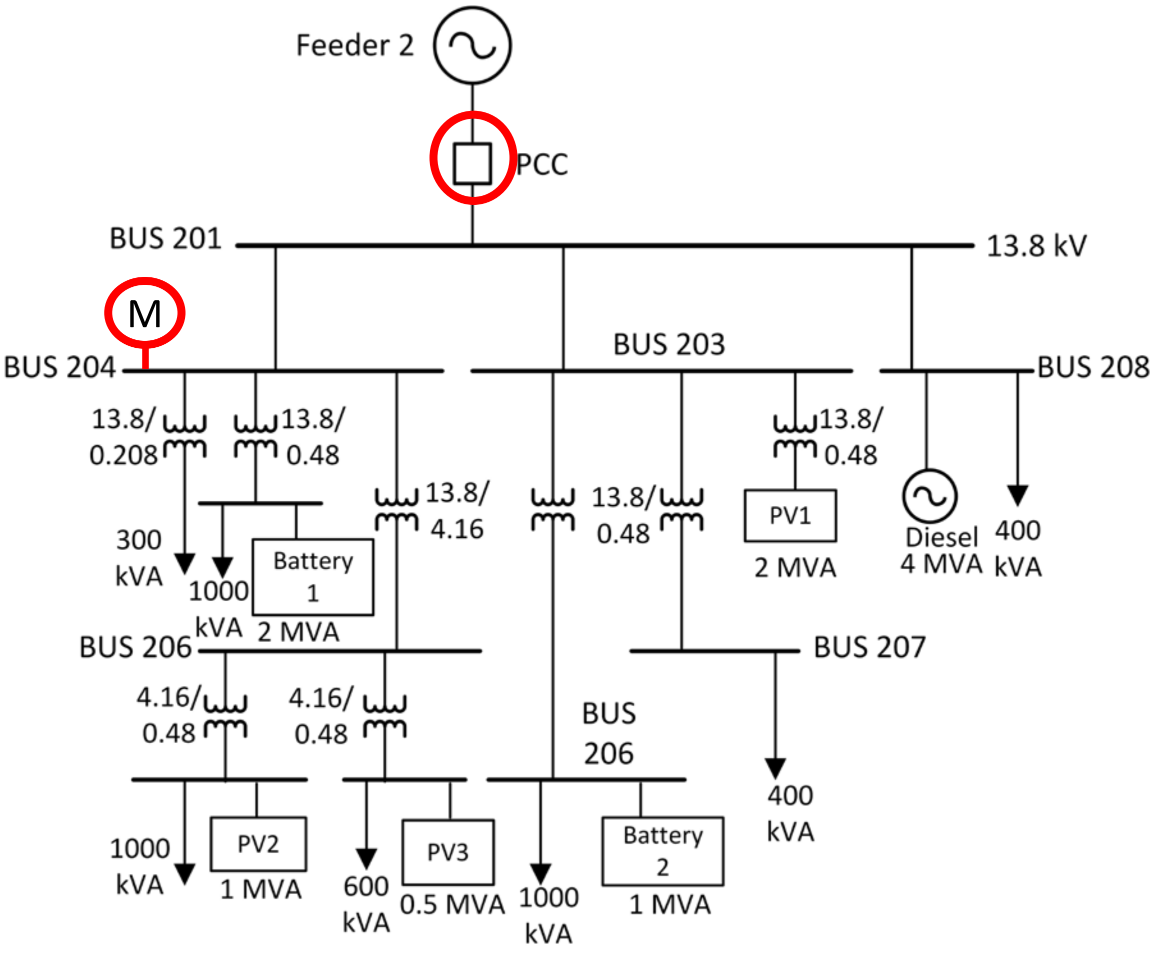
Simulation Results

Simulation Setup

- Study different renewable penetration levels with different control strategies:
  - All the scenarios defined in the table are simulated.
  - Two dynamic events are applied: (1) unplanned islanding at 6 seconds and (2) switching in a 170-kVA induction motor at Bus 204 at 14 seconds in islanded mode.

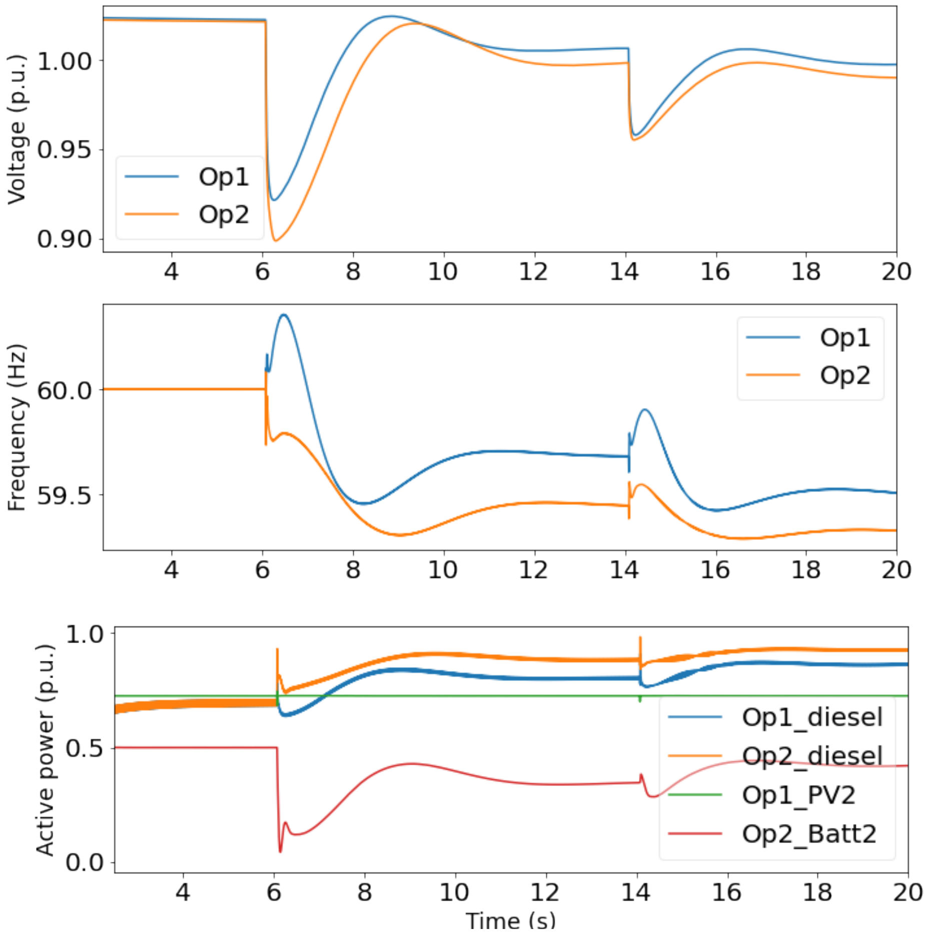


Frequency response after a dynamic event



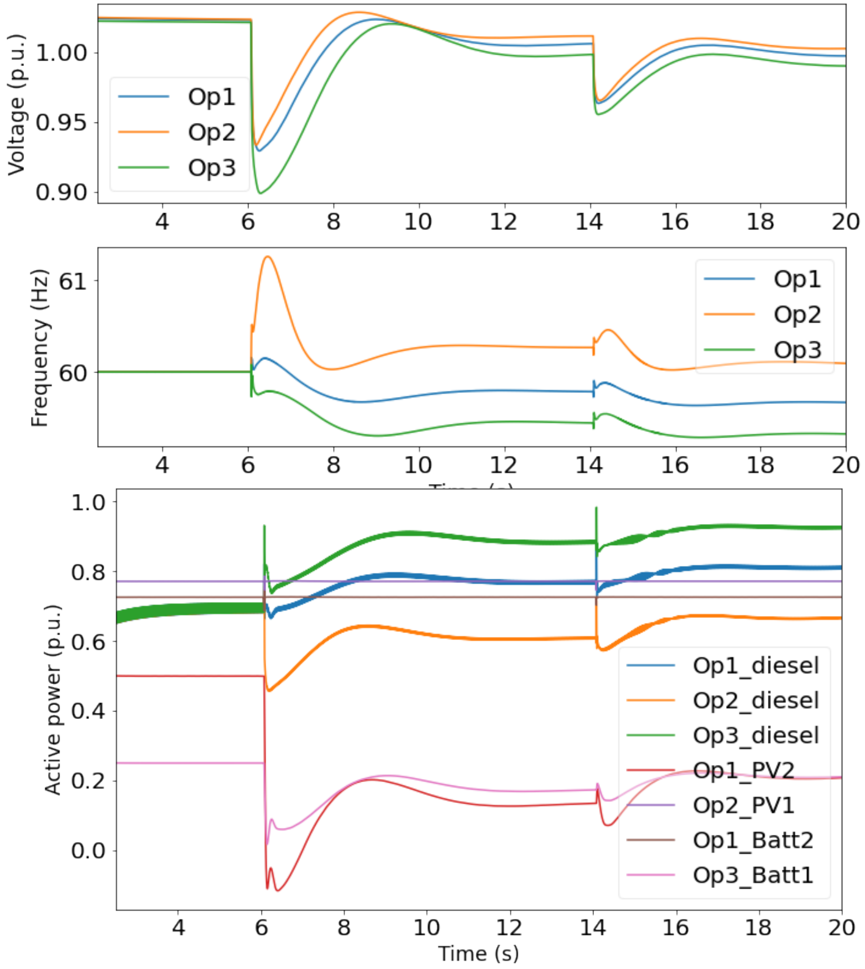
Simulation Results

- 20% renewable penetration



Option 1: 1-MVA PV; Option 2: 1-MVA battery

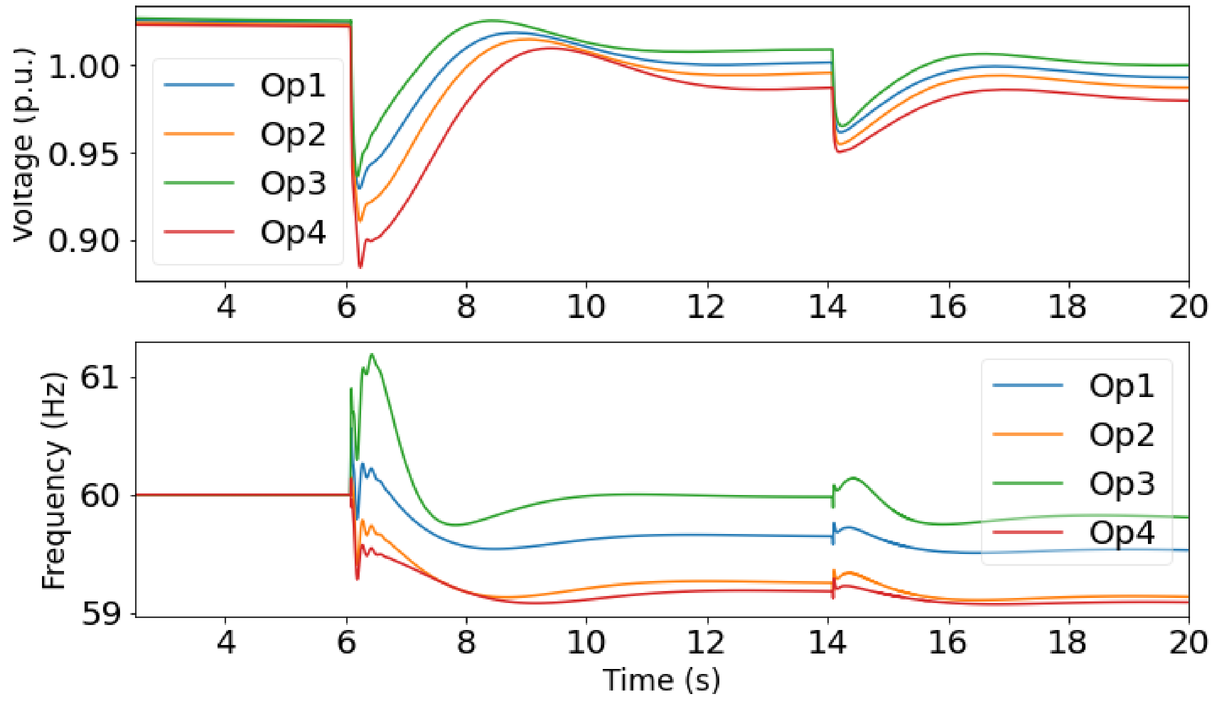
- 40% renewable penetration

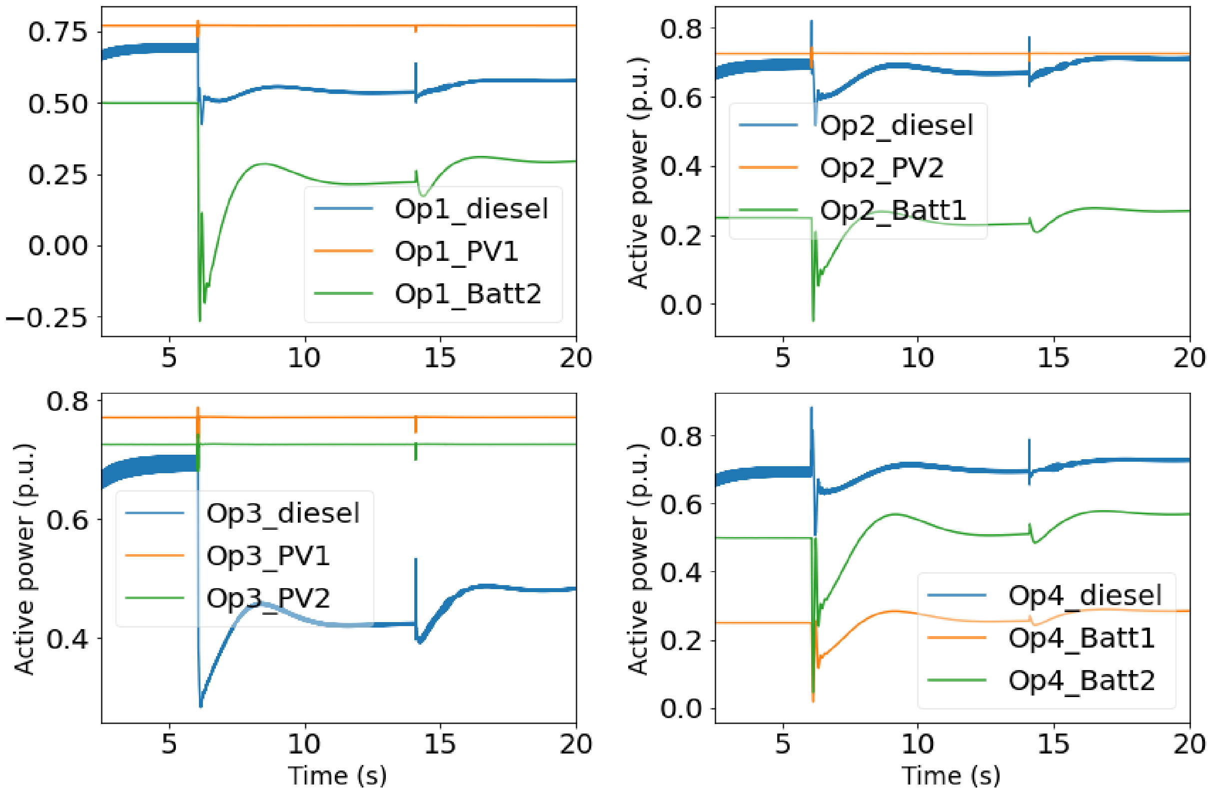


Option 1: 1-MVA PV and 1-MVA battery; Option 2: 2-MVA PV; Option 3: 2-MVA battery

Simulation Results

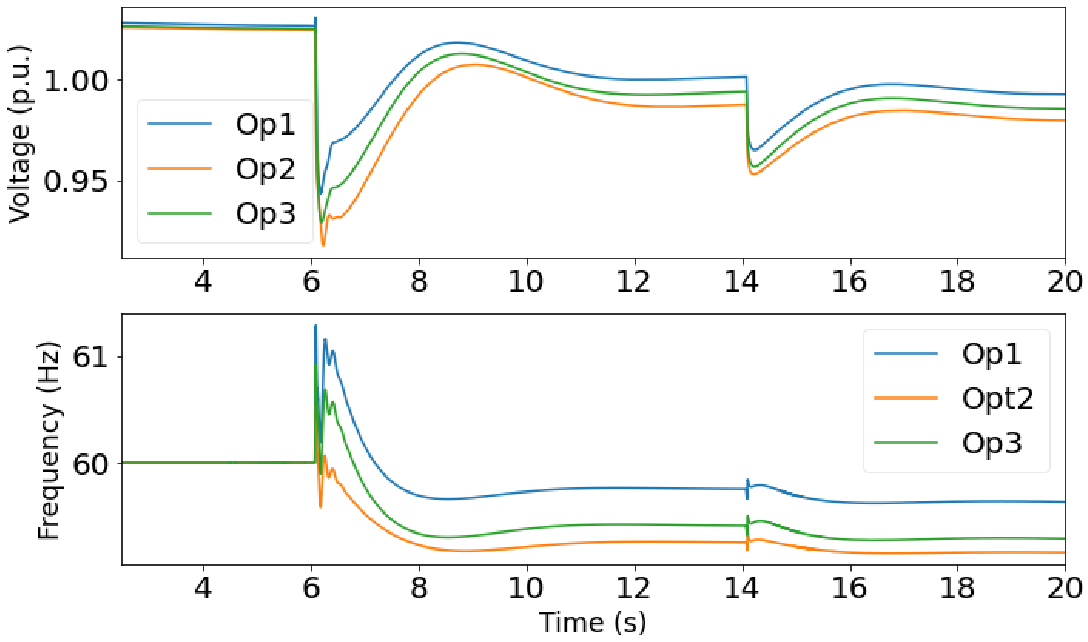
- 60% renewable penetration:
  - Option 1: 2-MVA PV and 1-MVA battery
  - Option 2: 1-MVA PV and 2-MVA battery
  - Option 3: 3-MVA PV
  - Option 4: 3-MVA battery

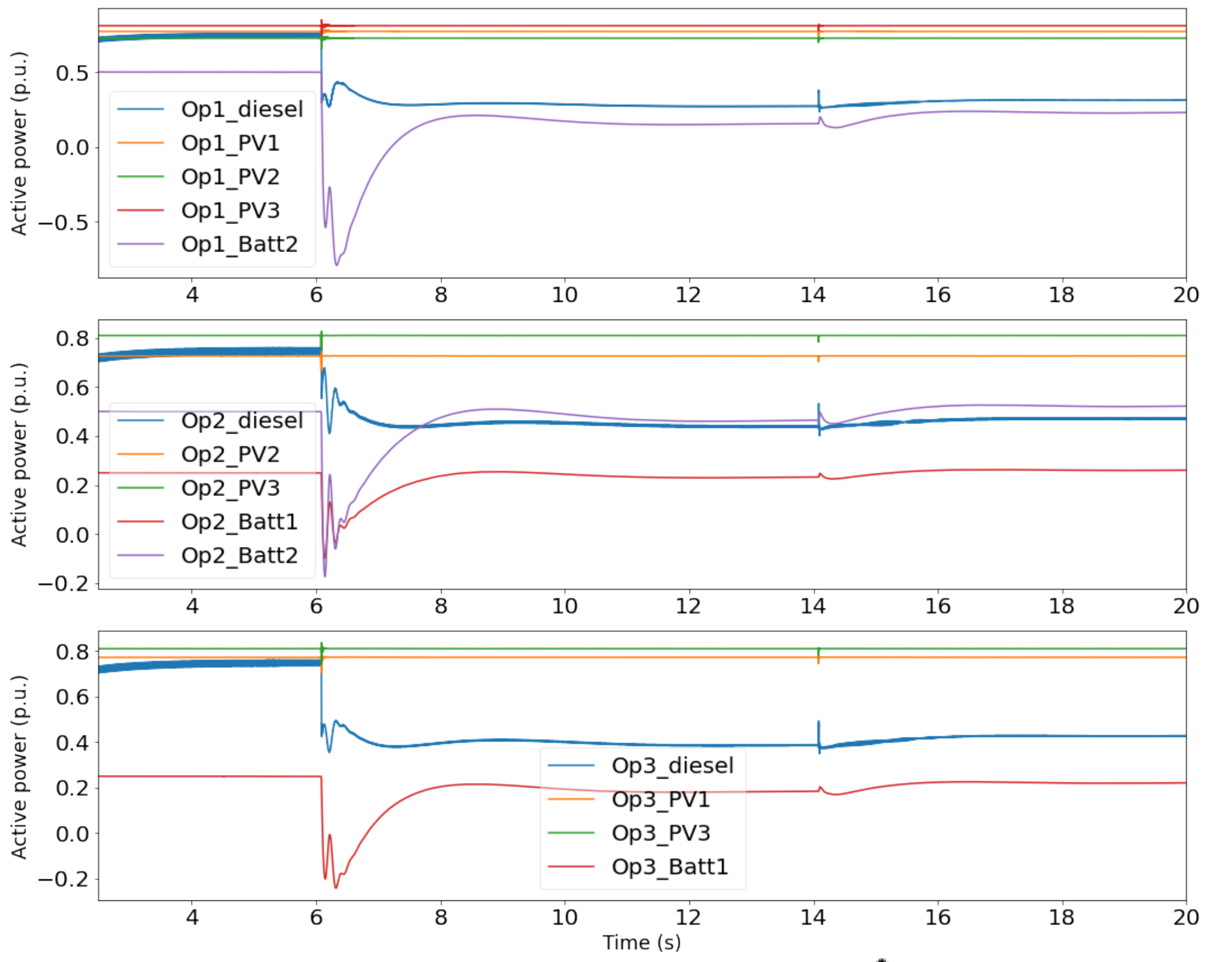




Simulation Results

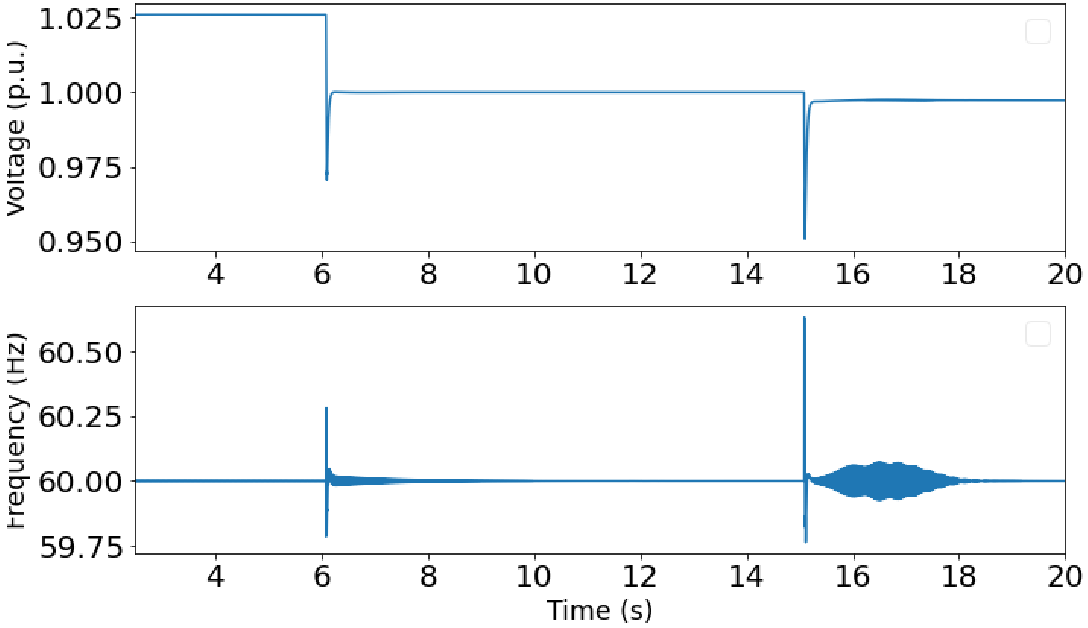
- 80% renewable penetration:
  - Option 1: 3.5-MVA PV and 1-MVA battery
  - Option 2: 1.5-MVA PV and 3-MVA battery
  - Option 3: 2.5-MVA PV and 2-MVA battery

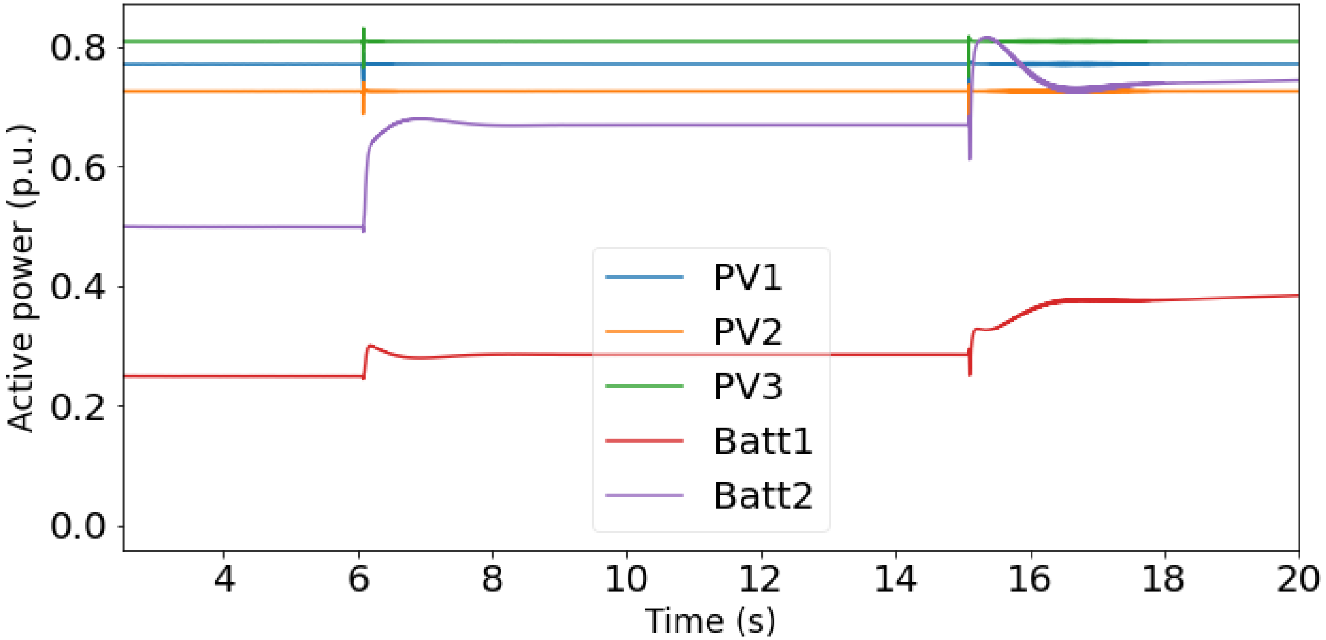




Simulation Results

- 100% renewable penetration:
  - 3.5-MVA PV and 3-MVA battery
  - GFM inverters operate in isochronous mode.





Conclusions

- The scenario with mixed SG+GFL+GFM has the best transient and steady-state stability in voltage and frequency, and more GFL capacity also achieves better transient and steady-state stability.
- Compared to GFM inverters, GFL inverters can provide a faster power response with larger transients (overshoot and/undershoot) to compensate for the deviations in the frequency and voltage when running parallel to the SG.
- When SG exists in the system, the only advantage of the GFM seems to be to smooth and slow down the system transients because of the power sharing process between the fast-responding GFM inverter and the slow-responding SG; however, a 100% renewable microgrid without SG has a much faster transient response.

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