Positive sequence and EMT domain modeling of grid forming hybrid plants for transmission studies

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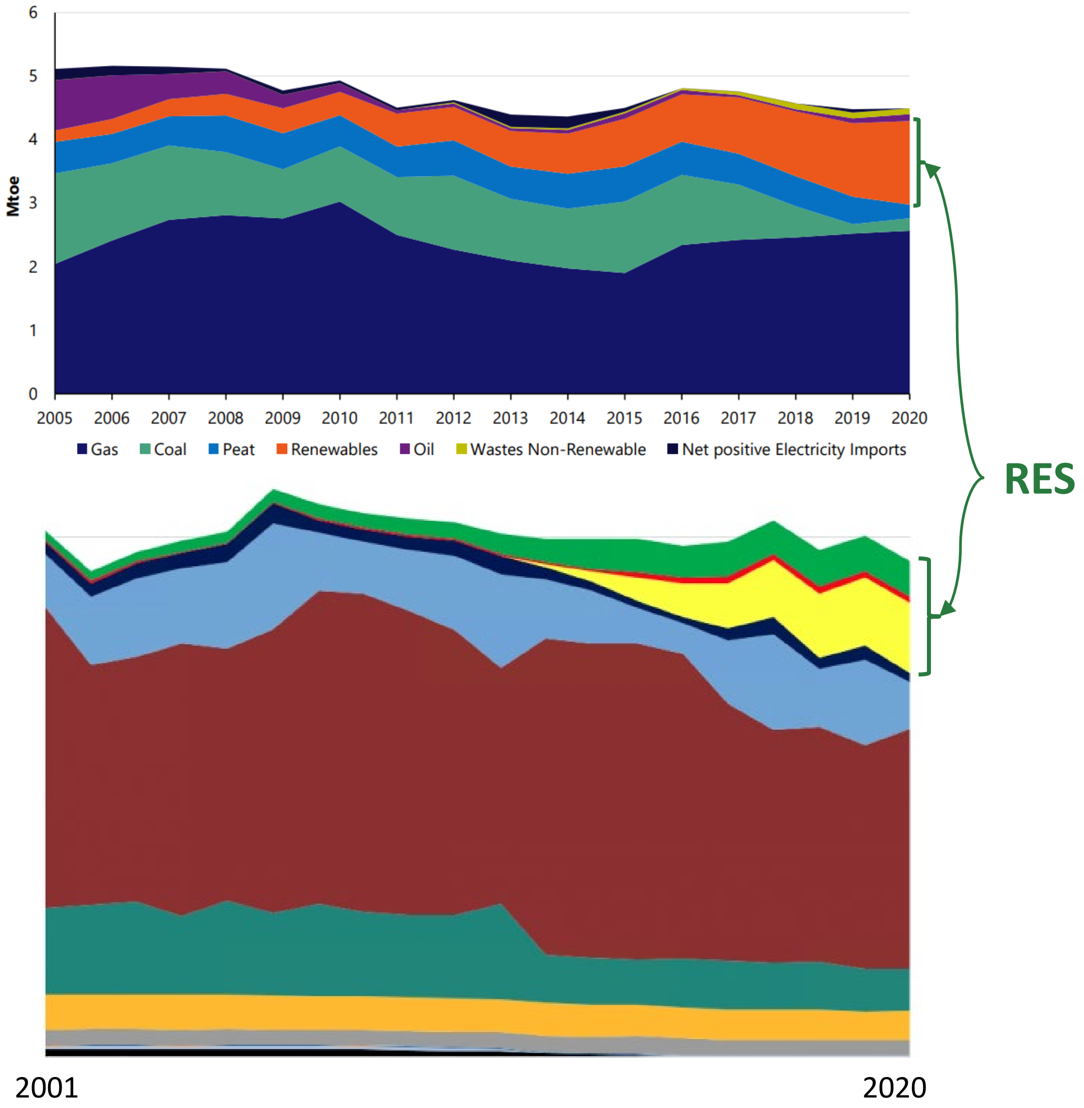
Background

- » Large scale renewable energy sources (RES) power plants beginning to have a large share in energy production in power systems
  - United Kingdom – 43% annual contribution of RES, 2020 [1]
  - Ireland – 42% annual contribution of RES, 2020 [2]
  - California – 94.5% instantaneous RES, 2019 [3]
- » Challenges due to increasing penetration of RES:
  - Frequency and stability issues
  - Problems with resource adequacy due to the intermittency of RES
- » Hybrid power plants are suitable in addressing these challenges, while simultaneously increasing the penetration of zero carbon energy sources



Electricity generation by fuel type in Ireland [1] (top) and California [4] (bottom)

Existing Hybrid Power Plants

Stillwater GeoSolar, NV

- Capacity: 26.4 MW solar PV, 2 MW solar thermal, 33 MW geothermal

Permian Energy Center, TX

- Capacity: 420 MW solar PV, 40 MW (40 MWh) battery
- Short term battery storage for use in ancillary services markets and in shoulder hours

El Hierro, Canary Islands

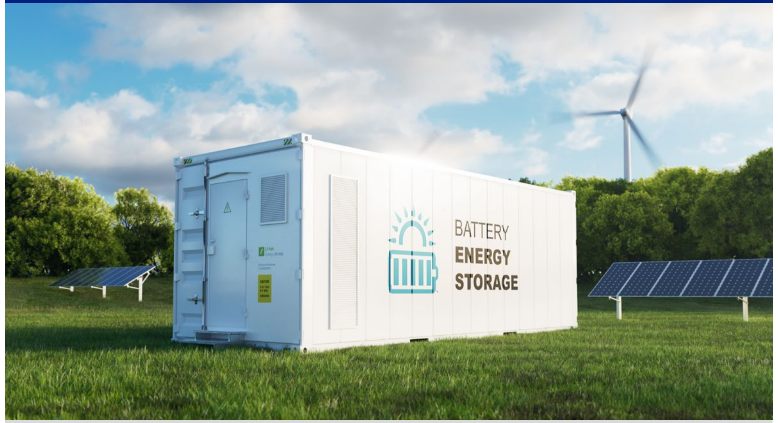
- Capacity: 11.5 MW wind, 6 MW pumped storage
- Met 54% of energy for the island in 2019, 100% penetration over an 18-day period

Agnew Renewable Energy Microgrid, Australia

- Capacity: 18 MW wind, 4 MW solar PV, 13 MW (4 MWh) battery, 21 MW gas/diesel
- Up to 85% renewable penetration, forecasted to average 50-60% renewable energy in long term

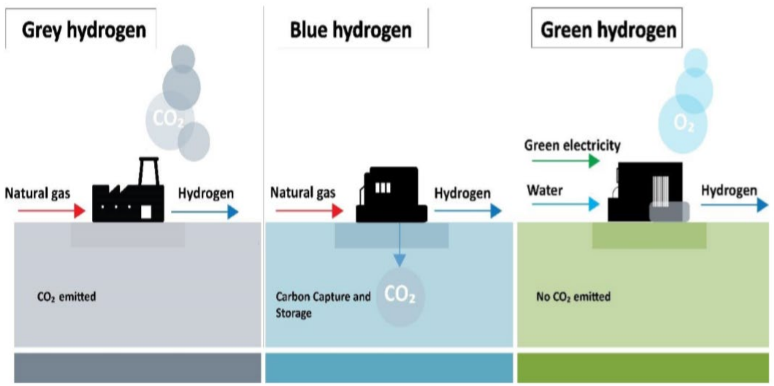
Benefits of Hybrid Power Plants

Enhancement of RES in transmission systems



» Reduce curtailment of RES
» Help RES participate in ancillary service markets
» Improve energy yield by integrating RES with storage
» Storage with RES plants without increasing interconnection rating

Integration with P2X



» Production of alternative fuels from low/zero carbon sources
  - Hystock project, The Netherlands

Replace/supplement thermal generation

» Solar thermal integrated with coal/gas plants to boost boiler temperature without burning fossil fuels
  - Kuraymat, Egypt
  - Kogan Creek Solar Boost Project, Australia*

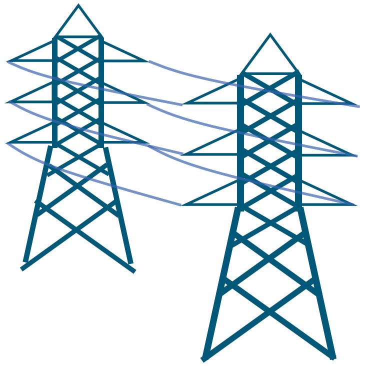
» Gas/diesel generator plus solar PV/wind reduces emissions while ensuring energy security

Challenges of Hybrid Power Plants

Forecasting

» Accurate forecasting when combining wind, solar, storage is complex, penalties for inaccurate forecasting

Interconnection



» Will the addition of storage to an existing plant require interconnection studies and/or system upgrades?

Telemetry

» Varying requirements on telemetry (CAISO and NYISO require monitoring of each unit, PJM require monitoring at POI)

Managing SOC

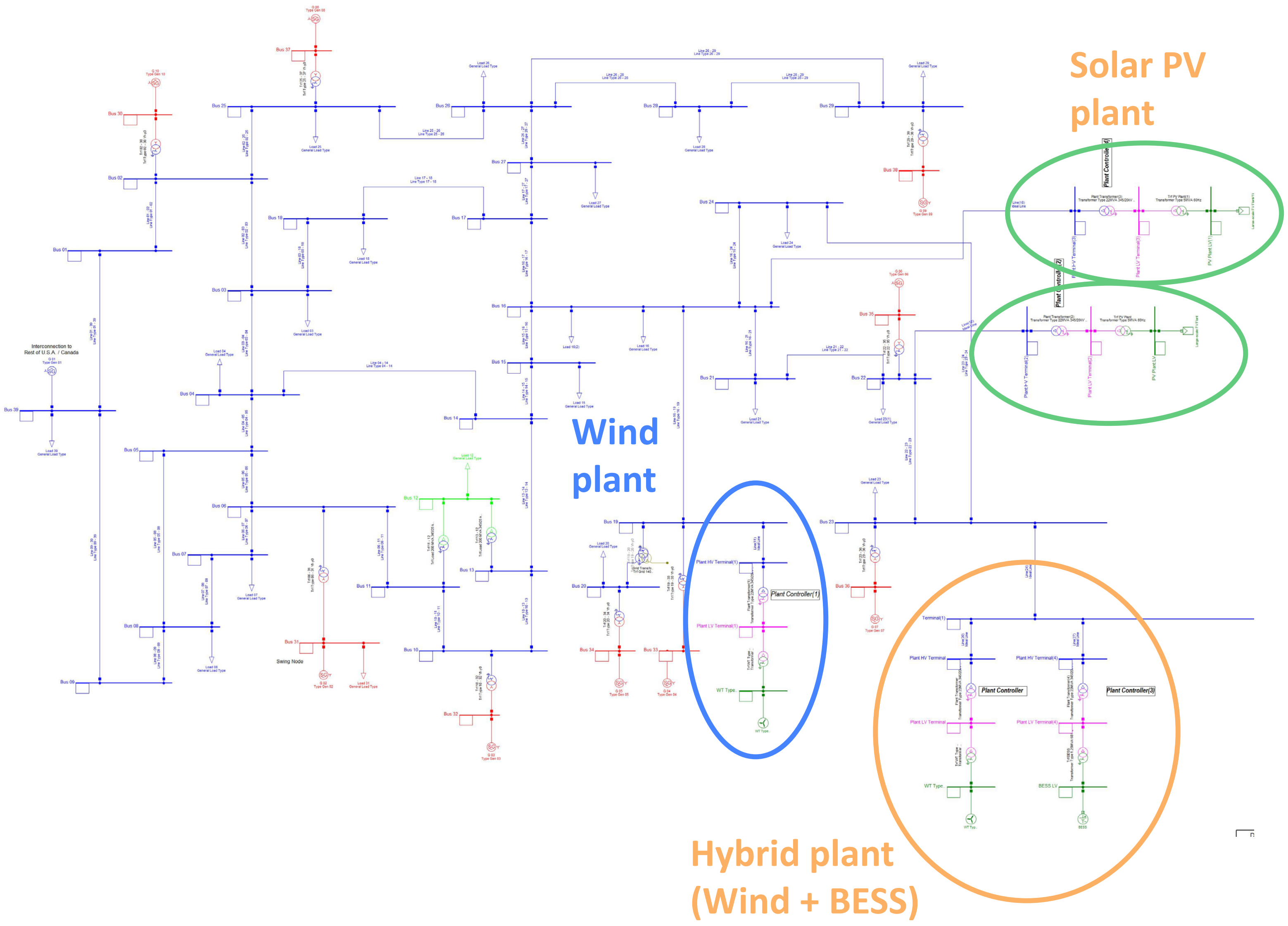
» Plant operator must manage the SOC of any energy storage units to ensure dispatch schedules can be met

Transmission Planning Challenges

- Questions
  - Can hybrid plants improve frequency stability in systems with a high IBR penetration?
  - Are hybrid plants capable of grid forming?
- Case studies
  - Positive sequence domain
    - Assess impact of hybridizing an existing RES plant with the addition of BESS behind POI to different network scenarios
    - Modelled in DIgSILENT PowerFactory
  - EMT domain
    - Assess grid forming abilities of hybrid plants in 100% IBR networks
    - Modelled in PSCAD®

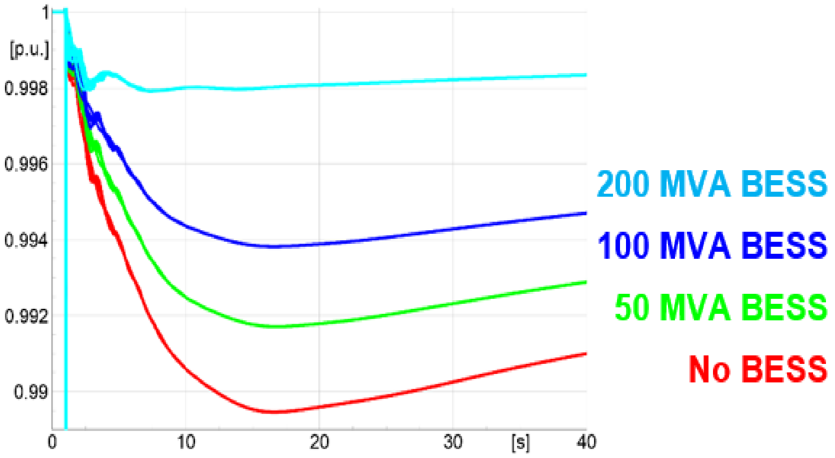
Positive Sequence Simulations

- IEEE 39 bus system
- Generic WECC models of 2 wind and 2 solar PV plants integrated into the power system to achieve 50% RES penetration
- One BESS integrated with a wind plant to form hybrid plant

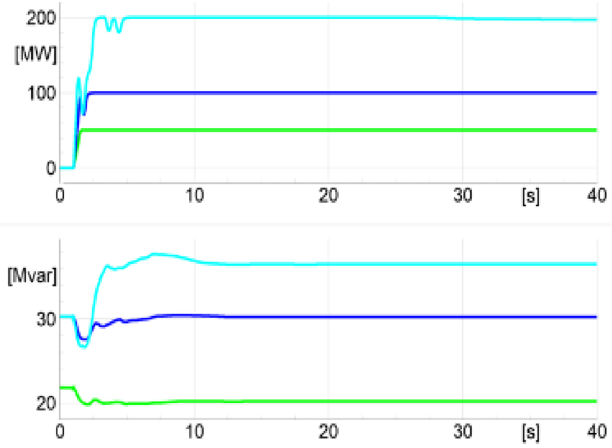


Positive Sequence Simulations

System Frequency (pu)



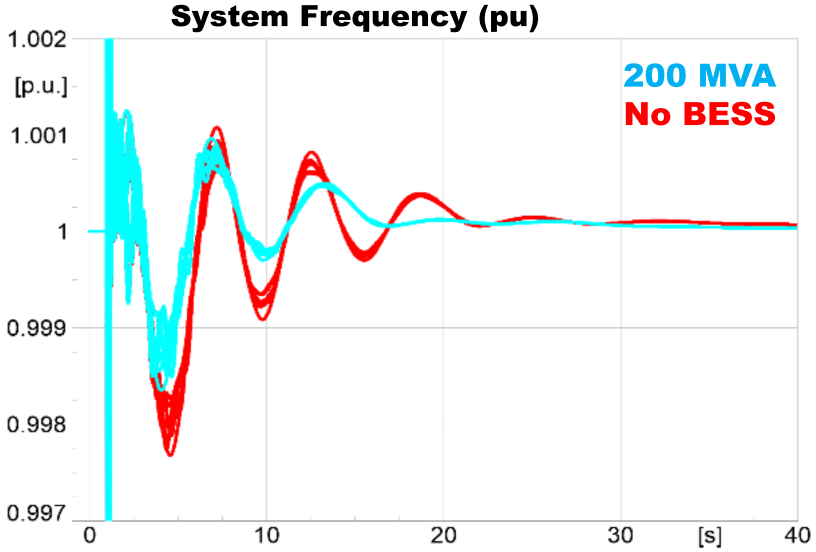
BESS Power Output

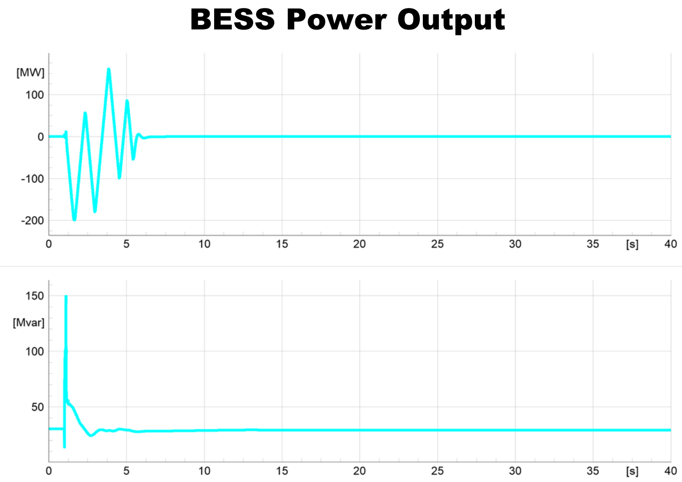


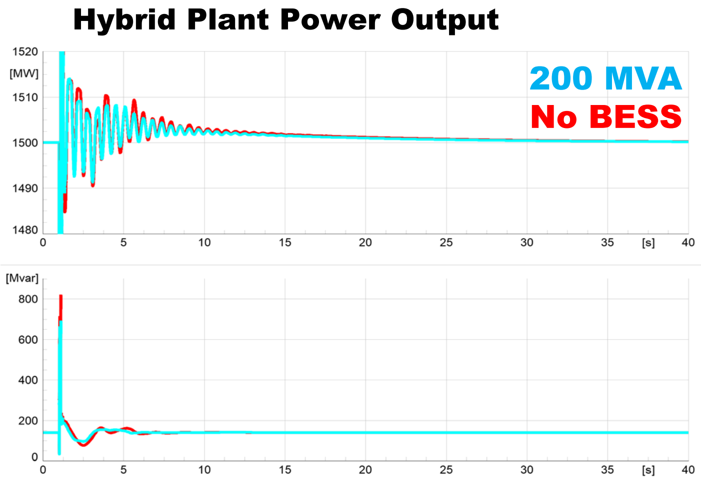
Hybrid Plant Power Output

- » 250 MW generator outage
  - System frequency response improves with the addition of BESS (frequency nadir is improved, and maximum RoCoF reduced)
  - BESS ramps up power much quicker than governor response to reduce generation/load imbalance
  - Hybrid plant exhibits reduced oscillation of output power with the BESS compared to without BESS

Positive Sequence Simulations







» Three phase to ground short circuit fault at nearby busbar (Bus 21), cleared after 0.1s

- System frequency response improves with the addition of the BESS (improved nadir, reduced change of UFLS)
- BESS modulates power output in response to system oscillations to damp down frequency oscillations
- Hybrid plant again exhibits less oscillation in power output with BESS compared to without BESS

EMT Simulations

» With many hybrid plants being inverter-based resources, with very fast transients and shorter timescales of system dynamics, it is important to verify the behaviour of the plant in the electromagnetic transient (EMT) domain

» It will be possible soon for power systems to be 100% fed from IBR

» Hybrid plants will be assessed for their grid forming capabilities

System Setup

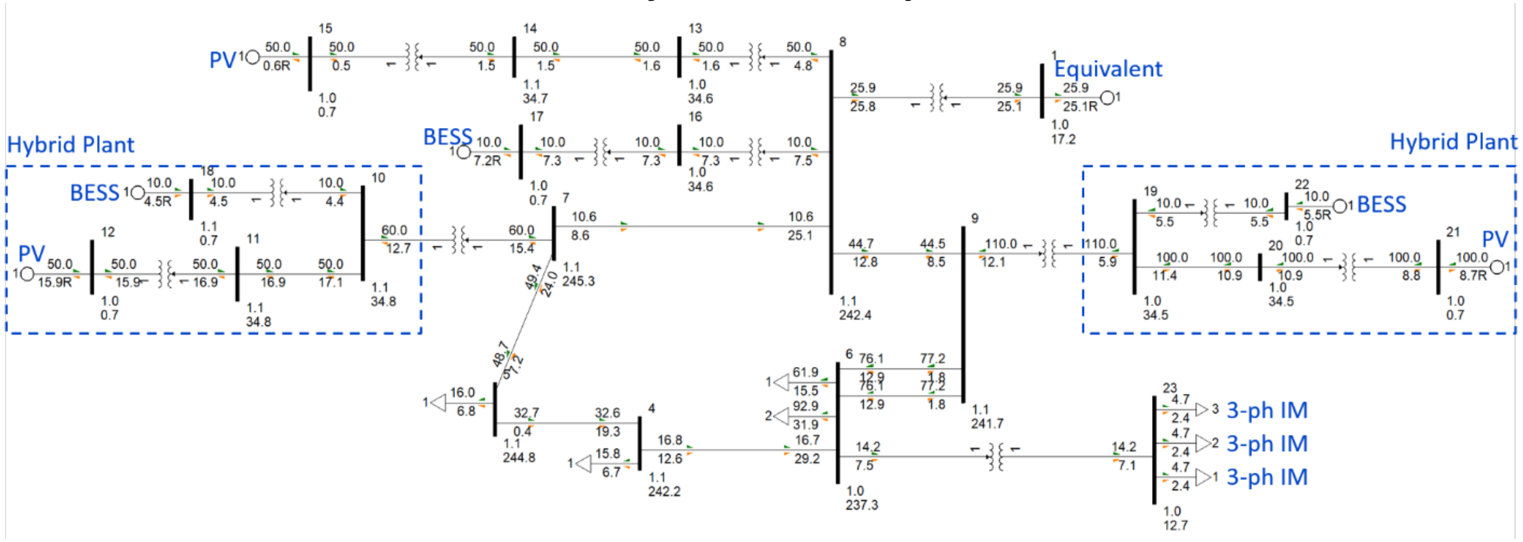
» Simulated in PSCAD®

» Both hybrid plants shown are PV plants with BESS

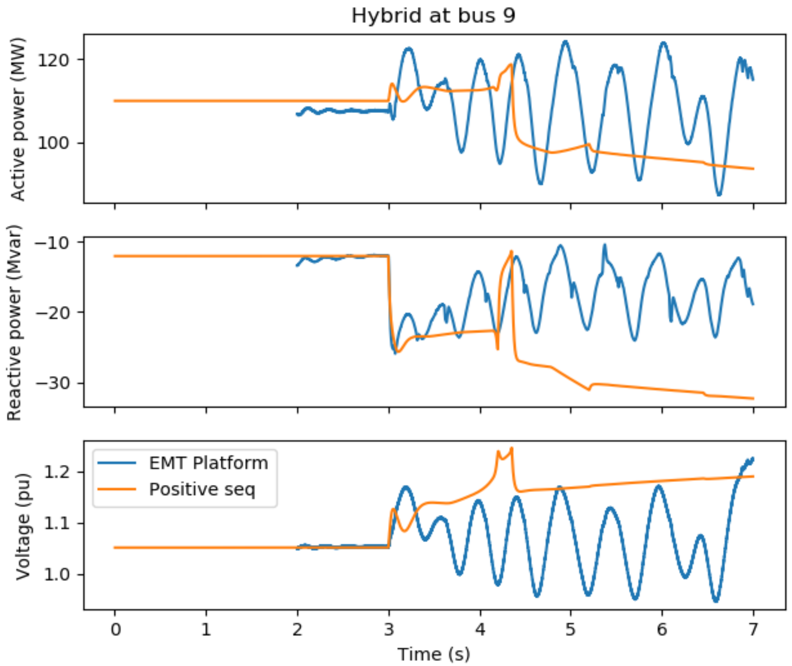
- Bus 9 – 110 MVA PV plant, 30 MVA BESS
- Bus 10 – 60 MVA PV plant, 30 MVA BESS

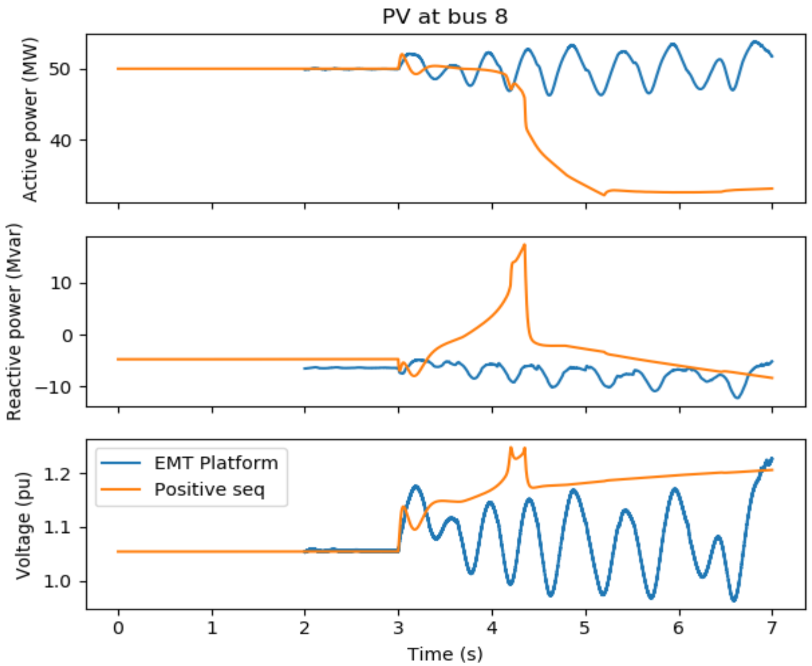
» Co-located plant with PV and BESS connecting to bus 8

» Plant responses are tested when system equivalent is disconnected

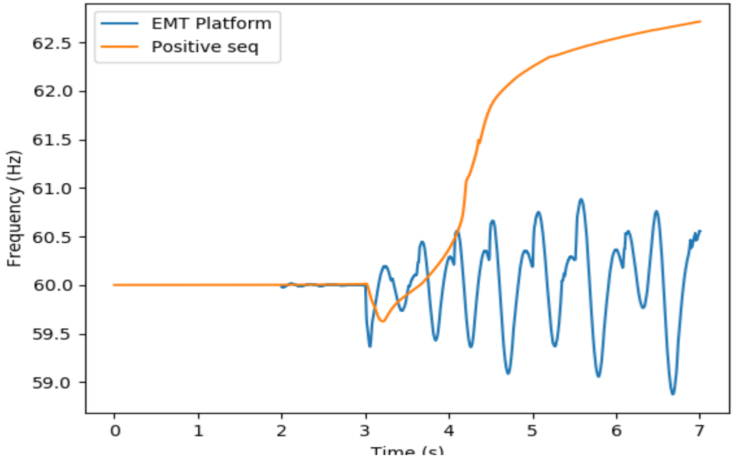


Simulation Results



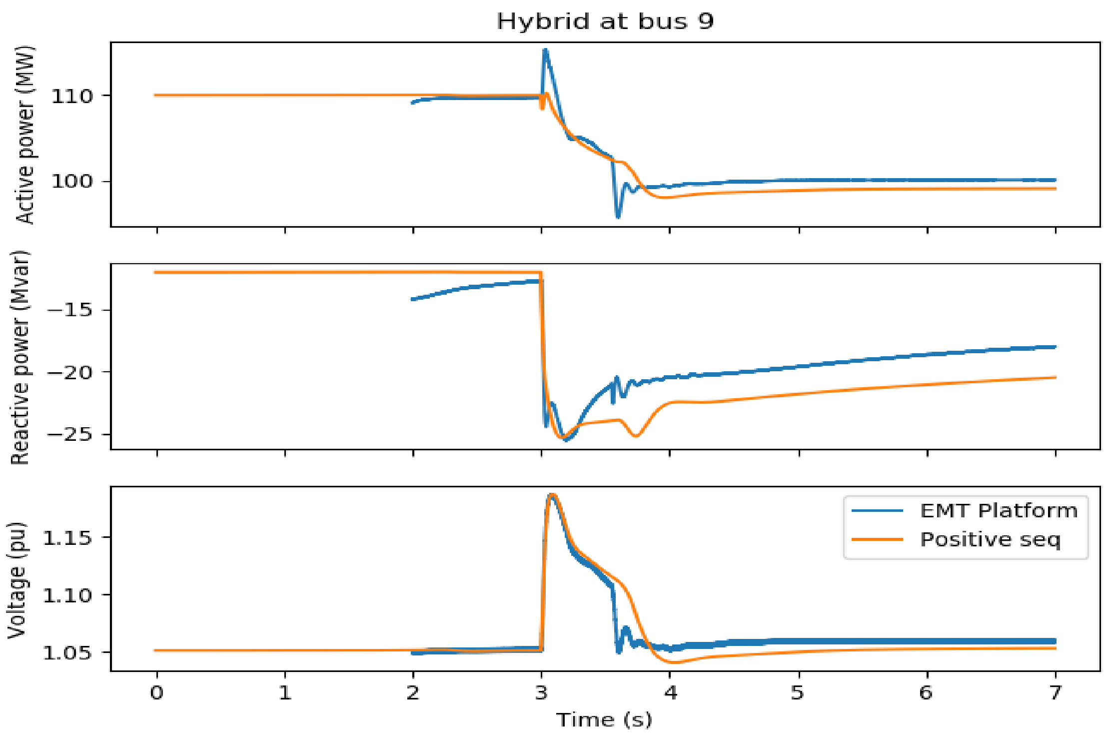


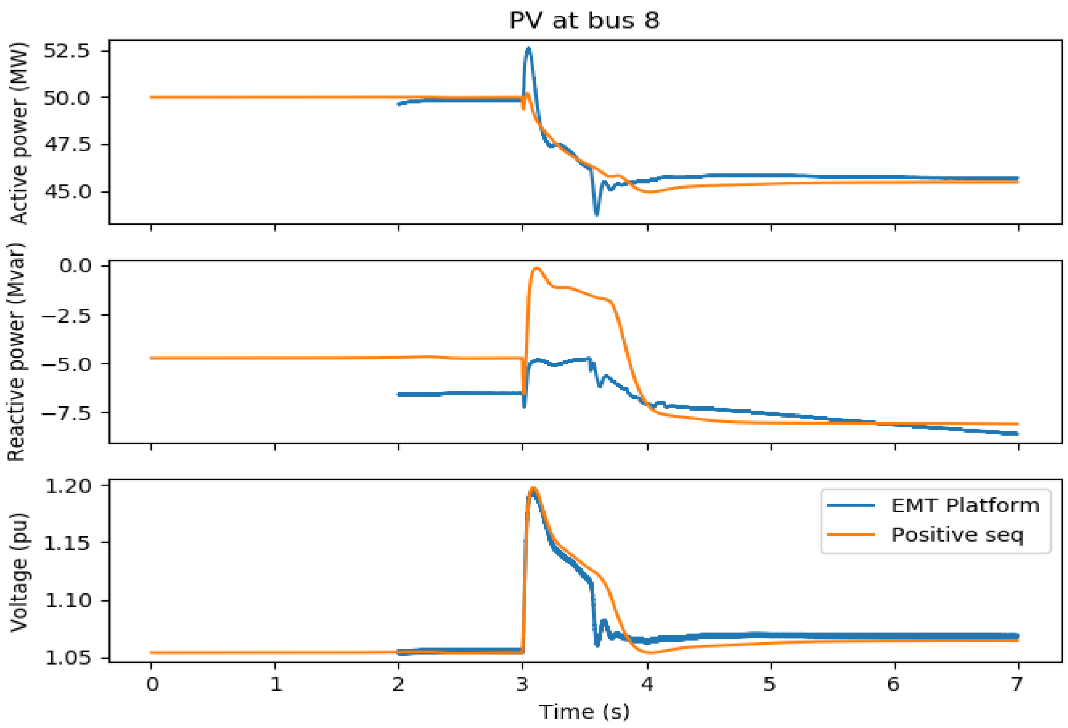
System frequency



- System equivalent disconnected at t=3.0s, giving 100% IBR network
- System equivalent drawing 25 MW/Mvar prior to disconnection. All IBR in the resulting network after disconnection of system equivalent have sufficient headroom to accommodate the change
- With the PV plants in grid following mode, the island is unable to remain stable following the disconnection of the system equivalent (BESS in grid forming mode)
- The differences between the positive sequence and EMT simulations are significant, but both show that something is amiss in the network. A system planner could simulate the network in positive sequence and make a case to carry out a more detailed study

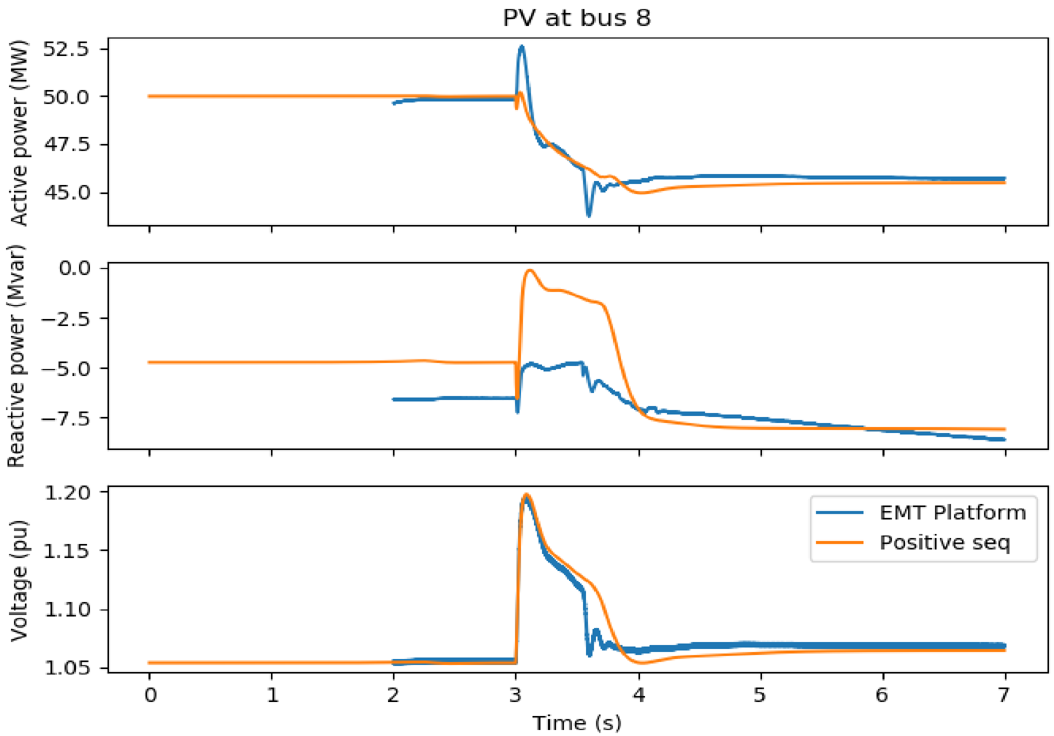
Simulation Results

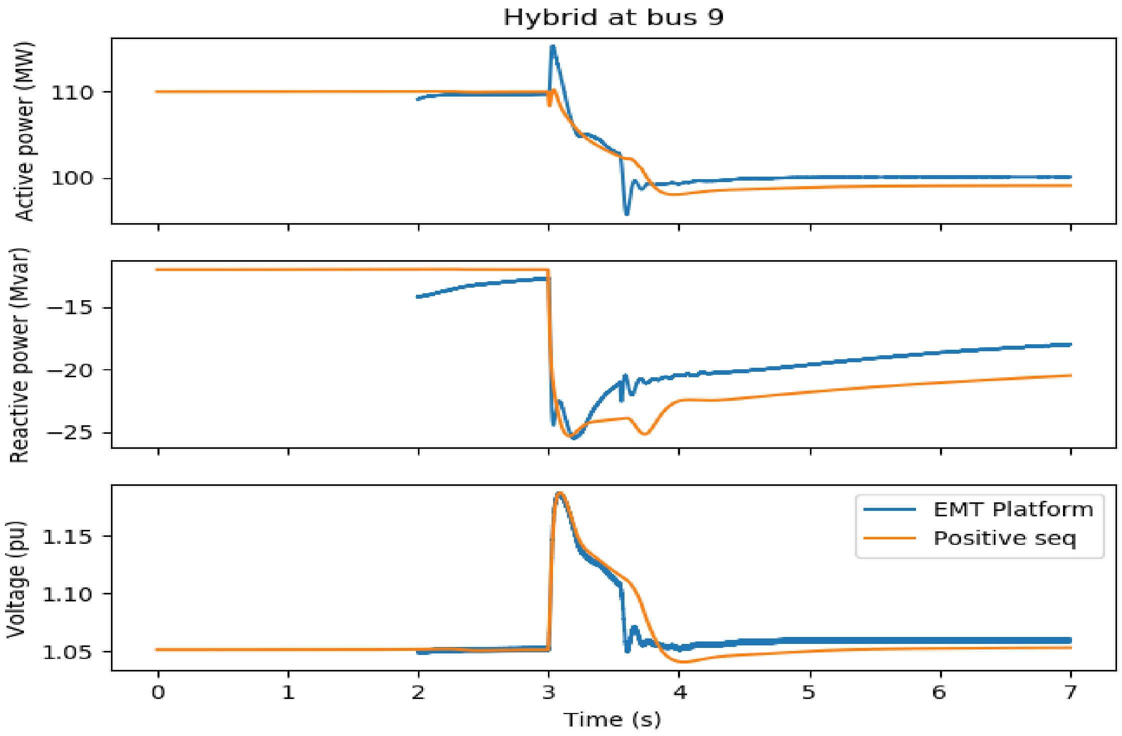




- » Without any changes to the ratings of the devices in the network, the PV plants are enabled to provide frequency support at a ramp rate of 10pu/s
- » PV plants actively contribute by reducing their power output
- » This has a clearly beneficial impact on system stability in both positive sequence and EMT scenarios
- » Improved coherency between positive sequence and EMT simulations now that the island is stable

Simulation Results





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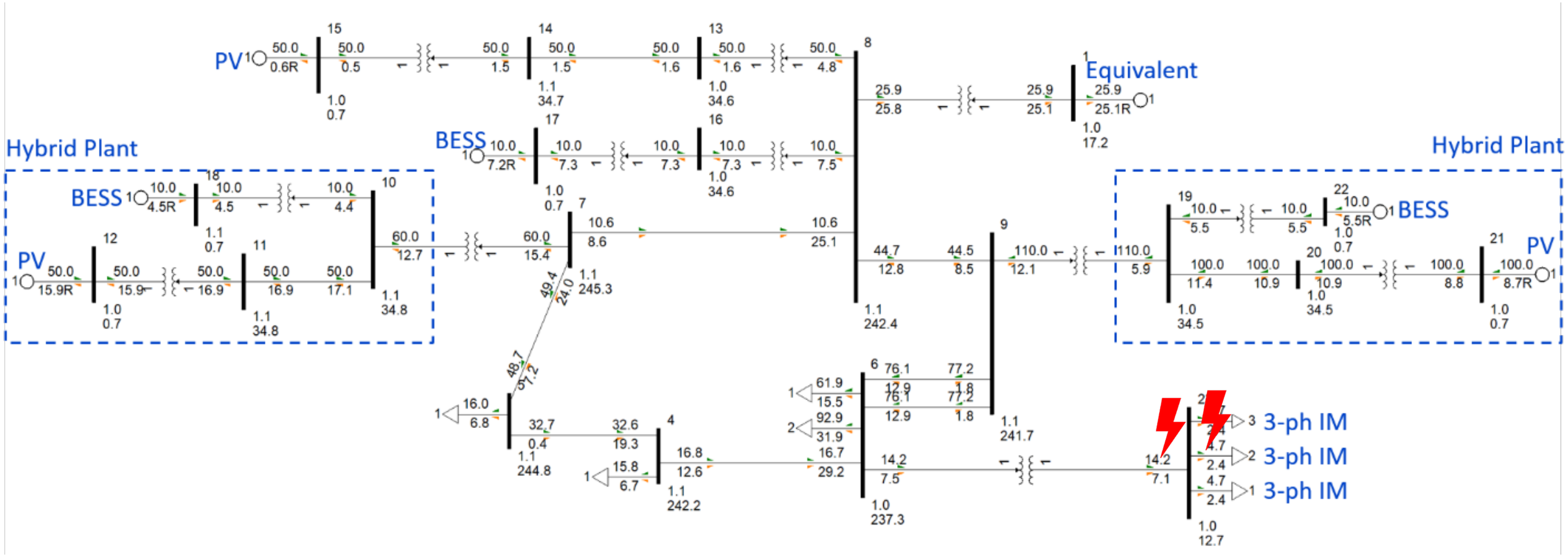
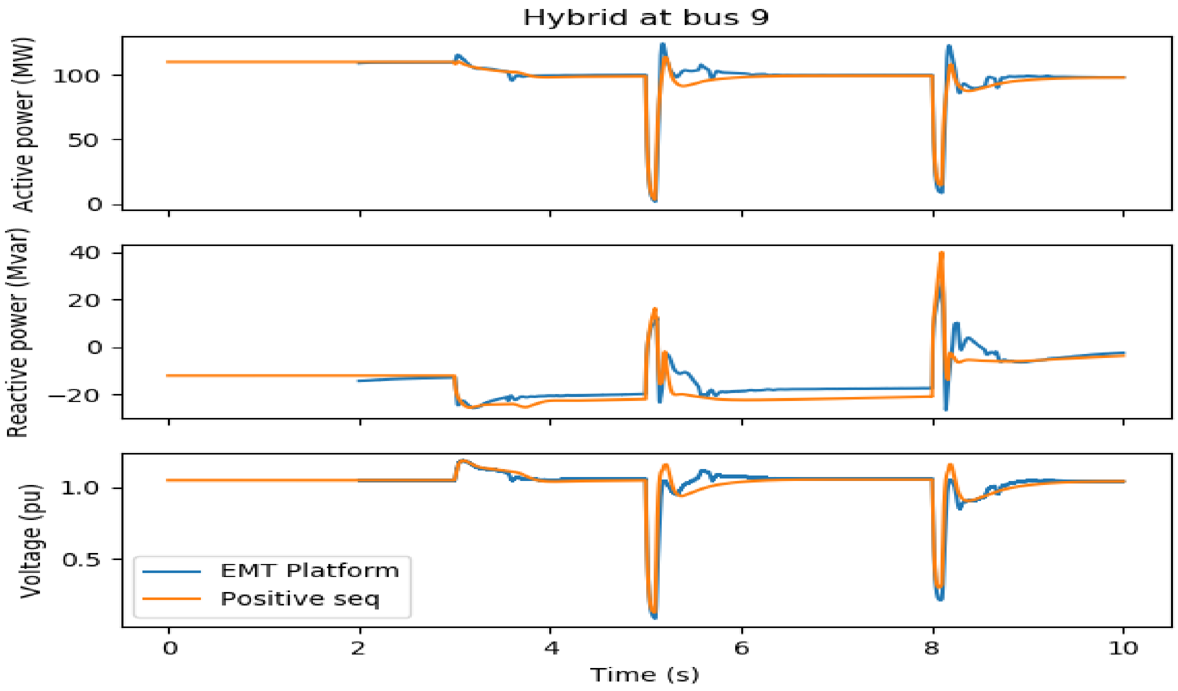
Simulation Results

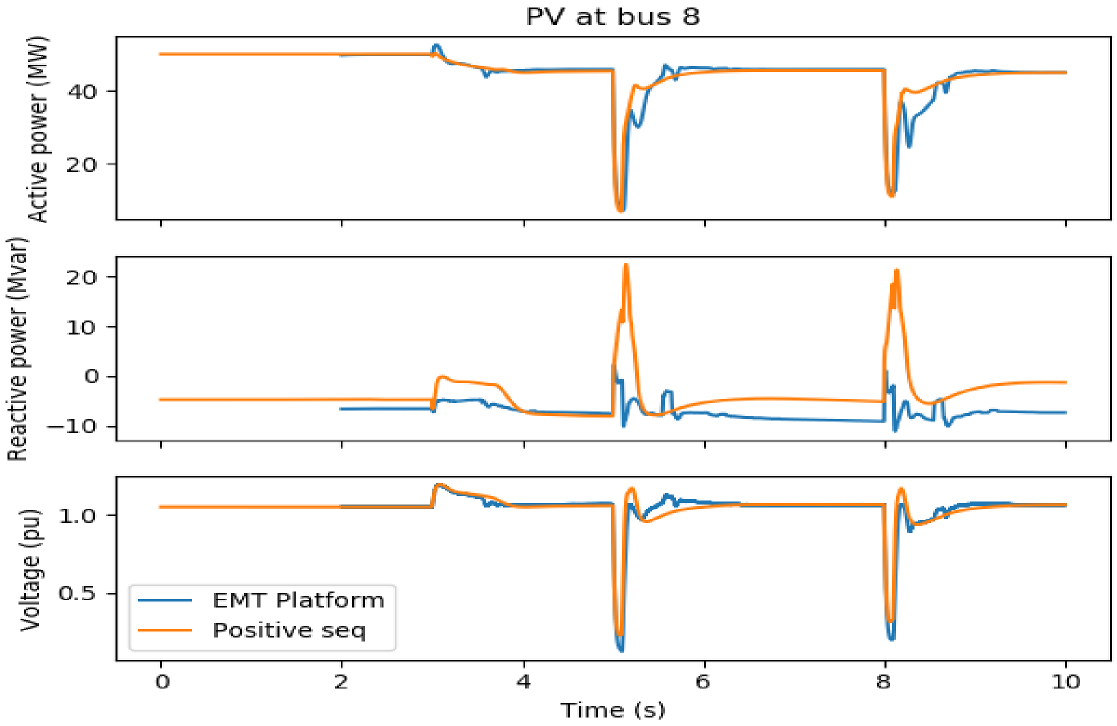


» System equivalent is disconnected at t=3.0s, with 2 subsequent three phase to ground faults

» Faults applied either side of the induction motor load bus

Simulation Results





» Agreement between positive sequence and EMT models (provided appropriate parameterization)

» Improvements in positive sequence models can allow a transmission planner to obtain more visibility into the behaviour of future power networks

Conclusion

- The inclusion of only BESS in grid forming mode may not be sufficient for a system unless a large rating of BESS in grid forming mode is considered
- It is important to consider the ramp rate limits of devices
- Induction motor load versus static load behaviour can provide different response characteristics
- Continuous improvement of models across software platforms is needed

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- Brad Finkbeiner (SPP)
- Scott Baker (PJM)

Sources

[1] – "Energy in Ireland: 2021 Report," Sustainable Energy Authority of Ireland, Dublin, Ireland, December 2021. Accessed: 18/02/2021. [Online]. Available: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/energy-in-ireland/

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[3] – California ISO. "Monthly Renewables Performance Report: April 2021." CAISO.com. http://www.caiso.com/Documents/MonthlyRenewablesPerformanceReport-Apr2021.html

[4] – "Electricity Generation Capacity and Energy." energy.ca.gov https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy (accessed Apr. 14, 2022).

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