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Modeling and analysis of modern power systems including DVPPs

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with support from Edu Prieto, Marc Cheah, Jie Song, Carlos Collados, Vinicius Lacerda, Saman Dadjo, Josep Fanals, Josep Arévalo, Jaume Girona and all colleagues from the AC/DC grids group in CITCEA-UPC and eRoots

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Related to POSYTYF – WP1

WP1

Scenario definition, system modelling & specifications for RES-based DVPP

Task 1.1 Scenario definition	Task 1.2 General system design	Task 1.3 Specification definition for actual and future scenarios
Task 1.4 Role assignment	Task 1.5 Modelling guidelines EMT/Phasor simulation	Task 1.6 Co-simulation

Agenda

Low-inertia power systems

DVPP Grid services / Renewable power plants and loads

Conclusions

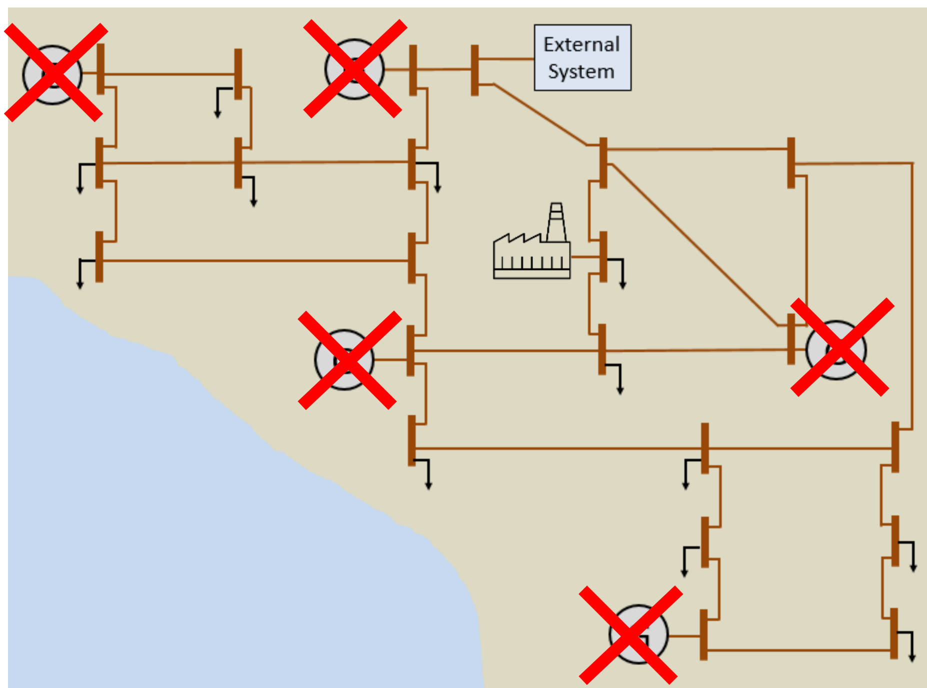
Low-inertia power systems

DVPP Grid services / Renewable power plants and loads

Conclusions

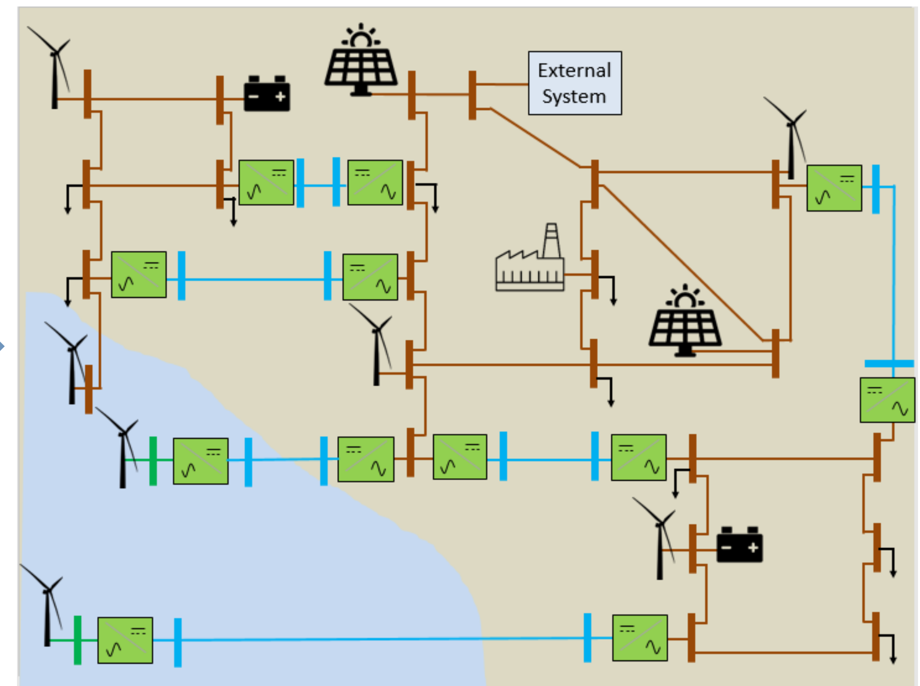
The network transition

Conventional network



AC network · Classic generation · System loads

Modern network



AC network · PV generation · Wind generation

DC network · Energy storage · Power electronics

Power electronics in power systems

Increasingly present in…

- Renewables (Wind, PV, Ocean, some hydro, …)
- FACTS / Energy storage / HVDC
- Electric vehicle / Industrial loads

Main features

- Full controllability / Fast dynamics possible
- Very limited overload capability
- Very limited inertia

Challenges due to the nature of power electronics

- Control interactions & stability? Inertia? Grid forming / following converters? Converter synchronization?
- Protections?
- Level of possible integration?

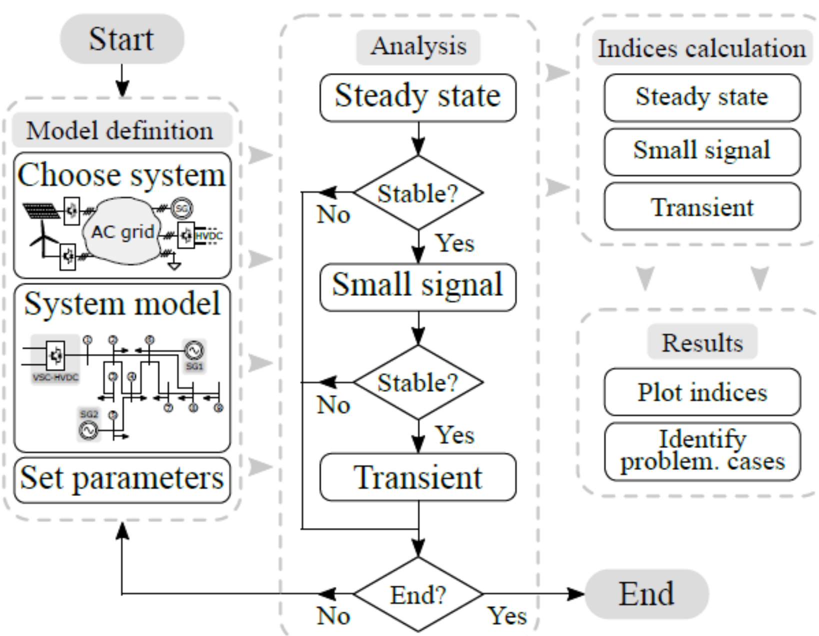
Research challenges – Systems dominated by converters

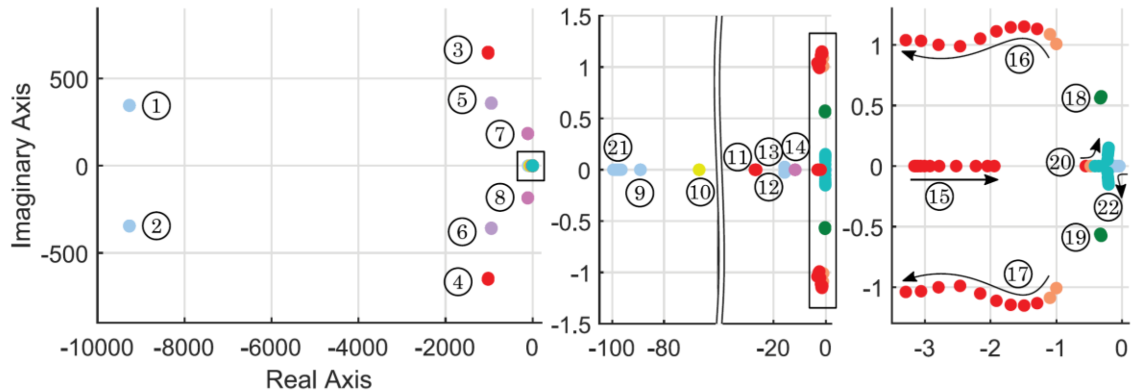
Some open questions:

- The system has low inertia, is there a problem? Can we control the frequency in low-inertia systems with fast converter control? The fast ones take the hard work → Coordination needed.
- Grid forming or grid following converters:
  - Should we move to 100 % grid forming (voltage source behaviour)?
  - Can we combine inside wind or solar power plants? What proportion?
  - Where do we need to locate grid forming?
  - Where is the limit?
- We need grid-forming converter to provide synchronization and form the grid, but do grid-forming converters need to provide inertia? In other words, should there be a requirement of “synthetic inertia”?
- What is the meaning of frequency? How it will change? Do we want to change it?

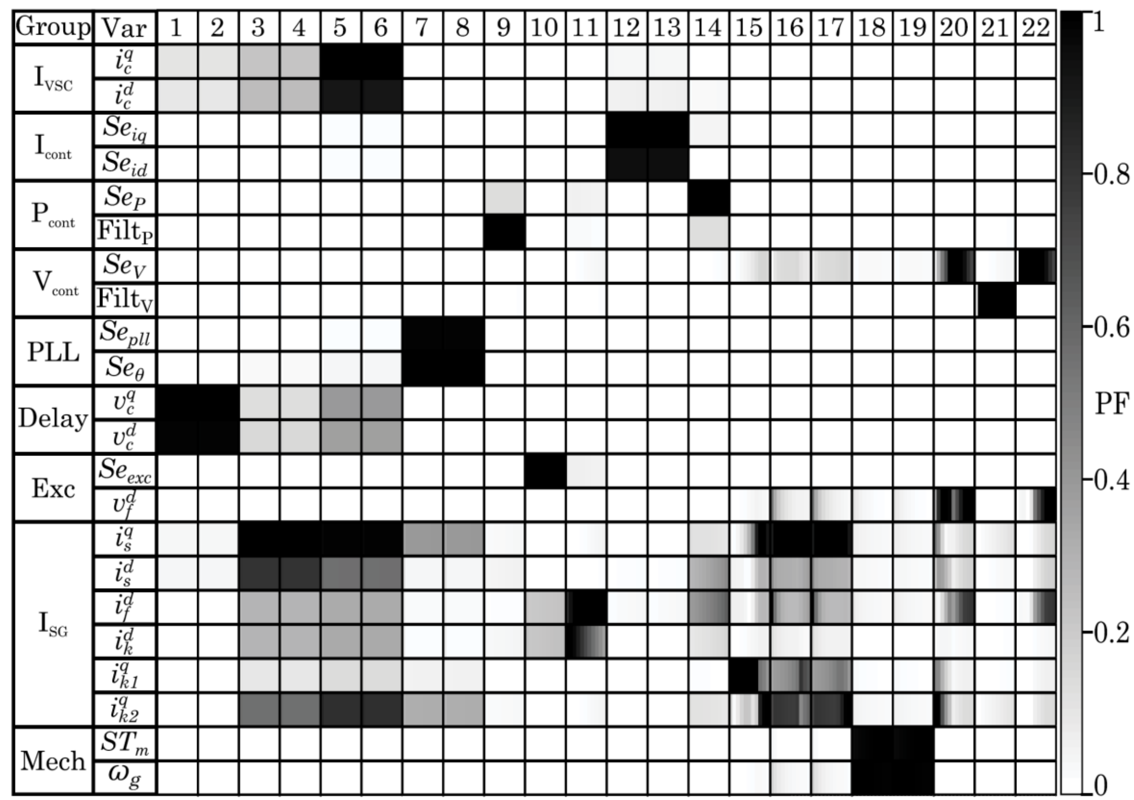
Examples studies

- Root-causes of instability?
- Consideration of different control schemes and settings
- Index-based methodology
- Consideration of different power flows
- Steady-state, small signal and transient analysis



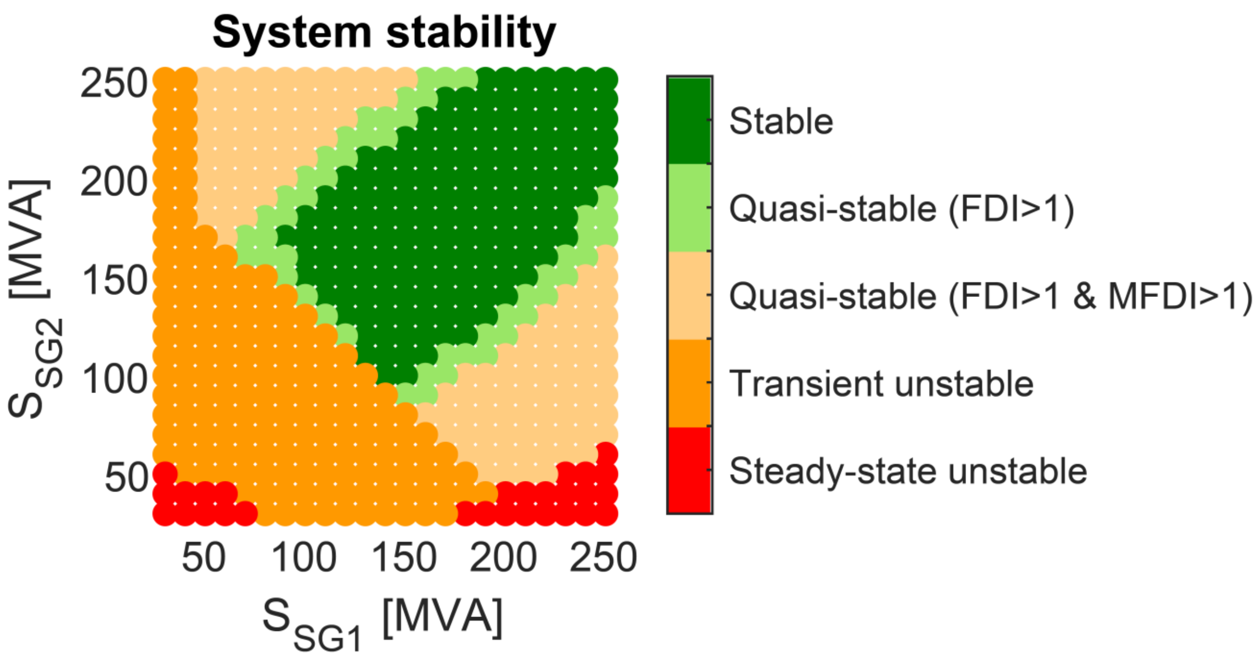


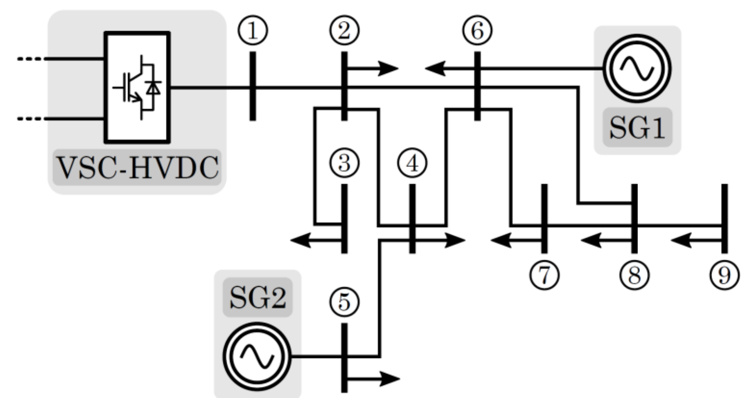
(a)

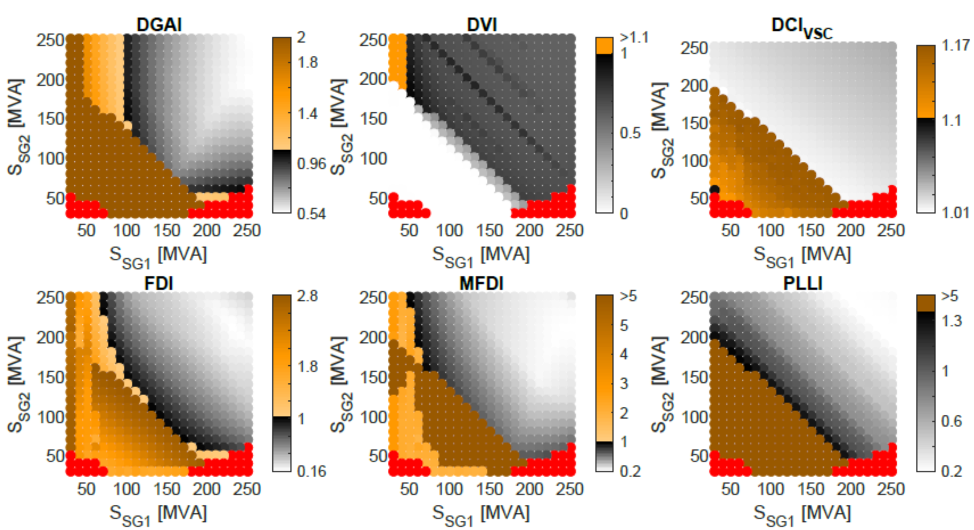


(b)

Stability Analysis of Systems With High VSC Penetration: Where Is the Limit?, IEEE Trans PWRD 2020







Dynamic Generator Angle Index (DGAI)
Dynamic Voltage Index (DVI)
Dynamic Current Index (DCI)
Frequency Derivative Index (FDI)
Maximum Frequency Deviation Index (MFDI)
PLL Index (PLLI)

Research challenges – converter saturation

Specific converter characteristics:

- Overload limitation (Current saturation, voltage → current source behavior)
- High controllability (Great adaptability, but potential interactions)

Understanding short-circuits (complex with interacting converter controllers during the fault). New methods required combining:

- Converter saturations / current source behavior
- Grid support schemes in the converters

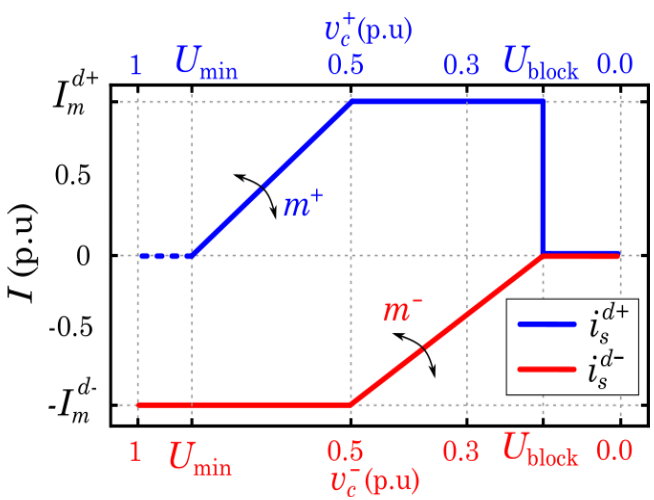
Short-circuit calculations

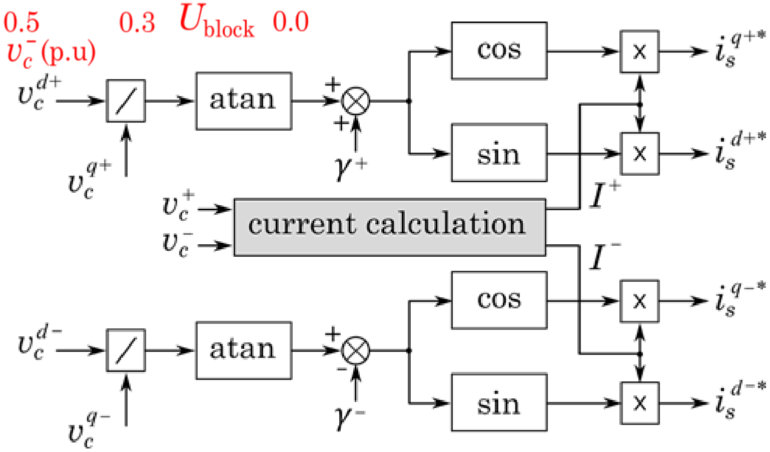
- What grid equivalents can we use? New approaches needed!
- What is the meaning of short-circuit power and short-circuit ratio in power electronics dominated power systems?

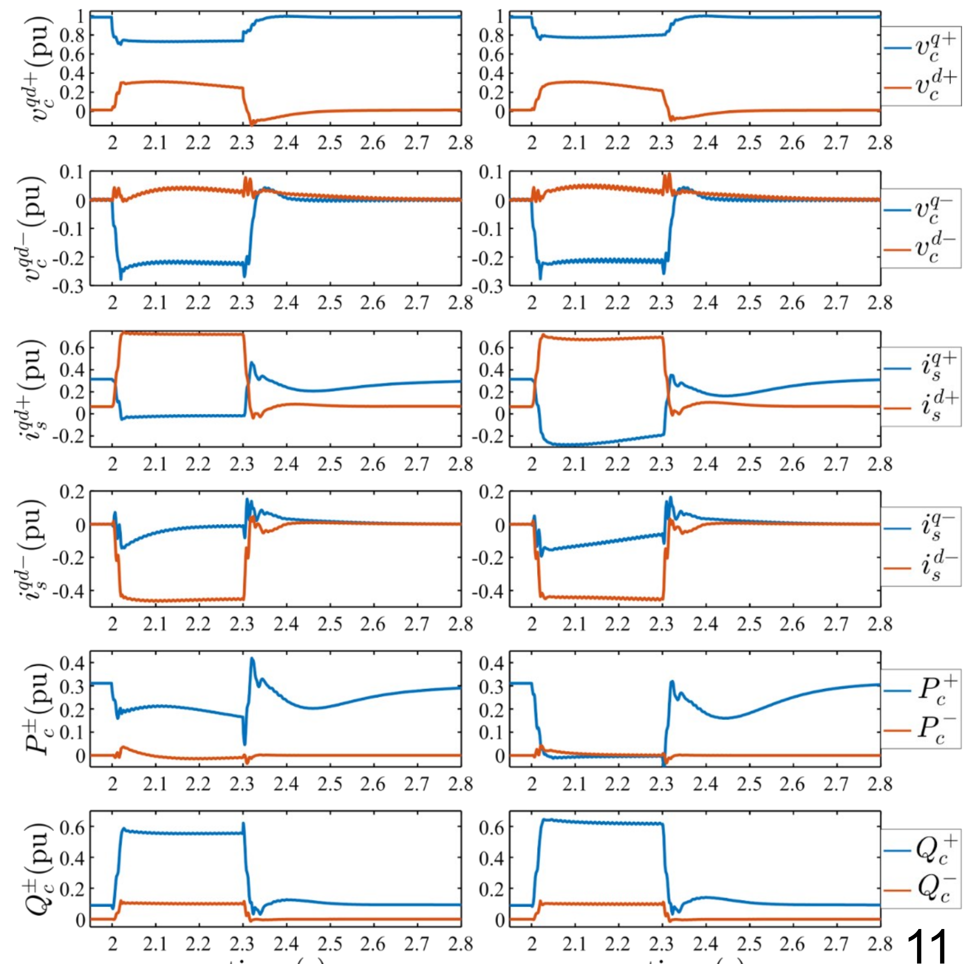
Research challenges: **Fault ride-through**

Understanding short-circuits (complex with interacting converter controllers during the fault). New methods required combining:

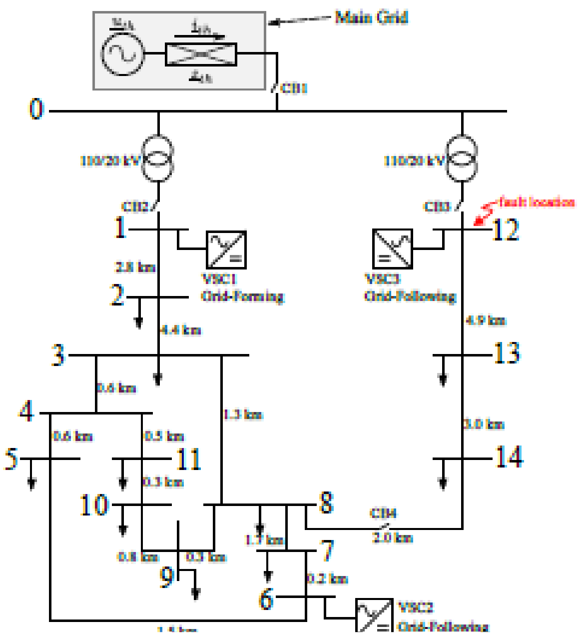
- Converter saturations / current source behavior
- Grid support schemes in the converters + Fault ride-through
- Balanced / unbalanced faults

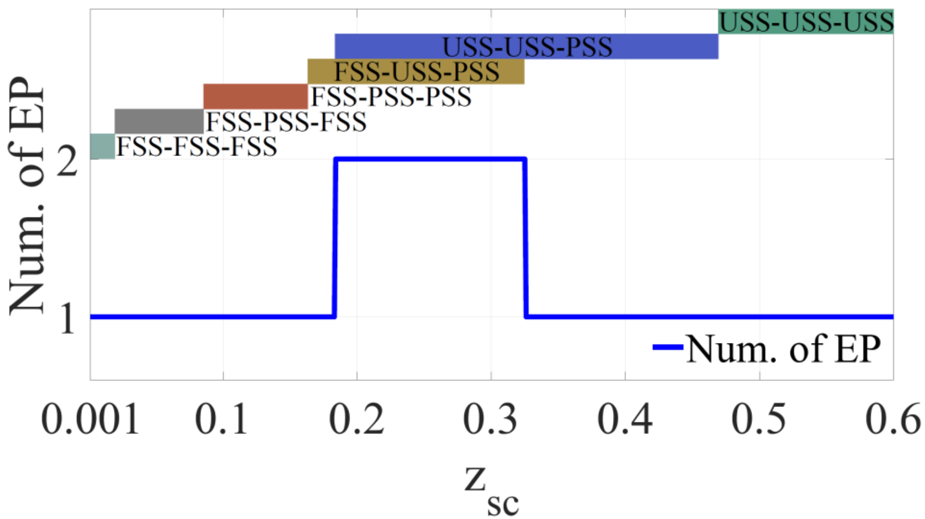


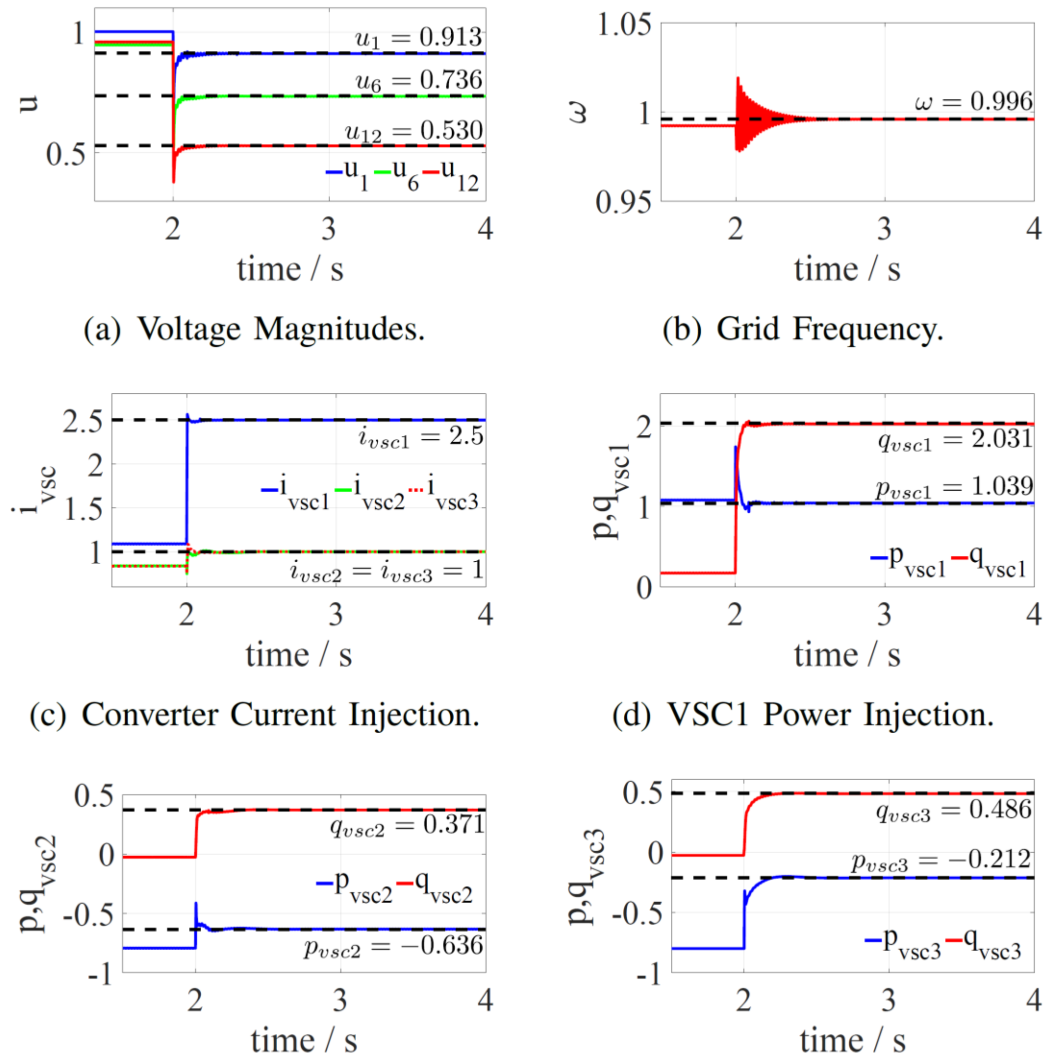




Research challenges: **Shortcircuit calculation**







(a) Voltage Magnitudes.

(b) Grid Frequency.

(c) Converter Current Injection.

(d) VSC1 Power Injection.

(e) VSC2 Power Injection.

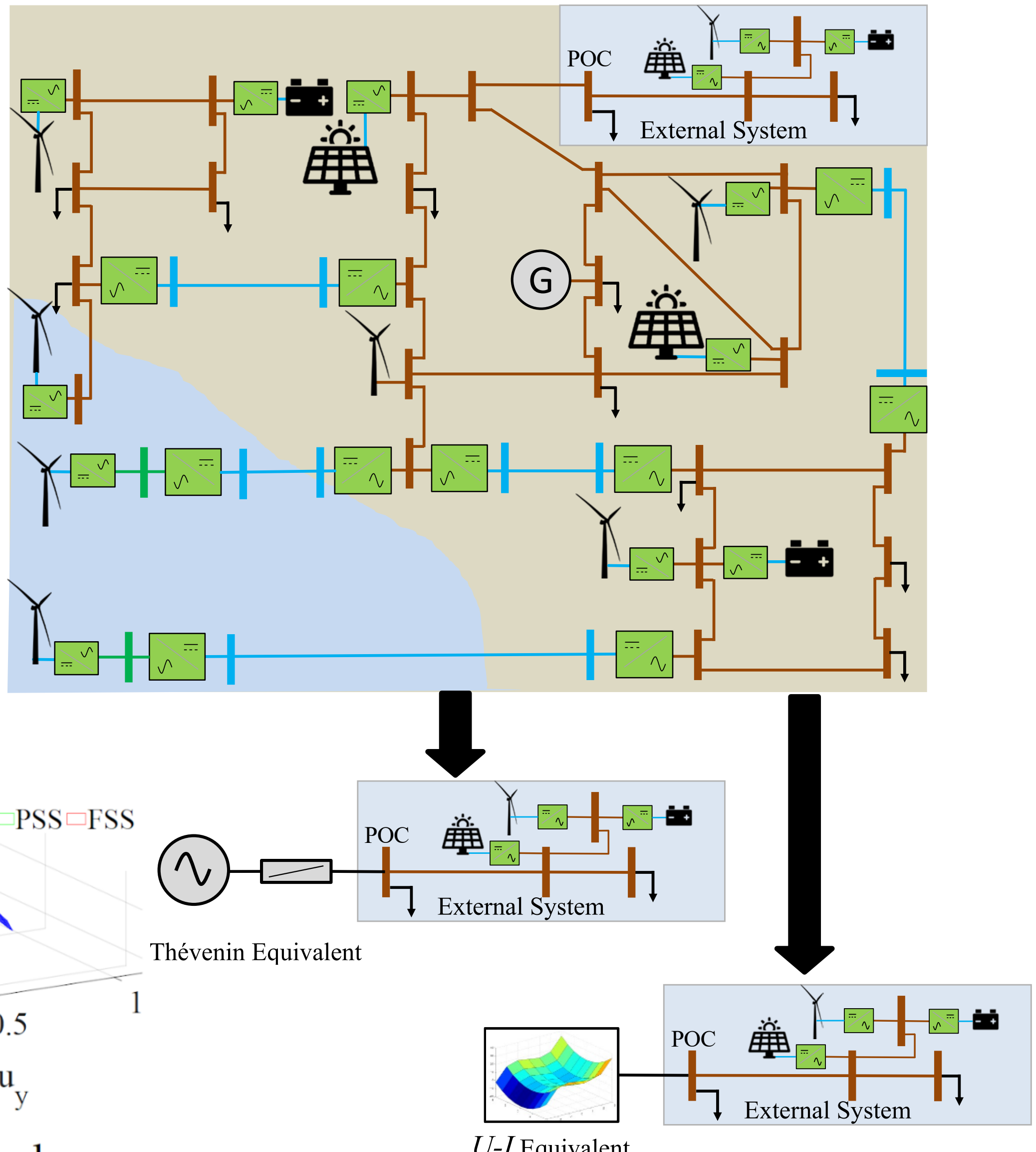
(f) VSC3 Power Injection.

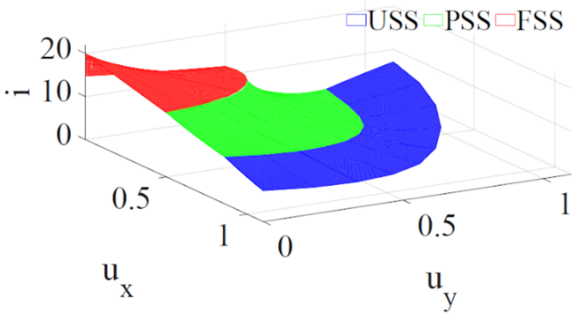
Short-Circuit Analysis of AC Distribution Systems Dominated by Voltage Source Converters Considering Converter Limitations IEEE Trans Smart Grid 2021

Research challenges: **Grid equivalents**

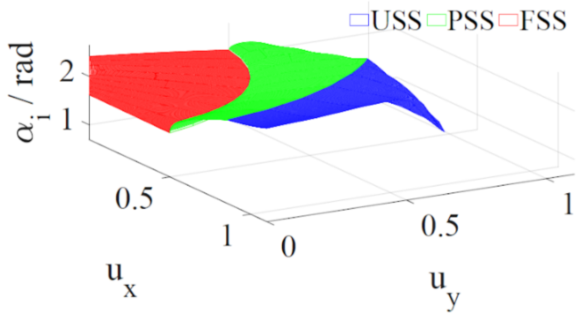
Grid equivalents for power systems dominated by power electronics

- What is the meaning of short-circuit power in modern power systems?
- Thevenin equivalent needs to be redefined, as it does not capture the saturation of converters.
- Voltage to current maps?





(a) Output current magnitude



(b) Output current angle

Low-inertia power systems

DVPP Grid services / Renewable power plants and loads

Conclusions

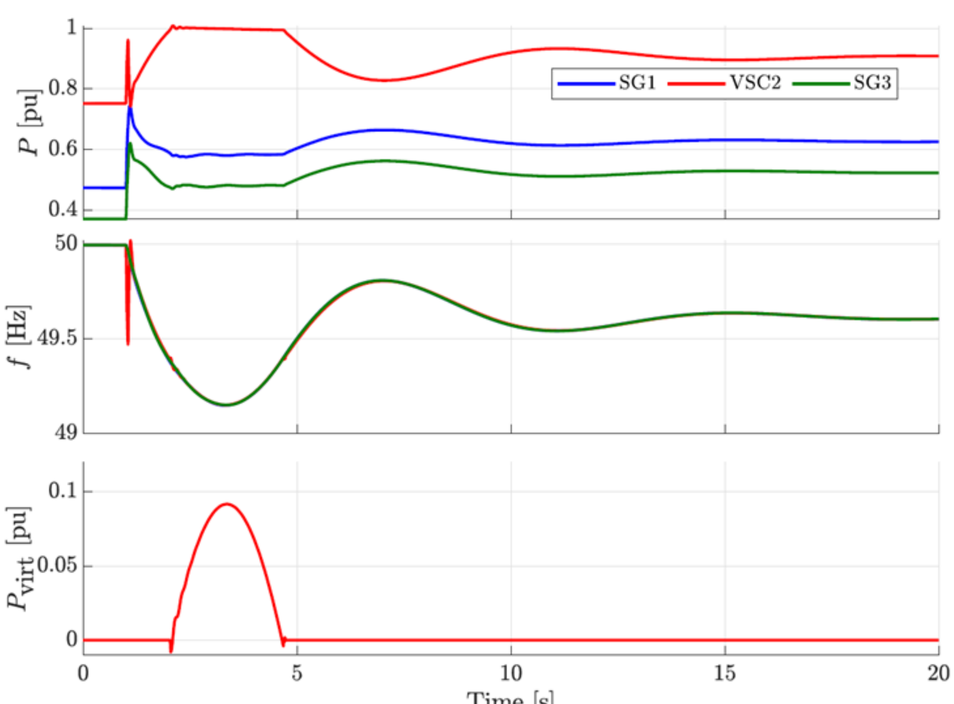
Grid forming converters

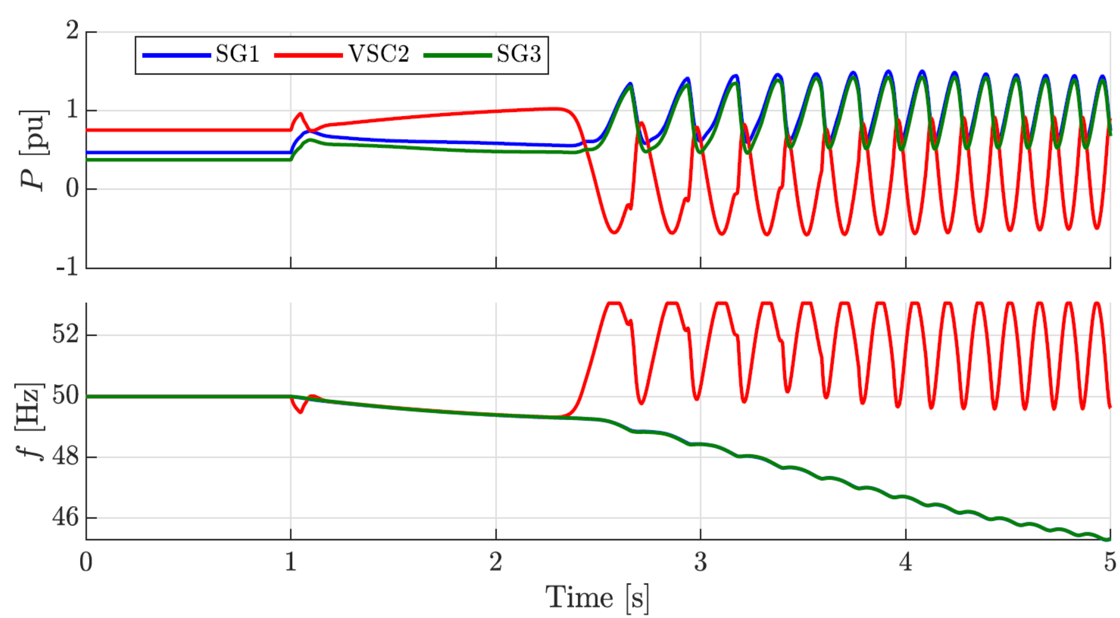
Grid forming converters increasingly needed

Challenges on how to handle limits! (current, voltage, power)

Grid forming fault ride-through

Converters may be operating at maximum operating point or very close to it. What to do when the grid-forming demands more power than the available? Some solutions exist, but are they "true" grid forming?





Renewable power plants

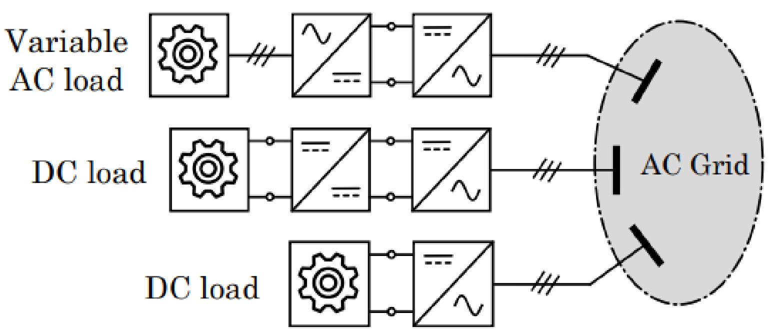
- Provide multiple services, including grid-forming and black-start
- Grid-forming control with resource limitation – what to do when we exceed the resource available and the GF demands more power?
- System resiliency provision by allowing islanded operation and resynchronization
- (Fast) frequency control and inertia provision (if needed)
- Voltage control
- Power oscillation damping
- Dynamic Virtual Power Plants
- Integration with energy storage systems and loads (H2 electrolyzers, EV chargers, …)

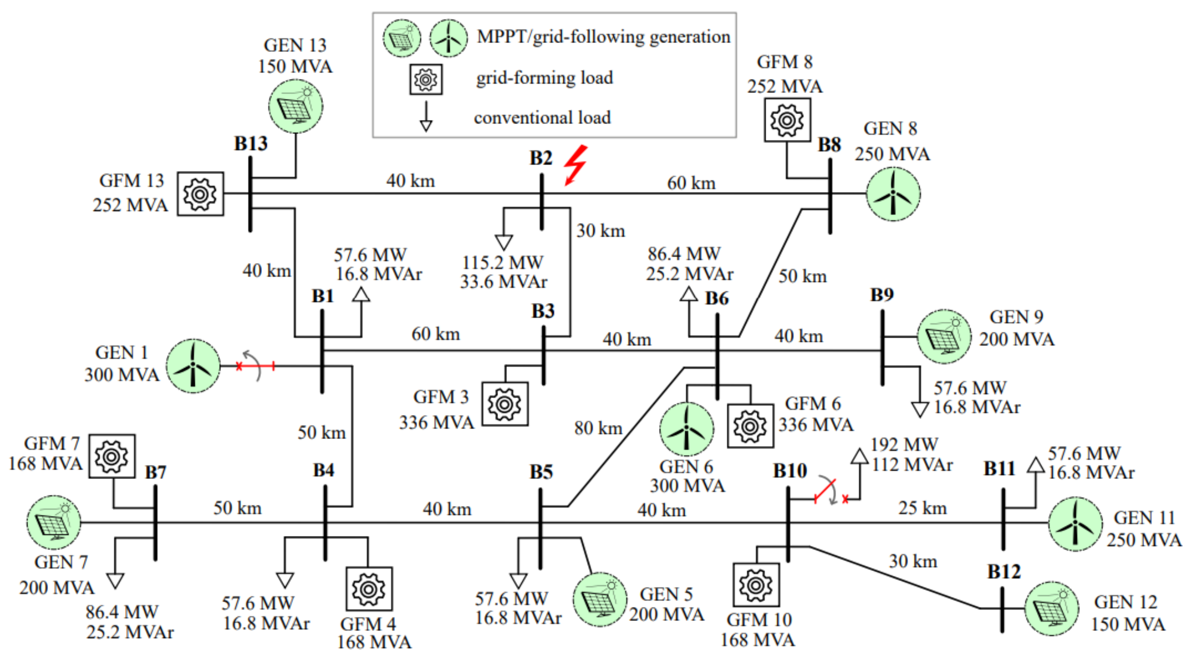
Grid forming loads

Should we implement grid-forming loads and grid-following generators?

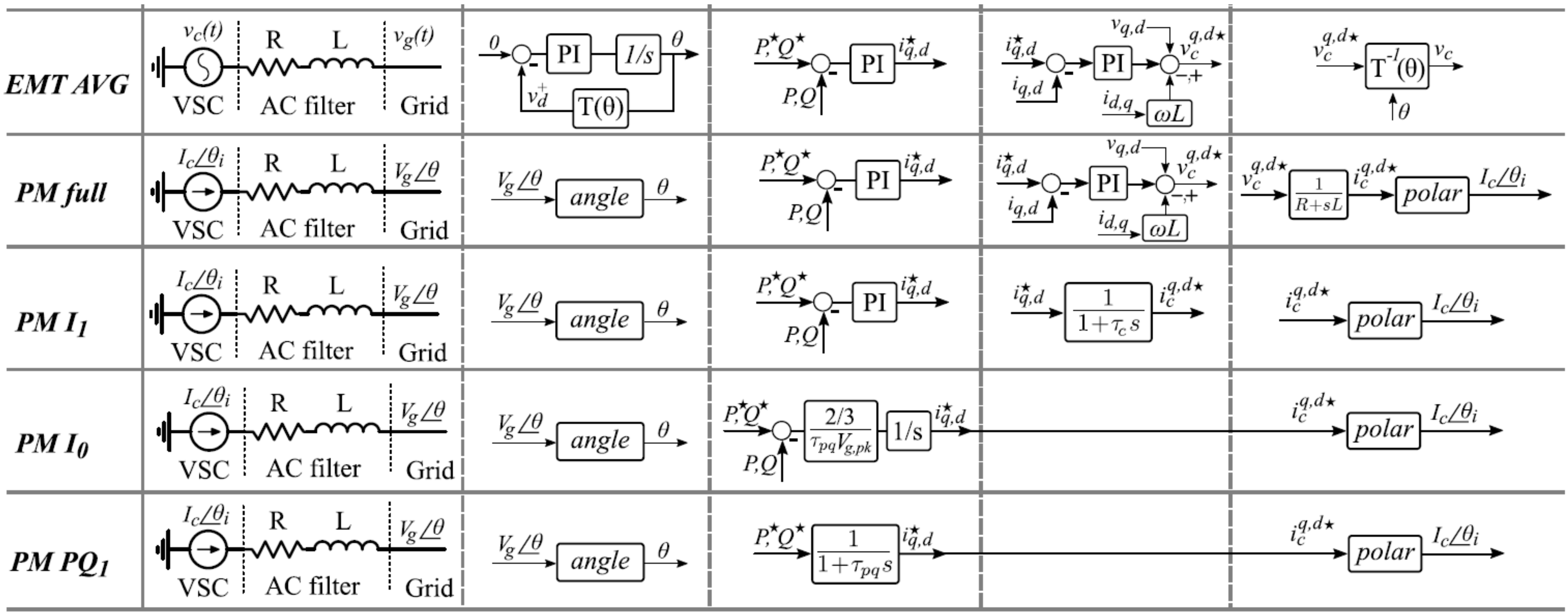
Potential change of paradigm in future power systems:

- Current operators operate mainly generation with some demand management
- Future operators might operate mainly loads with some generation management





Research challenges: **Tools for simulation and analysis?**

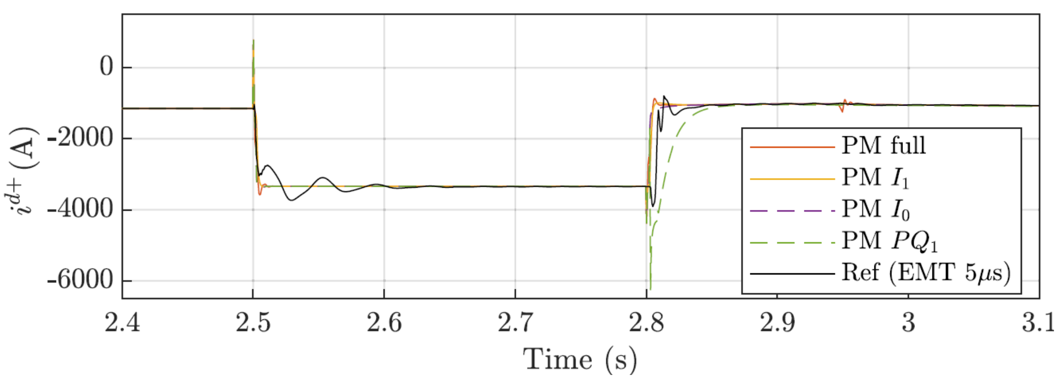


Cosimulation?
Dynamic phasors?
Multilinear approach?

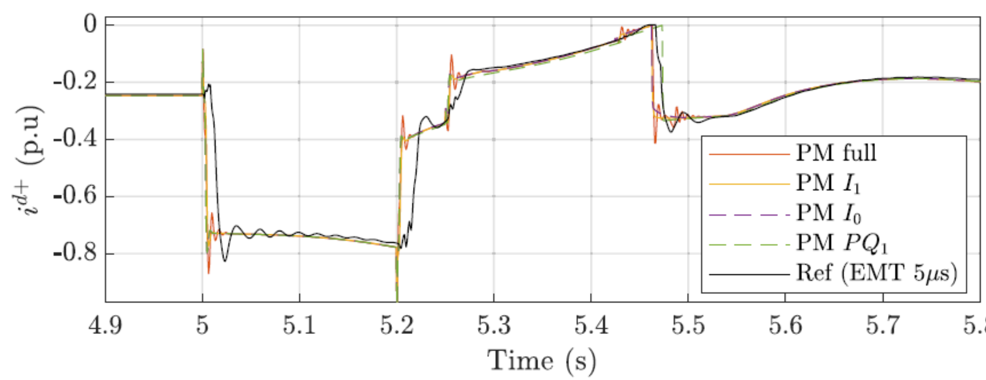
Phasor Modelling Approaches and Simulation Guidelines of Voltage-Source Converters in Grid-Integration Studies, IEEE Access, 2022.

Research challenges: **Tools for simulation and analysis?**

- Full-waveform EMT Simulation models of grids dominated by converters can become unfeasible depending on the size of the grid.
- Phasor models can provide reasonable results for low-frequency events.
- Dynamic phasors or even full EMT simulation are current options for studies with high-frequency components.
- New opportunity for intermediate methods, that are precise for a few kHz range but more efficient than full-waveform EMT (trade-off between precision and computational requirements).



Test 3 – i^{d+} simulated by each model at 600 μs.



Test 3 CIGRE system – VSC 1 i^{d+} simulated by each model at 850 μs.

Phasor Modelling Approaches and Simulation Guidelines of Voltage-Source Converters in Grid-Integration Studies, IEEE Access, 2022.

Low-inertia power systems

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Conclusions

Conclusions

- Low-inertia power systems are raising several challenges that need to be address to shape future power systems.
- European grid is already a hybrid AC/DC power system which will increase its complexity.
- Renewable power plants need to provide additional services including grid-forming operation.
- More active loads can contribute in several services.
- Dynamic VPP can enhance these services by appropriately aggregating and distributing them
- Important challenges in modeling and simulation
- Many challenges and opportunities for research!

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