IEEE ENERGY CONVERSION CONGRESS & EXPO Detroit, Michigan, USA Oct. 9-13

Transient Stability Study of a Real-World Microgrid with 100% Renewables

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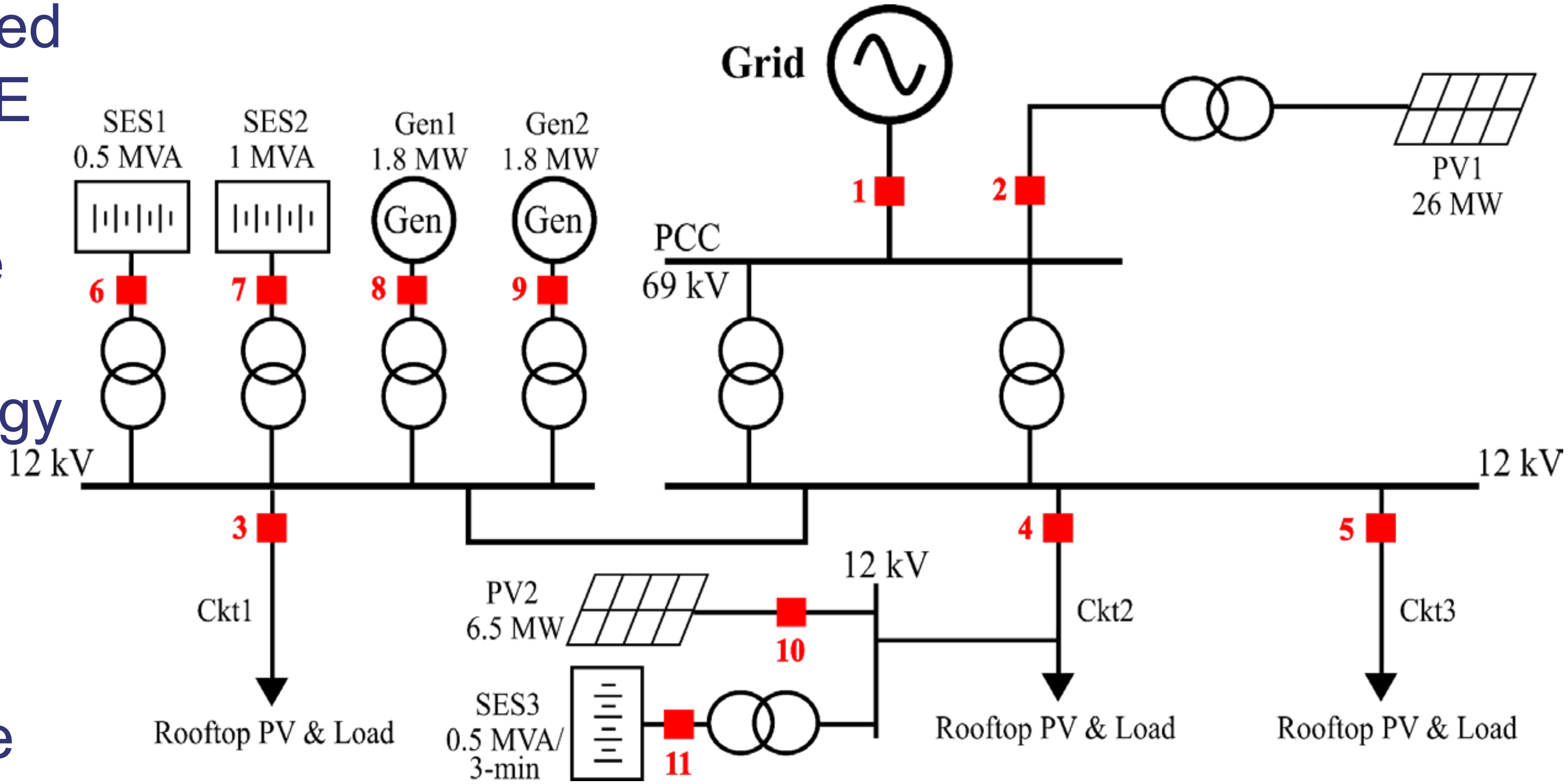
OVERVIEW

- Transient stability of multiple grid-forming and grid-following inverters in a 100% renewable microgrid is not studied.
- High-fidelity electromagnetic transient (EMT) model of a real-world microgrid is required.
- Inverter models need to match field deployed studies.
- Different dynamic operating conditions are required to study inverter model response.
- Outcome of the study will assist the field deployment.

BORREGO SPRINGS MICROGRID

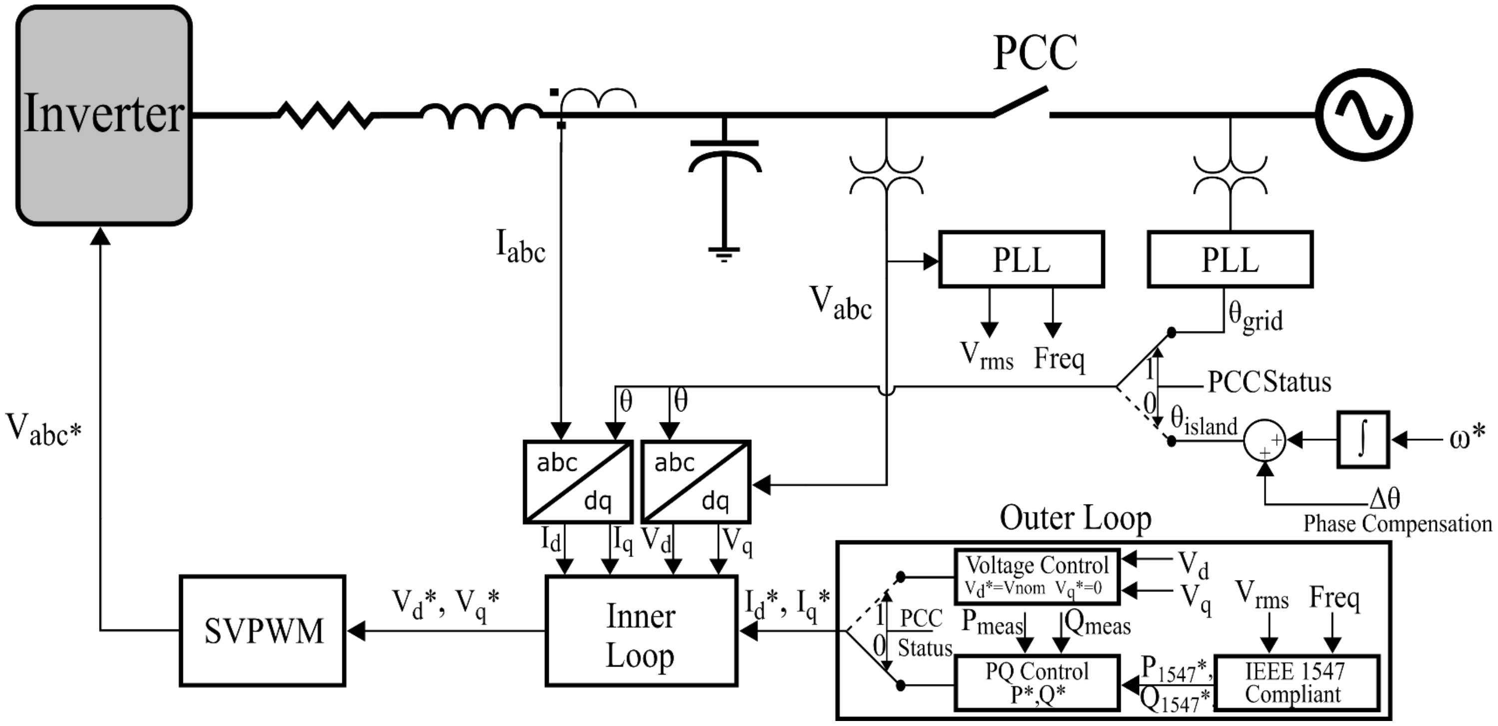
- Passive network is developed in PSCAD based on SDG&E model.
- SES1 and 2 are utility scale battery storage systems; SES3 is ultracapacitor energy storage system.
- Gen1 and Gen2 are diesel generators (back up).
- Ckt1, 2 & 3 has three phase dynamic loads.



- PV1 is dispatchable; PV2 is non-controllable and operates in unity power factor.
- Rooftop PV operates in unity power factor with total installed capacity of 5.4 MW.

GRID FORMING INVERTER (GFM)

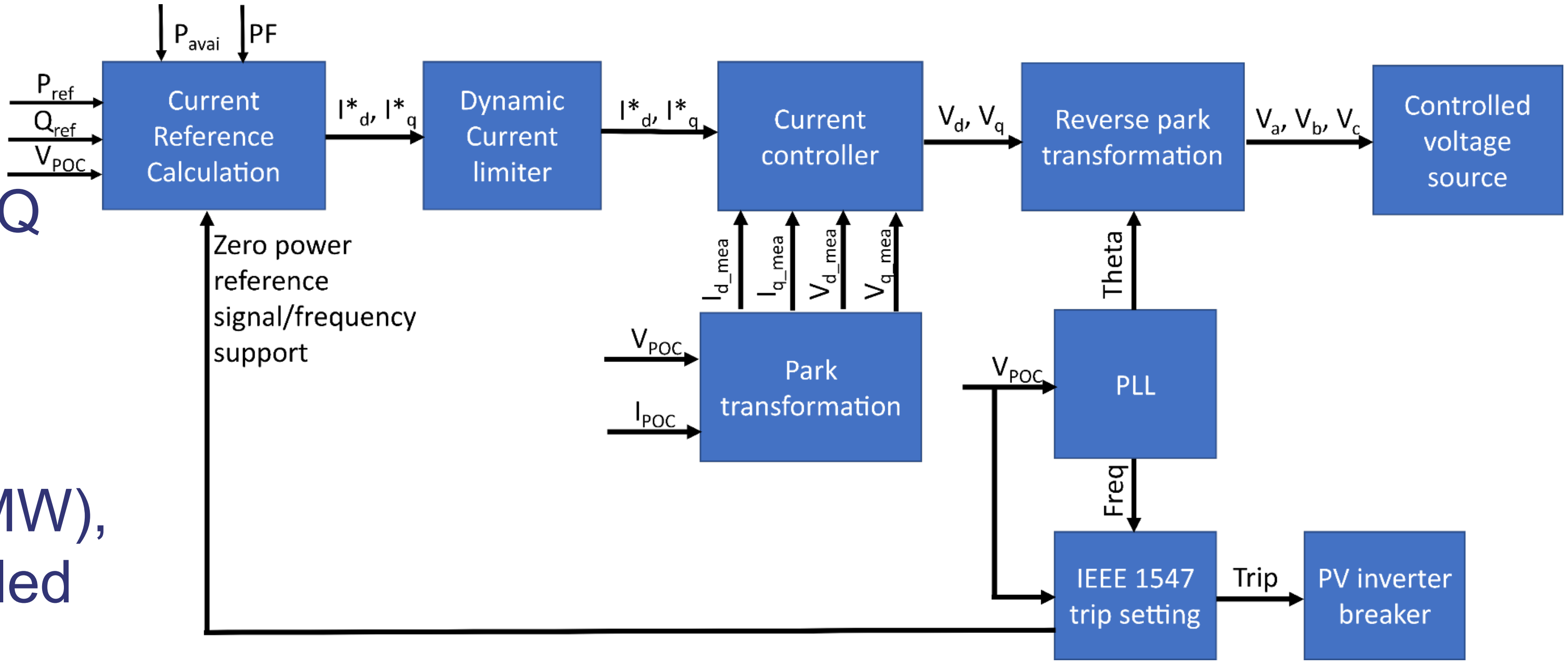
- Average switch model with DC/AC inverter dynamics.
- Operational modes:
  - VF control (startup)
  - PQ control (grid-connected)
  - VF control islanding master (islanded mode)
- IEEE 1547-2018 compliant in PQ control mode.



- **Smooth islanding transition is possible by adding the phase angle difference between grid and self generated phase angle to GFM phase angle**.
- Grid supporting functions: 1) Real/reactive power priority 2) Ride-through mode.
- SES1 and 2 (BESS) are modeled as GFM inverters.

GRID FOLLOWING INVERTER (GFL)

- Voltage controlled source average model.
- GFL model can work in PQ control or smart inverter function (volt-var with var priority).
- PV1 (26 MW), PV2 (6.5 MW), and rooftop PV are modeled as GFL inverters.

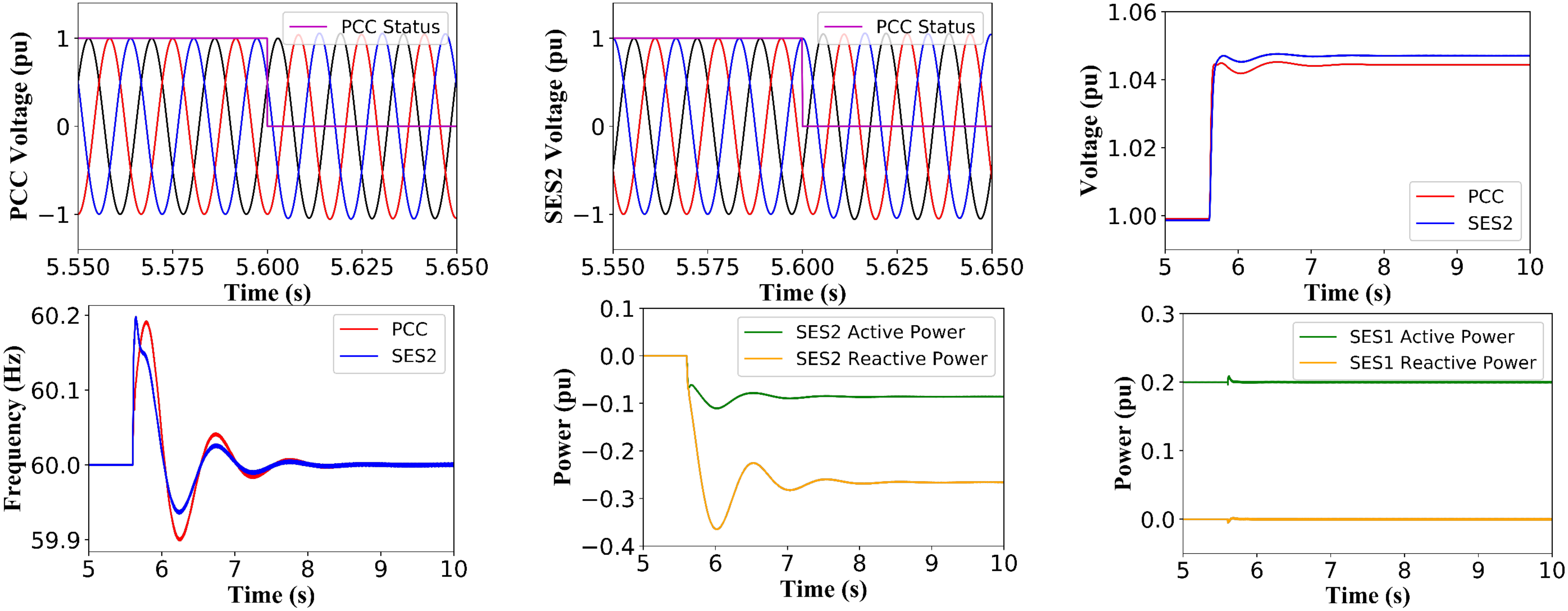


- PV1 is IEEE 1547-2018 compliant and rooftop PV are IEEE 1547-2003 compliant.
- PV1 is aggregated and modeled using 20 GFL inverters of 1.3 MW each.
- Rooftop PV is aggregated as 82 inverters of different ratings and locations.

SIMULATION SETUP AND TEST SCENARIOS

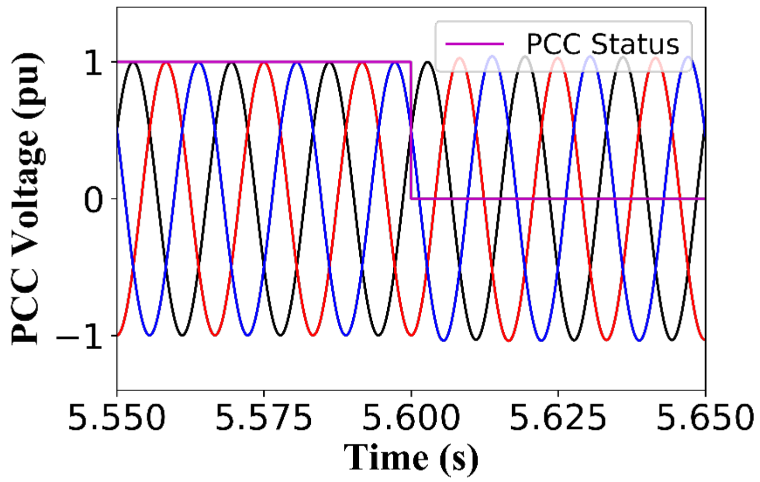
- High-fidelity PSCAD model has 106 inverters including SES1, 2 & 3.
- Borrego model is split into three networks using Bergeron model; 1) transmission, Ckt1 with rooftop, SES1, 2 and PV1; 2) Ckt2 with rooftop, PV2; 3) Ckt3 with rooftop.
- Due to the limitation of traveling wave time, simulation time step is fixed at 25 μs.
- PV1 is not included in the test scenarios due to light loading conditions.
- Morning load and solar data from SDG&E are used for the test scenarios.
- Different dynamic test scenarios are simulated to evaluate the stability and reliability of 100% renewable microgrid.
    - Scenario #1: Unplanned islanding with SES1 in GFL and SES2 in GFM
    - Scenario #2: Unplanned islanding with SES1 & 2 in GFM (Isochronous mode)
    - Scenario #3: Unplanned islanding with SES1 & 2 in GFM (droop mode)
    - Scenario #4: Black start of Ckt1

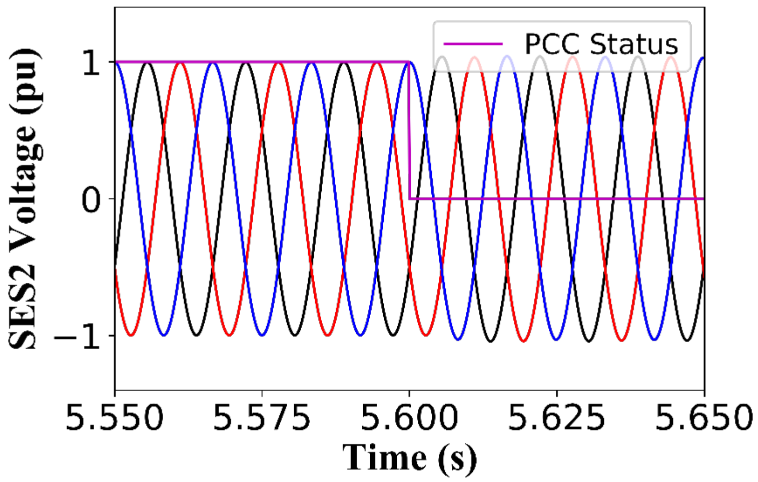
SCENARIO #1: SES1 (GFL) AND SES2 (GFM)

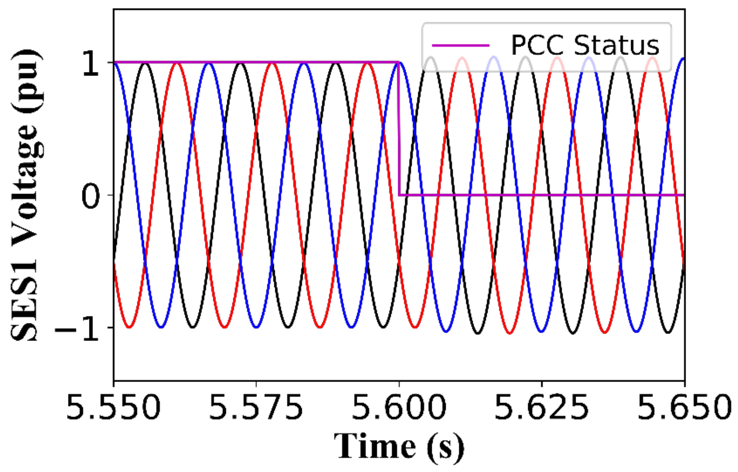


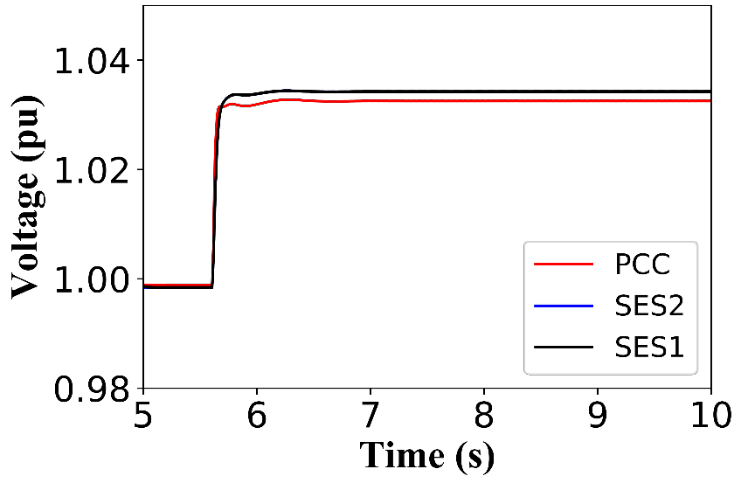
- Microgrid frequency overshoots by 0.2 Hz and dampens within 3 sec.
- SES2 power measurements show the settling time of 2 sec.

SCENARIO #2: SES1 AND SES2 (GFM VF CONTROL, ISOCHRONOUS MODE)



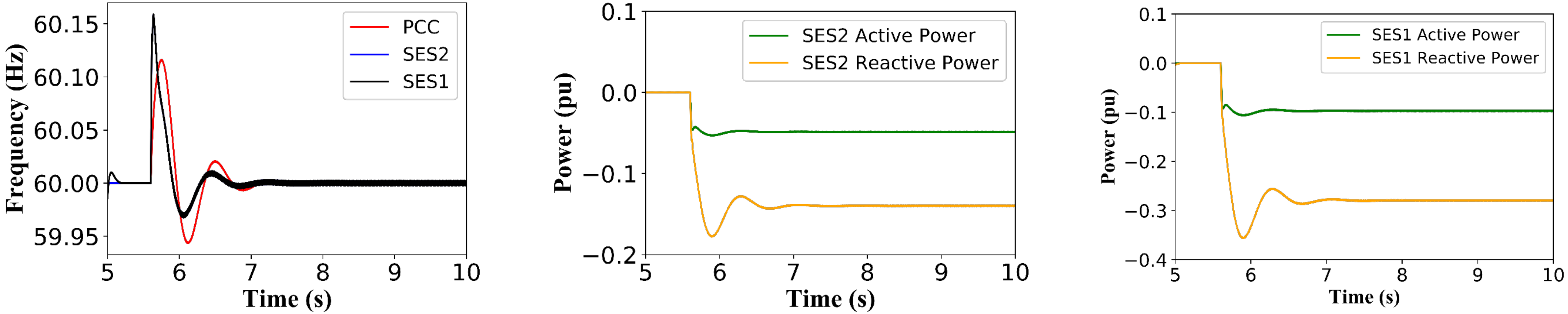






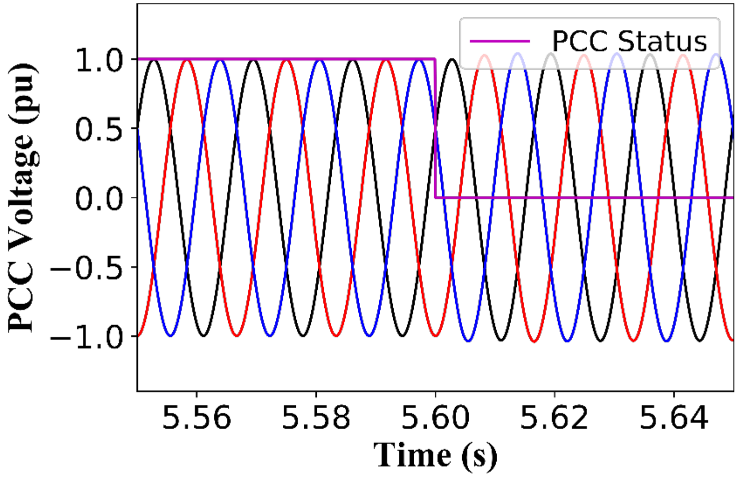
- Instantaneous voltage of PCC, SES1, and 2 show the smooth transition from grid-connected to islanded.
- SES1 and 2 terminal voltage rises to 1.03 p.u. due to excess reactive power in the microgrid.

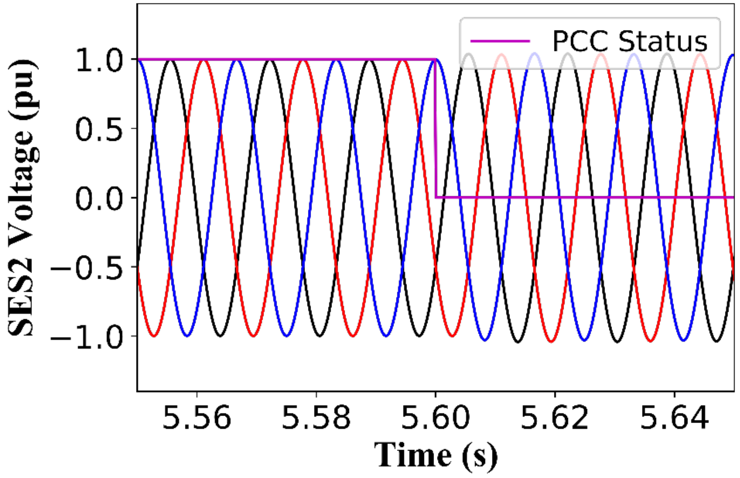
SCENARIO #2: SES1 AND SES2 (GFM VF CONTROL, ISOCHRONOUS MODE)

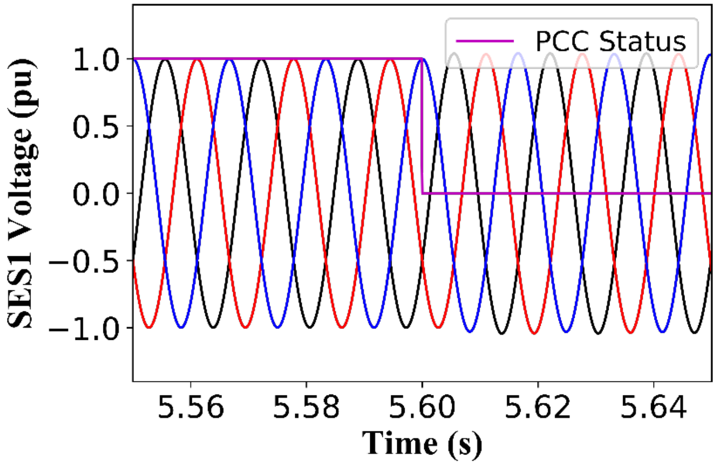


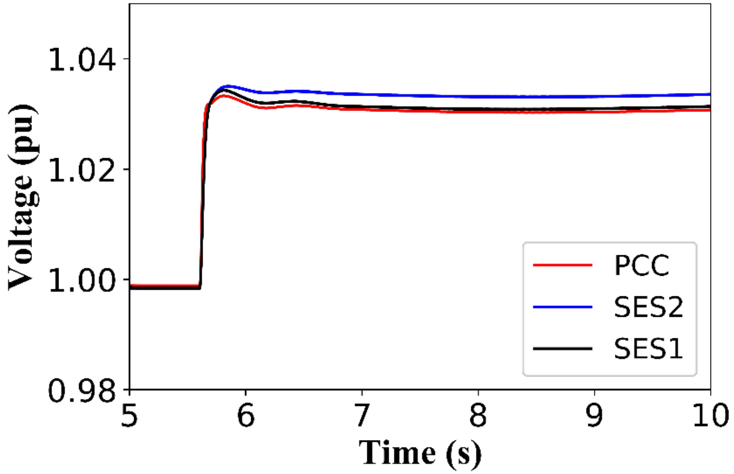
- ➢ Frequency result show the maximum overshoot of 0.15 Hz.
- ➢ Damped frequency oscillations settling time is 1.5 sec.
- ➢ SES3 is not required to inject any power because frequency is within deadband limit.
- ➢ Results show that scenario #2 provides better transient response than scenario #1.

SCENARIO #3: SES1 AND SES2 (GFM VF CONTROL, DROOP MODE)



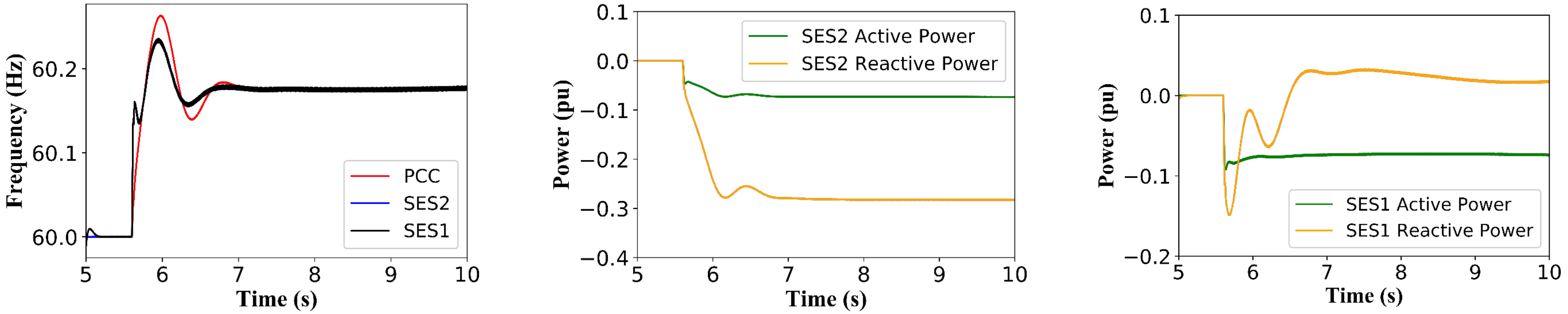






- SES1 & 2 droop constants are set to 4%.
- PI control in outer loop is changed to PD control for stability.

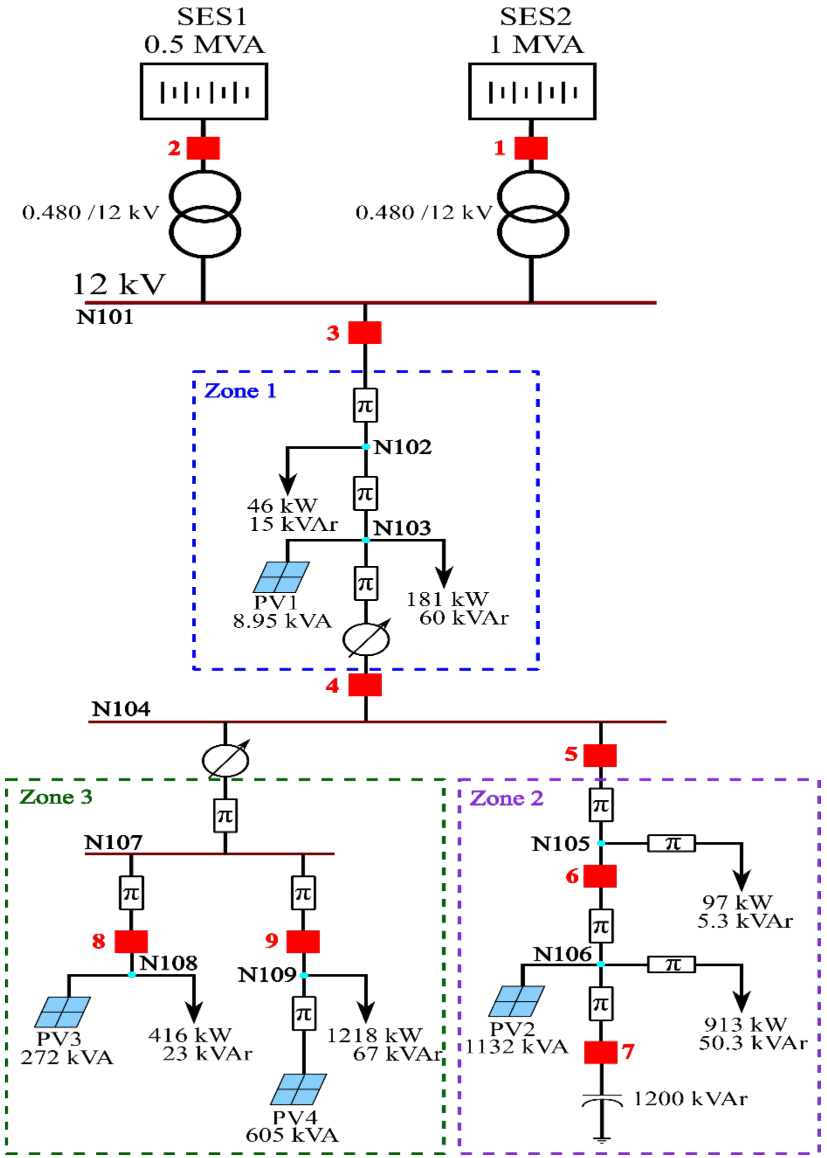
SCENARIO #3: SES1 AND SES2 (GFM VF CONTROL, DROOP MODE)



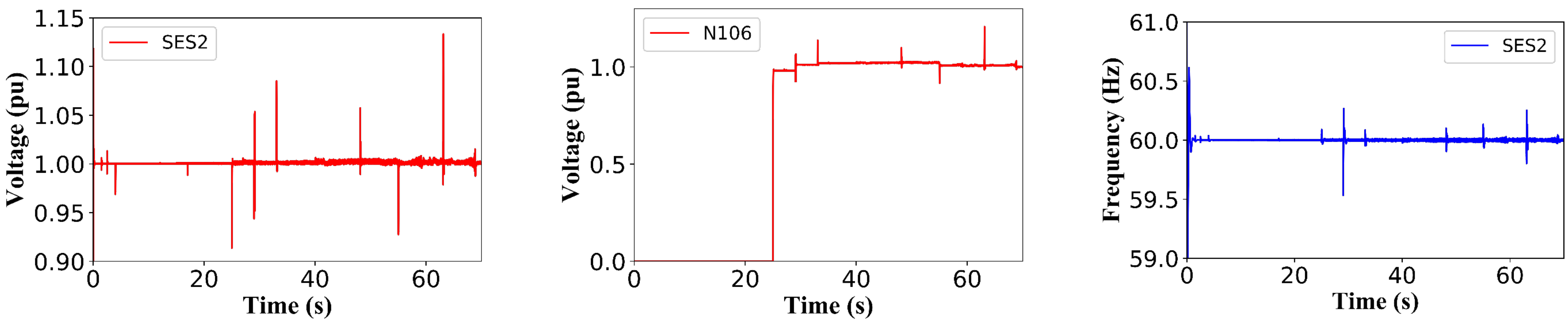
- Microgrid frequency settles above 60 Hz due to droop mode.
- Frequency and damped oscillations show similar settling time compared to scenario #2.
- More challenging scenarios like load steps and generation loss are required to determine the GFM operating mode (isochronous, droop).

BLACK START OF CKT1

- SES2 is used as GFM to black start ckt1.
- SES1 operates in GFL mode along with rooftop PV.
- Ckt1 has three zones based on utility black start sequence; zone1 has light, and balanced load; zone2 & 3 has heavy unbalanced load.
- Morning load and solar data from SDG&E are used for the ckt1 load and PV generation.
- Rooftop PV comes online 8 sec after the connected bus is energized.
- Accelerated black start is performed to reduce the total time in PSCAD simulation.

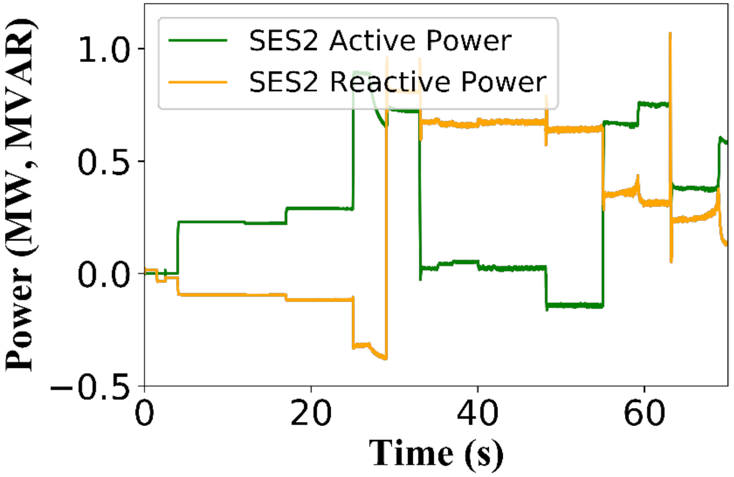


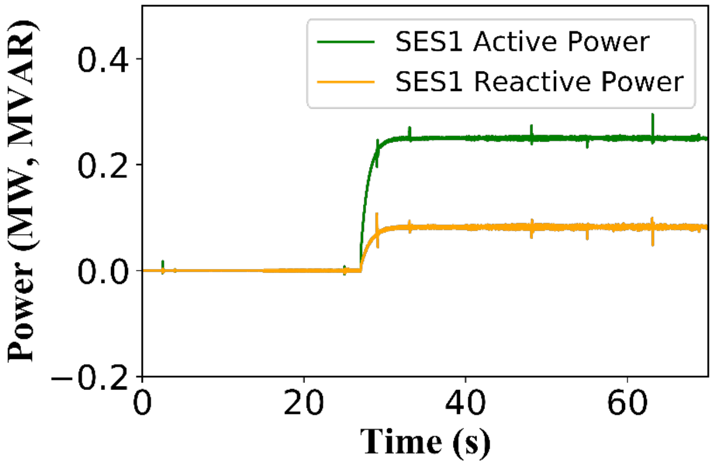
SCENARIO 4: CKT1 BLACK START

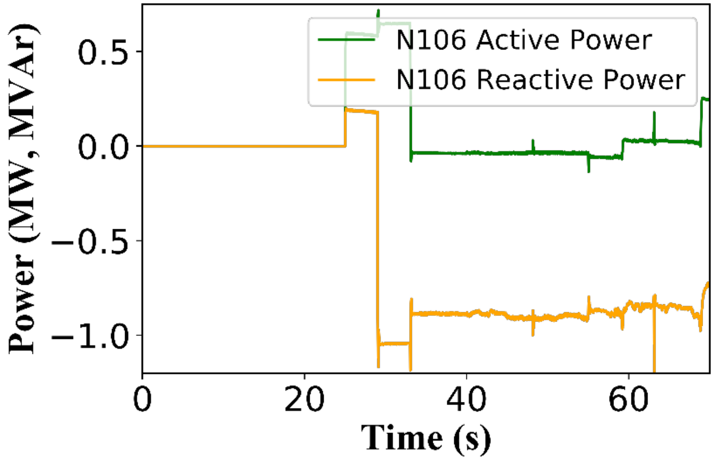


- Voltage and frequency measurements show the transients which are caused by cap bank and rooftop energization.
- Notch filter tuned to second harmonic is used to suppress noise caused by unbalanced load after 27 sec.
- Third and fourth harmonics makes the measurement noisy with each unbalanced load.

SCENARIO #4: CKT1 BLACK START







- SES2 power measurements show that BESS rating is not exceeded.
- SES1 is required to achieve the load and generation balance during zone2 & 3 load switching.

CONCLUSION

- High-fidelity PSCAD model with 86 inverters is simulated under unplanned islanding and black start scenarios.
- Unplanned islanding scenario results show the smooth transition between grid-connected and islanded mode.
- Two GFM inverters in islanded mode showed better transient response but droop mode required the PD control in outer loop.
- More test scenarios are required to determine optimal mode (Isochronous or droop).
- Ckt1 black start is successful with SES2 as GFM source.
- Positive sequence dq0 control can only control fundamental components.
- Negative-sequence control or harmonic compensation control is required to eliminate the noise in the measurements.

Thank You

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NREL/PR-5D00-83644

This work was supported by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory 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's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 9027. 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.