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unifi consortium
universal interoperability for grid-forming inverters

Study of Seamless Microgrid Transition Operation Using Grid-Forming Inverters

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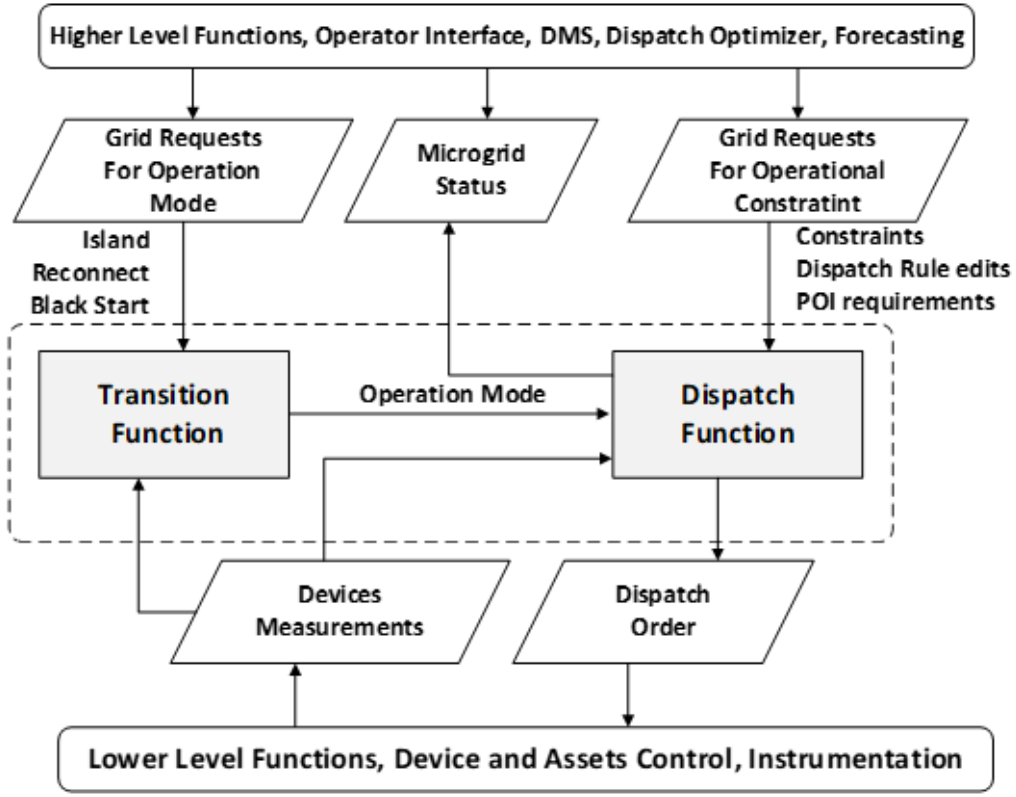
Background & Objectives

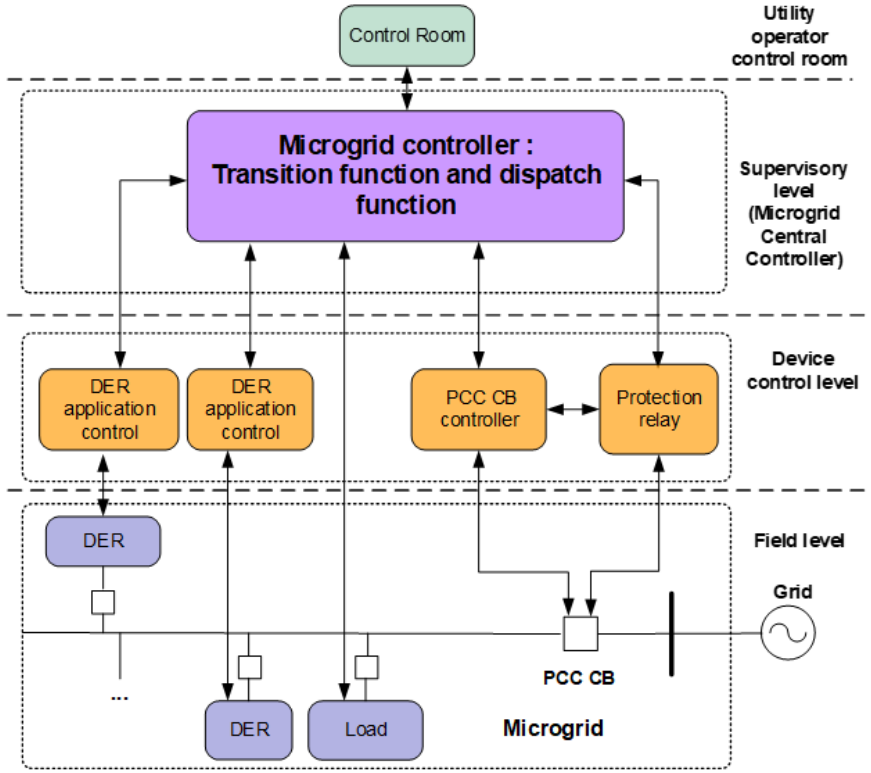
- Traditionally, grid-forming (GFM) inverters must switch between grid-following (GFL) and GFM control modes during microgrid transition operation.
- Today's inverter technology allows GFM inverters to always operate in GFM control mode, so it is worth exploring how to use them to achieve smooth microgrid transition operation.
- **Goal of this work**: Study operational techniques to achieve seamless microgrid transitions by dispatching a GFM inverter.
  - We propose three techniques and compare them analytically and validate them through pure hardware experiments.

This concept is demonstrated through a pure hardware setup with one commercial GFM inverter.

Microgrid Control System

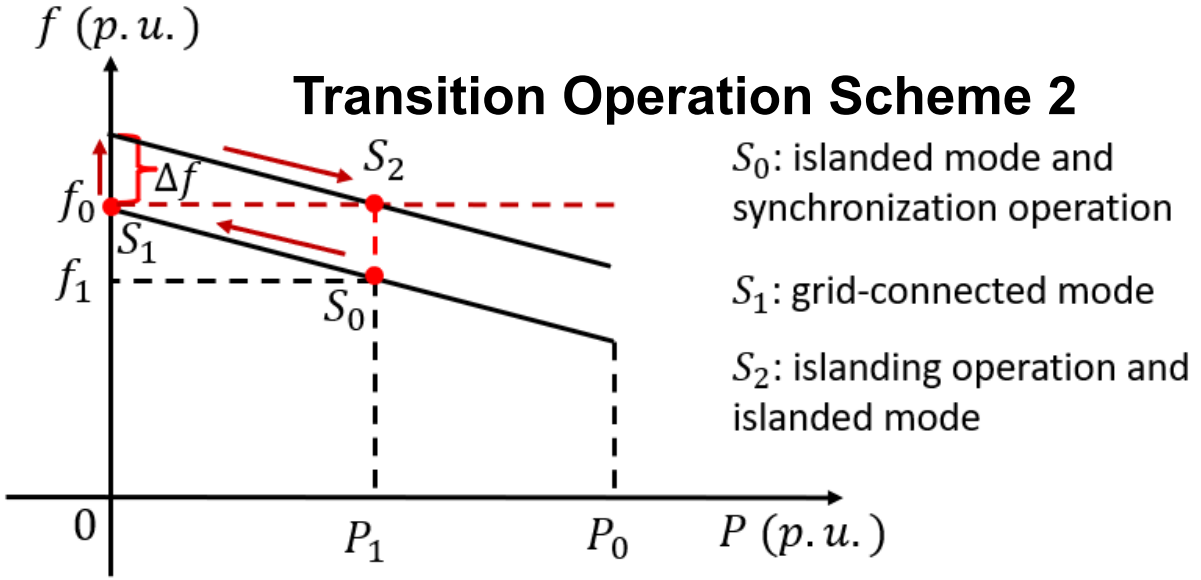
- The interoperability for microgrid transition operation:
  - Coordination between the microgrid controller and grid assets (GFM inverter, PCC controller, etc.)
  - Key principle: Synchronize the microgrid voltage with the grid-side voltage for synchronization operation and minimize the PCC power flow before islanding operation.



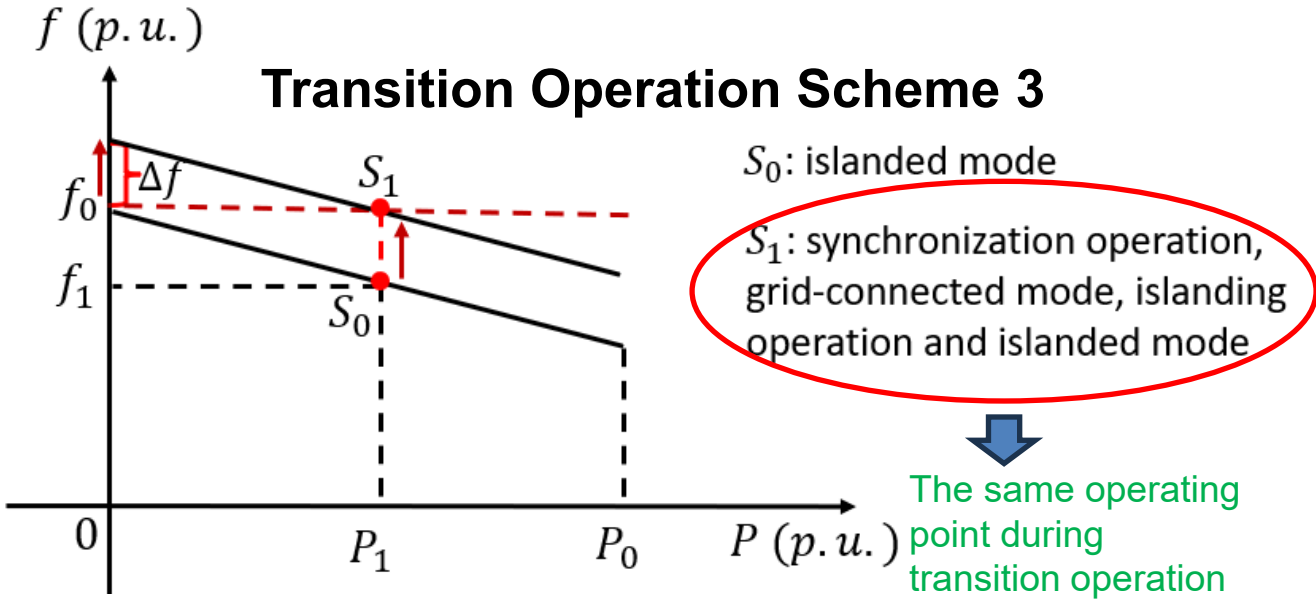


Techniques for Smooth Microgrid Transition

- **Transition operation—scheme 1 (traditional method):**
  - GFM inverter switches between PQ control (grid-connected) and VF control (islanded)
  - Synchronization operation: Generate the same power during synchronization.
  - Islanding operation: Generate the same power during islanding operation.
- **Transition operation—schemes 2 and 3:**
  - GFM inverter always operates in VF control in both grid-connected and islanded mode.



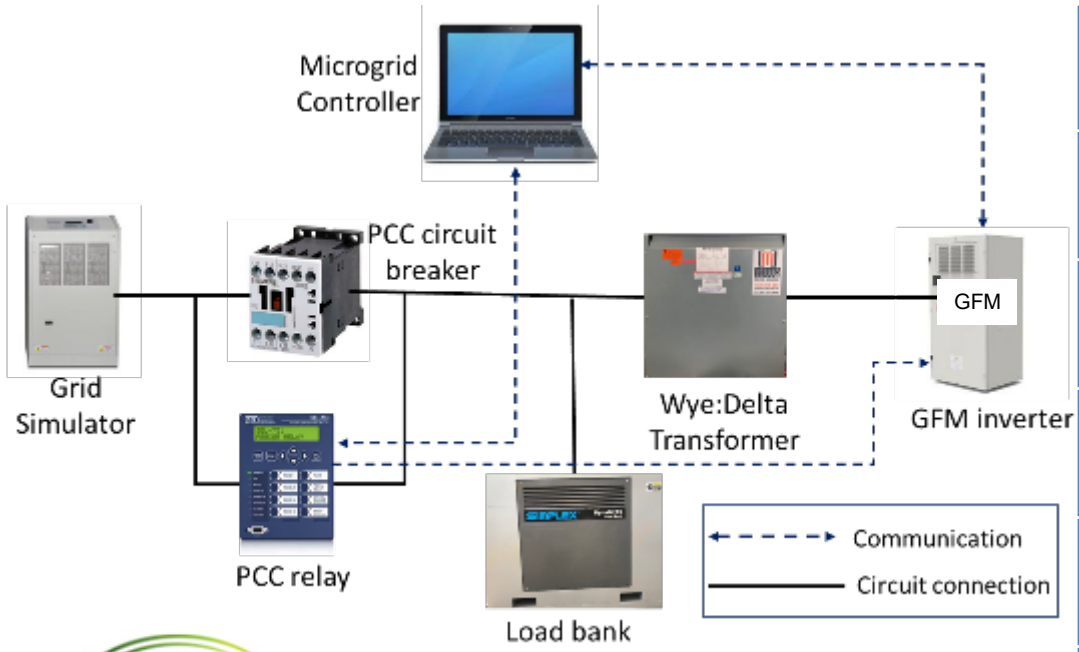
$$\Delta f = m * P_1 * 60$$



Experiment Setup

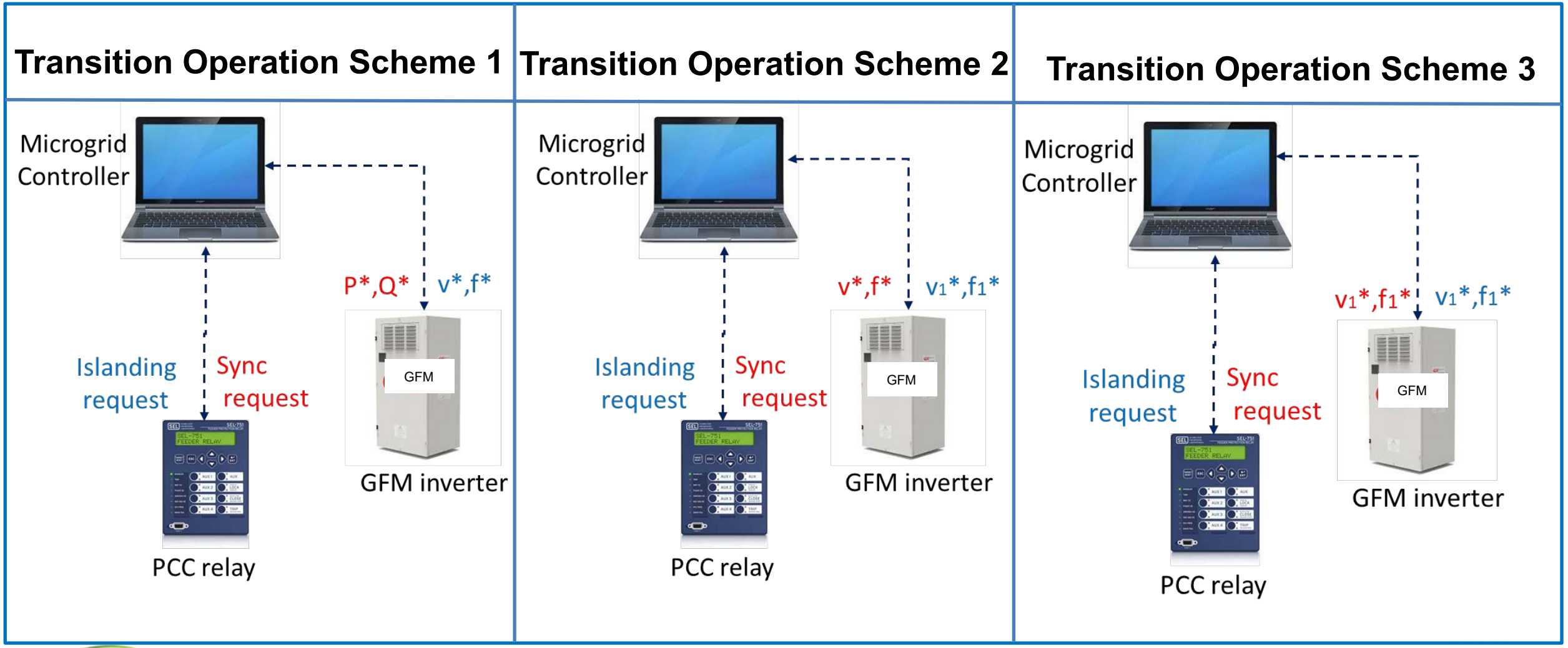
System Configuration

- A commercial GFM inverter supplying load with 50% of its capacity
- A full microgrid setup with microgrid controller, PCC breaker, PCC relay, load bank, grid simulator, the GFM inverter, and transformer.



Element	Capacity	Configuration/Feature
Grid simulator	45 kVA	Internal voltage reference (60 Hz and 277 V)
PCC circuit breaker	111.9 kW	150 HP, 3-phase contactor
PCC relay	n/a	Δθ: 3°, Δv: 0.03 p.u., Δf: 0.02 Hz
Transformer	75 kVA	Delta: 480 V, wye: 480/277 V, Current: 90 A, Z: 4.4%
Inverter	30 kVA	Droop: 0.64% (f-P) and 6.8% (v-Q)
Load bank	100-kVA RL load	15-kW R load

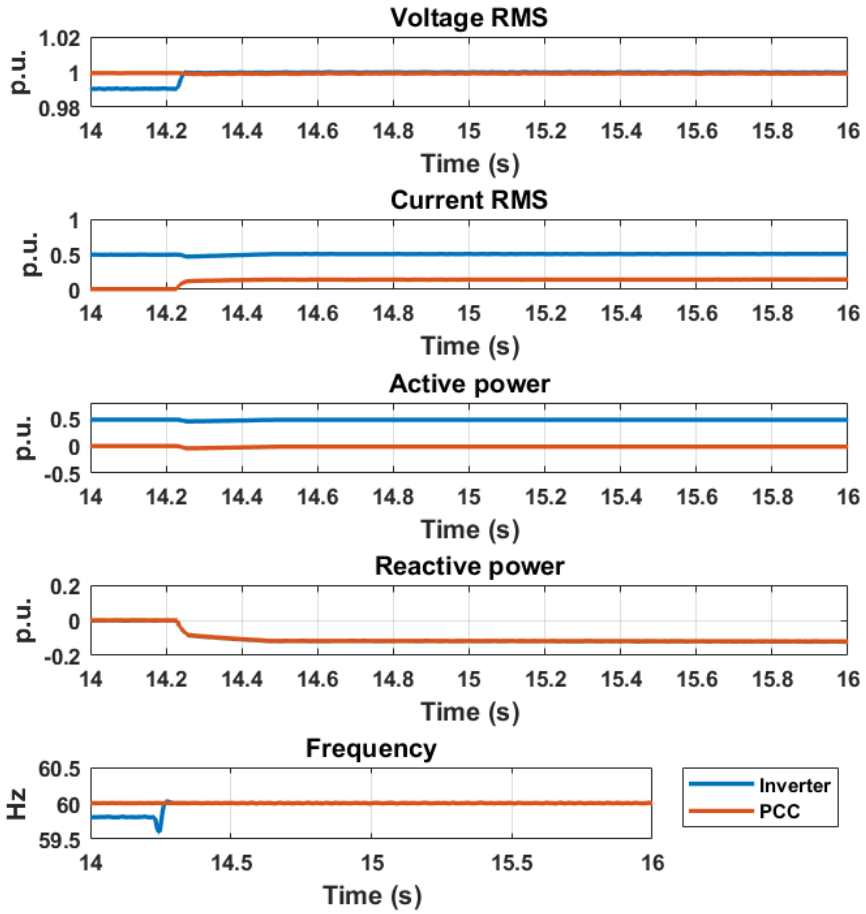
Experiment Configuration



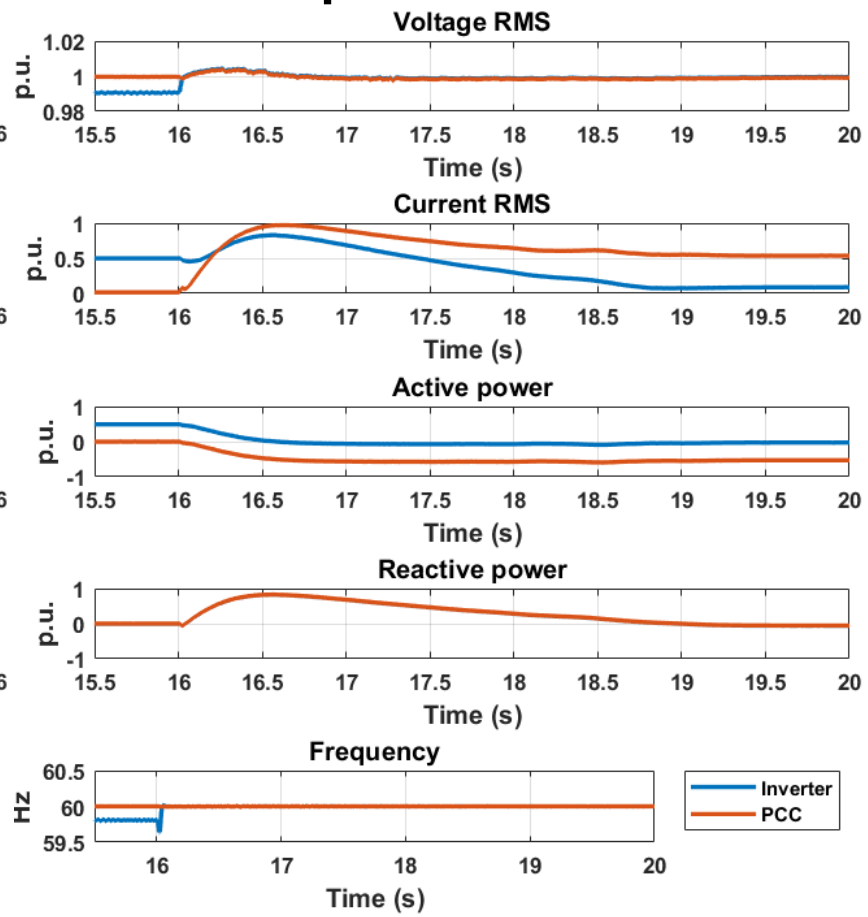
$v^* = 1, f^*$=60 Hz & v_1^*=1, f_1^*=60+$m * P * 60$ $(m = 0.6\%, P = 0.5)$

Experiment Results–Synchronization Operation

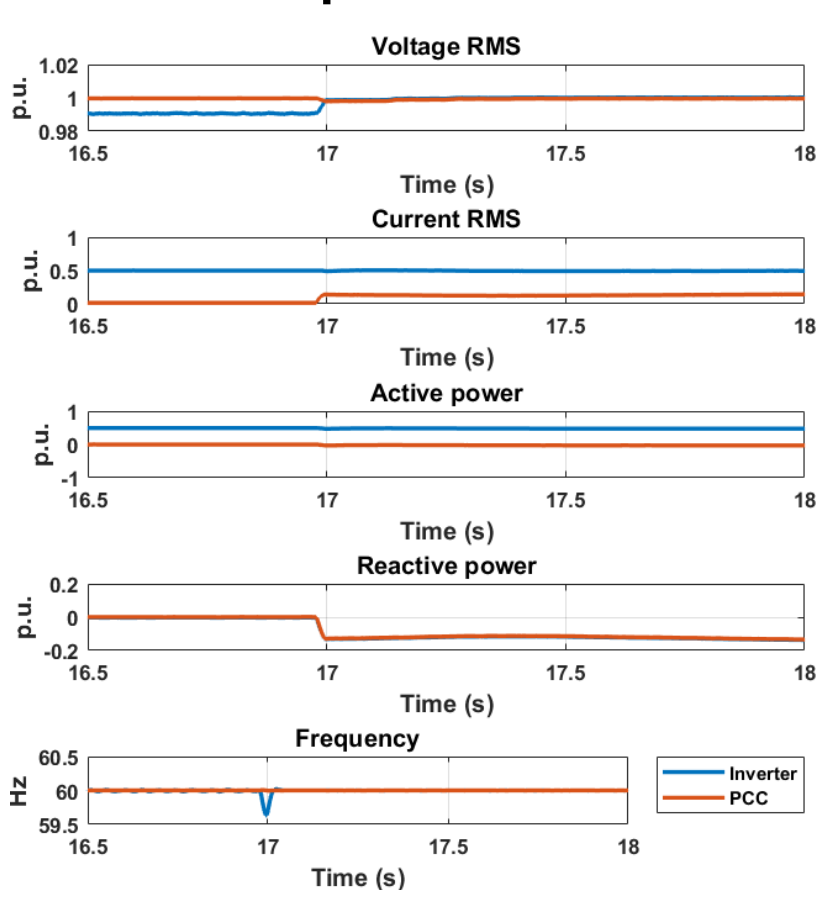
Transition Operation Scheme 1



Transition Operation Scheme 2



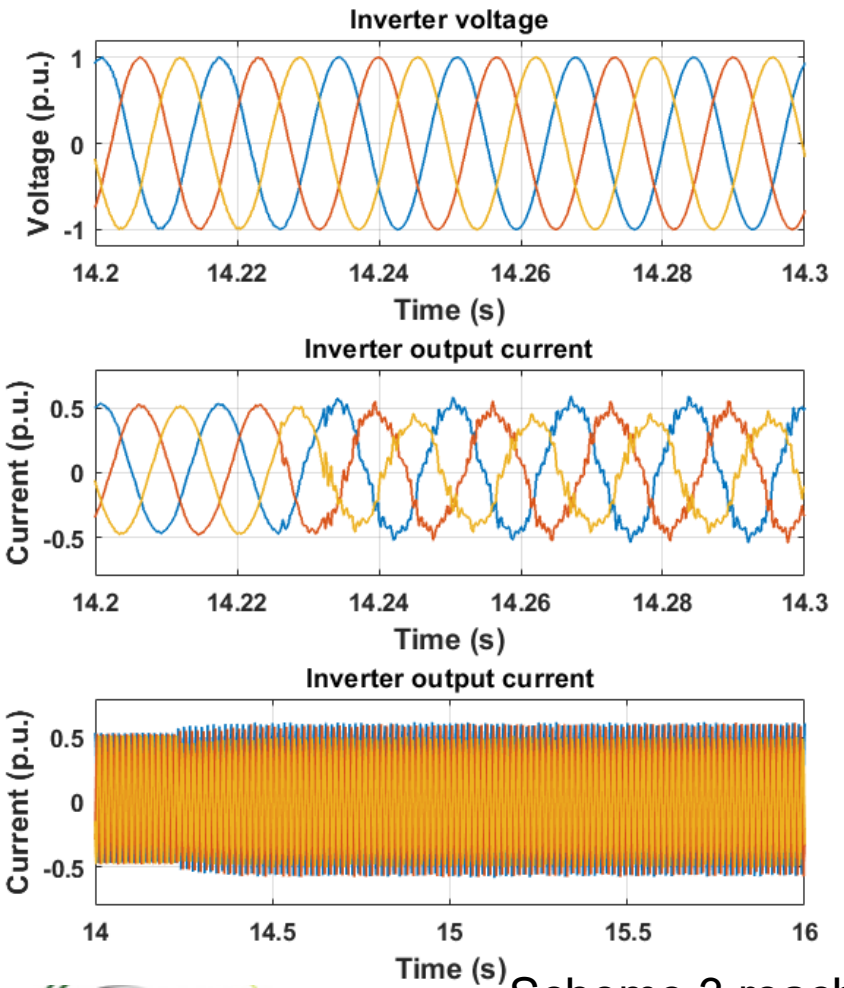
Transition Operation Scheme 3



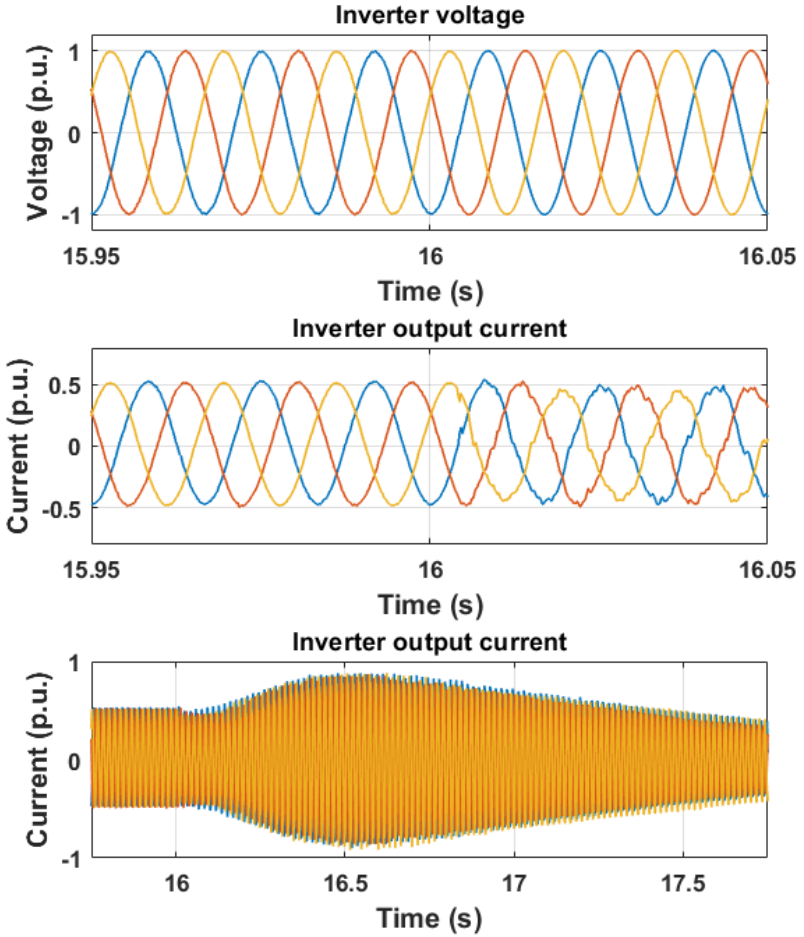
Scheme 3 reaches steady state the fastest with the smallest transients.

Experiment Results–Synchronization Operation

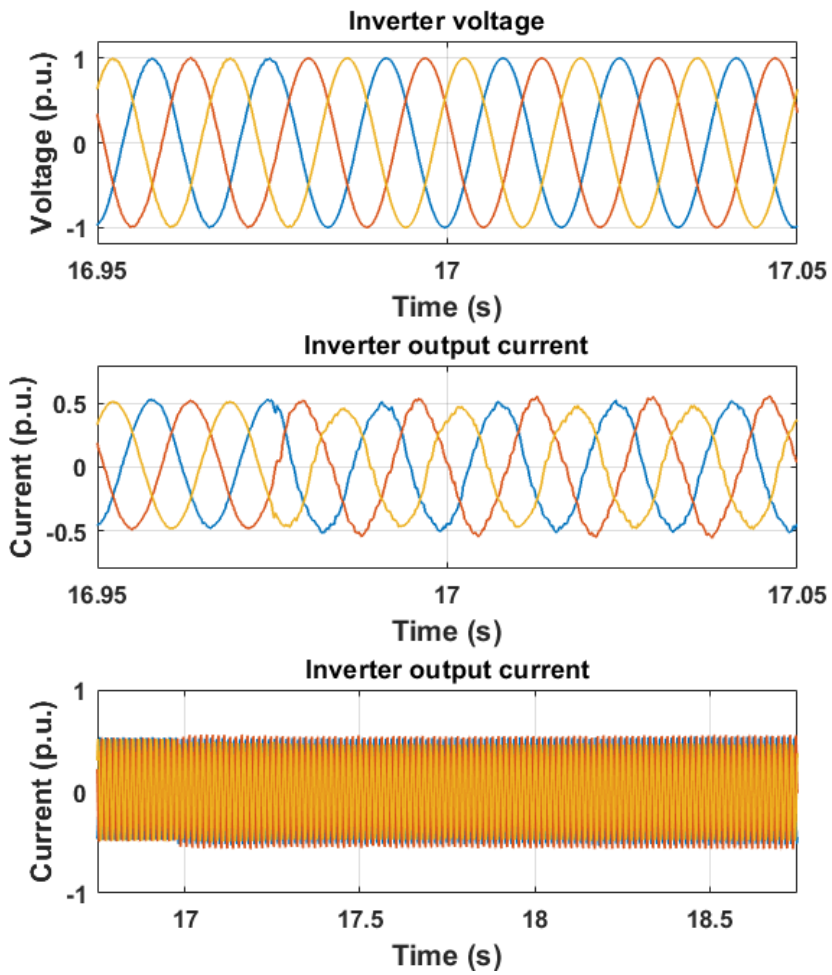
Transition Operation Scheme 1



Transition Operation Scheme 2



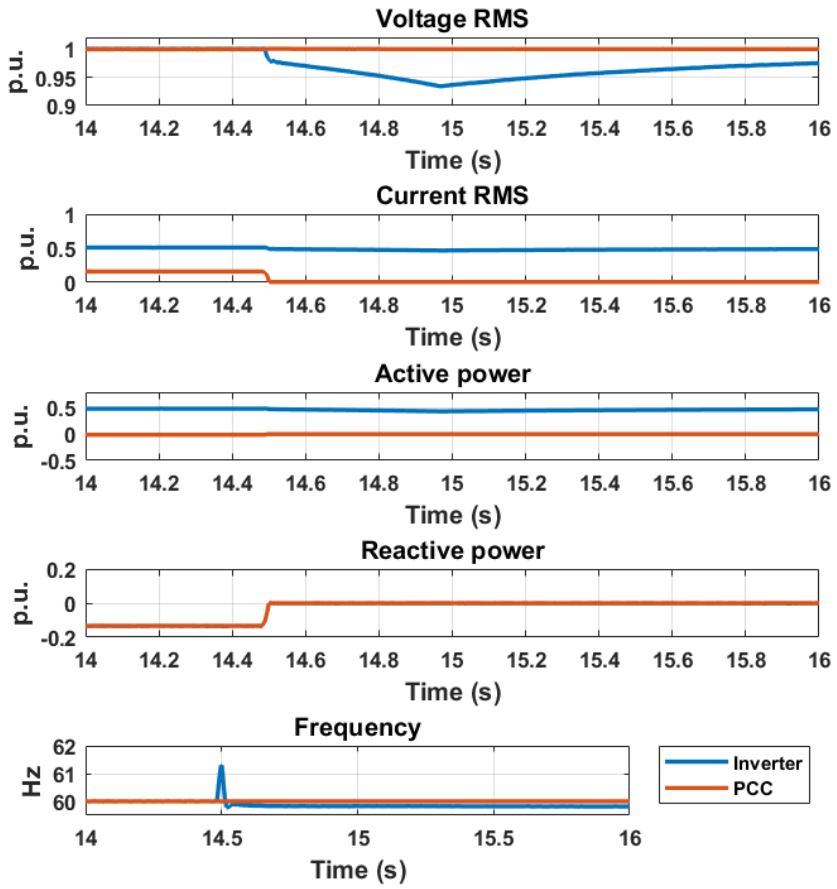
Transition Operation Scheme 3



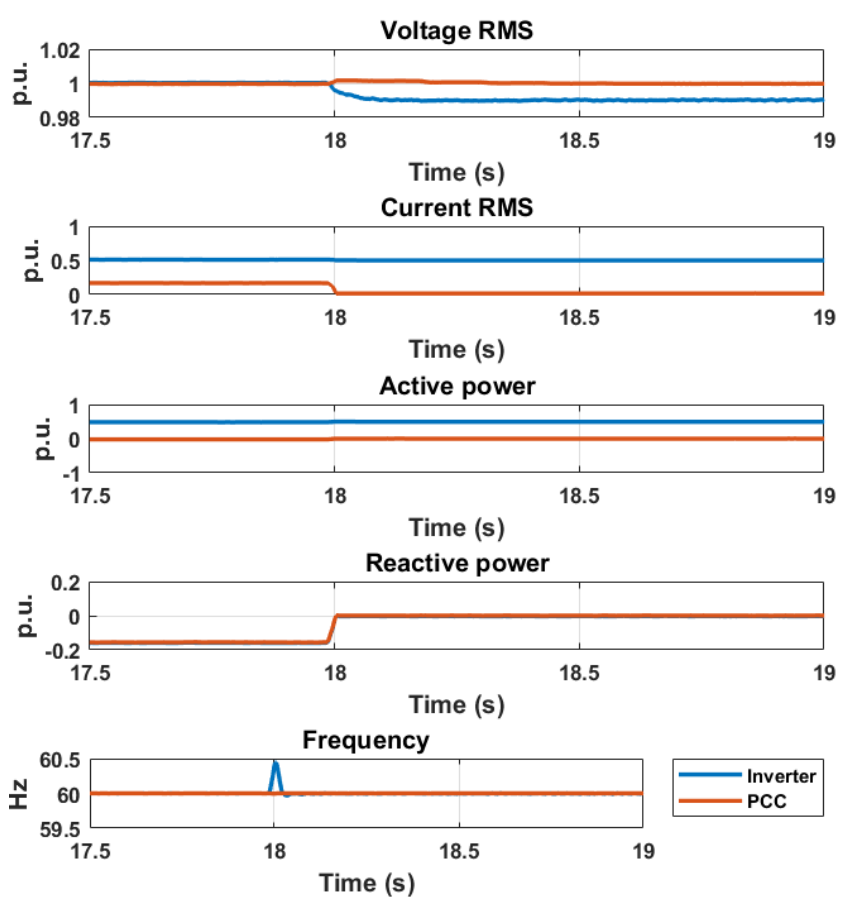
Scheme 3 reaches steady state the fastest with the smallest transients.

Experiment Results–Islanding Operation

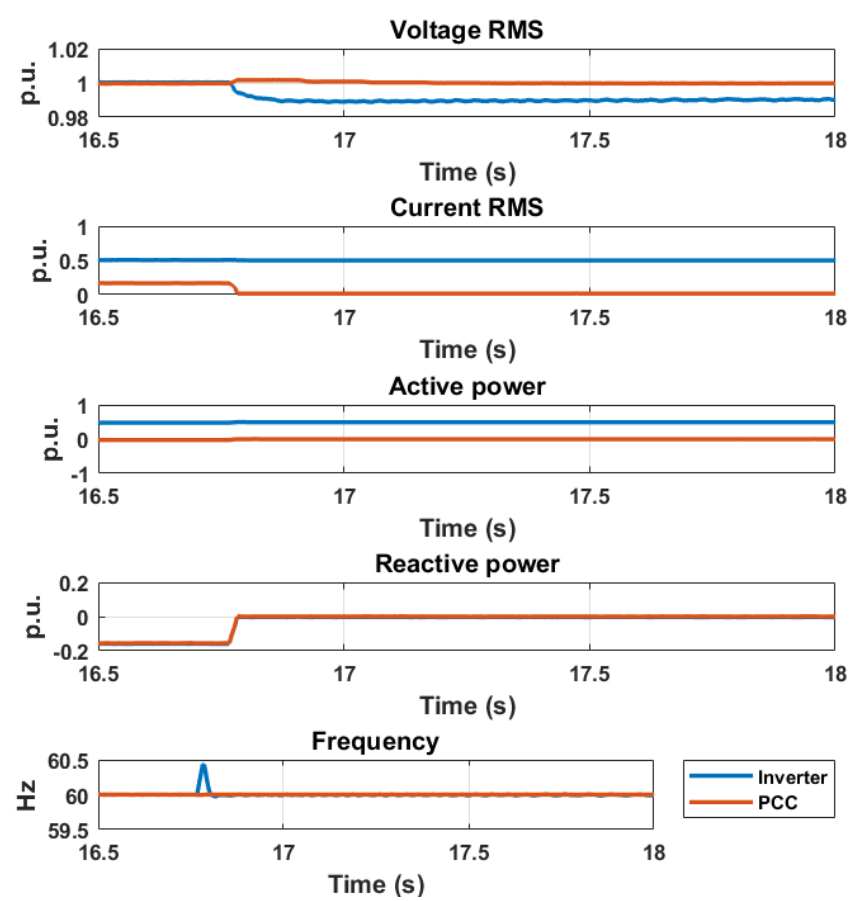
Transition Operation Scheme 1



Transition Operation Scheme 2



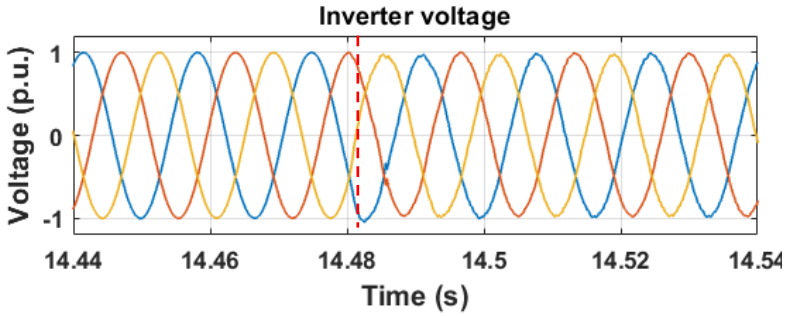
Transition Operation Scheme 3

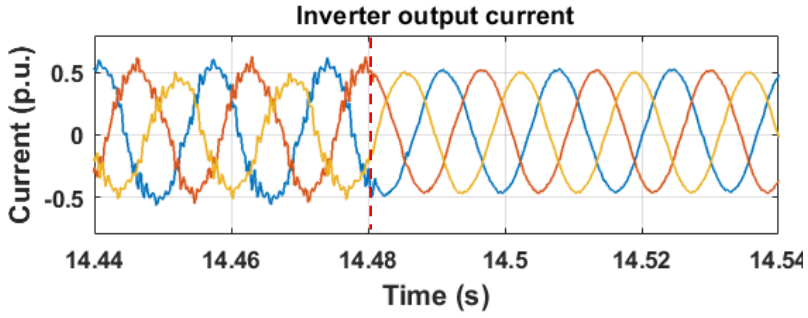


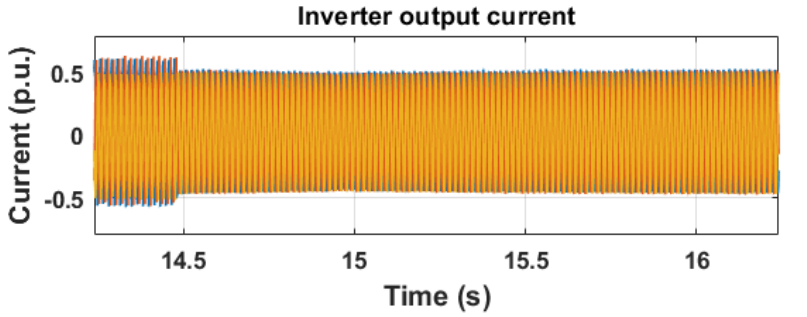
Schemes 2 and 3 have similar transient responses:
Both are faster than Scheme 1 and have smaller transients.

Experiment Results–Islanding Operation

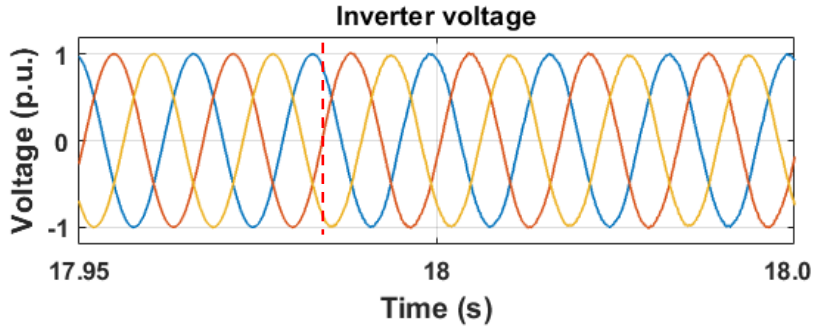
Transition Operation Scheme 1

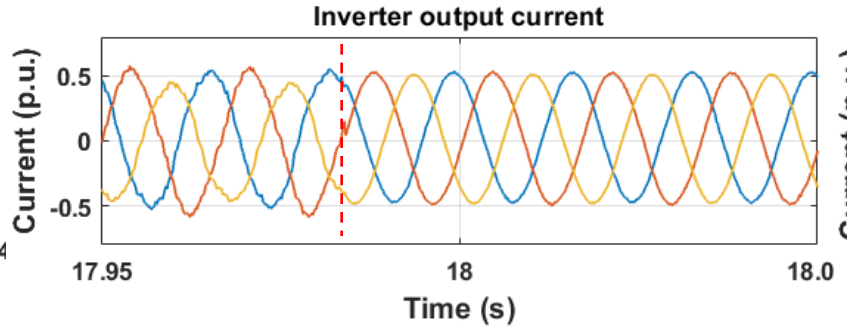


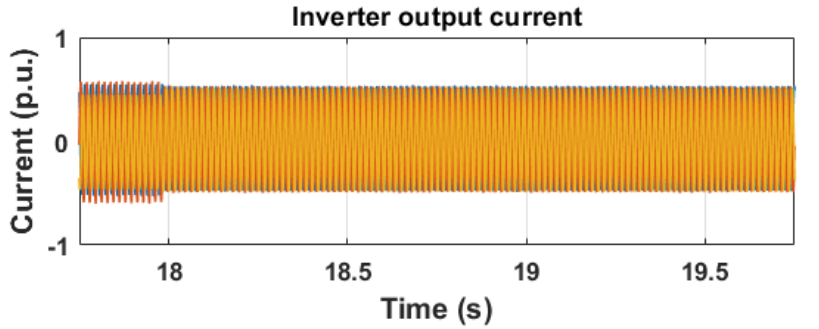




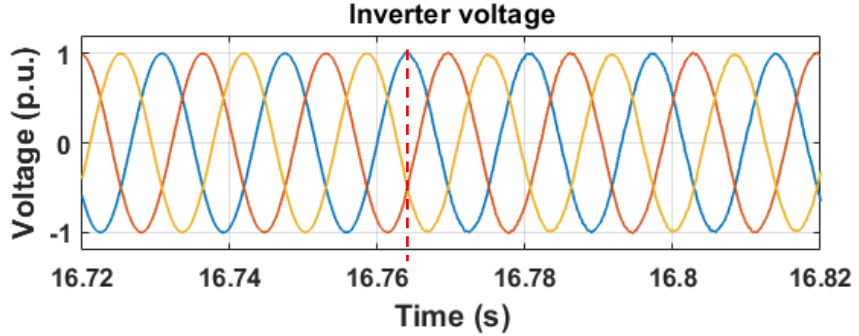
Transition Operation Scheme 2

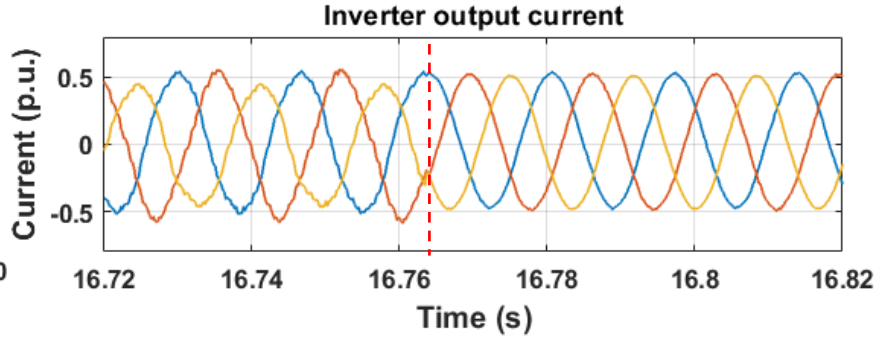


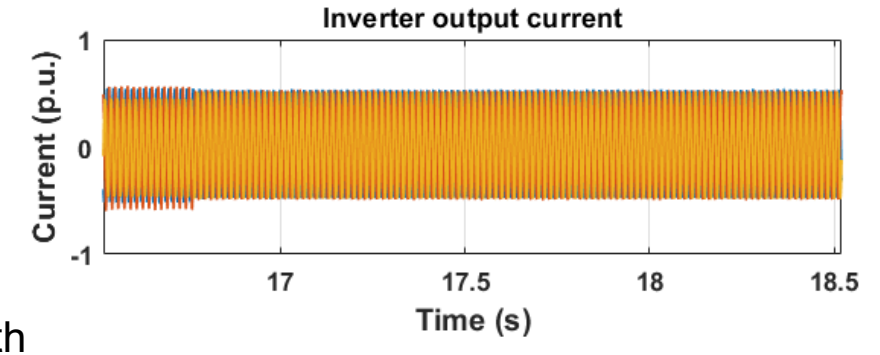




Transition Operation Scheme 3







Schemes 2 and 3 have similar transient responses with smaller transients in voltage and current than Scheme 1.

Conclusions

- Scheme 3 has the best transition operation because the GFM inverter operates at the same operating point before and after the transition operation.
- Ensuring smooth microgrid transition operation requires that the GFM inverter(s) maintain the same operating points (v, f, P, Q, and phase angle) during the transition operation in addition to minimizing the PCC power flow.
- GFM inverter switching from PQ control to VF control during islanding operation causes some delays, and the GFM inverter takes longer to stabilize the system voltage.
- Future work will be on testing Scheme 3 in a larger microgrid system with multiple GFM inverters.

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