Impact of re-synchronization strategies on the power sharing of grid-forming converters at black start

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1. Black start restoration process

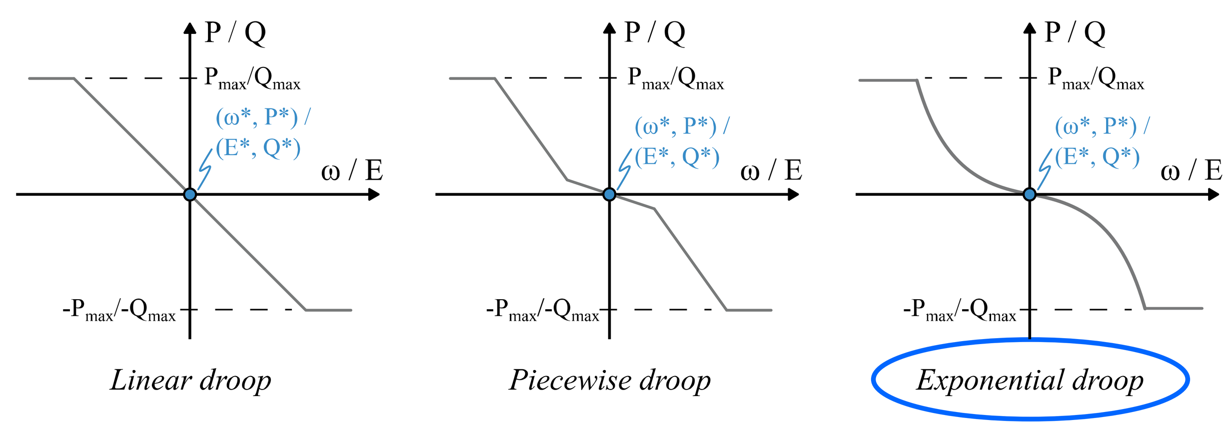
1. Restoration plan activation
- Determine the extension of black out
- Decide the restoration strategy

2. Re-energization and stabilization
- Black start units (GFM or SG) energize cranking paths
- Other generators start and help in the re-energization
- Coordination between generators is needed

3. Re-synchronization
- Asynchronous power islands are re-synchronized to unify the power grid.

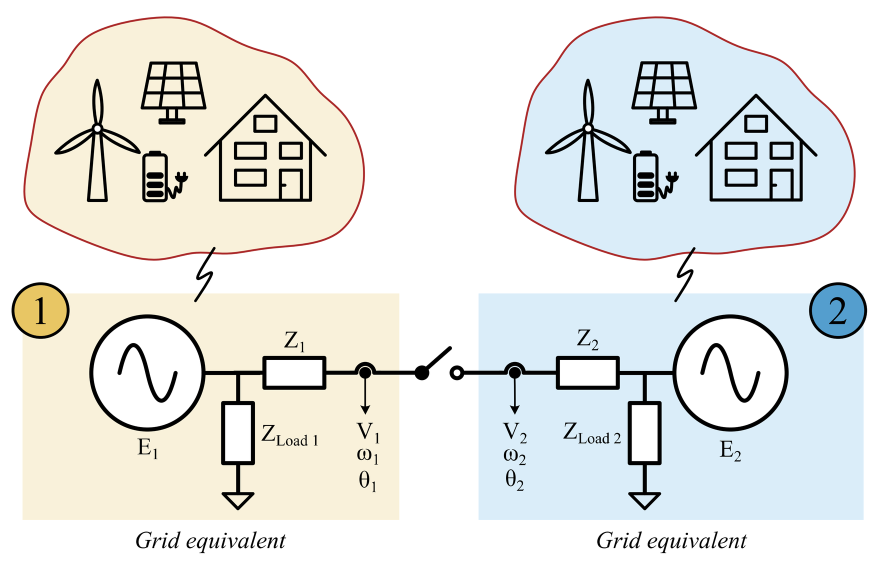
2. Droop control curve parametrization

- Coordination between BS units is achieved with droop control
- Different types of droop curves (linear/non-linear)



- Interesting for BESS to prioritize energy duration
- Support mainly during severe excursions

3. Re-synchronization algorithm

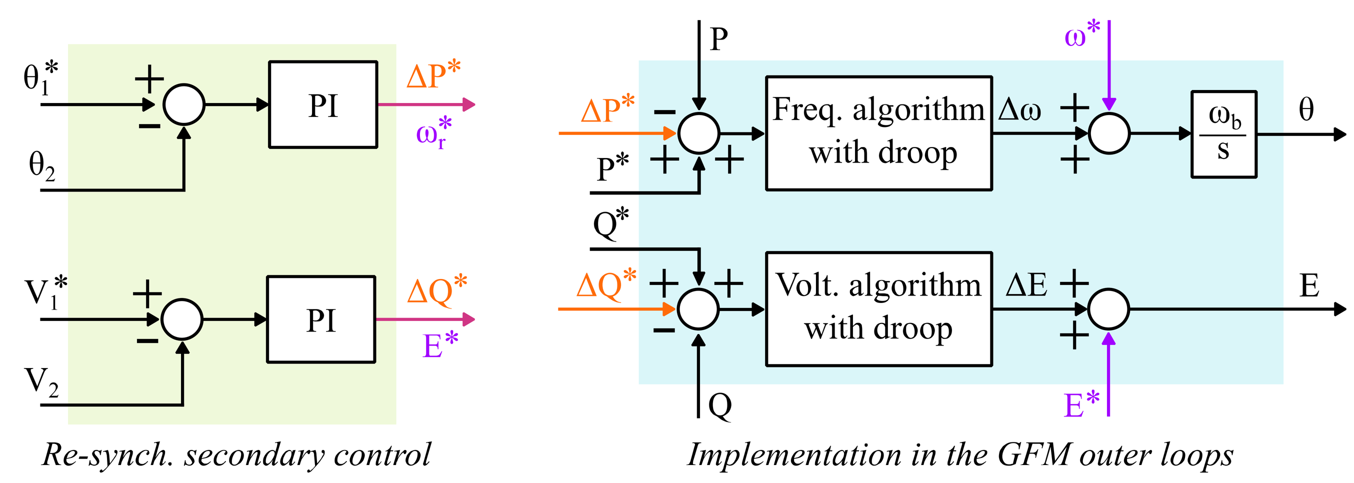


What is required to do a successful re-synchronization?

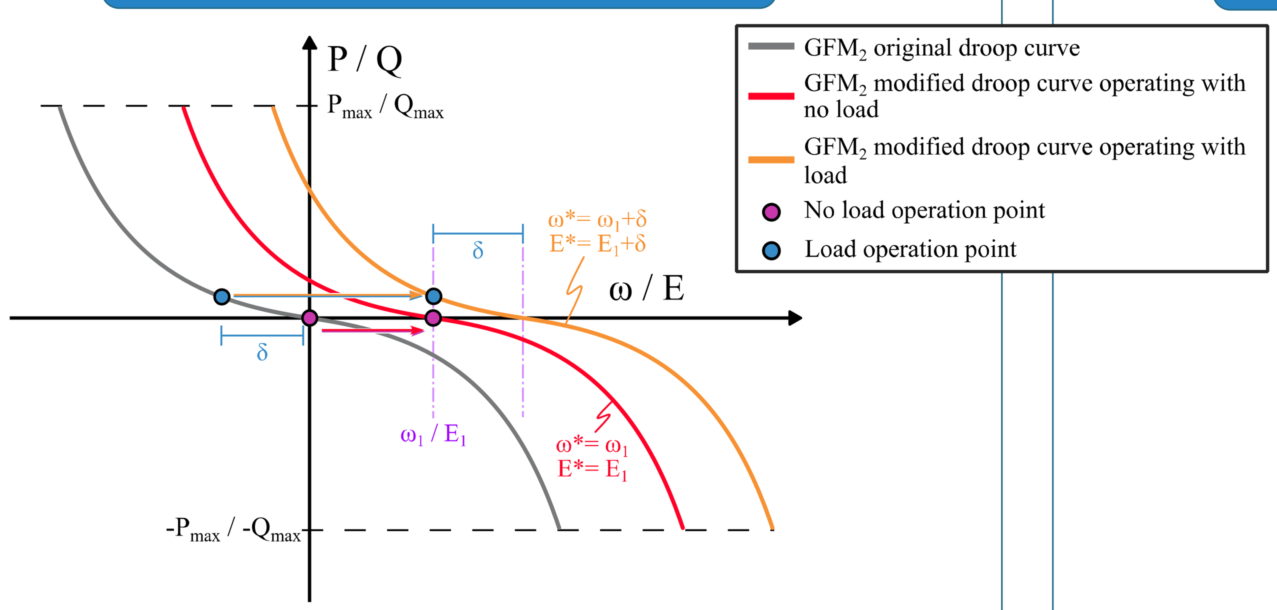
- **Voltage amplitude**, **frequency** and **phase** at both sides of the breaker in-between **must match**.

How is the re-synchronization carried out?

- Slow secondary controls to **modify setpoints**
- Setpoint modification changes droop curve

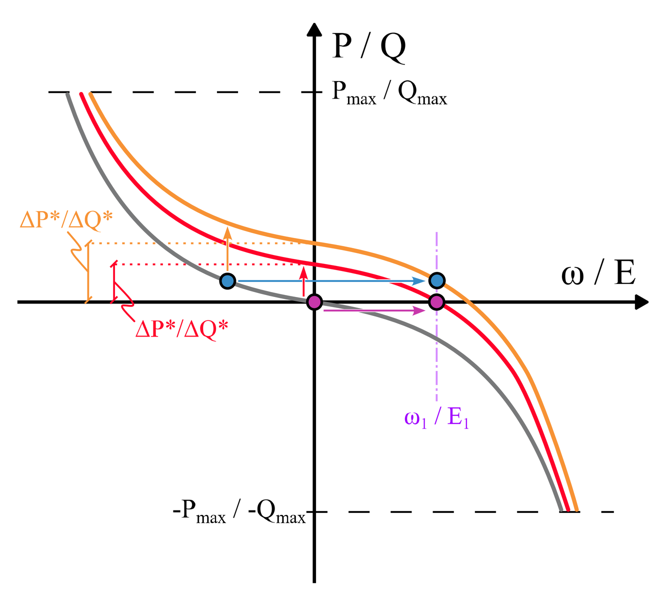


A. V/f setpoint modification



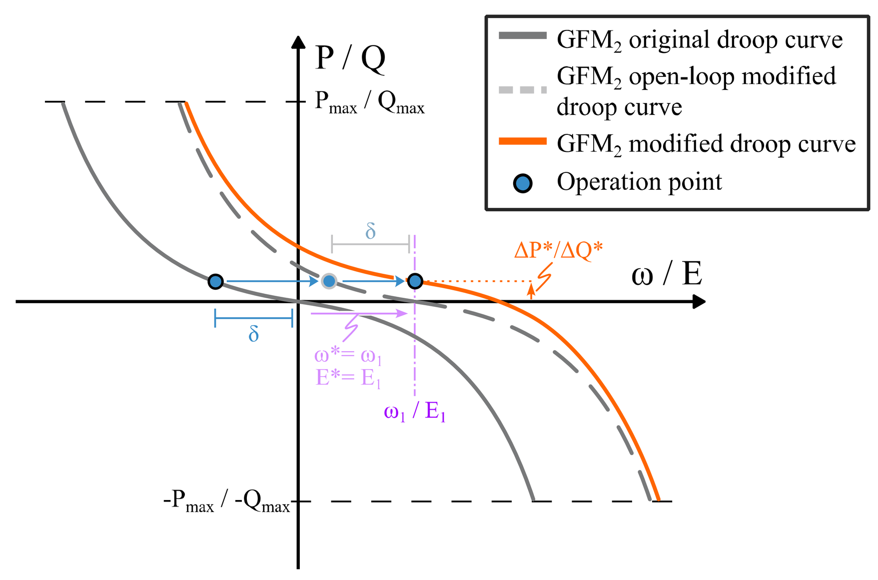
- Horizontal displacement of droop curve
- Center $(\omega_1/E_1+\delta)$ depends on the initial operating point

B. Power setpoint modification



- Vertical displacement of droop curve
- Increased droop at ω_1/E_1 → "make grid 1 follow grid 2"

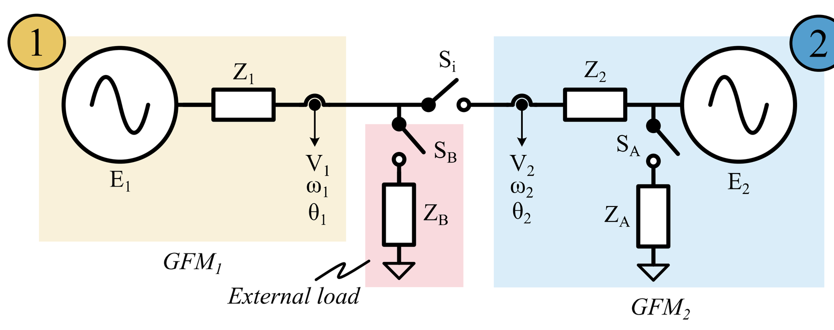
C. Hybrid modification



- Diagonal displacement of droop curve
- Centered at ω_1/E_1 regardless of the initial operating point → "make grid 2 follow grid 1"

4. Test case scenario

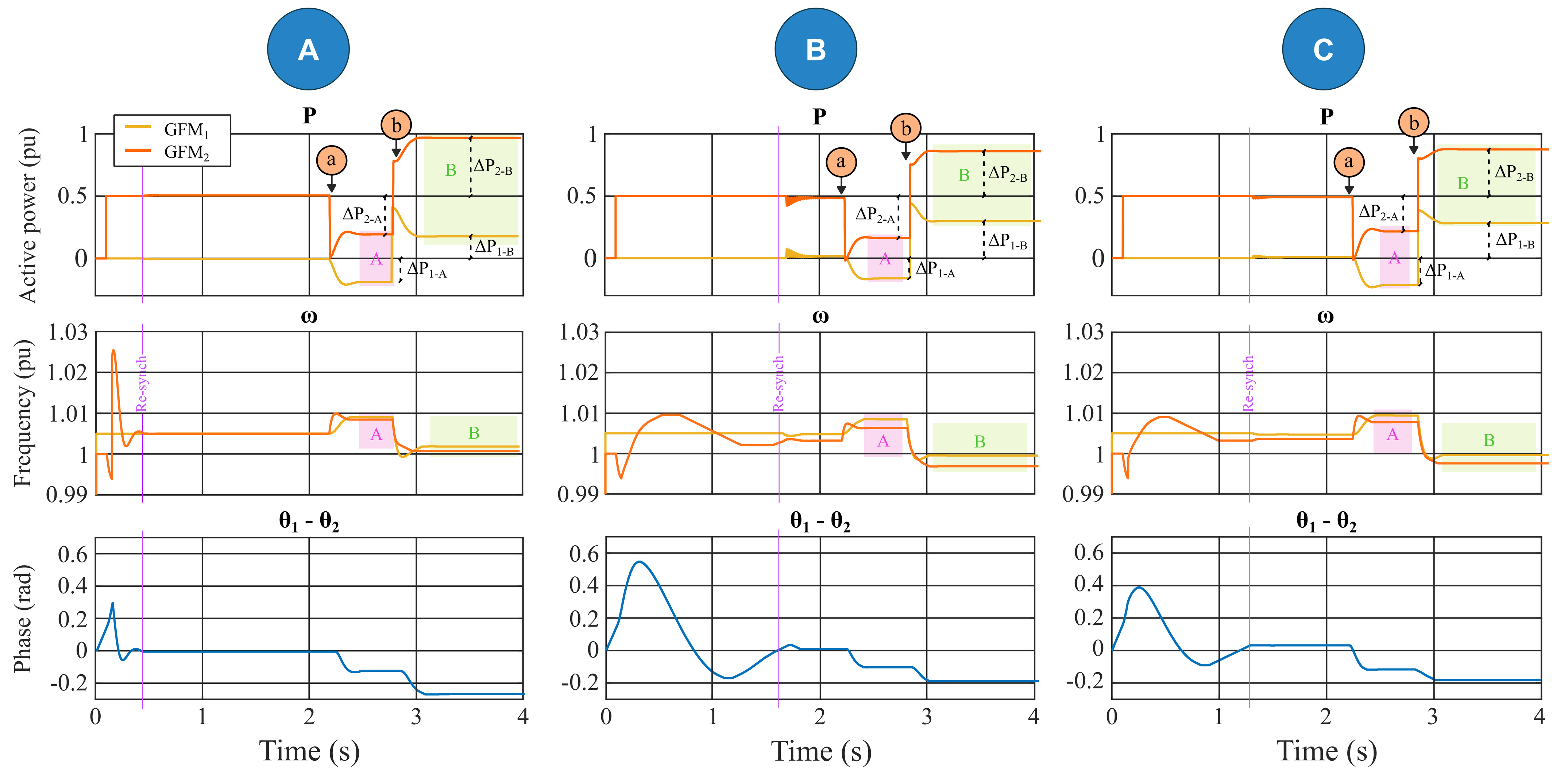
- Simplified scenario of 2 GFMs, GFM_2 with local loads (Z_A) and an external common load Z_B. GFM_2 is re-synchronized to GFM_1.
- Only active power is analyzed.



GFM_1 → linear droop
GFM_2 → exponential droop

Time	0 s	0.1 s	0.15 s	2.2 s	2.8 s
Action	$\omega_1^*=1.005\,pu$, $\omega_2^*=1\,pu$	S_A closed ($P_{Z_A}=0.5\,pu$)	Re-synch. enabled	S_A opened	S_B closed ($P_{Z_B}=1.16\,pu$)

5. Simulation results



A
- Shortest re-synchronization time
- A perturbation: $\Delta P_{GFM_2}=-0.31\,pu$
- B perturbation: $\Delta P_{GFM_2}=0.47\,pu$
- Highest ΔP against load power increase

B
- Longest re-synchronization time
- A perturbation: $\Delta P_{GFM_2}=-0.34\,pu$
- B perturbation: $\Delta P_{GFM_2}=0.35\,pu$
- Highest ΔP against load power decrease

C
- Intermediate re-synchronization time
- A perturbation: $\Delta P_{GFM_2}=-0.28\,pu$
- B perturbation: $\Delta P_{GFM_2}=0.37\,pu$
- More balanced response against load changes

6. Conclusions

- This work has analyzed how the re-synchronization strategy can affect the post-re-synchronization power sharing for a general non-linear droop.

Strategy A
- Fastest re-synchronization
- Not robust → depends on initial operation point
- Highest ΔP under load increase → due to extra right displacement δ

Strategy B
- Slowest re-synchronization → due to loop dynamics
- Increased ΔP against deviations from GFM_2 setpoints
- Useful if GFM_2 is stronger than GFM_1

Strategy C
- Intermediate re-synchronization time
- Balanced response against load changes
- Useful if GFM_2 re-synchronizes with a much stronger grid/generator (GFM_1)

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GRID FORM
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