CIGRE US National Committee
2021 Grid of the Future Symposium

Transient Stability Analysis Framework for Performance Evaluation of Microgrids with an Energy Storage System and a Synchronous Condenser

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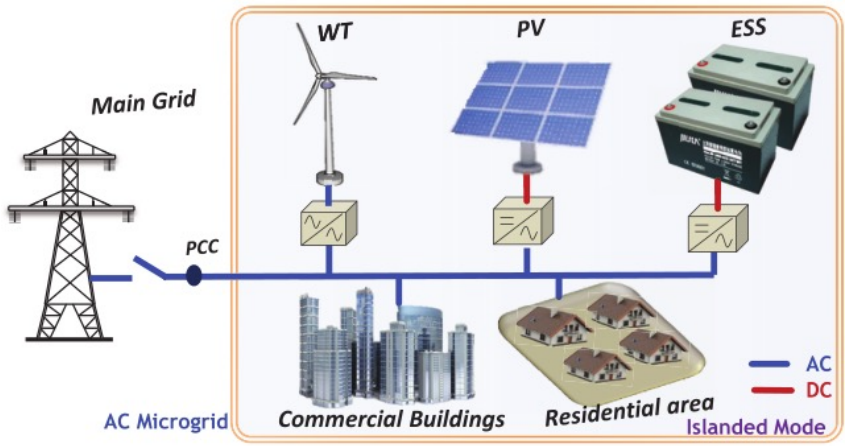
Introduction

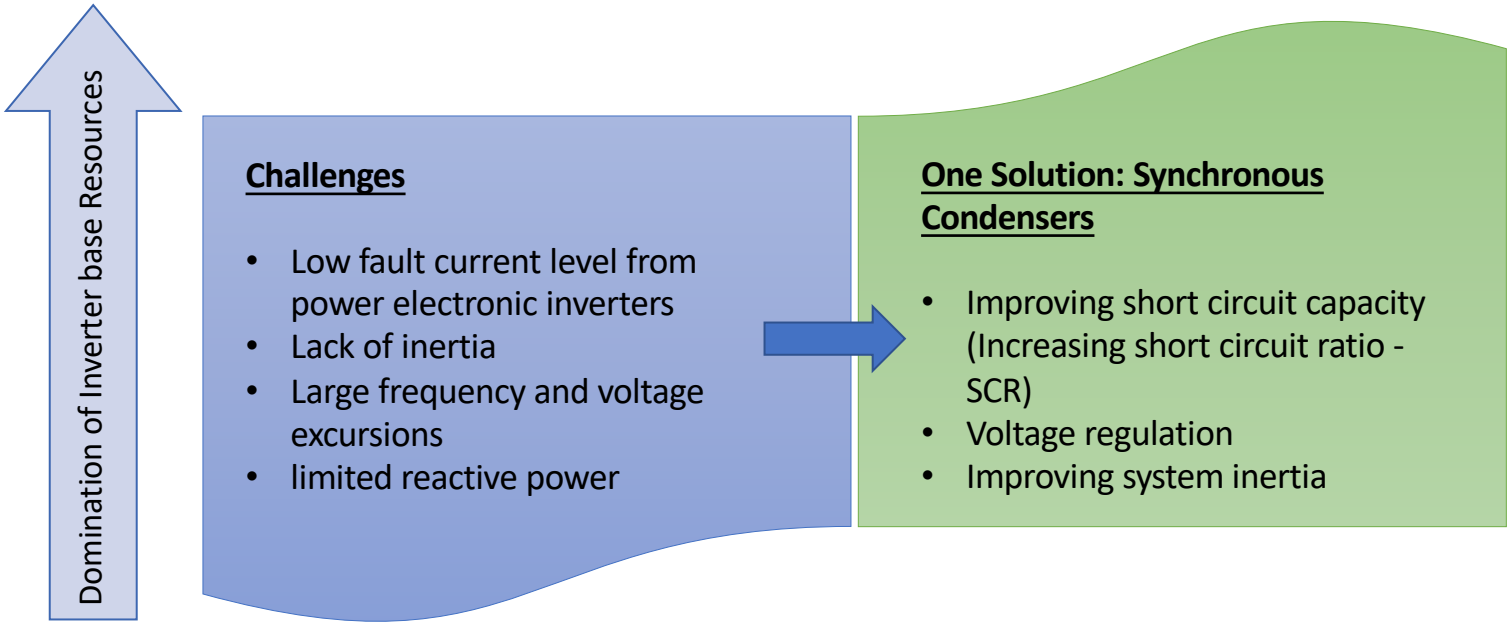
- Many microgrid deployments are based on Inverter base Resources (IBR):
  - Energy storage only
  - Solar + energy storage
  - Solar / wind + fuel cell + energy storage
- IBR offers flexibility in controls, but makes Protection System design very challenging for islanded operation:
  - Large reduction in short circuit capacity from grid connected (several 1000s amps) to islanded mode (a few 100 amps)
- Reactive power management and voltage regulation could be challenging
  - Limited reactive power



Inverter-base Microgrid

Problem Statement

Due to the increasing penetration of inverter-based resources, the grid is experiencing challenges related to reduced fault current and system inertia; specifically, during isolated operation for Microgrids



Transient Stability Analysis Framework for Microgrid

The framework offers a streamlined process for evaluating microgrid operation based on major transient events that would commonly occur during an islanded mode or transitioning to the islanded mode:

Transition	Black Start	Step Load Increase	Load Rejection	Internal Faults
• Transition of a microgrid from a grid connected to an islanded mode under a large power mismatch (greater than 30%)	• Black start and load restoration in steps greater than 1/3 of microgrid size	• Step load increase that changes the power balance more than 1/3 of the microgrid size	• Load rejection (load drop about 1/3 of microgrid load)	• Temporary faults internal to the microgrid (symmetrical or asymmetrical faults)

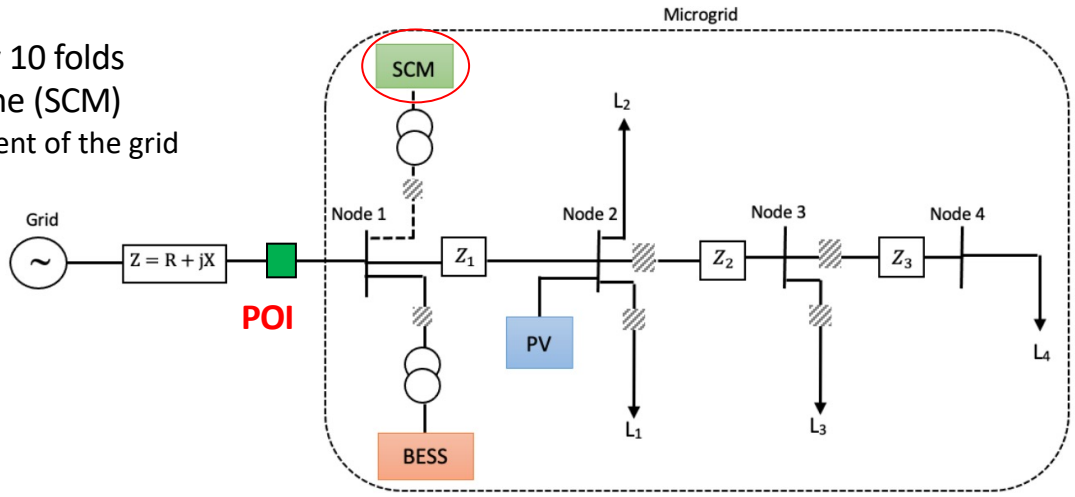
Benchmark Microgrid

- **12.47 kV, 3.5 MW customer loads**
- **5 MW / 10 MWh BESS (main source)**
- **Distributed PV systems (about 150kW)**

1. BESS only: reduction in fault current by 10 folds
2. BESS + Synchronous Condenser Machine (SCM)
   - Designed to be closer to the fault current of the grid connected mode

Change in Fault Current – BESS Only

Fault current (kA)	Grid Connected Mode	Islanded Mode
Node 1	5.9 kA	0.65 kA
Node 4	1.5 kA	0.55 kA

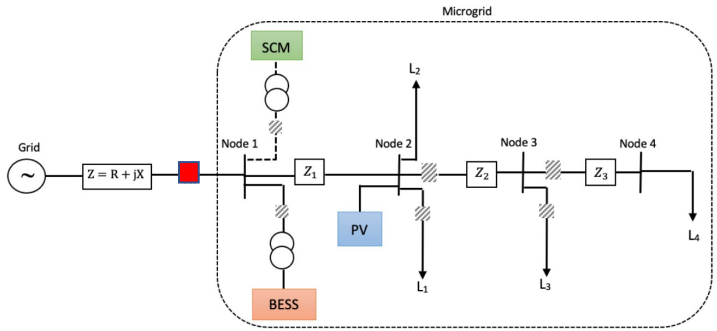


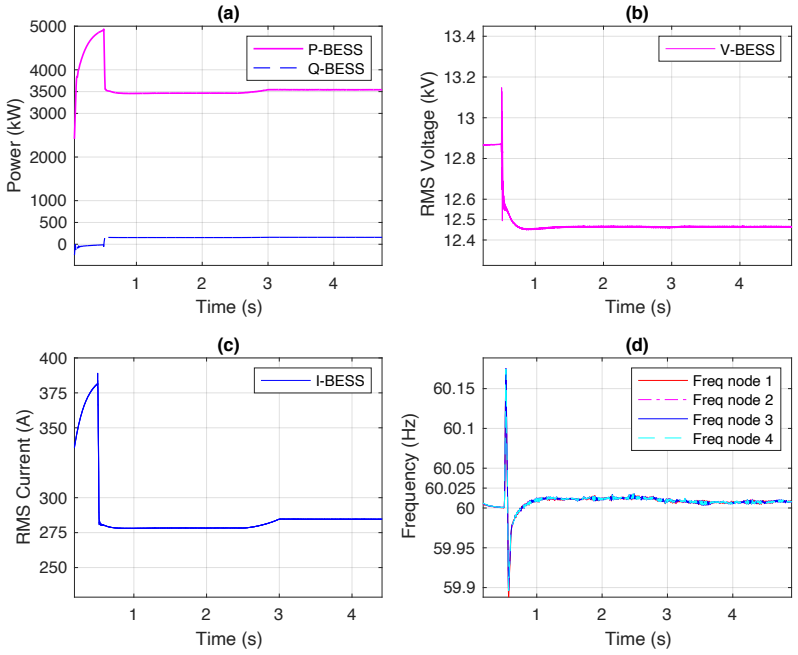
Microgrid benchmark system

Microgrid Operation with BESS Only

Case 1A: Transition of a microgrid from a grid-connected to an islanded mode

- The **islanding** happens at t=0.5 s by opening the breaker before node 1.
- The battery's reference active and reactive power in the grid-connected mode is set as 5 MW and 0, respectively.
- Islanded mode is stable.



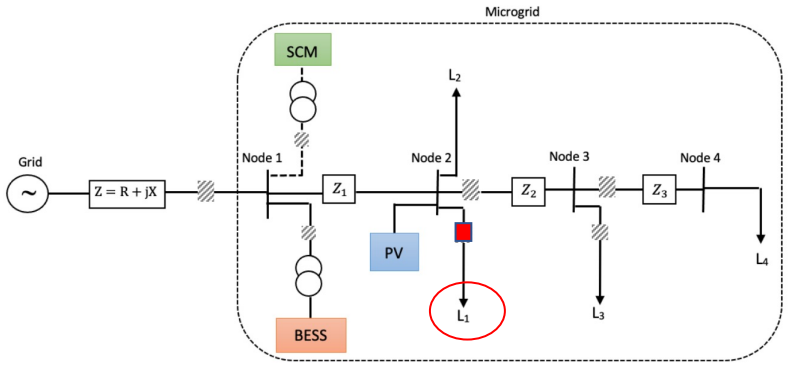


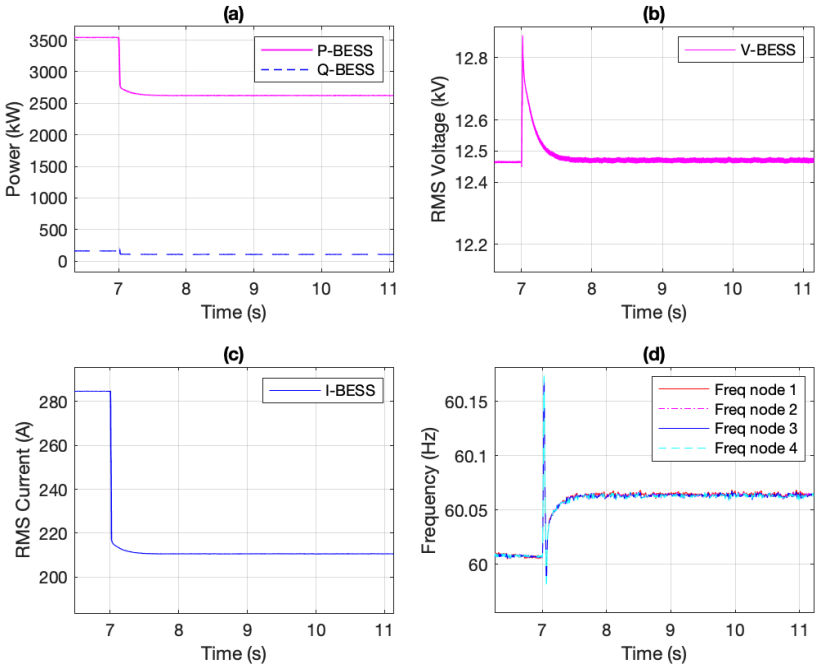
BESS Performance

Microgrid Operation with BESS Only

Case 2A: Load rejection

- **1 MW load rejection** happens at t=7 s in the islanded microgrid at node 2.
- Voltage and frequency are well regulated in a permissible range by BESS (**no power quality issue**).



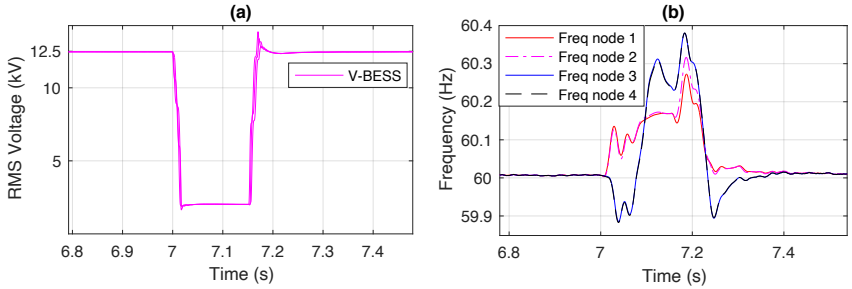


BESS Performance

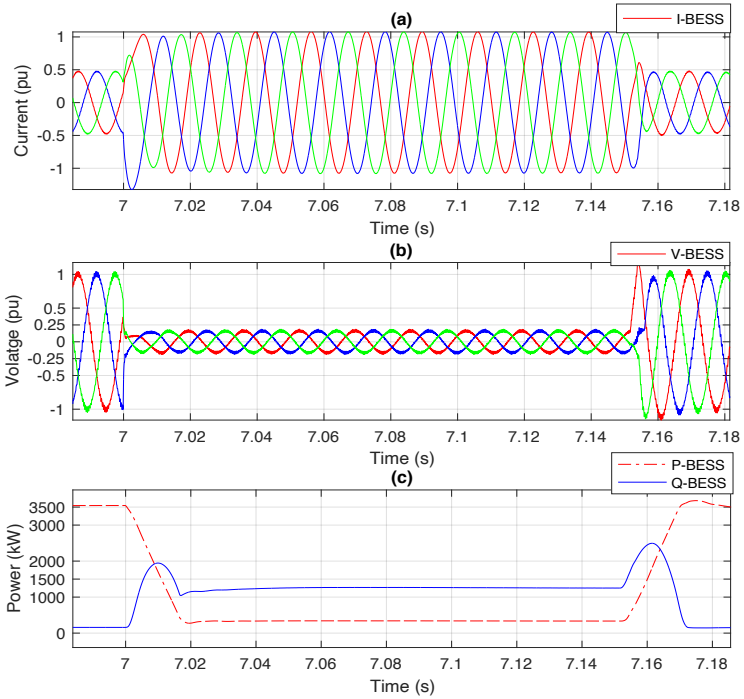
Microgrid Operation with BESS Only

Case 3A: Temporary symmetrical fault

- A three-phase to ground fault is applied at t=7 s at node 3 and cleared after 9 cycles.
- The observed **short circuit current** is about **650 A.**



Voltage and Frequency Excursions

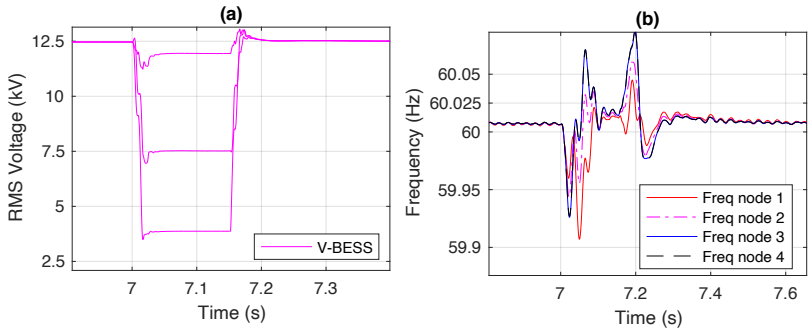


BESS Performance

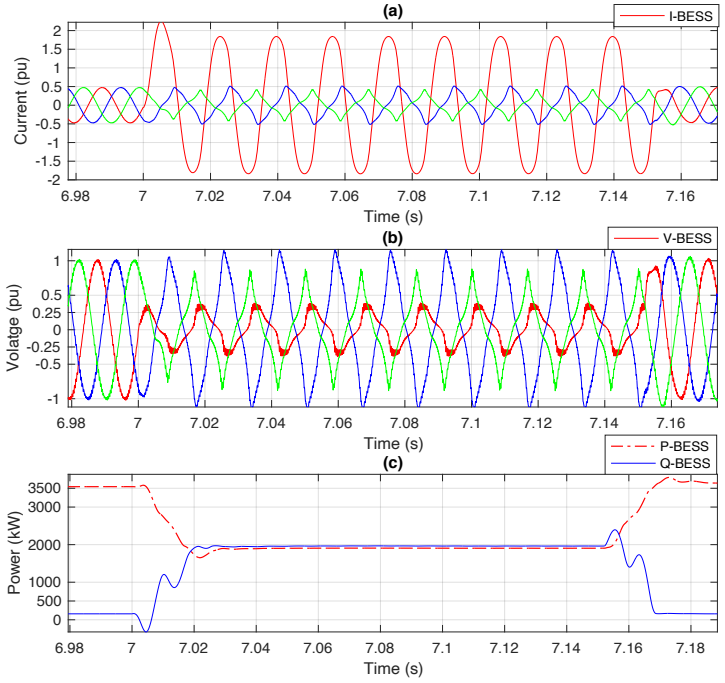
Microgrid Operation with BESS Only

Case 4A: Temporary asymmetrical fault

- An asymmetrical fault (single phase to ground fault) applied at t=7 s, for 9 cycles at node 3.
- The voltage, currents, and frequency are affected during the fault duration, and the recovery is made after clearing the fault at t=7.15 s.



Voltage and Frequency Excursions

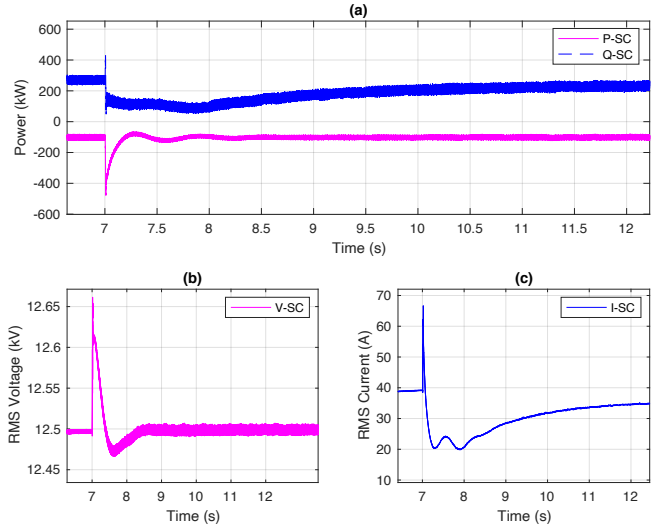


BESS Performance

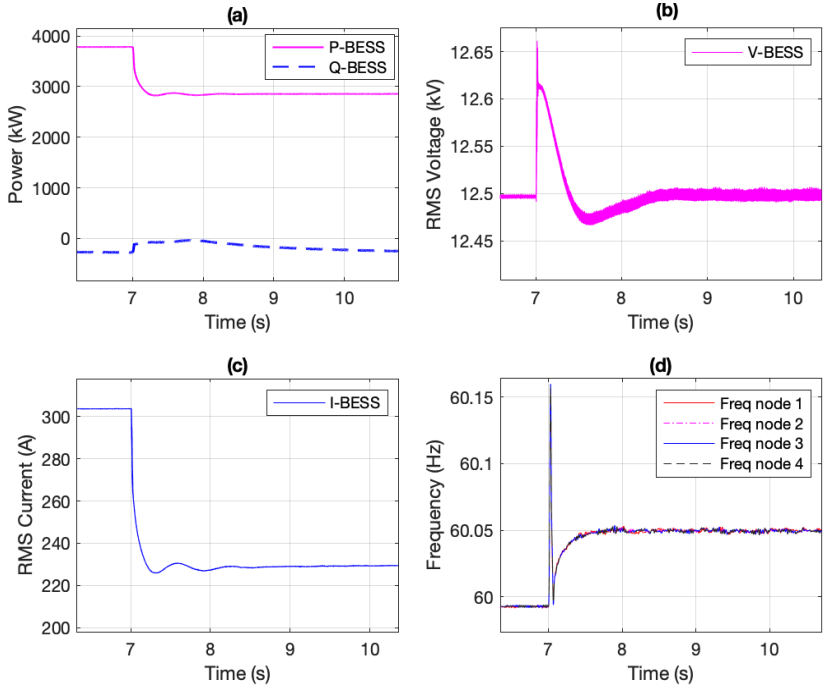
Microgrid Operation with BESS plus SCM

Case 1B: Load rejection

- A 1 MW load rejection happens at t=7 s in the islanded microgrid at node 2.
- Islanded mode is stable (**no power quality issue**).



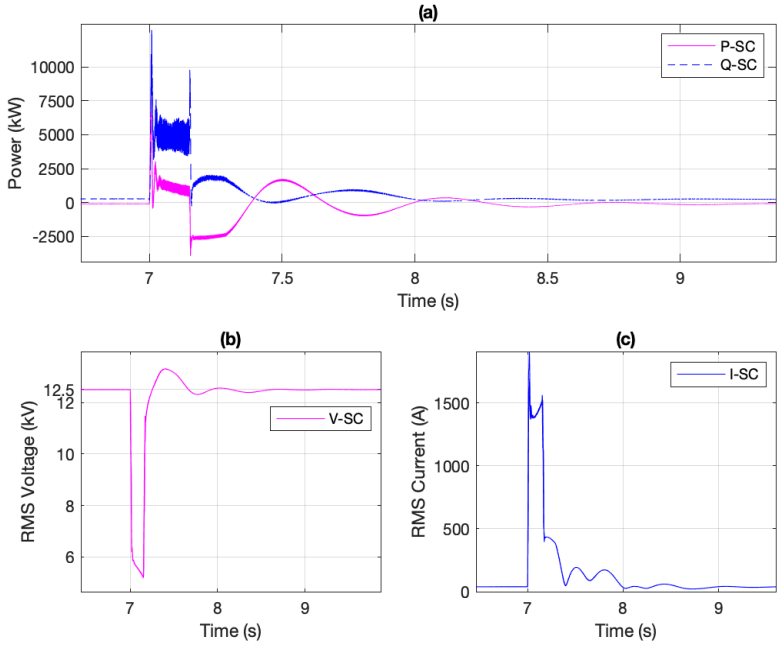
SCM Performance



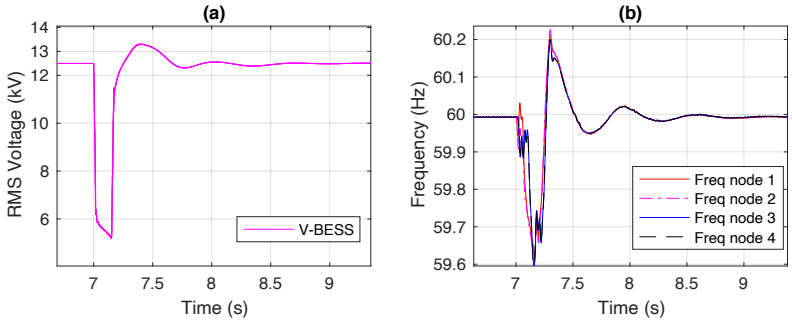
BESS Performance

Microgrid Operation with BESS plus SCM

Case 2B: Temporary symmetrical fault



SCM Performance

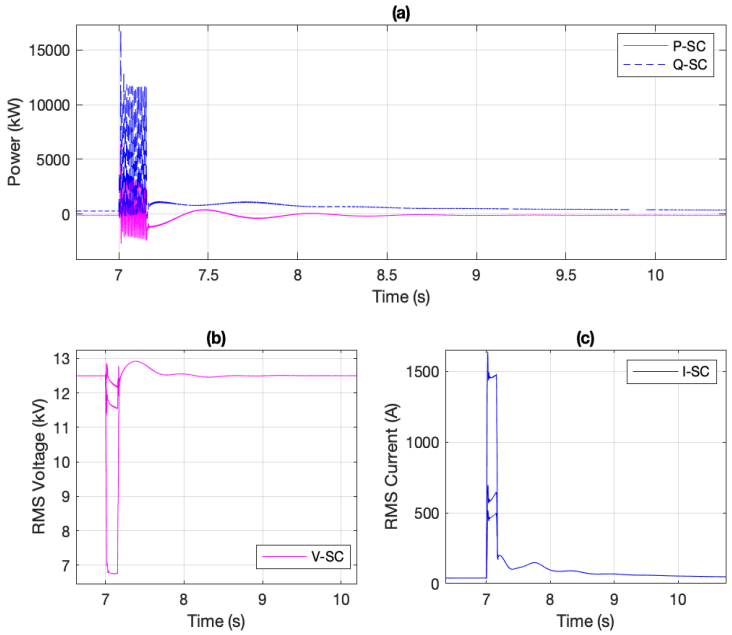


BESS Performance

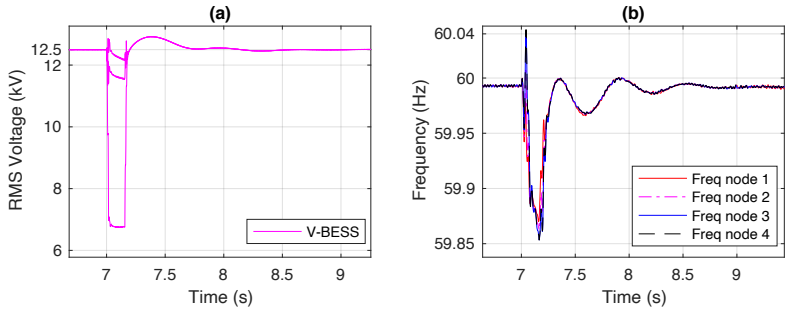
- **Voltage recovery** is smoother in the presence of SCM with less drop during the fault.
- Additional fault current contribution from SCM increases the total microgrid fault current **above 2000A**, representing an **SCR of 5**.

Microgrid Operation with BESS plus SCM

Case 3B: Temporary asymmetrical fault



SCM Performance



Voltage and Frequency Excursions

- In the presence of SCM, the **voltage recovery** and **current oscillations** are smoother with less deviations.

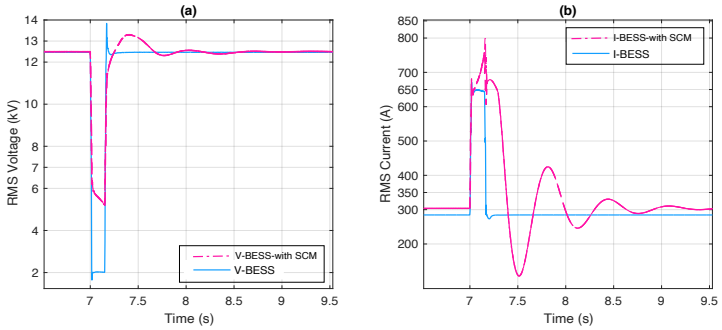
Comparative Analysis

Microgrid operation with BESS plus SCM:

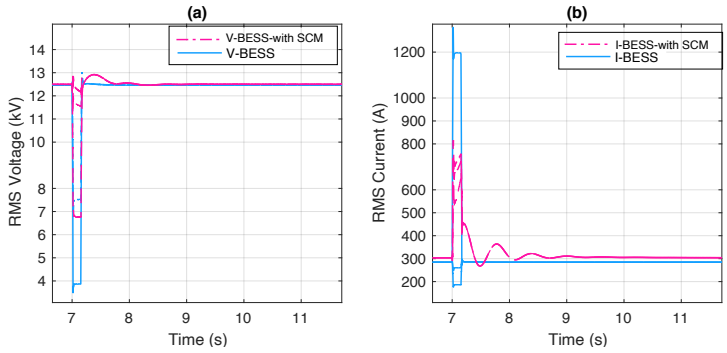
- **Smoother voltage recovery** with less deviation in the voltage magnitude during the fault.
- Significant **improvement in symmetrical fault current**, which facilitate proper protection system design and device to device coordination.

Comparison

	BESS only	BESS + SCM
TPH Fault	650 A	1875 A
ΔV for SLD Fault	69.6%	45.6%



BESS performance under a three-phase fault



BESS performance under a single-phase fault

Conclusion

- ✓ The transient stability analysis framework for a microgrid is studied for microgrid transient performance evaluation in the presence and absence of **SCM** in an islanded microgrid.
- ✓ Comprehensive results for comparative analysis of a microgrid operation **with/out SCM** for load rejection, symmetrical and asymmetrical faults are proposed to evaluate the microgrid transient stability and performance.
- ✓ The obtained results show that SCM can **improve the microgrid stability**, **increase the three-phase fault current level**, and **smooth the voltage recovery** when compared with cases without SCM.
- ✓ The **Optimal usage** of SCM may need other additional control loops for reactive power and voltage control to provide the required reactive power to the microgrid.
- ✓ A **supplementary frequency control loop** is needed to provide accurate synthetic inertia in an islanded microgrid to provide guaranteed frequency regulation post disturbances such as load rejection.

Thank you

Questions?