Green & Black-starting HVDC-connected Offshore Wind Power Plants

Grid forming control, Energization transients and Islanding capabilities

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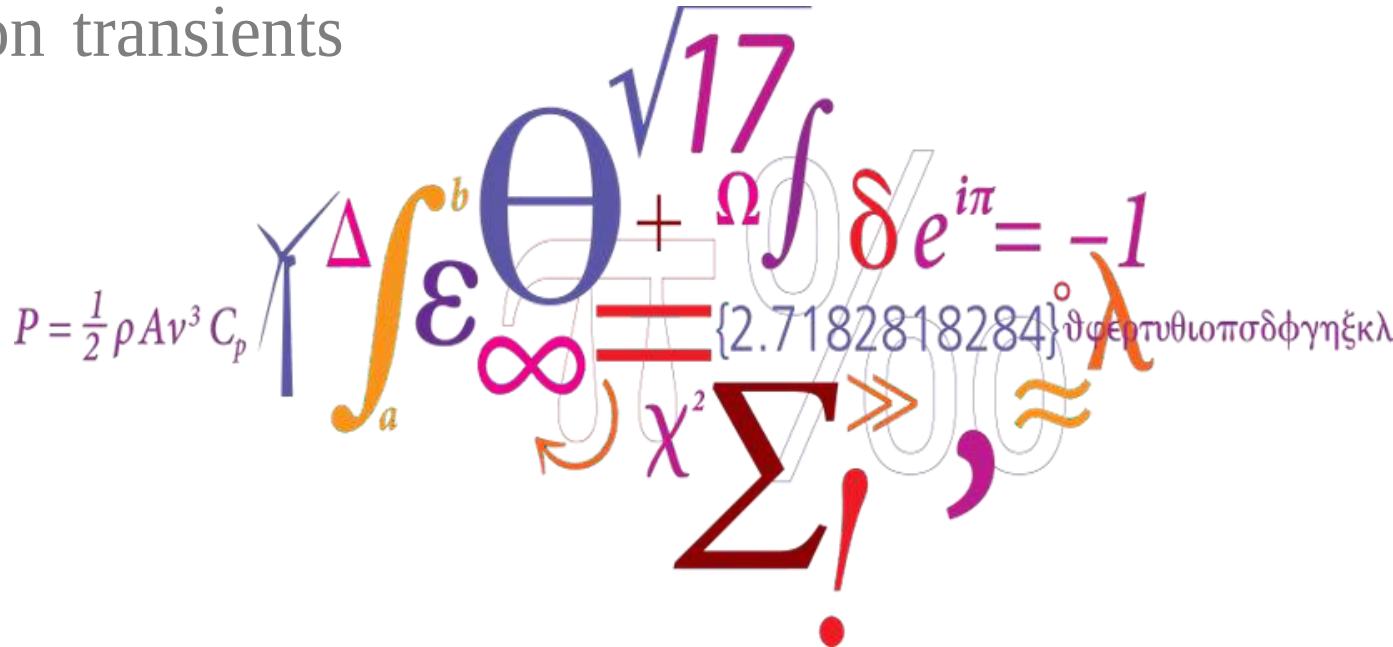


Background

Global warming

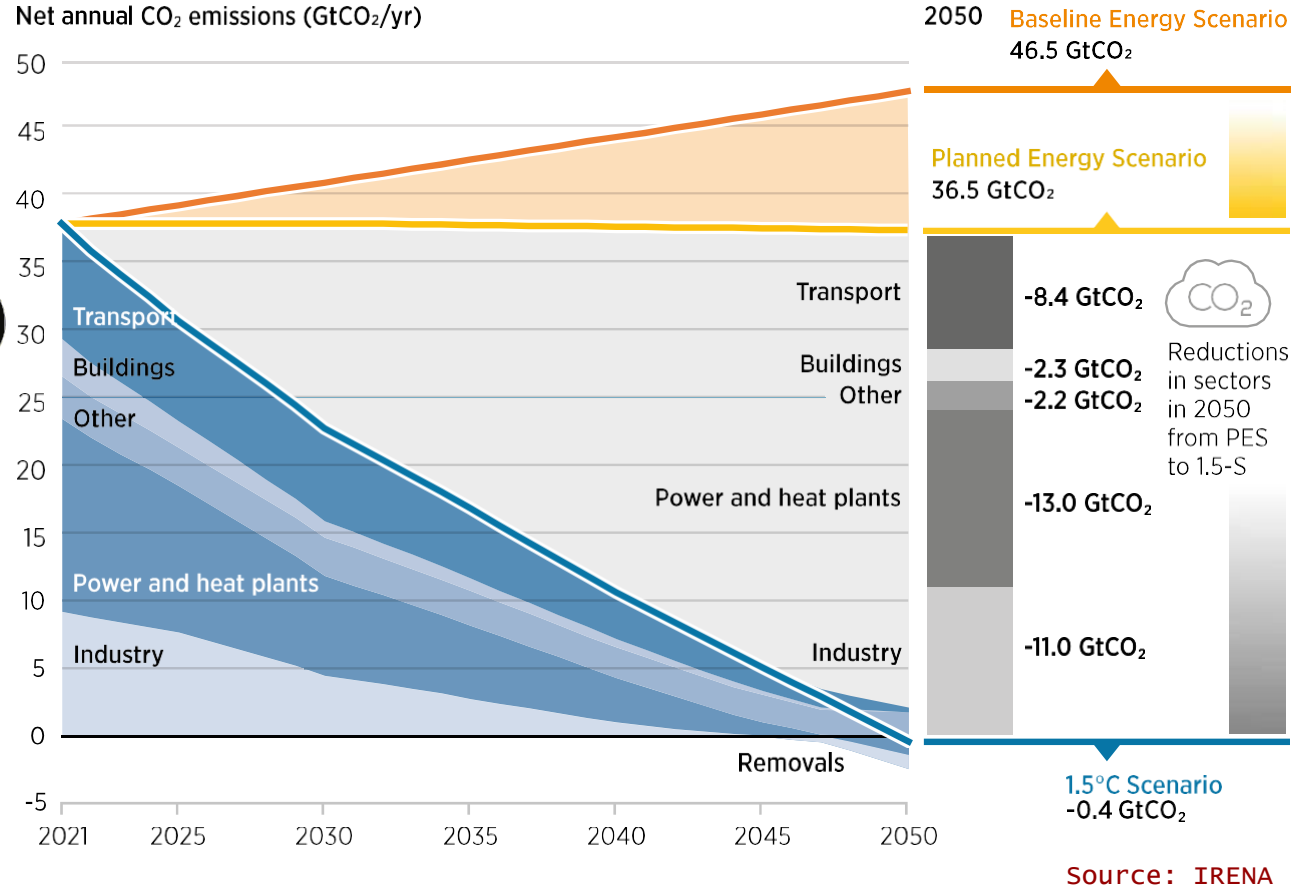
- Irreversible impact

Carbon neutrality

- Electricity as backbone

Green energy

- Renewable sources domination



Source: IRENA

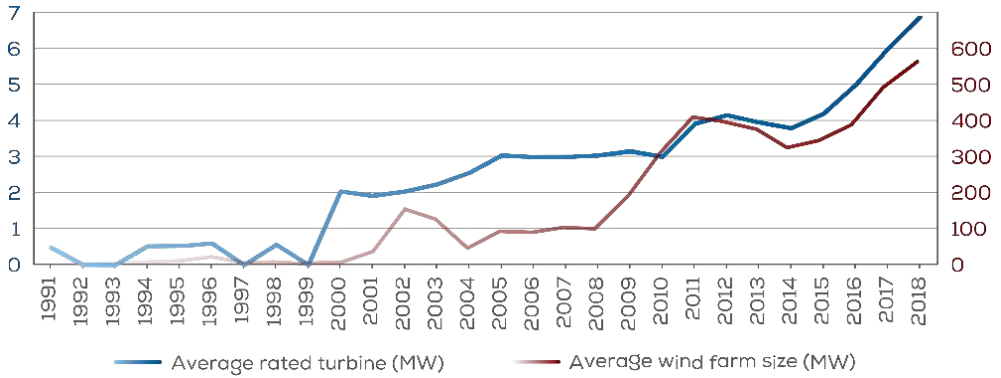
Key players

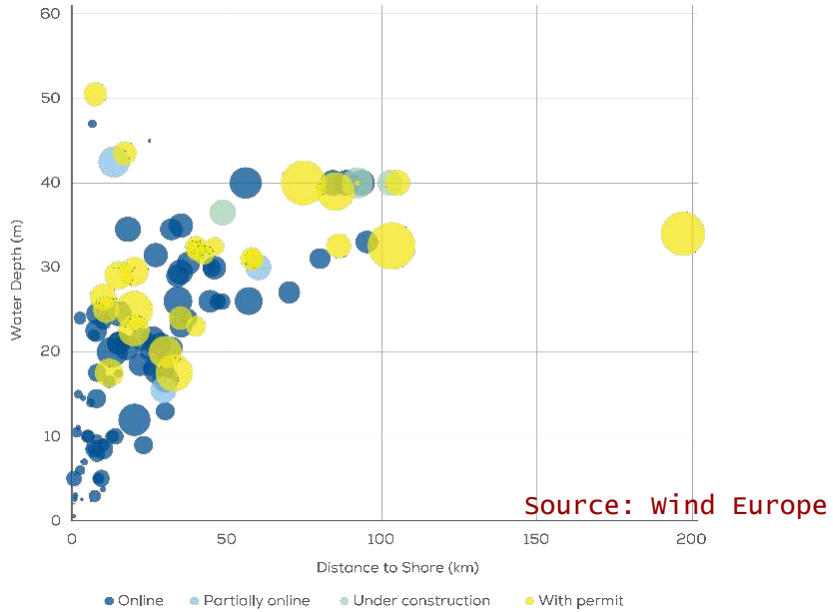
Offshore wind

- Larger & cheaper
- Farther & deeper

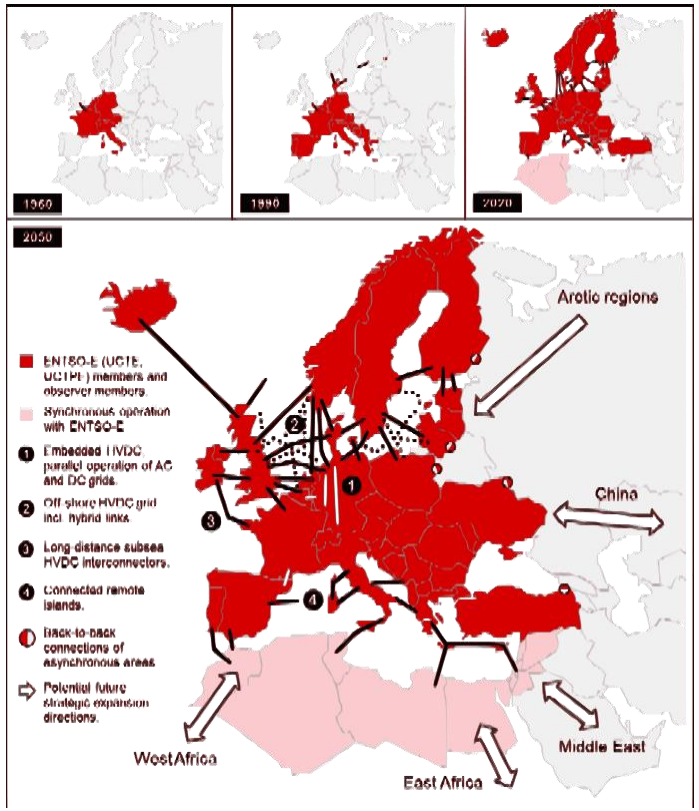
Interconnections

- HVDC





Source: Wind Europe



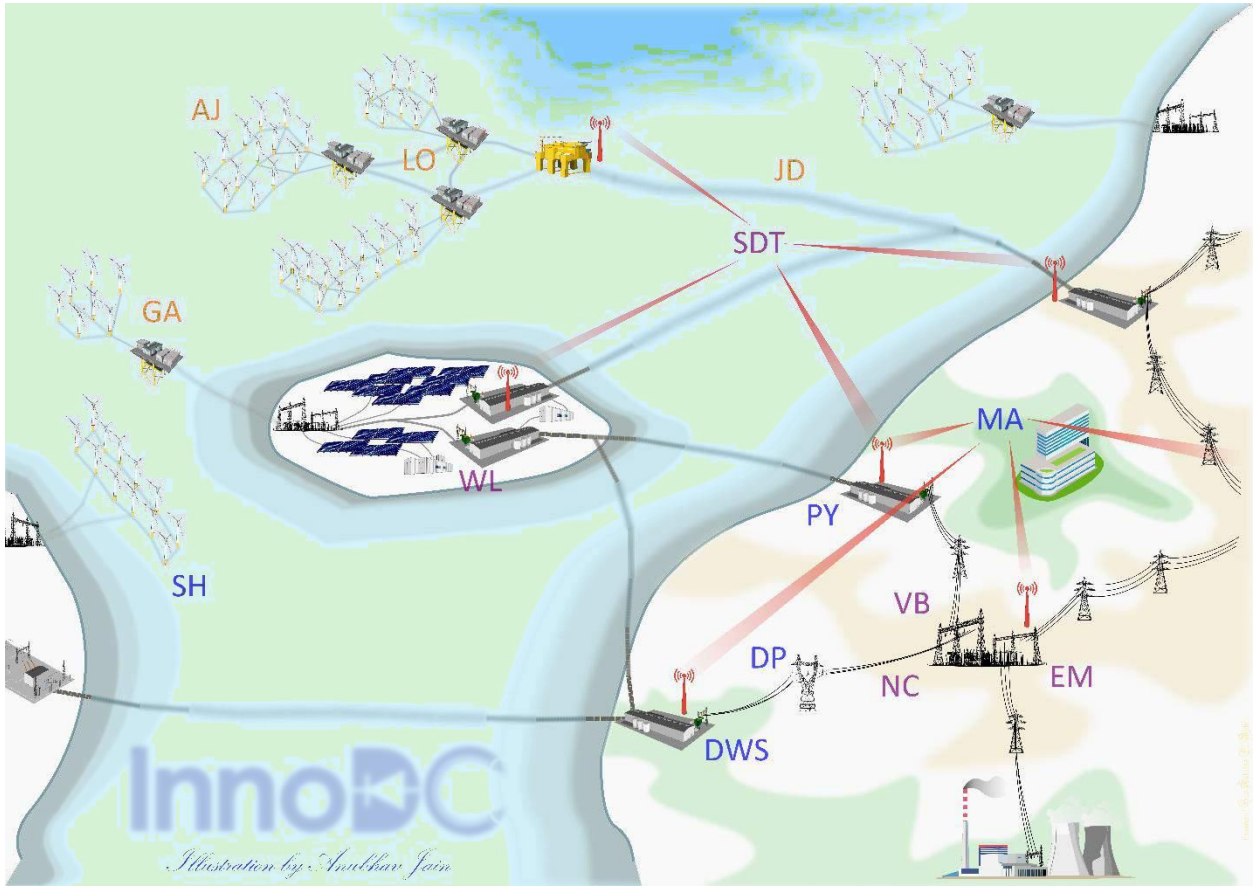
Source: Hitachi-ABB

Scope

INNovative tools for Offshore wind & DC grids

- 14 ESRs / 3 WPs
  - WP3: AC-DC grids
  - **WP2: large OWPPs**
  - WP1: key components

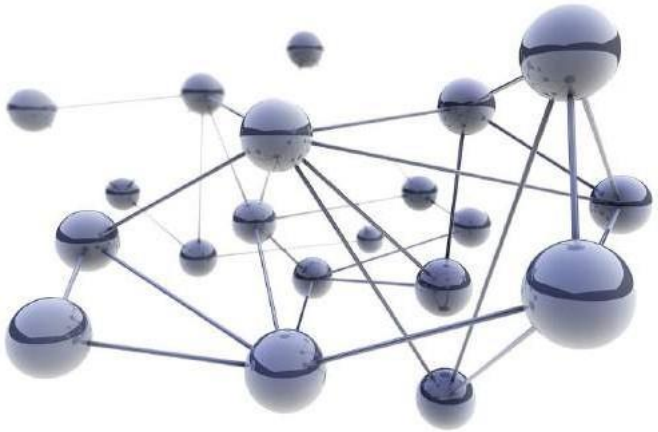
Blackstart & Islanding Capabilities of OWPPs

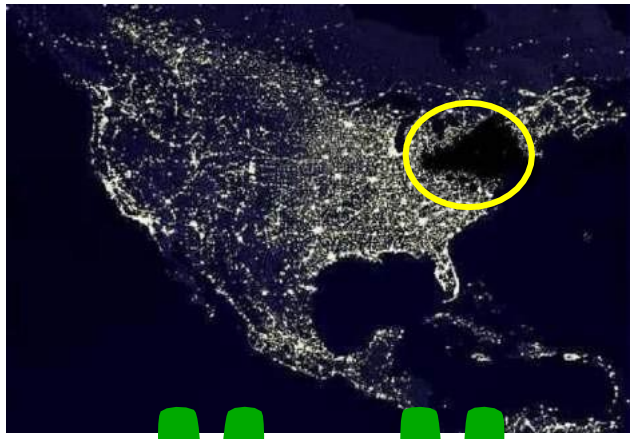


Motivation

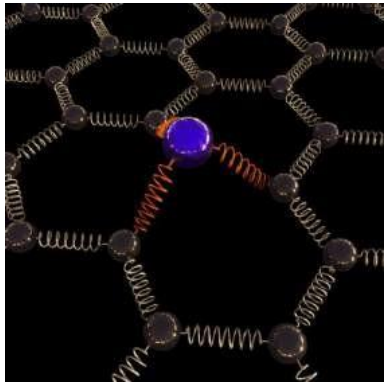
Power electronic converters

- Energy flexibility
- Grid expansion



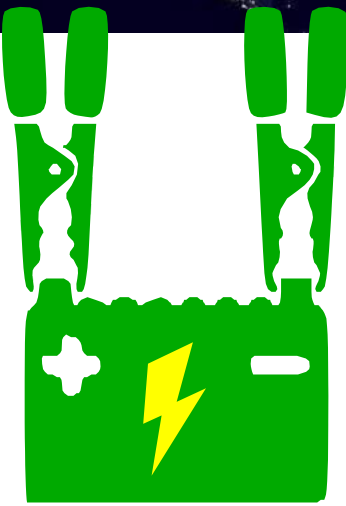


System instability → Blackout



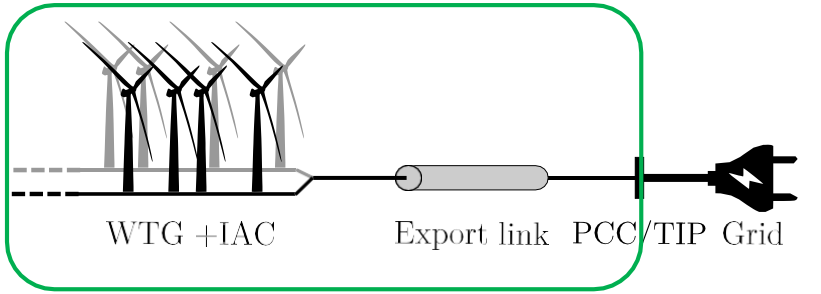
Credit: D. Kepaptsoglou, SuperSTEM

Restoration (TSO perspective)



Greenstart

Not blackstart

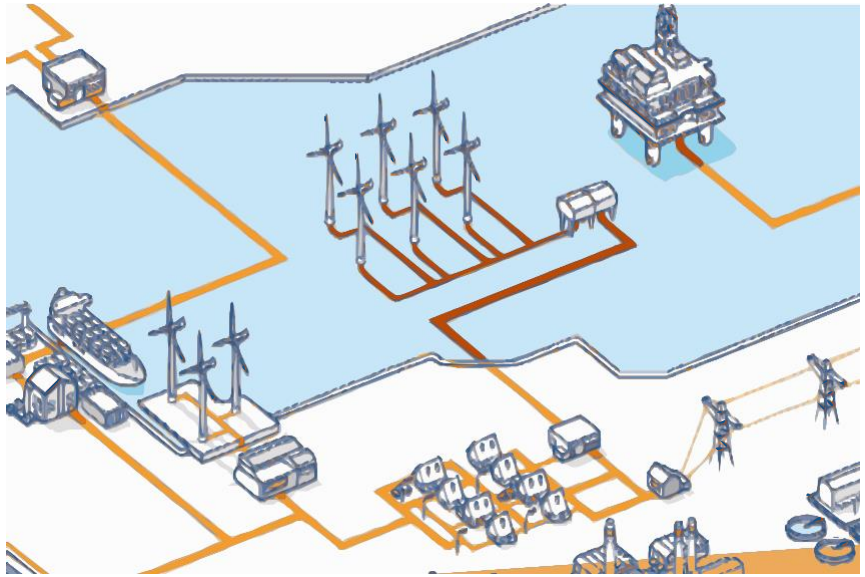


Aggregated Blackstart unit

Prepare
- Decision, Defense, Definition

Energise System
- Blackstart, Voltage propagation, Load recovery

Restore Load
- Block Loading, Meshing, Synchronization

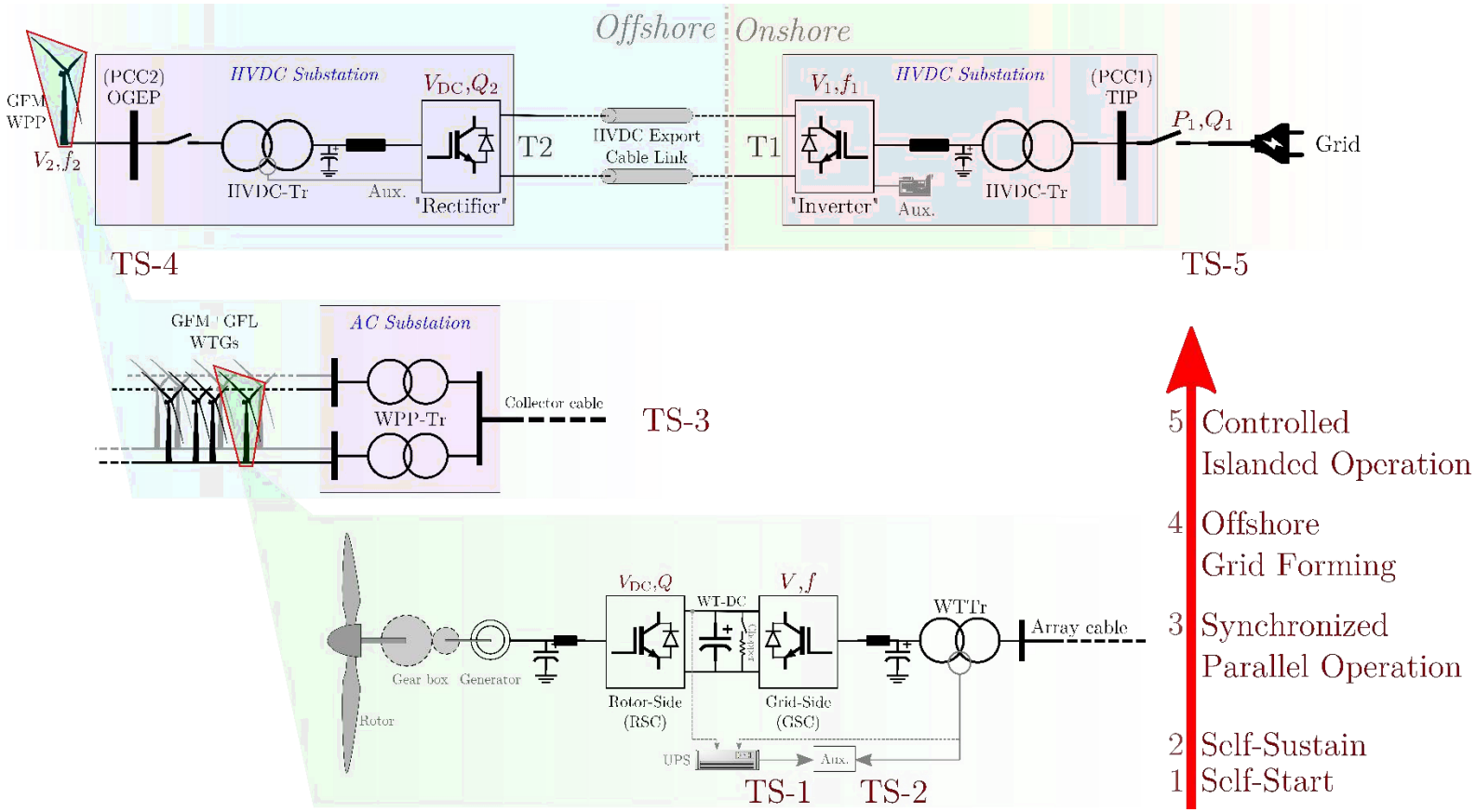


Source: Hitachi-ABB

Target states

Challenges

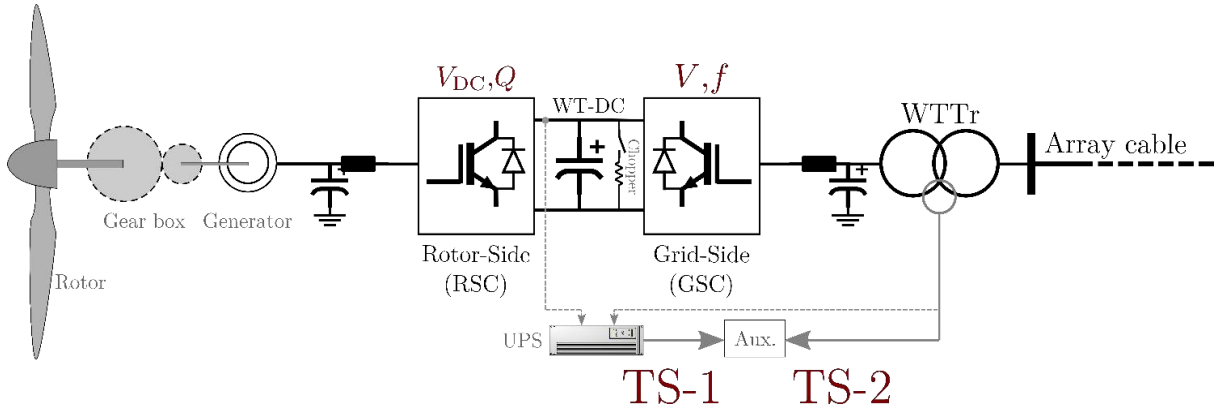
- Cable Var
- Trafo inrush
- Synchronization
- Weak grid
- Resonance rich
- Cross-couplings
- Low/negative damping
- Market



Research questions

- Can WTGs control offshore voltage & frequency while dealing with network energization transients?
- How do different controls behave in a challenging energization scenario and what are the limitations?
- Can WTGs maintain synchronised parallel operation to emulate a voltage source and operate a stable offshore power island?
- Can OWPP deal with energization transients of HVDC-transmission in a controlled manner?

TS-1,2 WTG self-Start & Sustain



Backup supply

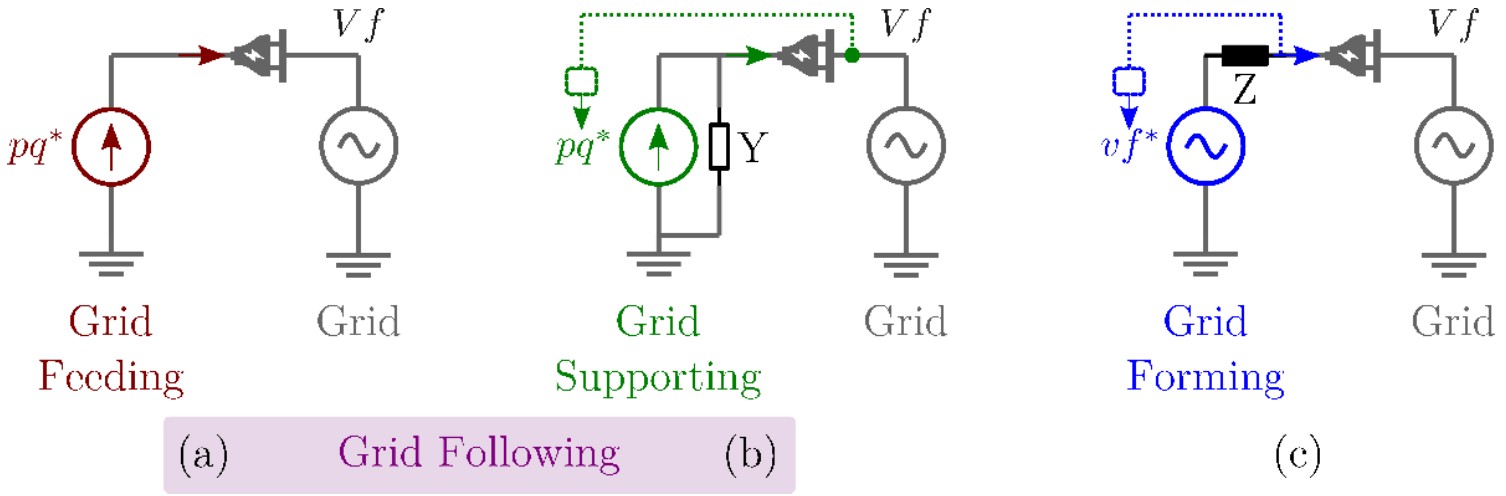
- Controls
- Measurement
- Protection

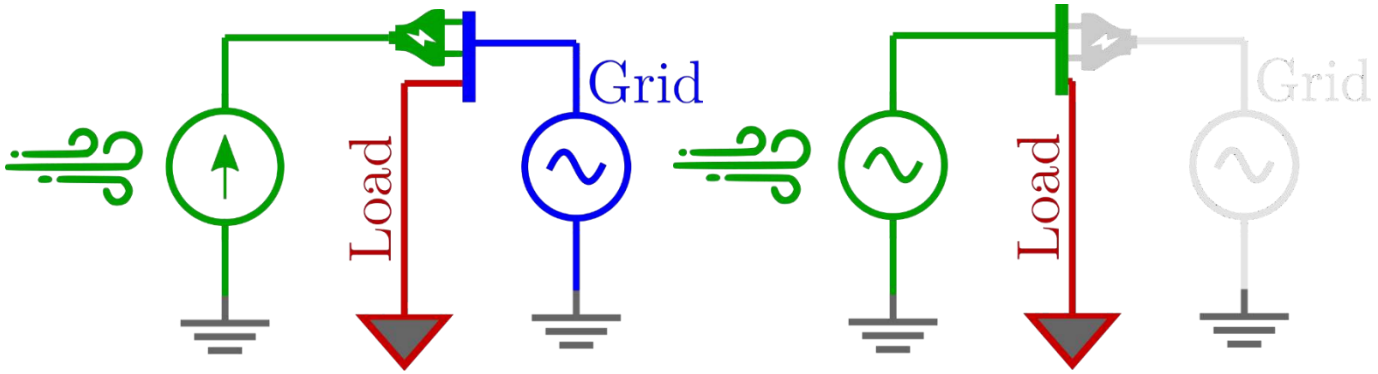
Rotor oriented

- Pre-charging
- Grid forming (GFM)
- House-load

GFM

Control philosophy



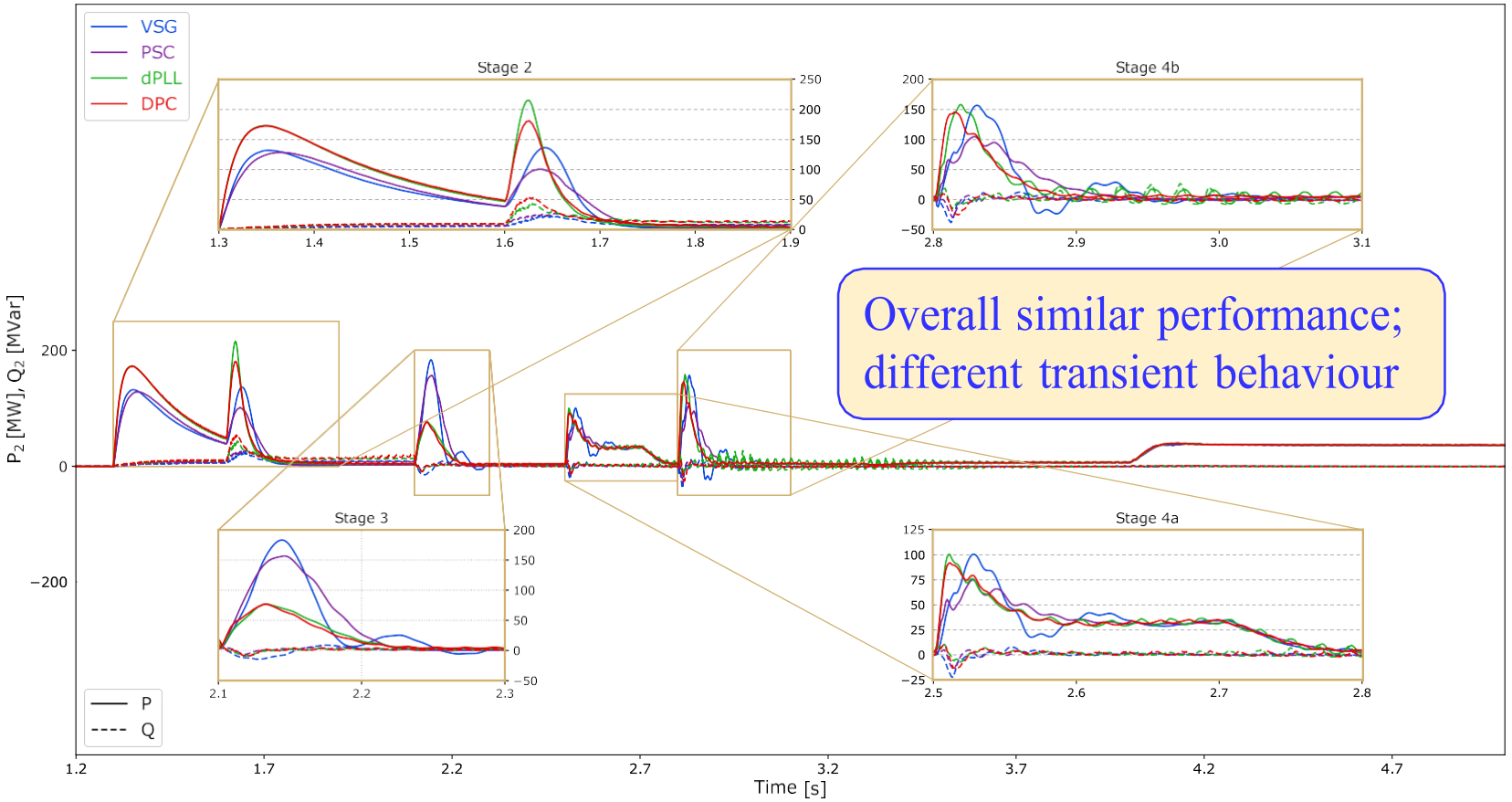


- Voltage control
- Current limitation
- Frequency control/Synchronization
- Power control
- Enhancements

GFM

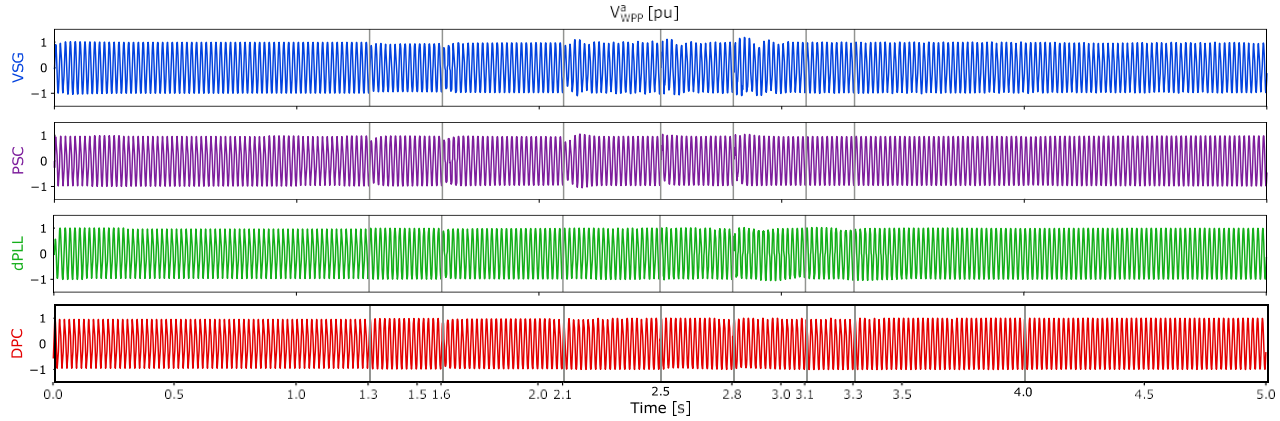
Control strategies

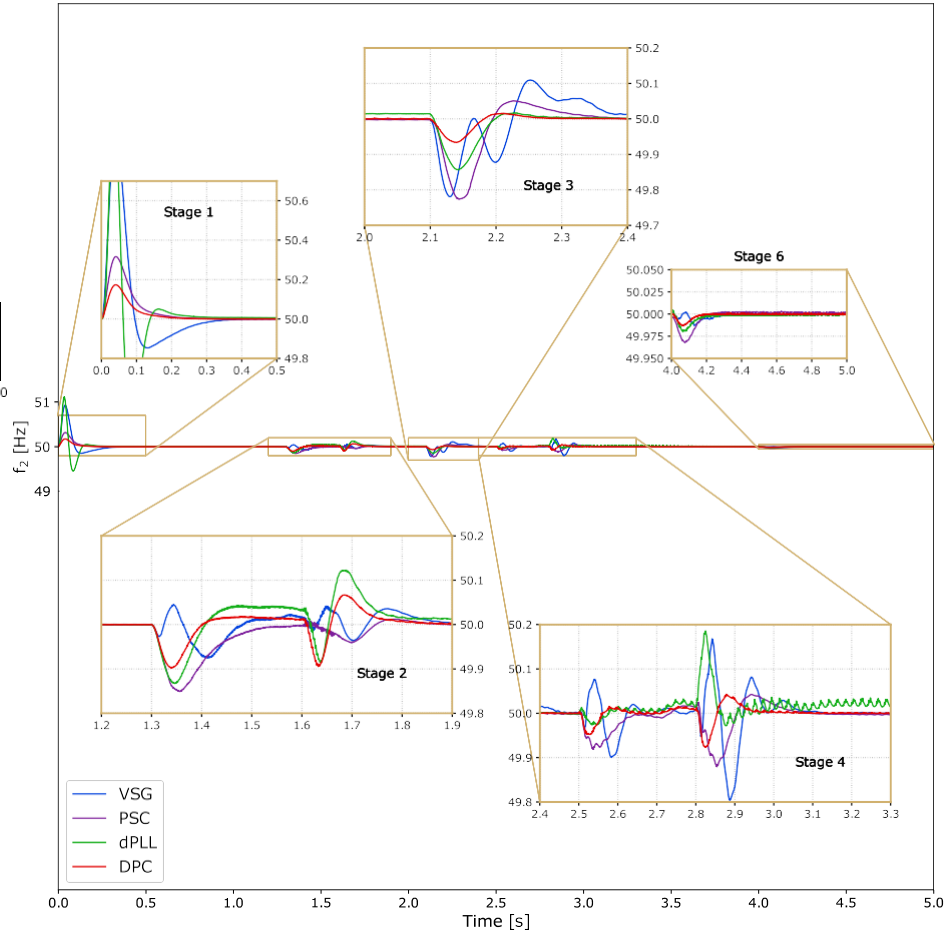
- ---
- Virtual Synchronous Generator
- Power Synchronization Control
- Distributed-PLL based
- Direct Power Control
- ---



GFM

Transient characteristics

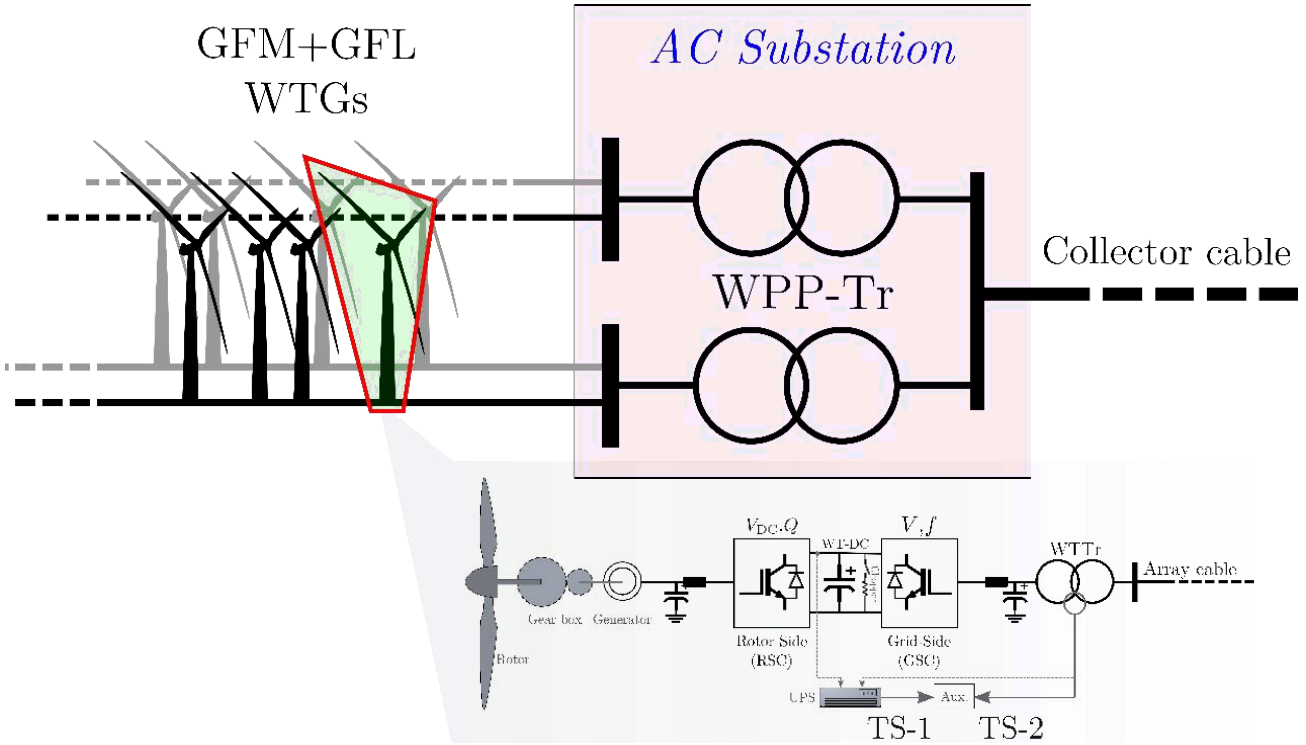




- Oscillatory modes & damping
- Transient dips/swing
- Tuning complexity
- DPC selected

TS-3

Offshore network



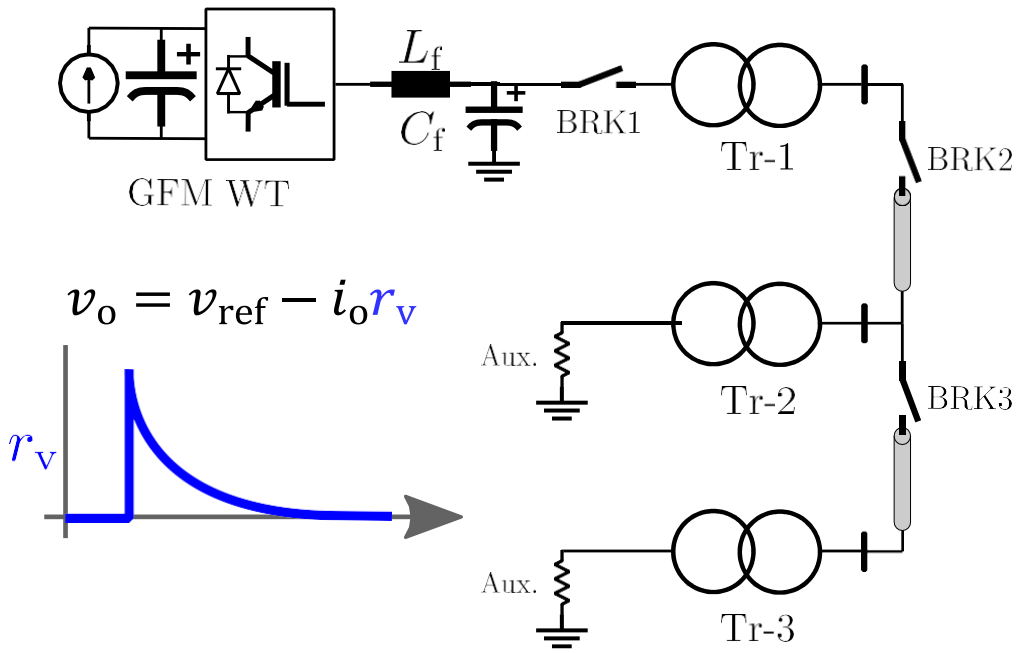
TS-3

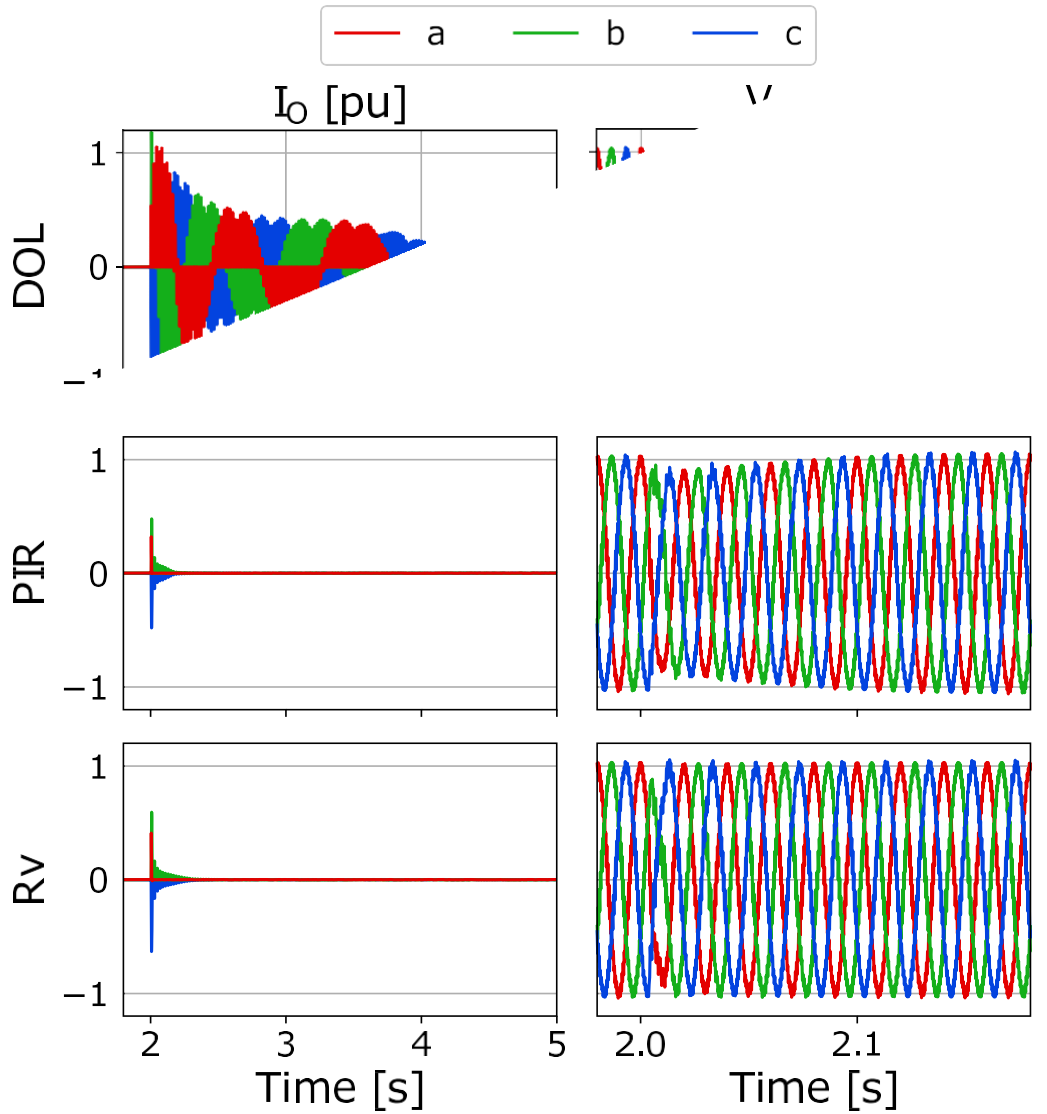
- Trafo inrush
- Cable Var
- Synchronization
- Parallel operation
- Islanding

TS-3

WTG Trafo

Virtual resistance for OCL

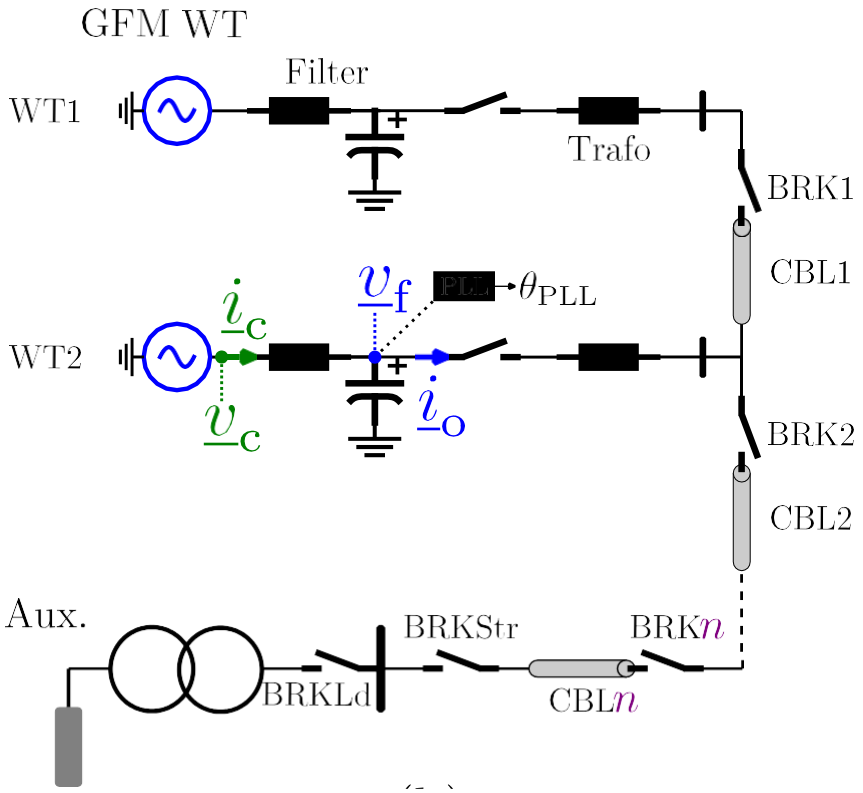


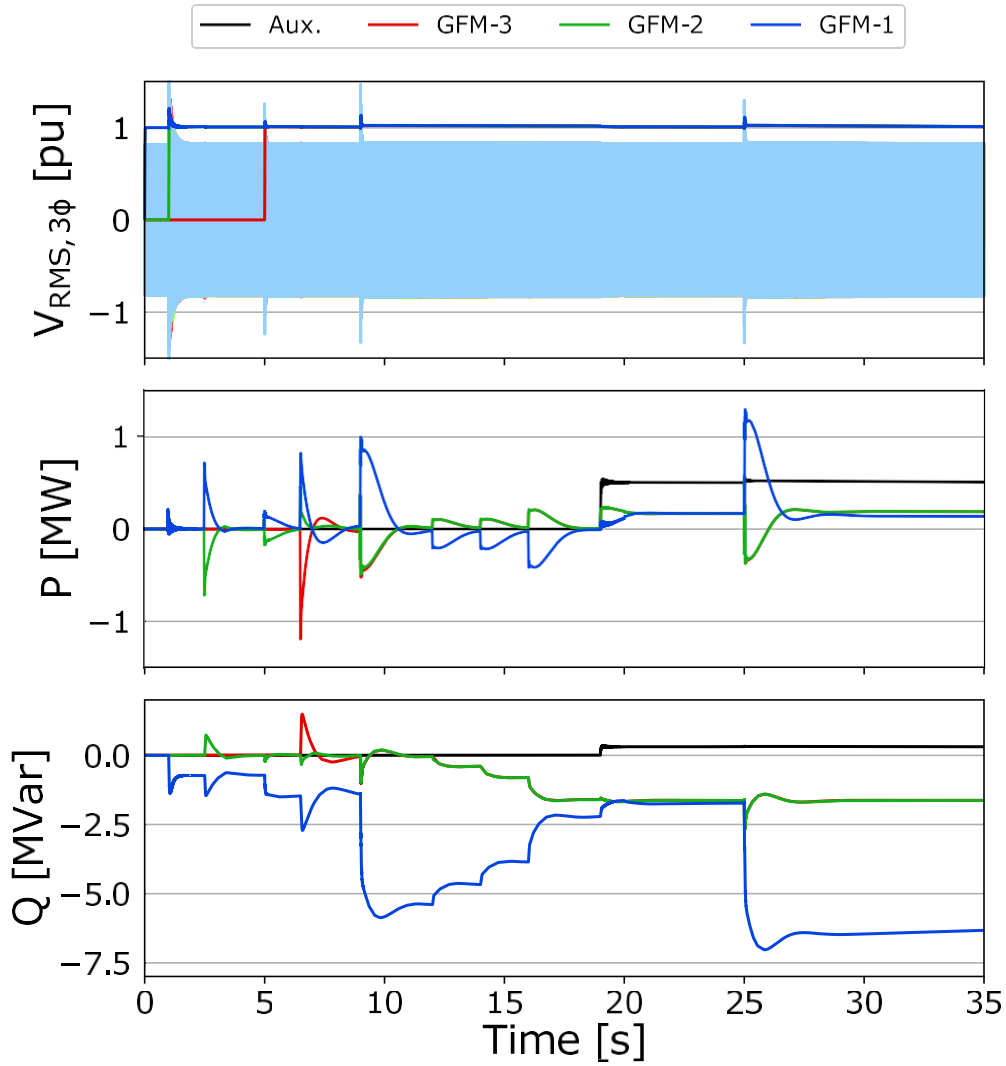


TS-3

WTG Sync

Synchronization loop added





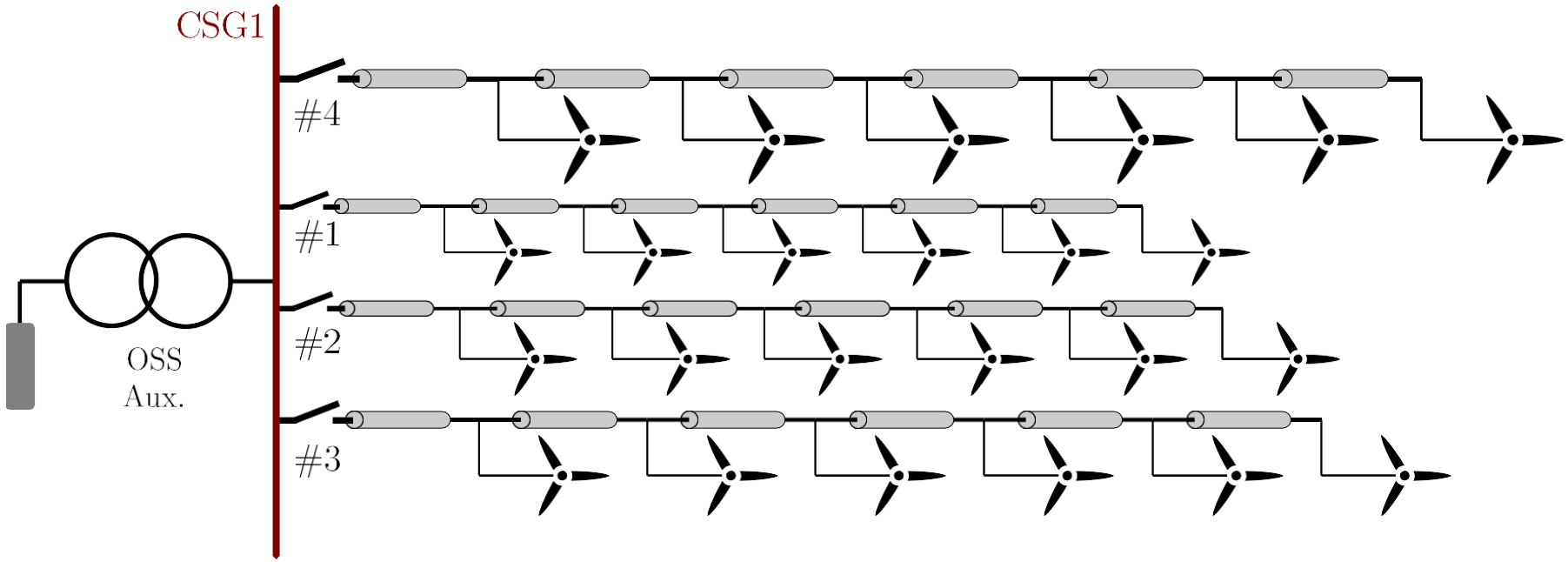
How many GFMers?

Cost

P/Q requirement

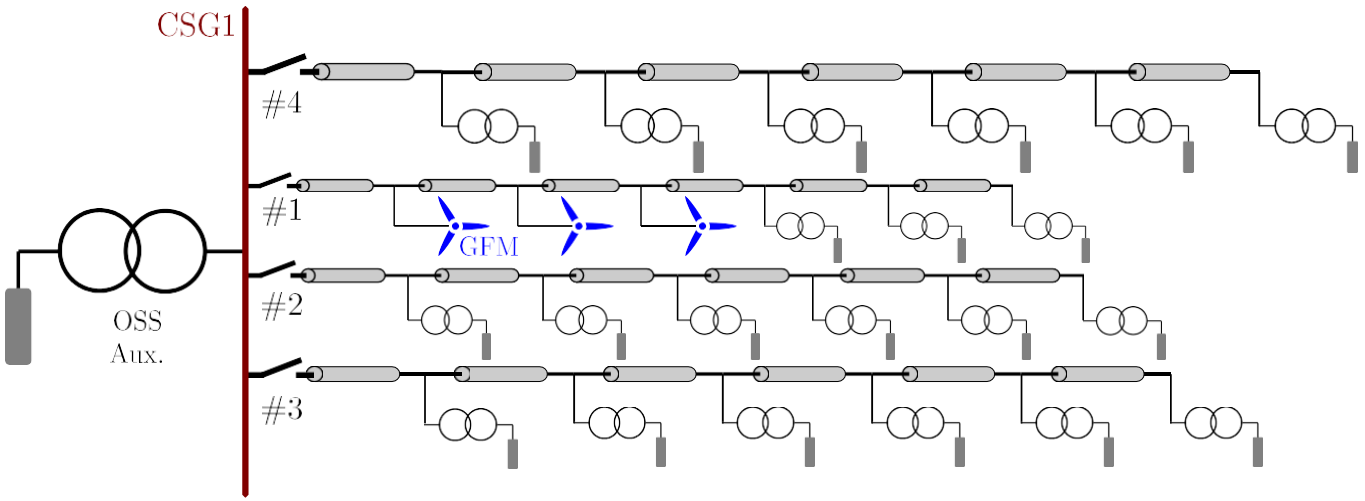
Sequence

Transient stability



TS-3

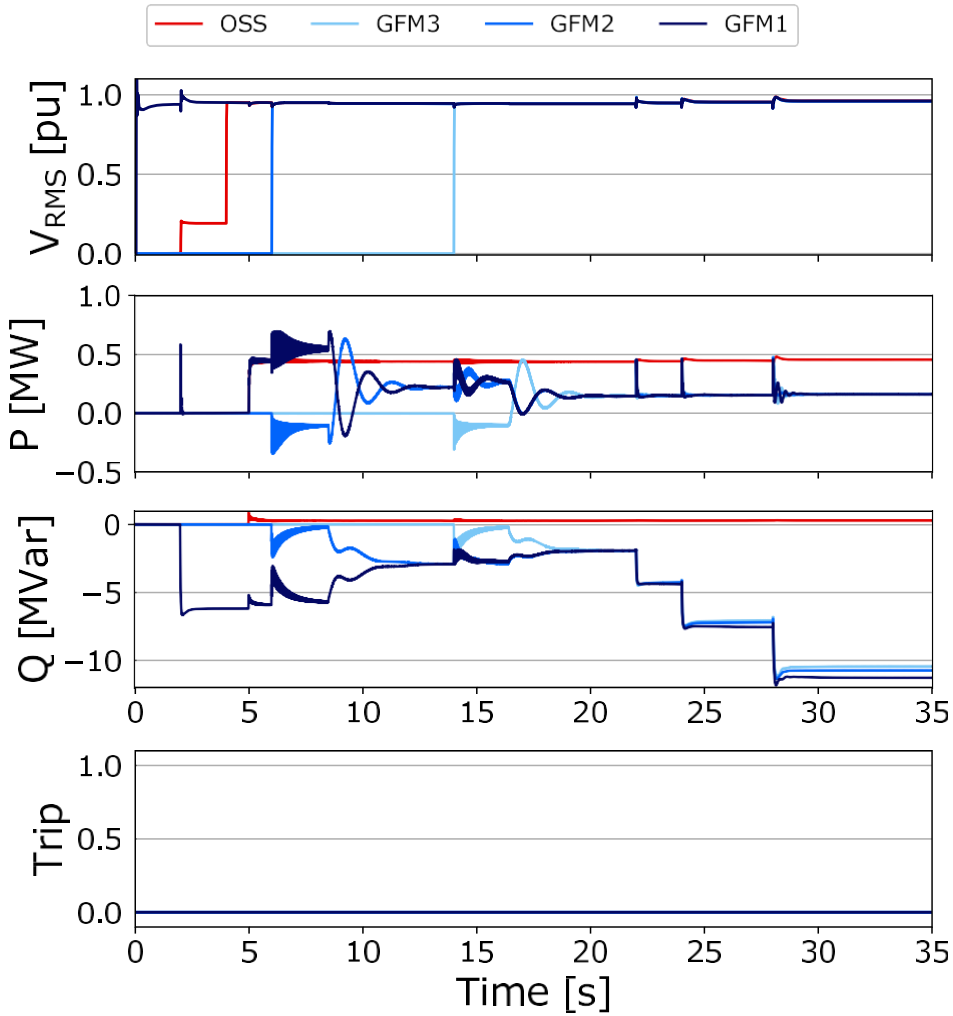
GFM only



$k_{P\theta} = 2$

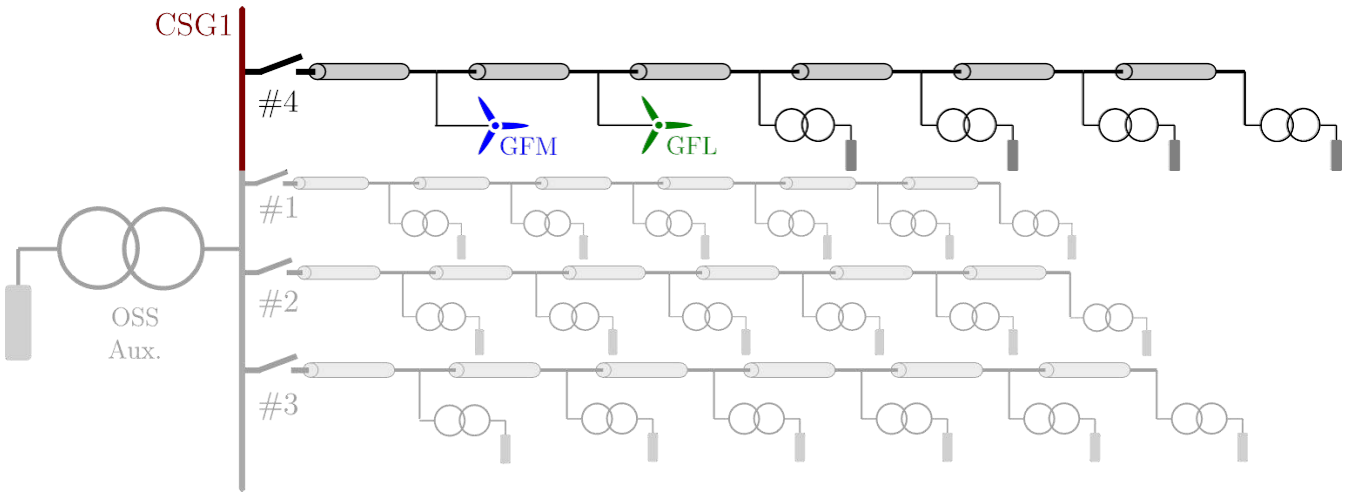
Fast synch vs

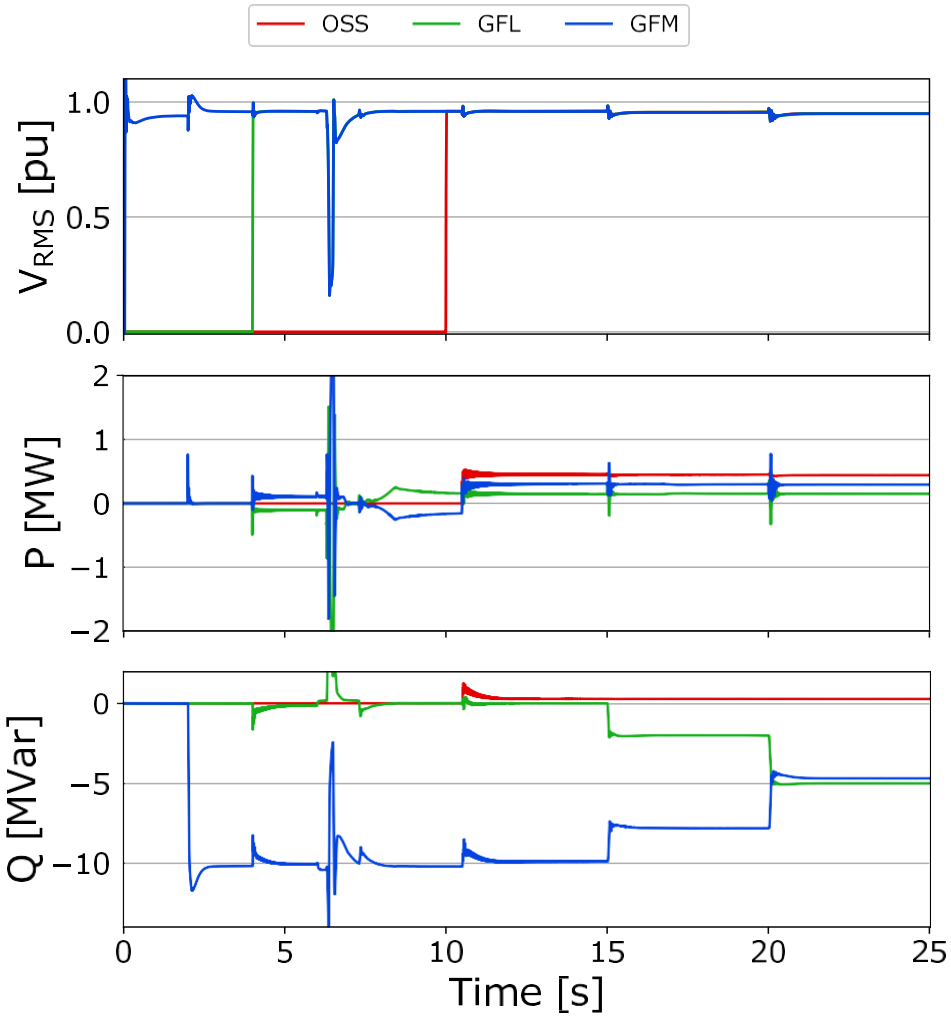
LoS



TS-3

GFL instead





$k_{P\theta} = 0$ Weak grid PLL

Tradeoff

Contributions

- ✓WTGs can control offshore voltage & frequency
  - Grid forming control
- ✓Grid forming controls differ in their transient response during energization
  - Multi-machine system tuning, GC requirements
- ✓WTGs can deal with network energization transients
  - Reserve, Virtual resistance, Soft-start
- ✓WTGs can maintain synchronised parallel operation
  - Transient instability (weak grid)
- ✓WTGs can emulate a voltage source and operate a stable offshore power island
  - Mix of GFM & GFL

Publications

"Grid-forming control strategies for black start by offshore wind power plants", in Wind Energy Science (EAWE), 2020. DOI: 10.5194/wes-5-1297-2020

"Blackstart from HVDCconnected offshore wind: Hard versus soft energization", in IET Renewable Power Generation (Wiley), 2021. DOI: 10.1049/rpg2.12010

"Virtual Resistance Control for Sequential Green-start of Offshore Wind Power Plants", under review in IEEE Trans. Sustainable Energy, 2021.

"Control Solutions for Blackstart Capability and Islanding Operation of Offshore Wind Power Plants", in proc. 17th International Wind Integration Workshop, 2018. DOI: 10.5281/zenodo.3269542

"Functional Requirements for Blackstart and Power System Restoration from Wind Power Plants", in proc. 2nd International Conference on Large-scale Grid Integration of Renewable Energy in India, 2019. DOI: 10.5281/zenodo.3460518

"Black Start by HVdc-connected Offshore Wind Power Plants", in proc. 45th Annual Conference of the IEEE Industrial Electronics Society (IECON), 2019. DOI: 10.1049/rpg2.12010

ACKNOWLEDGEMENTS

Thank You

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