Complex Frequency-based Control for Adaptive Frequency Regulation of Grid-Forming Converters

27/05/2026

Florian Bingel – Innovation Advisor

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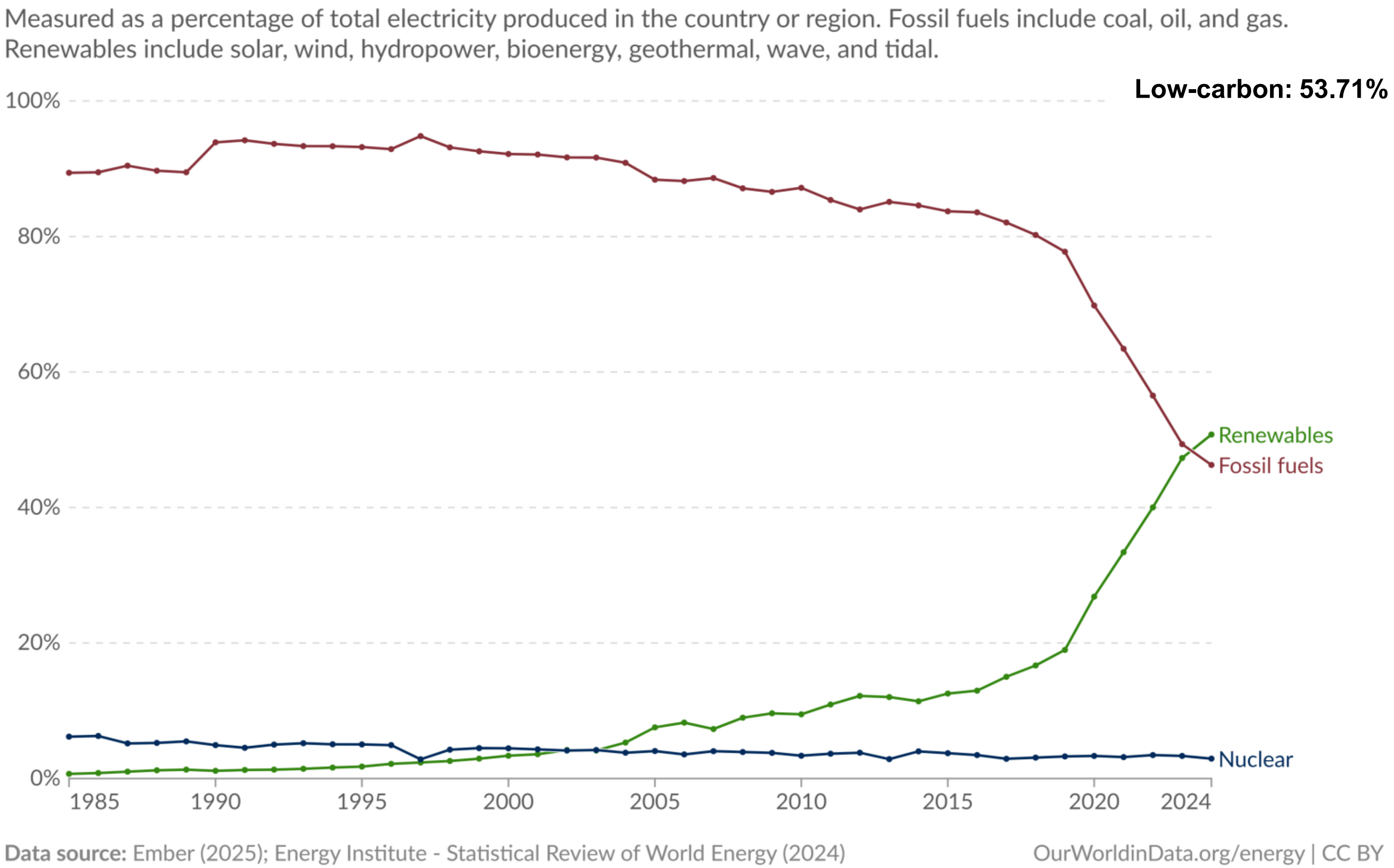
Energy Mix for Electricity of The Netherlands



Problem statement

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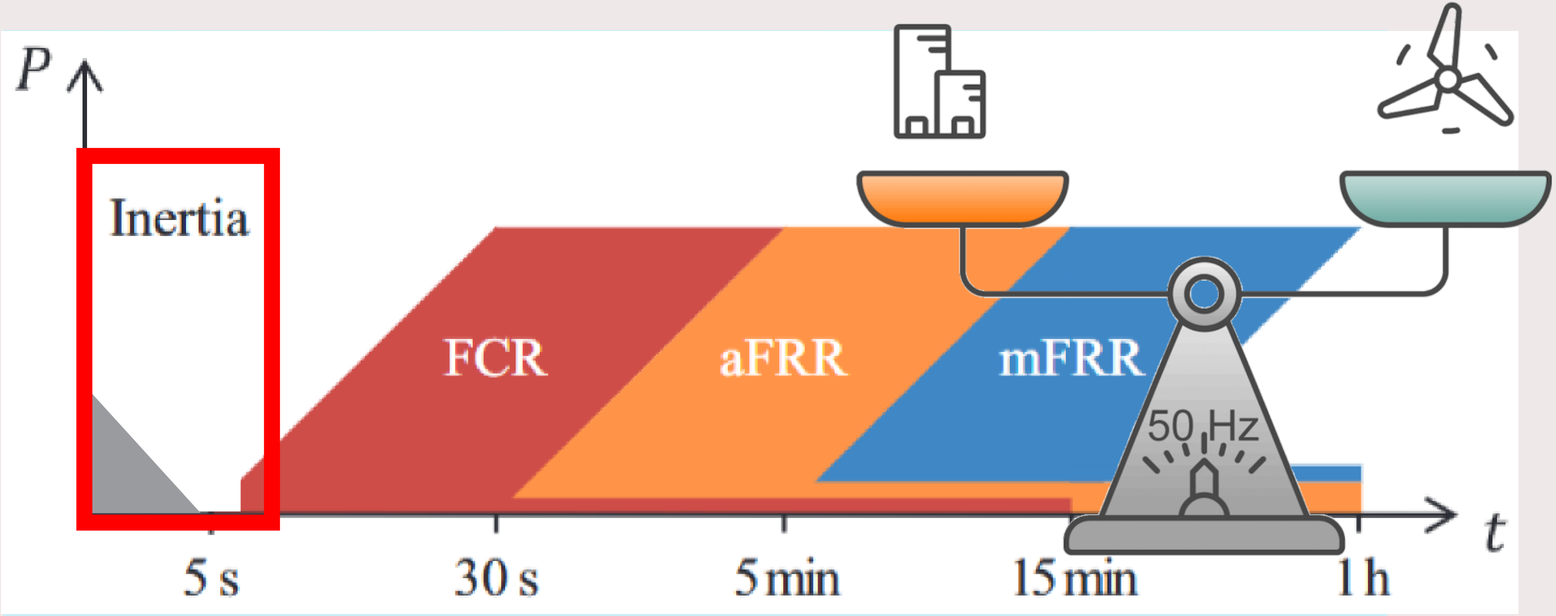

Enhanced contribution of photovoltaic power systems to frequency control in future power systems - Seidel - 2021 - IET Renewable Power Generation - Wiley Online Library

Ultracapacitors boost renewables with synthetic inertia

Problem Statement

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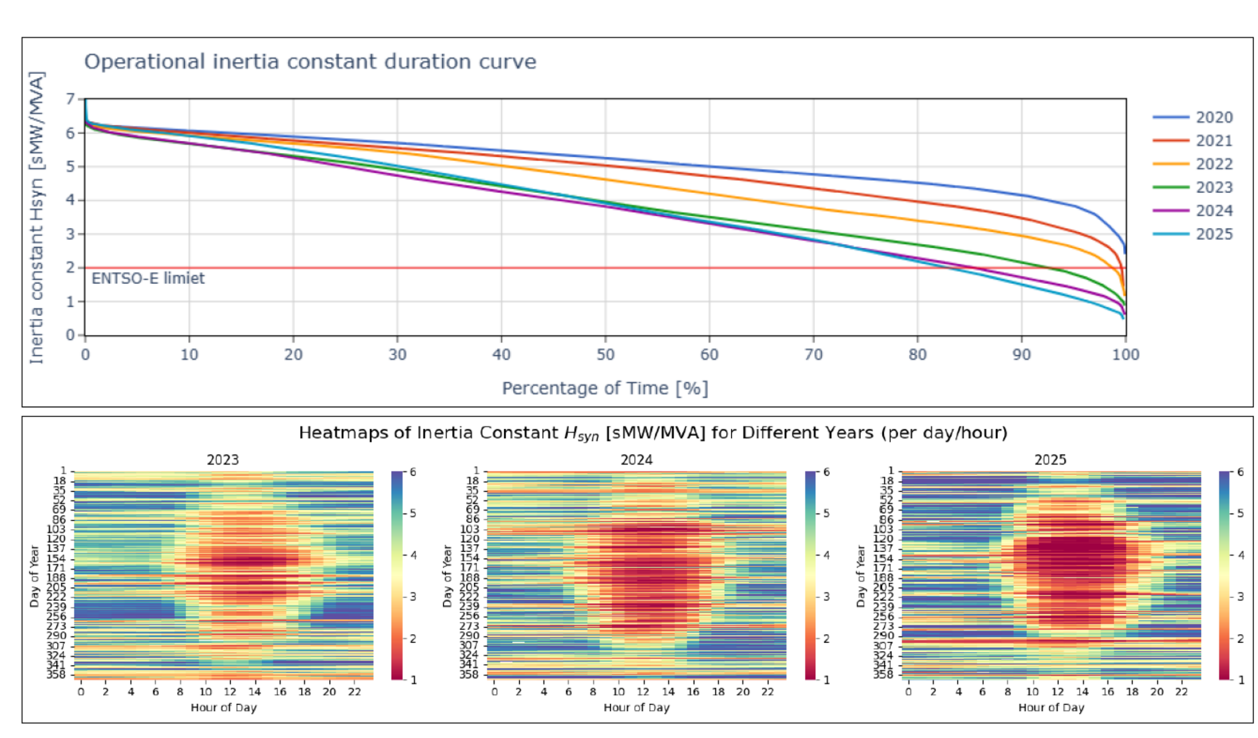
Problem statement



tennet TU/e

Grid Following versus Grid Forming

Problem Statement

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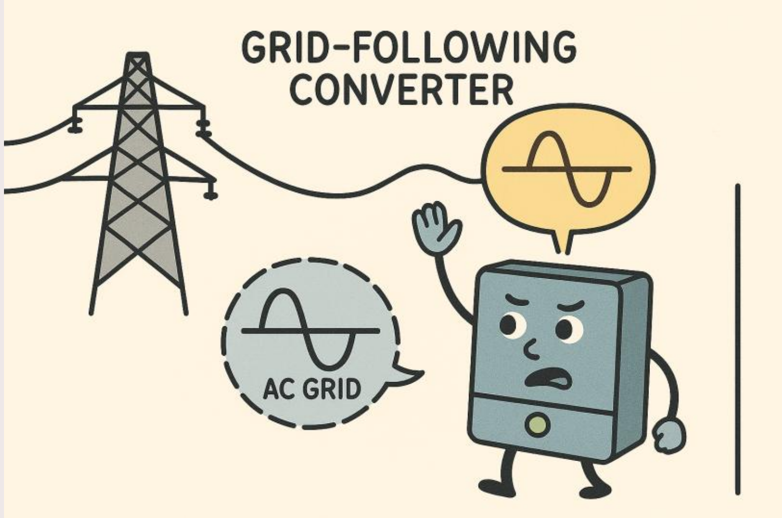
- Grid-Following is the widely implemented control strategy
  - Needs to lock on to grid voltage and frequency
  - Injects current based active (P) and reactive (Q) set-points



Problem Statement

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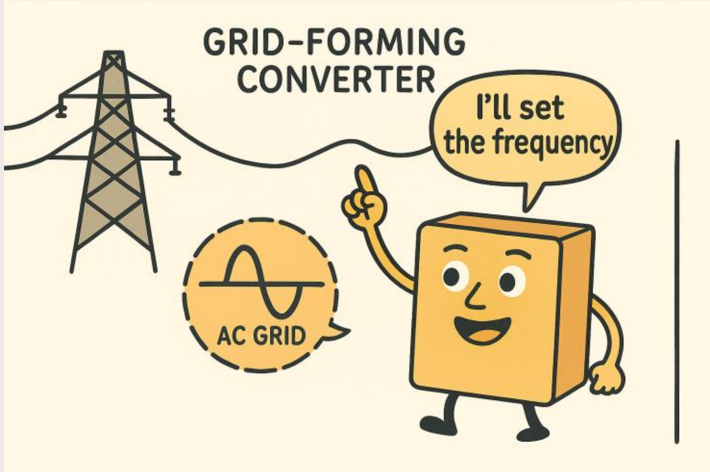
Grid Following versus Grid Forming

- Grid-Forming is a new type of control strategy
  - Sets own voltage phase and frequency based on set-points
  - Dynamically changes P and Q to achieve stable grid conditions



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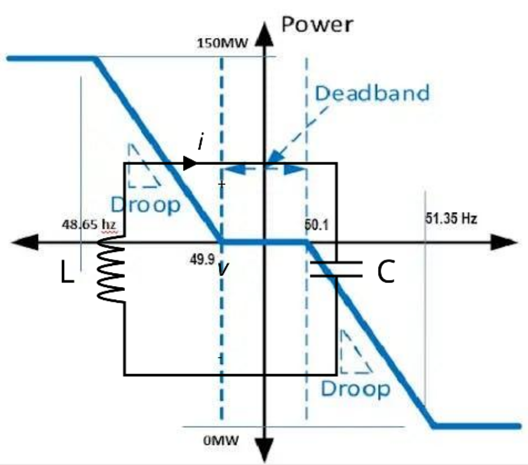
Grid Following versus Grid Forming



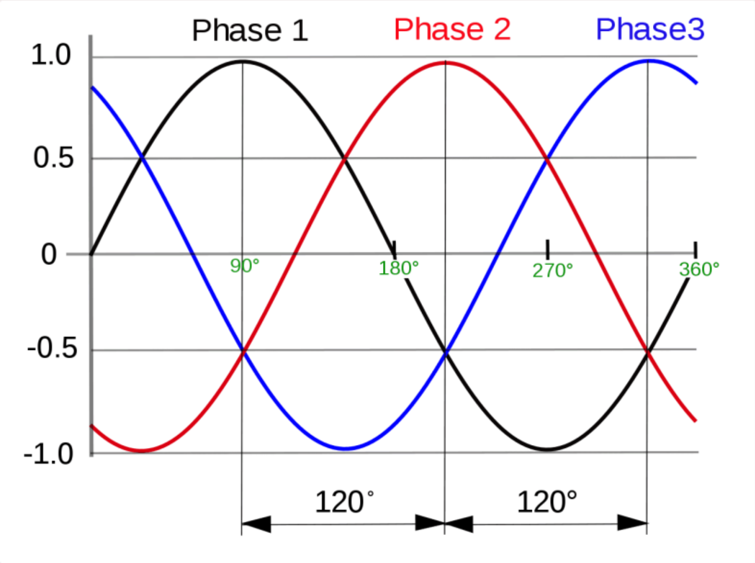
1. Virtual Synchronous Machine (VSM)
2. Droop Control
3. Virtual Oscillator Control (VOC)

Complex Frequency

Problem Statement

Method

Results



Testing Environment

Problem Statement

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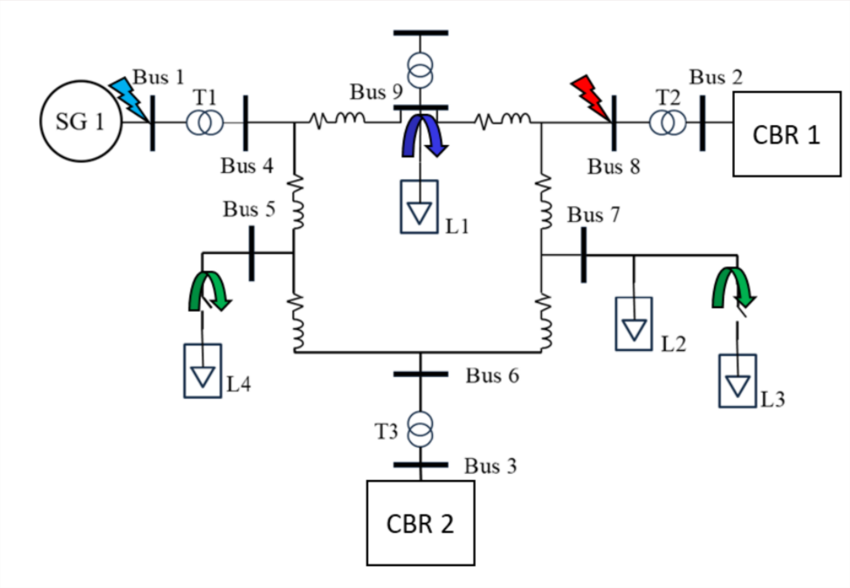
System II

- Case Study I: Addition of load
- Case Study II: Three phase to ground fault
- Case Study III: Load shedding
- Case Study IV: Single phase to ground fault



Results Case I: Addition of Load

f < 47,5 Hz
f > 51,5 Hz
|RoCoF|>1Hz/s

Problem Statement

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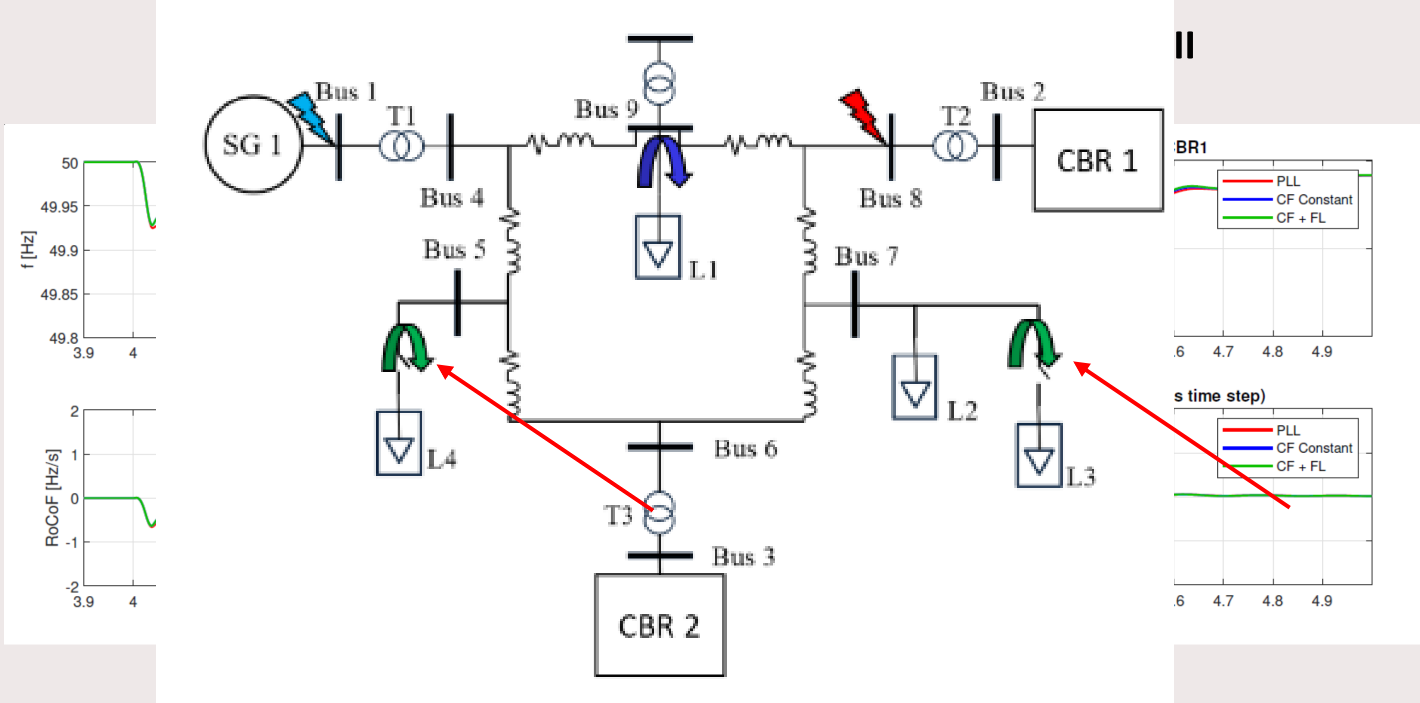

Results Case II: Three phase to ground fault

f < 47,5 Hz
f > 51,5 Hz
|RoCoF|>1Hz/s

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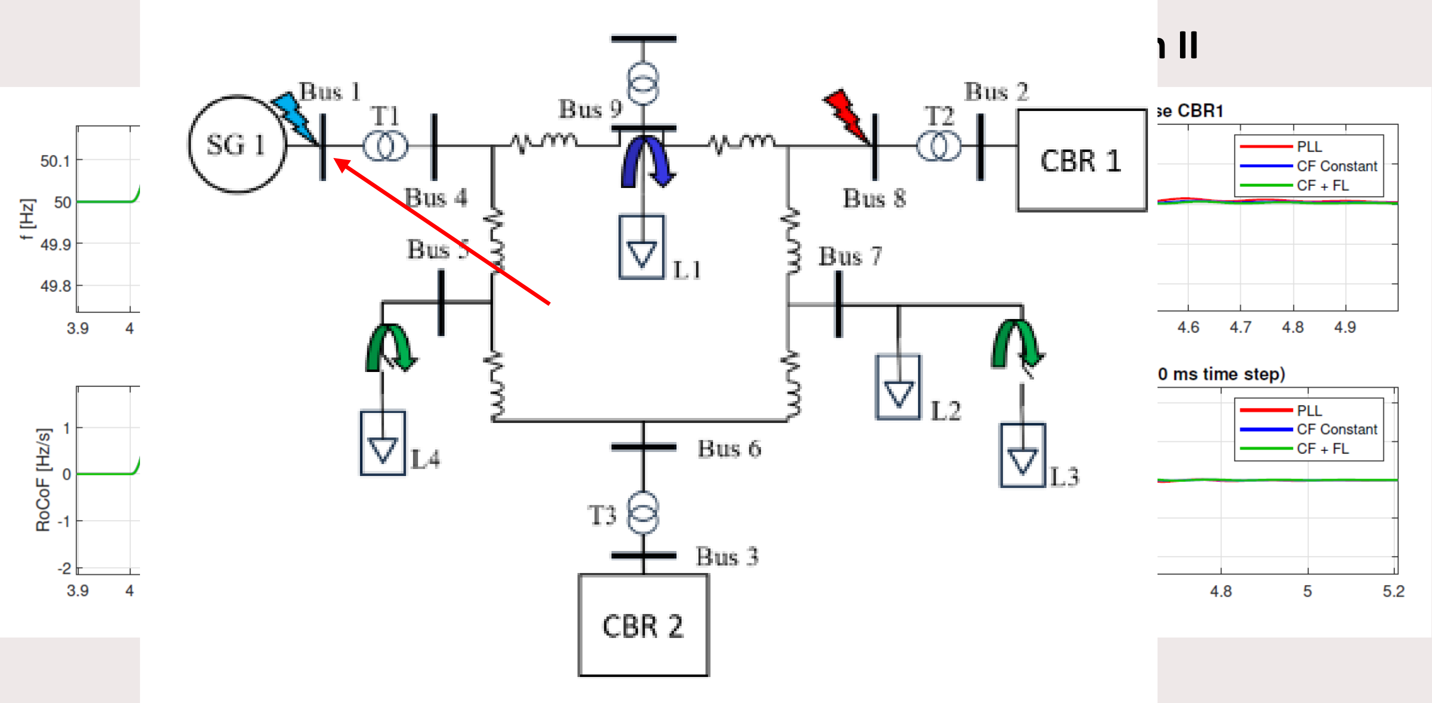

Results Case III: Load shedding

f < 47,5 Hz
f > 51,5 Hz
|RoCoF|>1Hz/s

Problem Statement

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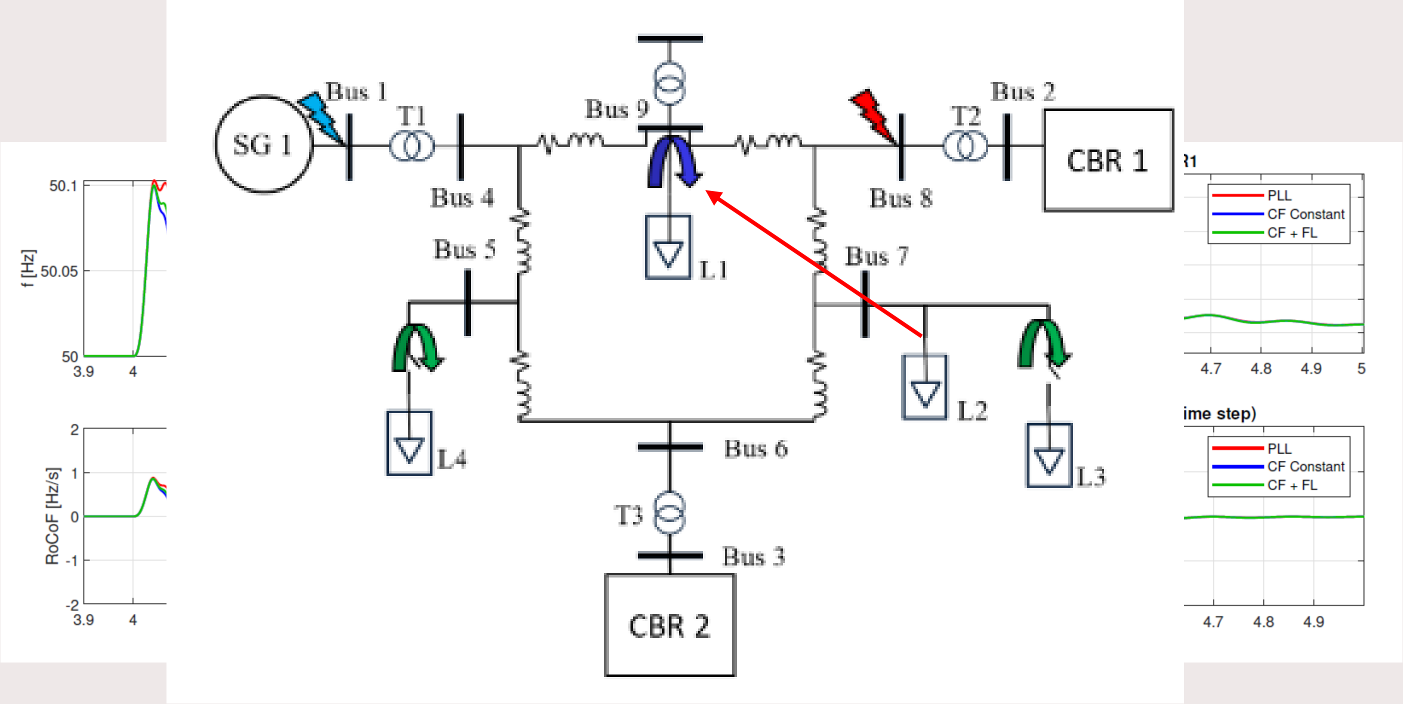

Results Case IV: Single phase to ground fault

f < 47,5 Hz
f > 51,5 Hz
|RoCoF|>1Hz/s

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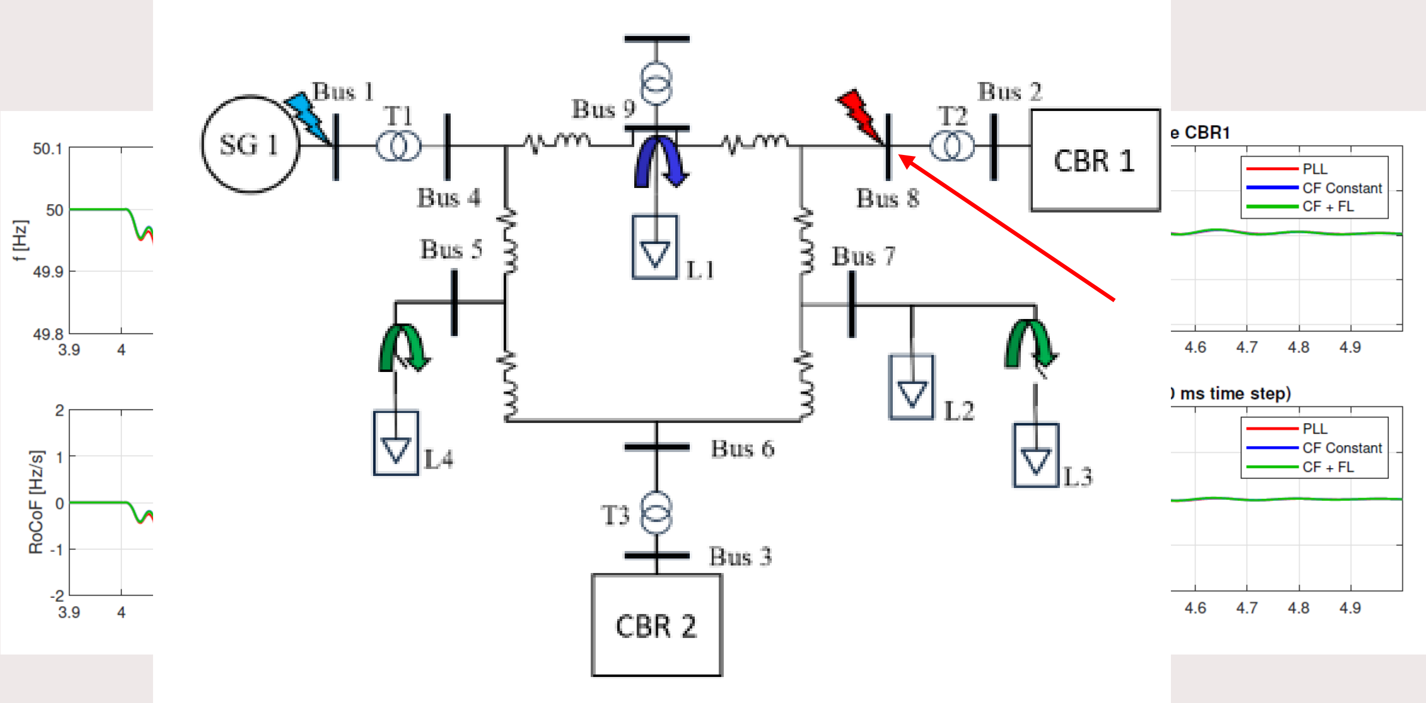

Problem Statement

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Discussion

\+ Proposed methodology is readily implementable by adding PMU at local bus

\+ Method is able to stay in operable ranges more so than existing methods

\- Time intensive process of tuning Fuzzy Logic controller

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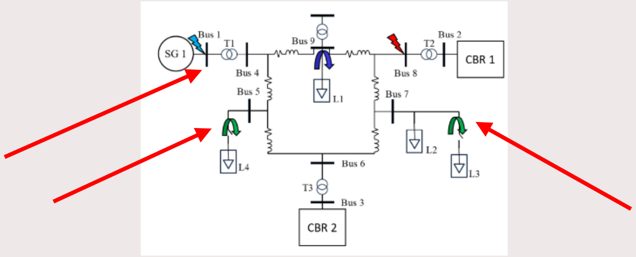
Thank you for your attention!

Florian Bingel – Innovation Advisor

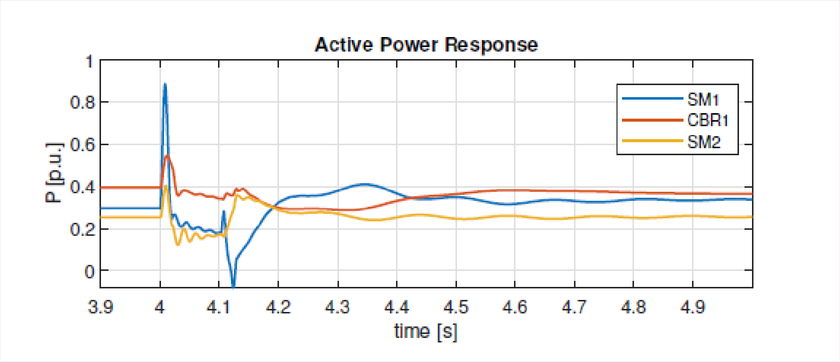
Additional Results

- Best case scenario
  System I Case I

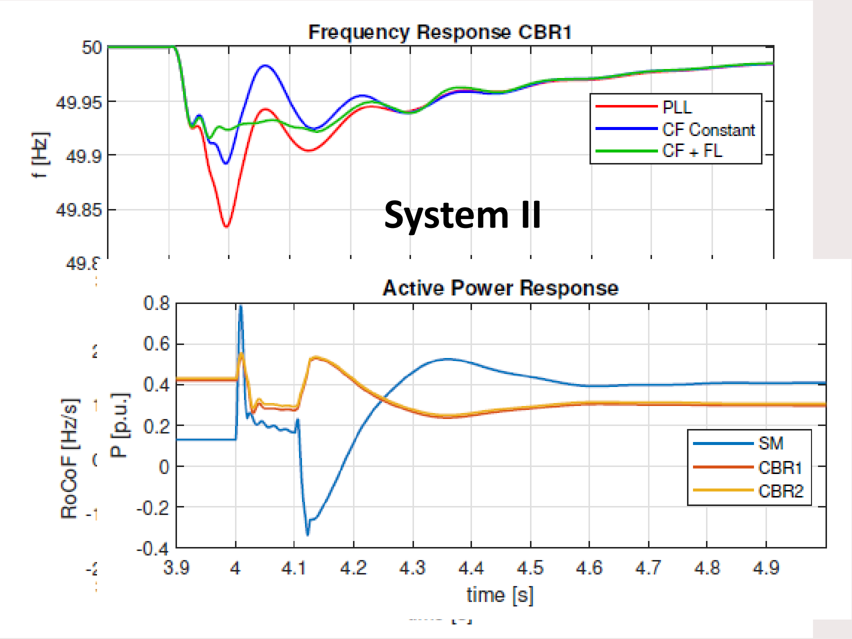
- Power sharing System I
  versus System II Case II



System I



System II



Spare slide: Control Structure

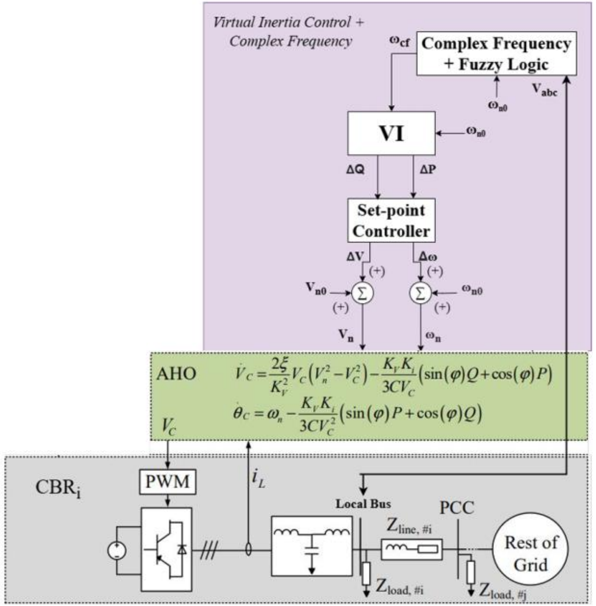


Fig. 2. Higher level representation of proposed control architecture.

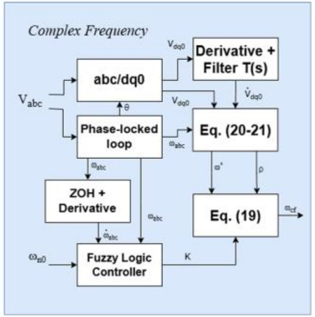


Fig. 3. Adaptive complex frequency-based control layer utilizing fuzzy logic.

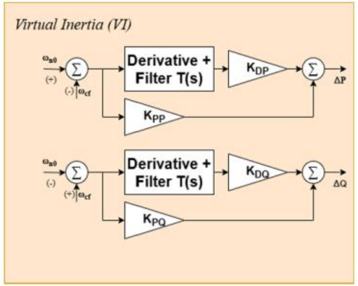


Fig. 4. Virtual inertia control layer.

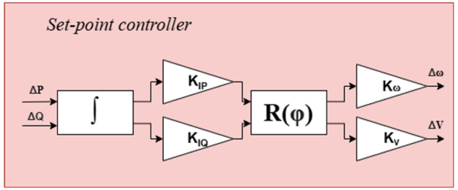
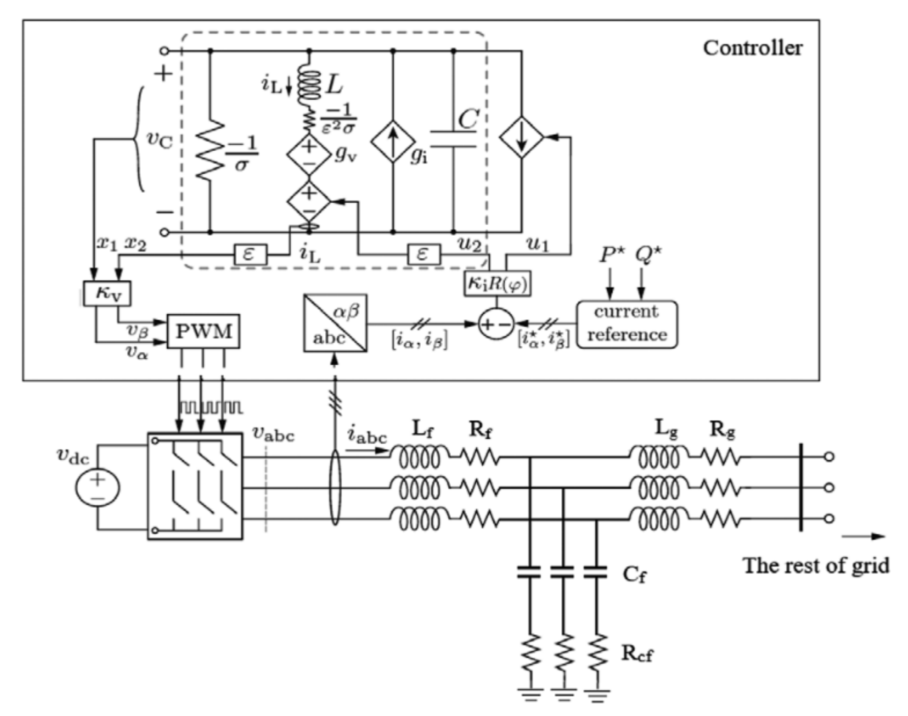


Fig. 5. Set-point controller control layer.

Spare slide: Theoretical Background: Andronov-Hopf Oscillators

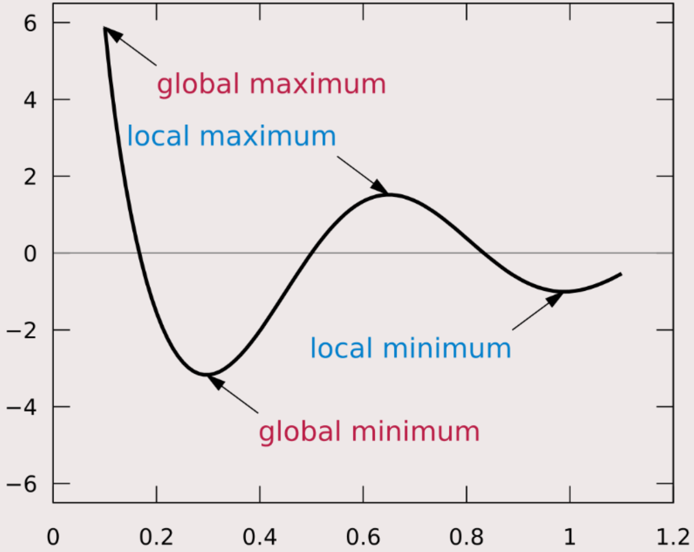
- This type of VOC is considered the most promising for its' ability to be dispatchable.
- Works in both grid-connected and islanded mode.
- Works in three-phase implementations.
- Design process based on explicit terms to define dynamic response of the converter.
- Needs additional control loop to help with inertia.

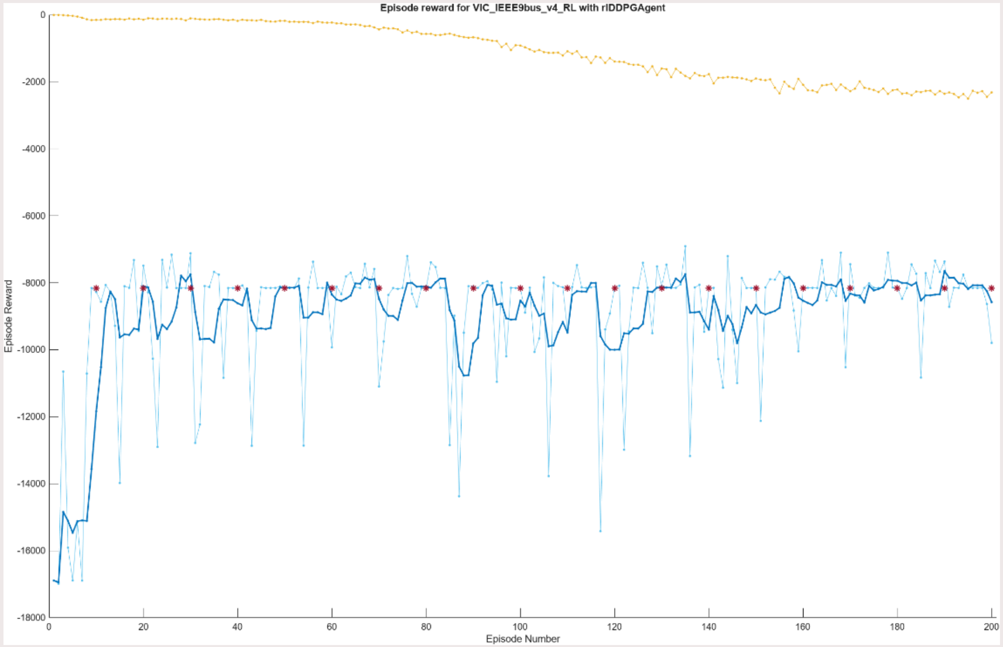


S. Azizi Aghdam and M. Agamy, "Virtual oscillator-based methods forgrid-forming inverter control: A review," IET Renewable PowerGeneration, vol. 16, no. 5, pp. 835–855, 2022. [Online]. Available:https://ietresearch.onlinelibrary.wiley.com/doi/abs/10.1049/rpg2.12398

Spare slide: RL problems

- Local versus global minima





Spare slides: Maasvlakte model