Sensitivity Analysis of Capacity and Location of GFM-BESS for Islanded Microgrid Stability

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1. Introduction

- Islanded microgrids require a voltage-forming source to maintain frequency and voltage after disconnection from the upstream grid. A grid-forming battery energy storage system, or GFM-BESS, can provide this reference function.
- In islanded operation, the GFM-BESS location is not only a placement decision. It determines the voltage-forming reference point of the feeder. Therefore, its location affects voltage profile, active/reactive power requirement, inverter loading, and frequency response.
- This poster evaluates the sensitivity of islanded microgrid stability to the capacity and location of a GFM-BESS using a reduced-order screening model.

2. Proposed Screening Framework

2.1 GFM-BESS Siting and Rating

- After islanding, the selected GFM-BESS bus is modeled as the voltage-forming reference bus.

$$V_{bBESS} = V_{ref}\angle 0$$

- The GFM-BESS rating is defined as $S_{BESS} = \rho P_{peak}$

  Where $\mathcal{B}_{cand} = \{2,6,13,18,25,30,33\}$, $\rho = \{0.15, 0.25, 0.35, 0.50, 0.70, 0.90\}$.

2.2 Islanded power requirement

- For each bus, the net demand is calculated from load and PV output.

$$P_{net,i} = P_{L,i} - P_{PV,i}$$

$$Q_{net,i} = Q_{L,i} - Q_{PV,i}$$

- The required complex power at the GFM-BESS reference bus is obtained as

$$S_{req}(t) = P_{req}(t) + jQ_{req}(t)$$

2.3 Frequency response and inverter constraint

- The reduced-order frequency response is modeled as

$$M\frac{d\triangle f}{dt} = P_{BESS}(t) - P_{req}(t) - D\triangle f(t)$$

- The inverter apparent-power constraint is

$$P_{BESS}^2(t) + Q_{BESS}^2(t) \le S_{BESS}^2$$

with $$S_{required}(t) = \sqrt{P_{BESS}^2(t) + Q_{BESS}^2(t)}$$

- This formulation captures the effect of GFM-BESS location on both frequency support and inverter P/Q burden.

3. Evaluation Metrics and Scenarios

3.1 Stability-oriented performance penalty

- A stability-oriented penalty is used to compare each GFM-BESS candidate.

$$J_{stab} = \omega_f J_f + \omega_r J_{ROCOF} + \omega_v J_V + \omega_o J_{overload} + \omega_s J_{SOC}$$

$$J_f = \frac{\max_t |f(t) - f_0|}{f_0 - f_{min}}, \qquad J_{ROCOF} = \frac{\max_t |ROCOF(t)|}{RODOC_{max}},$$

$$J_v = \frac{\sum_t \sum_i [(V_{min} - V_i(t))^+ + (V_i(t) - V_{max})^+]\Delta t}{N_t \Delta t N_b \Delta V_{base}}, \qquad J_{overload} = \frac{\sum_t (S_{required}(t) - S_{BESS})^+ \Delta t}{N_t \Delta t S_{BESS}}$$

- For each candidate pair (b,ρ), scenario-level penalties are averaged.

$$J_{stab,avg}(b,\rho) = \frac{1}{N}\sum_{s=1}^{N_S} J_{stab,s}(b,\rho)$$

3.2 Independent islanded-operation scenarios

- All scenarios start from the same pre-islanding condition.

Scenario	Operating condition
S1	Islanding only
S2	Islanding followed by load increase
S3	Islanding followed by PV generation reduction
S4	Islanding with simultaneous load increase and PV reduction

4. Results

- Bus 2 and Bus 6 show consistently low penalties, while Bus 18 remains the most unfavorable location. Increasing the GFM-BESS rating reduces the penalty, but it does not fully compensate for an electrically unfavorable reference location.
- The estimated Restored Load Ratio generally increases with the GFM-BESS rating. Bus 2 and Bus 6 achieve high load-supply capability with low stability-oriented penalties, whereas Bus 18 remains limited even at high ratings.

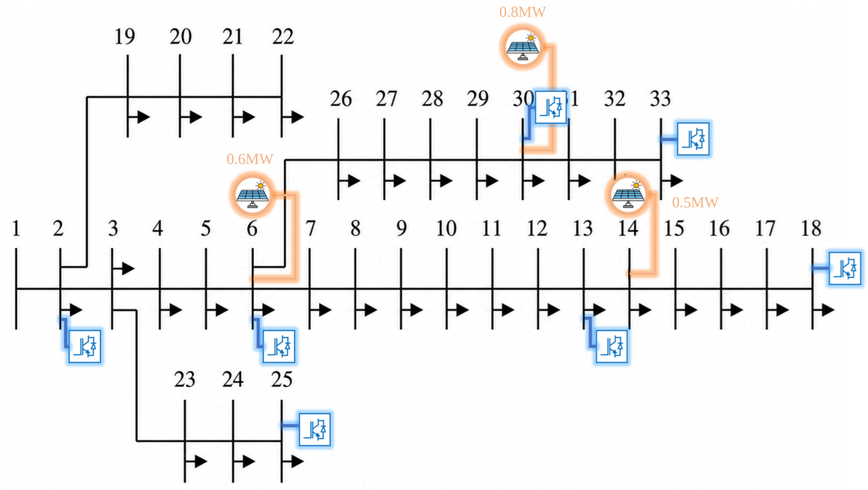

Fig. 1: Candidate GFM-BESS placement in the IEEE 33-bus islanded microgrid

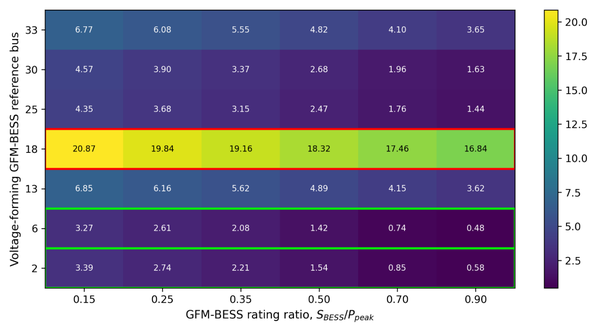

Fig. 2: Average stability-oriented penalty

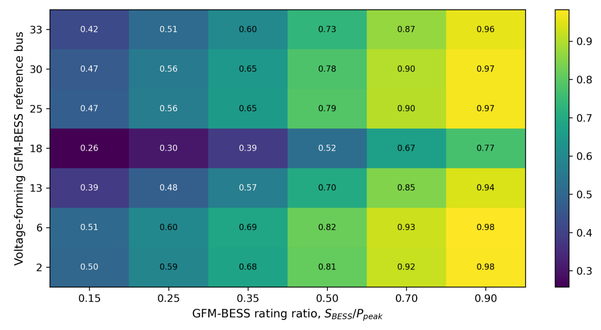

Fig. 3: Estimated Restored Load Ratio

5. Conclusion

- GFM-BESS capacity and location jointly affect islanded microgrid stability by changing the voltage-forming reference point and required P/Q support.
- Bus 2 and Bus 6 are promising reference locations, while Bus 18 remains unfavorable even with increased rating.
- Capacity expansion alone is insufficient without considering the electrical location of the GFM-BESS.EMT-level validation is required for selected best and worst cases.
- The proposed framework can be further extended to mixed GFM/GFL microgrids, where reference-forming source selection becomes critical during islanding and network reconfiguration.

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