CHIL Testbed of Consensus Control-Based Battery Energy Storage Systems

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Presenter: Li Bao

Outline:

- Introduction
- Consensus control design
- CHIL testbed
  - Topology of circuit
  - Configuration of testbed
- Experimental results
  - Grid-connected mode
  - Autonomous mode
- Conclusion

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Introduction

- Consensus control has been proposed in [1] to operate multiple battery energy storage systems.
  - Consensus control relies on distributed control and limited communication between adjacent batteries.

- Objective: A controller hardware-in-the-loop (CHIL) testbed is developed based on a microgrid with three parallel BESS connected to the standard IEEE 9-bus system.
  - Hardware-in-the-loop (HIL) testbed is usually developed to provide a practical, safe, and economic environment for the validation.
  - When the hardware under test consists only of controllers, this testbed is preferred to as a CHIL.

[1] J. Khazaei and Z. Miao, "Consensus control for energy storage systems," IEEE Transactions on Smart Grid, vol. 9, no. 4, pp. 3009–3017, July 2018.

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Consensus control design

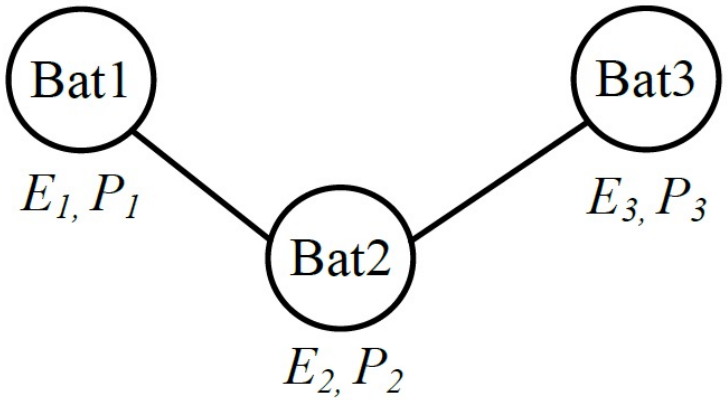

Figure 1. Three-phase-storage system.

The communication graph of the three-BESS microgrid can be expressed by Laplacian matrix L as:

$$L = \begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{D} - \underbrace{\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}}_{A}$$

The dynamics of each BESS can be written as:

$$\underbrace{\begin{bmatrix} \dot{E}_1 \\ \dot{P}_1 \end{bmatrix}}_{\dot{x}_i} = \underbrace{\begin{bmatrix} 0 & -1/3600 \\ 0 & 0 \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} E_1 \\ P_1 \end{bmatrix}}_{x_i} + \underbrace{\begin{bmatrix} 0 \\ 1 \end{bmatrix}}_{B} u_i$$

The control input is designed as

$$u_i = cK \sum_{j=1}^{n} a_{ij}(x_j - x_i) = cK \sum_{j=1}^{n} a_{ij} \begin{bmatrix} E_j - E_i \\ P_j - P_i \end{bmatrix}$$

Consensus control design

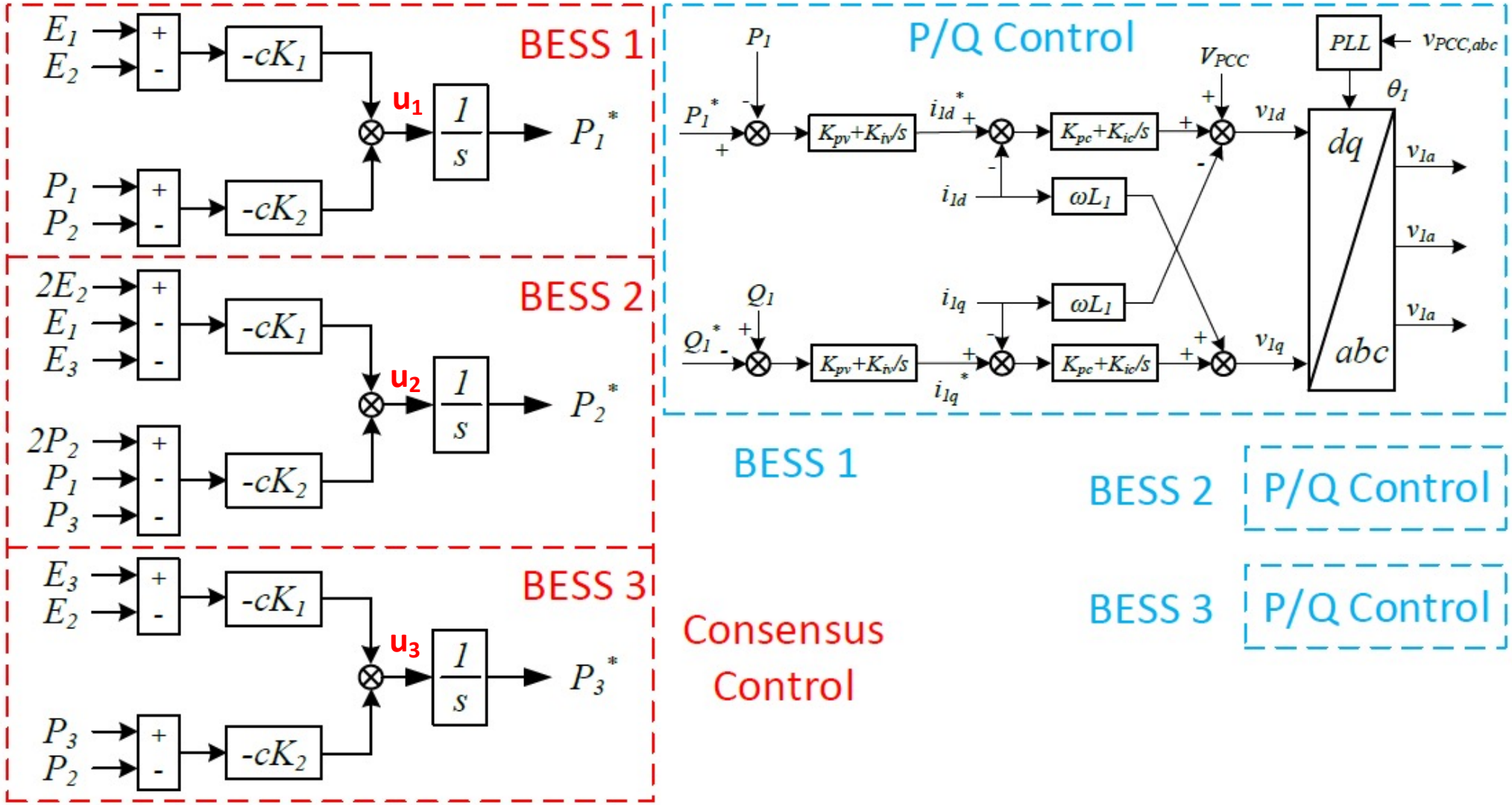

Figure 2. Control strategies for three BESS.

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Topology of circuit

A microgrid with three BESSs is integrated to grid. The grid is represented by IEEE 9-bus system including three synchronous generators and three loads.

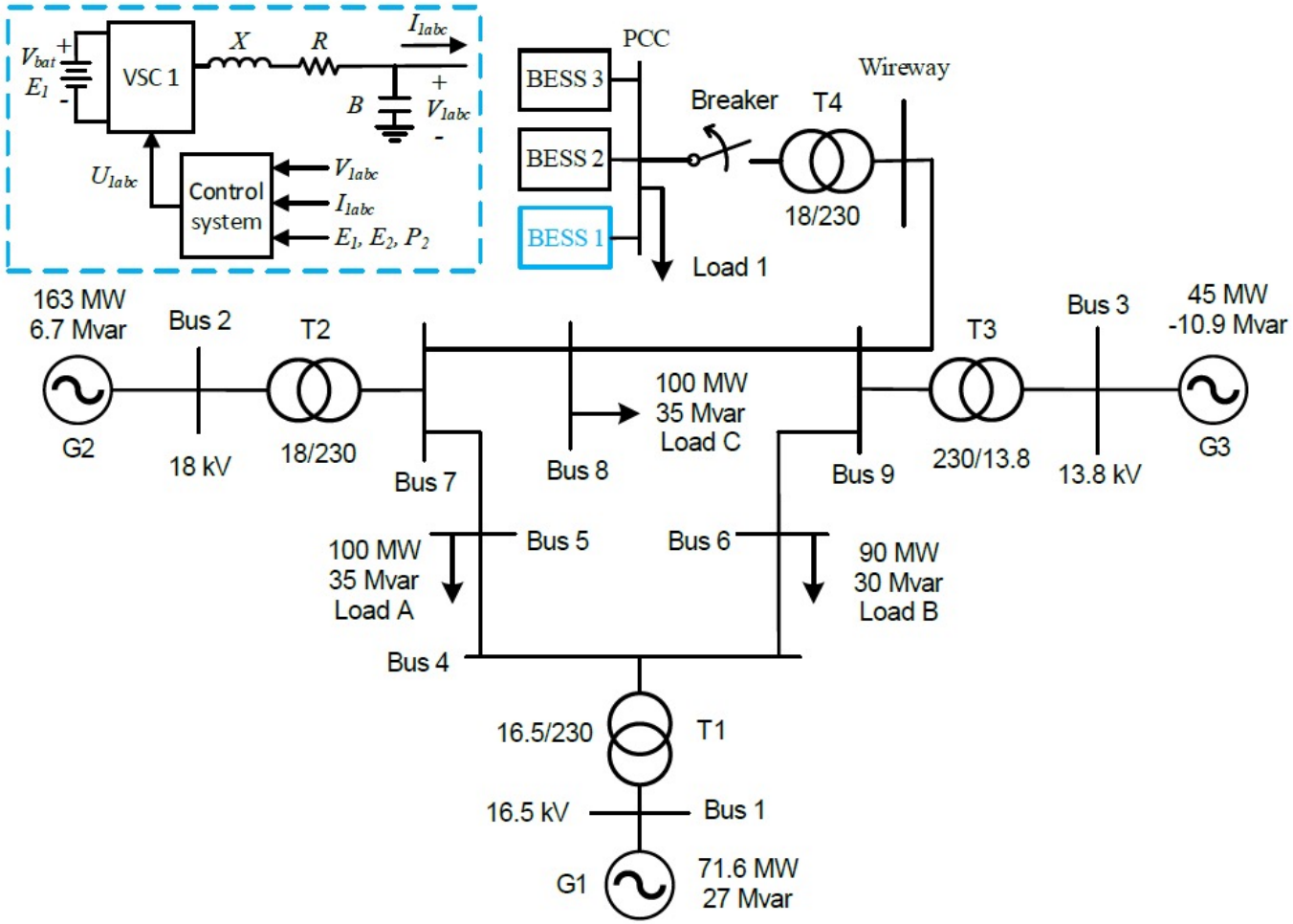


Figure 3. The microgrid including three energy storage systems is integrated to IEEE-9 Bus system.

Configuration of testbed

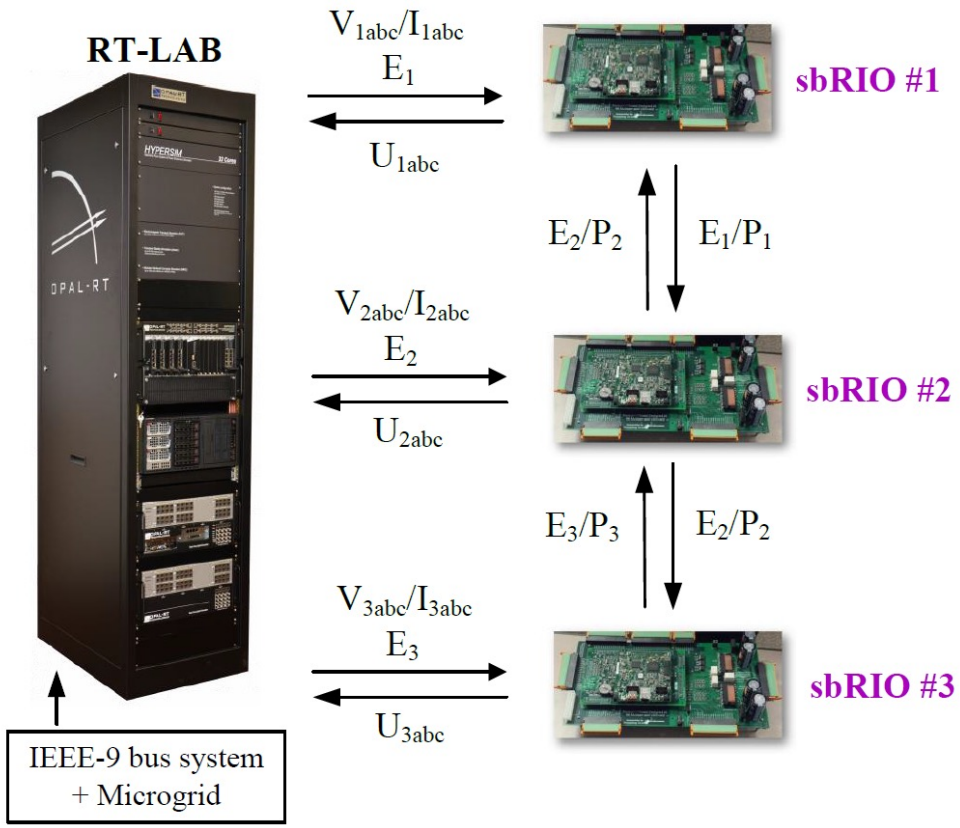
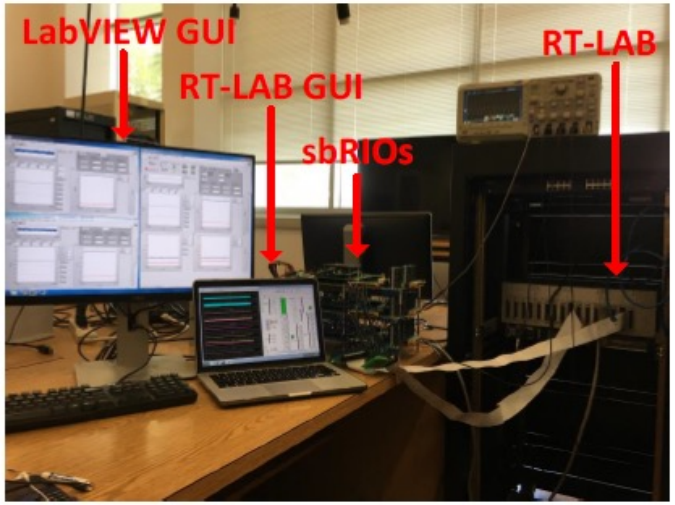


Figure 4. The overview of CHIL testbed.



(a)

(b)

Figure 5. (a) The photo of CHIL testbed built in our lab. (b) zoom-in photo to show the detailed connections of RT-LAB and sbRIOs.

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Experimental results

- The consensus control was tested under two modes:
  1. Grid-connected mode
  2. Autonomous mode

- When the microgrid is connected to IEEE 9-bus system, three BESS belonged to grid-following inverter-based resources under *P/Q* control.

- After the breaker become open, BESS 1 is selected to form the PCC voltage and the system frequency.

- BESS 1 is *V/f* control, BESS 2 and BESS 3 are consensus control.

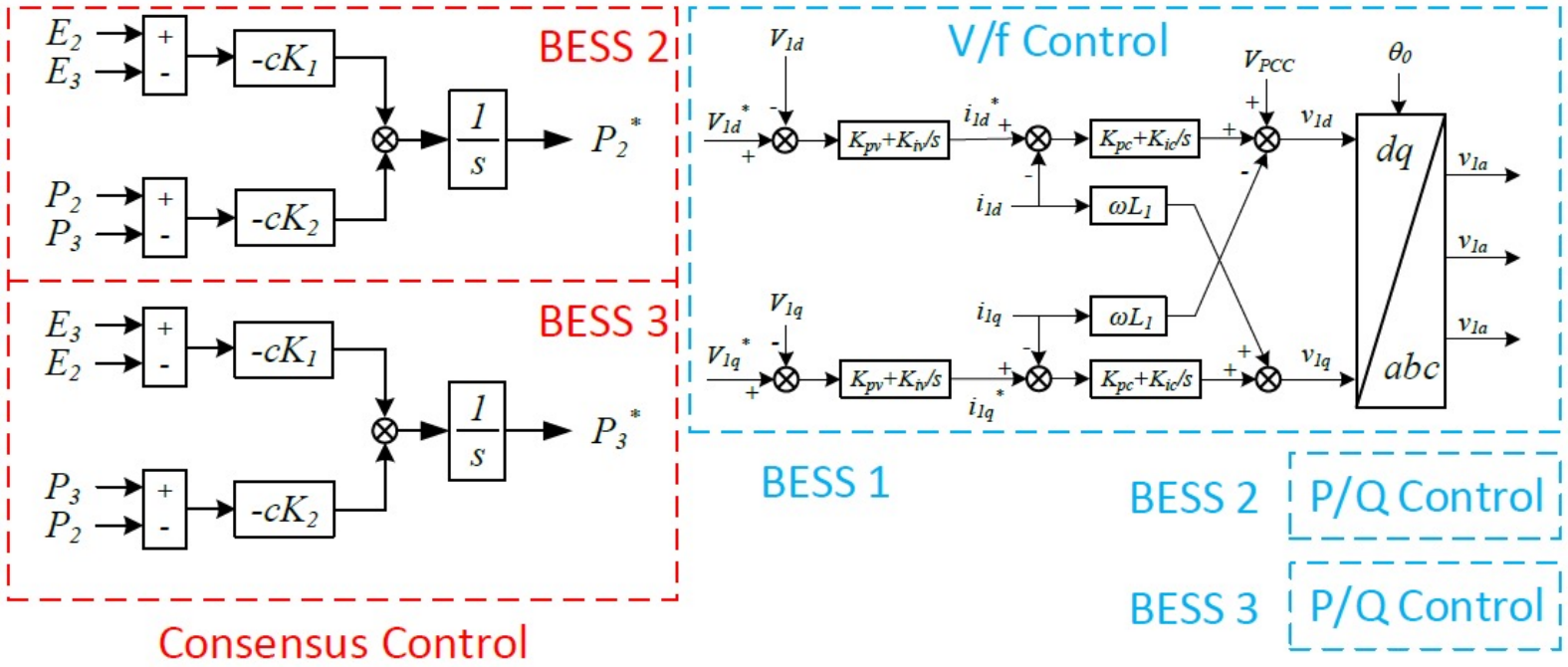
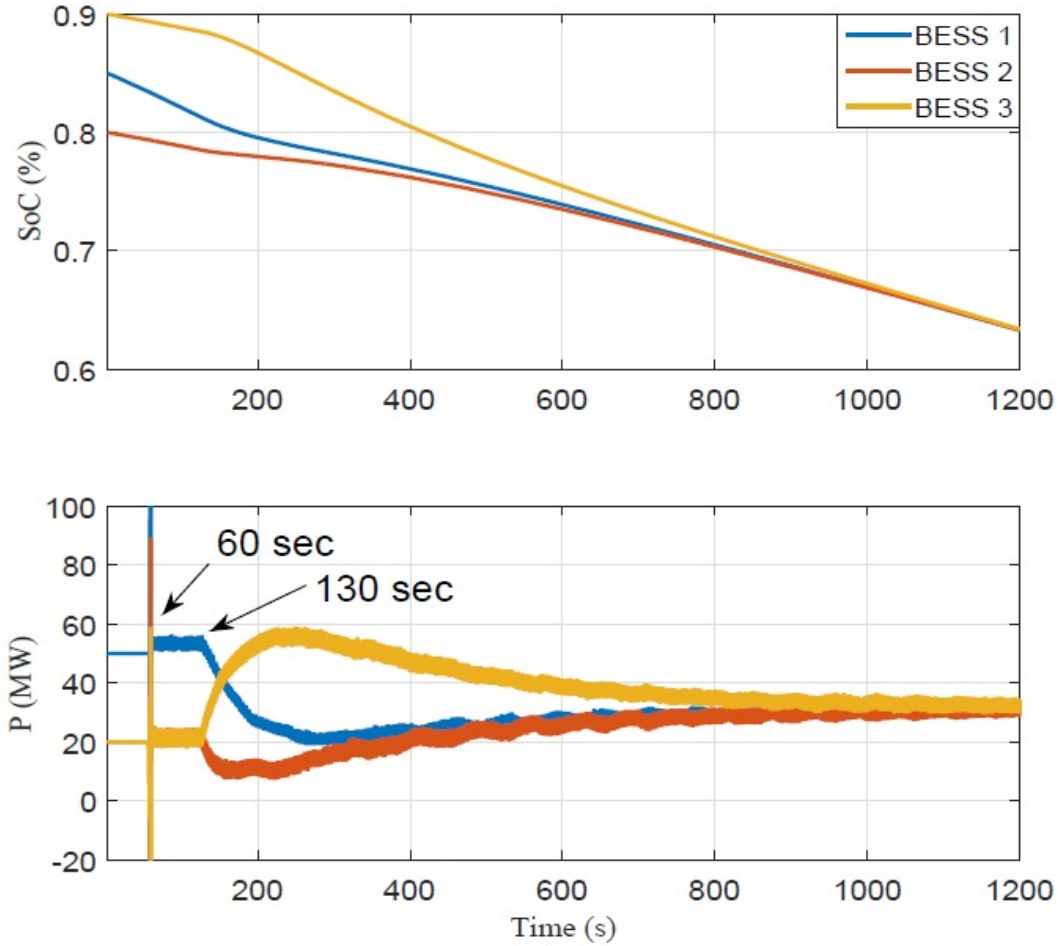
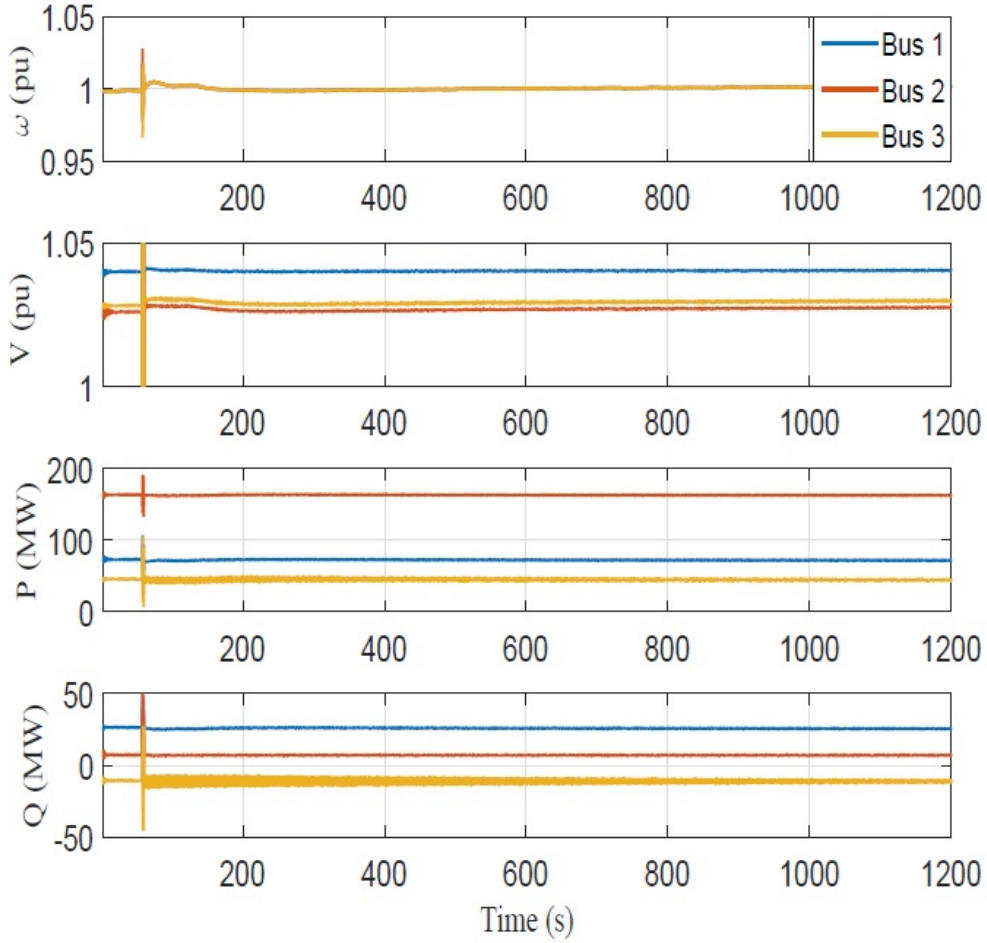


Figure 6. Control strategies for three BESS under the autonomous mode.

Grid-connected mode



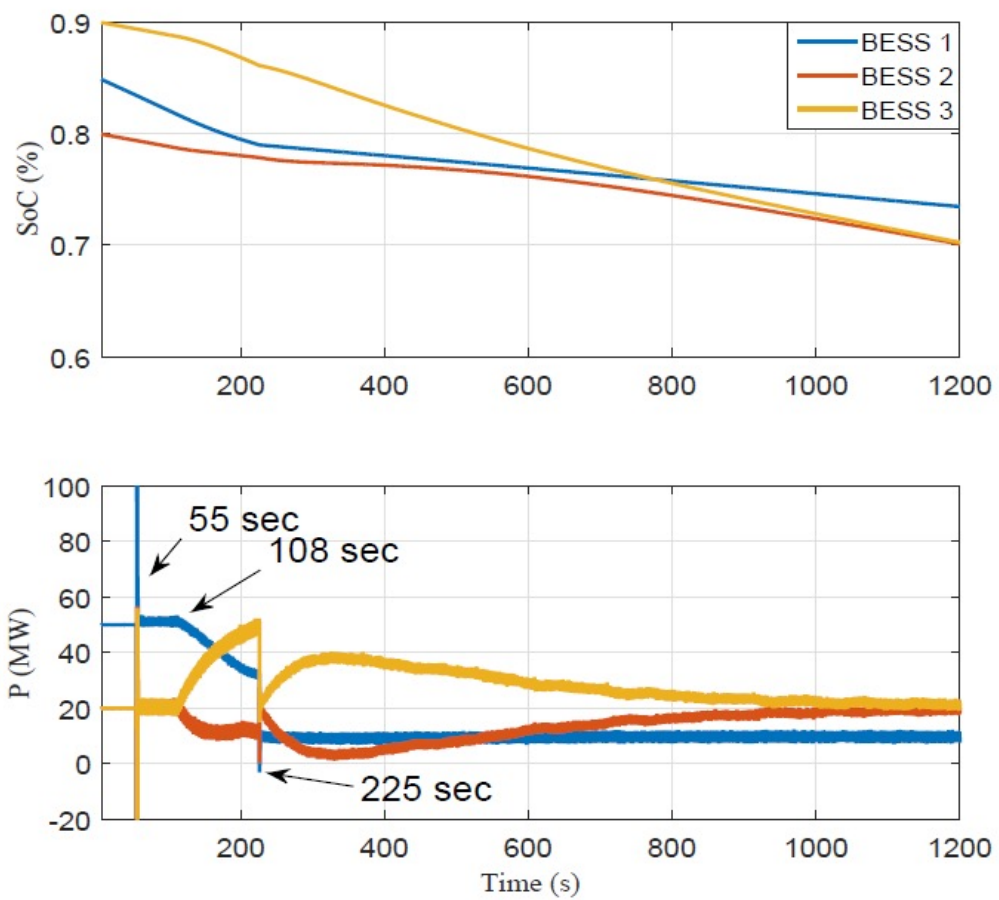
(a)



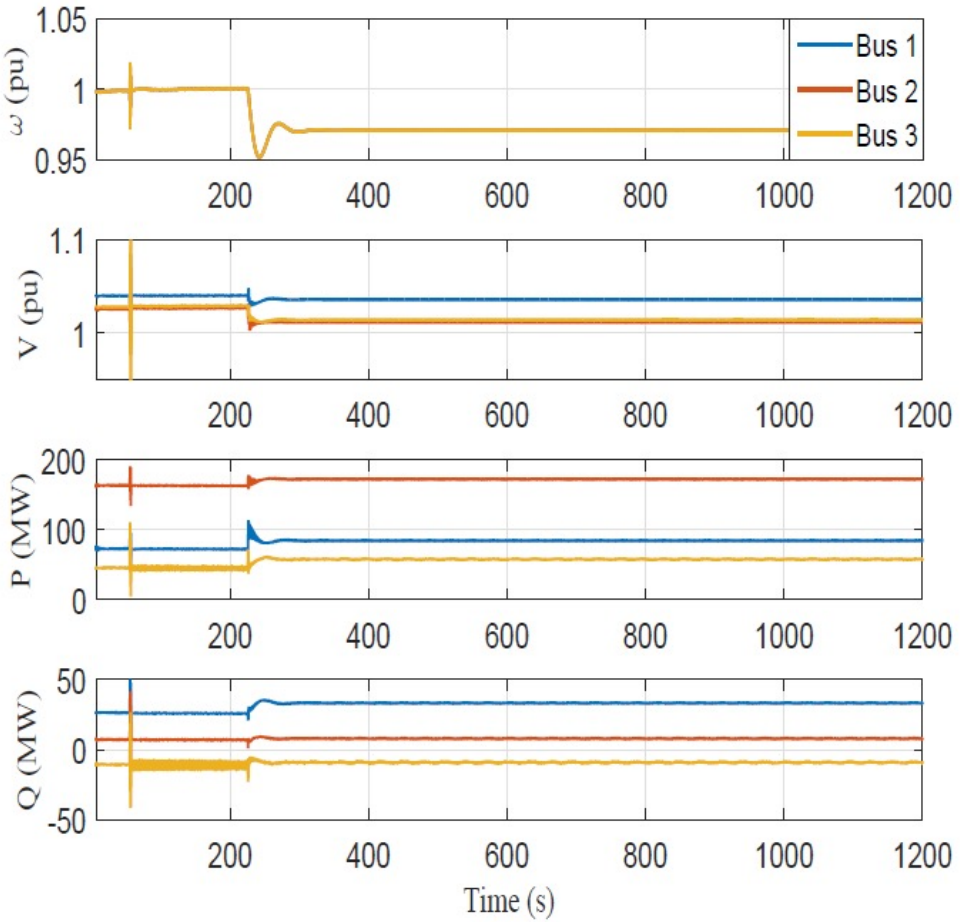
(b)

- Before 60 s, inverters in BESS is controlled by RT-LAB.
- At 60 s, sbRIOs is activated.
- At 130 s, the consensus control.
- Around 1100 s, the power signals of three BESS are converged at 30 MW.

Autonomous mode



(a)



(b)

- At 55s, sbRIOs starts to control inverters of BESS.
- At 108 s, the consensus control is activated.
- At 225s, the microgrid is disconnected from the IEEE 9-bus system.
- The energy and power of BESS 2 and BESS 3 are converged after 1100 s.
- After 250s, 3% drop in frequency due to disconnection.

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Conclusion

- CHIL testbed evaluation shows that consensus control is feasible.

- Consensus control has been implemented in sbRIOs.
  - The communications between sbRIOs are based on the analog input/output.

- The consensus control was tested under the grid-connected mode, autonomous mode, and the transient of connection mode change.
  - The real-time simulation results validated the good performance of consensus control in microgrids.

Thank you!