Workshop « Digitalisation, protection et stabilité des réseaux »

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Référent scientifique ADEME :
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Power Inverter Control for Low-Frequency Oscillations Damping

12/06/2025

SUMMARY

G2Elab Grenoble Génie Électrique Grenoble Electrical Engineering

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ADEME AGENCE DE LA TRANSITION ÉCOLOGIQUE

Introduction (1/3)
General context and challenges

Massive integration of Inverter-Based Resources (IBR) in power systems

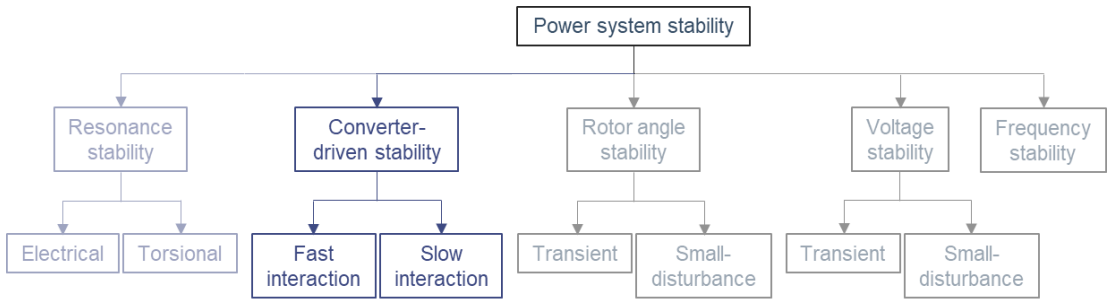
Challenges:

- Impact on power systems oscillatory behavior → case-specific

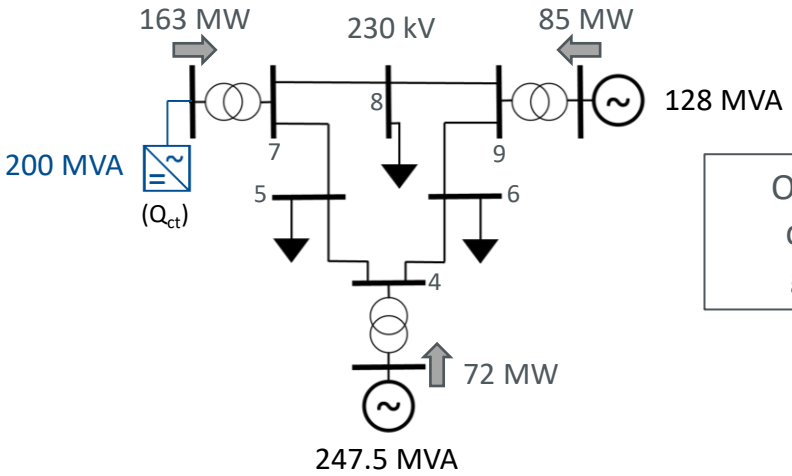
  European grid codes require:

  - IBRs not to worsen **system dynamics** → not to excite any existing **oscillatory mode**
  - TSO may require IBRs to include Power Oscillation Damping (POD) control

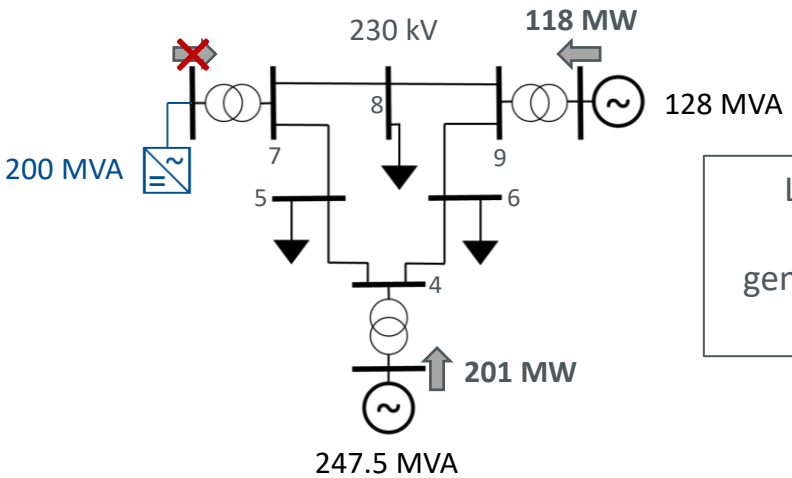
- Rapid and slow **dynamics of power systems** may not be decoupled anymore



Introduction (2/3)
Low-frequency oscillations (LFO) in power systems



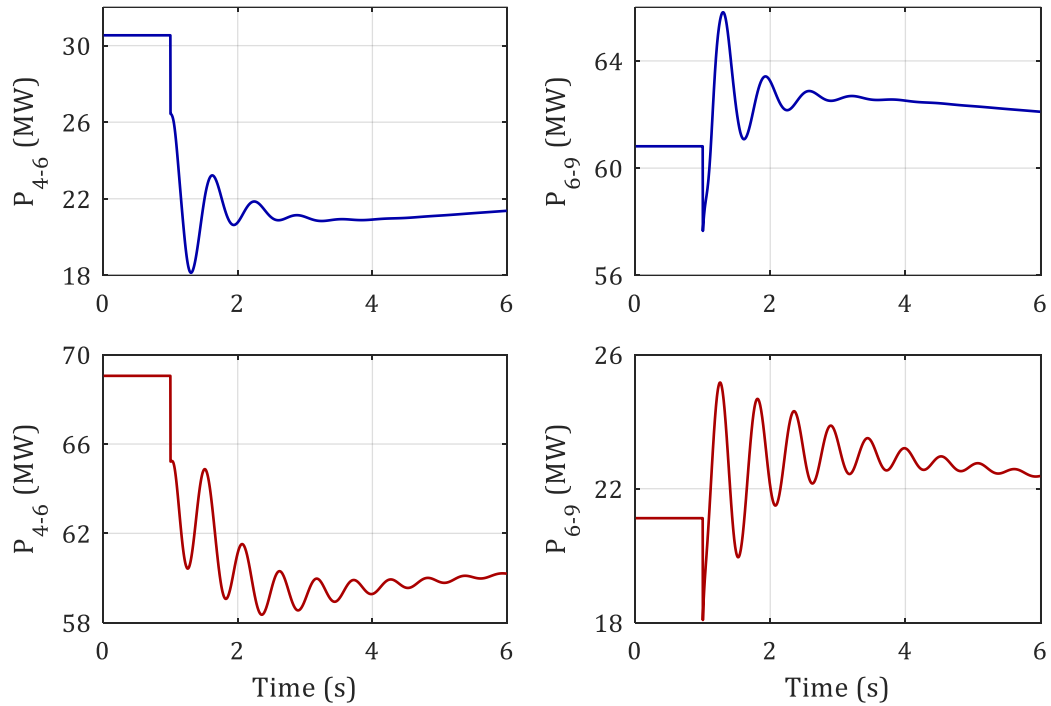
Original operating point → difference: nature of one generation unit (↓H_{total})



Load transfer from IBR to remaining synchronous generators (voltages & loading of equipment OK)

Active power transfer through lines between synchronous generators

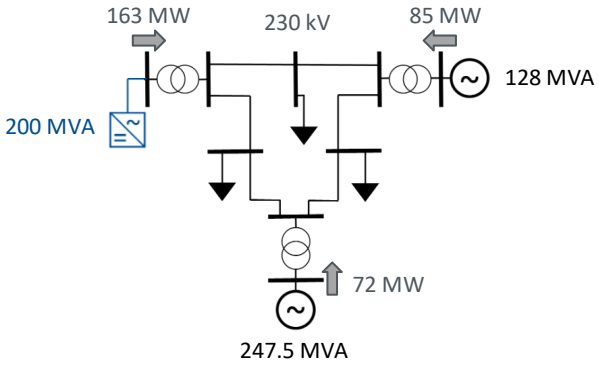
Event: load decrease of 10 %

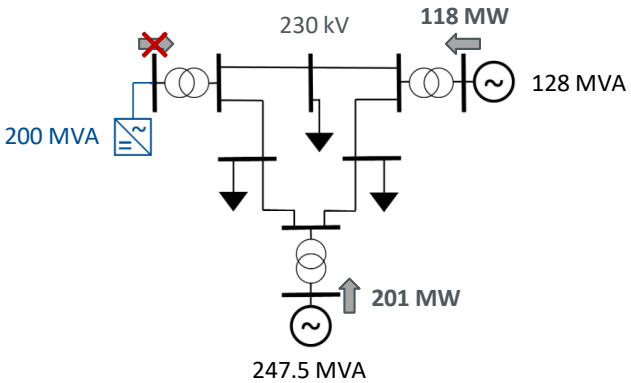


System behavior deteriorated

[11] EPRI, 'Model User Guide for Generic Renewable Energy System Models', 2023.

Introduction (3/3)
Approach and objective





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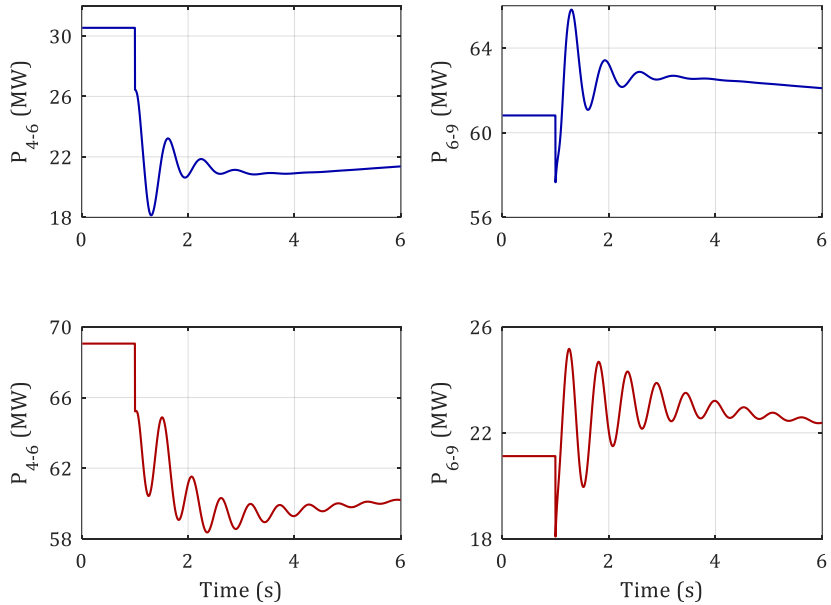
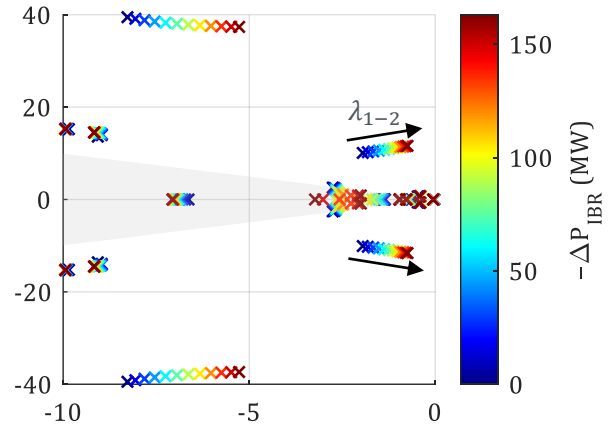


Modal analysis



λ_{1-2}	Damping ratio ζ (%)	Frequency (Hz)
Initial	19.0	1.6
Final	6.4	1.8

Participation factors → Nature of λ_{1-2}: electromechanical oscillations of synchronous generators (poorly damped in the final scenario)

The system is operating closer to the small-signal stability limit

Objective: improve system behavior, increasing its small-signal stability margin

Solution - Damping or stabilizing control

SG: Synchronous Generator
PSS: Power System Stabilizer
RES: Renewable Energy Source

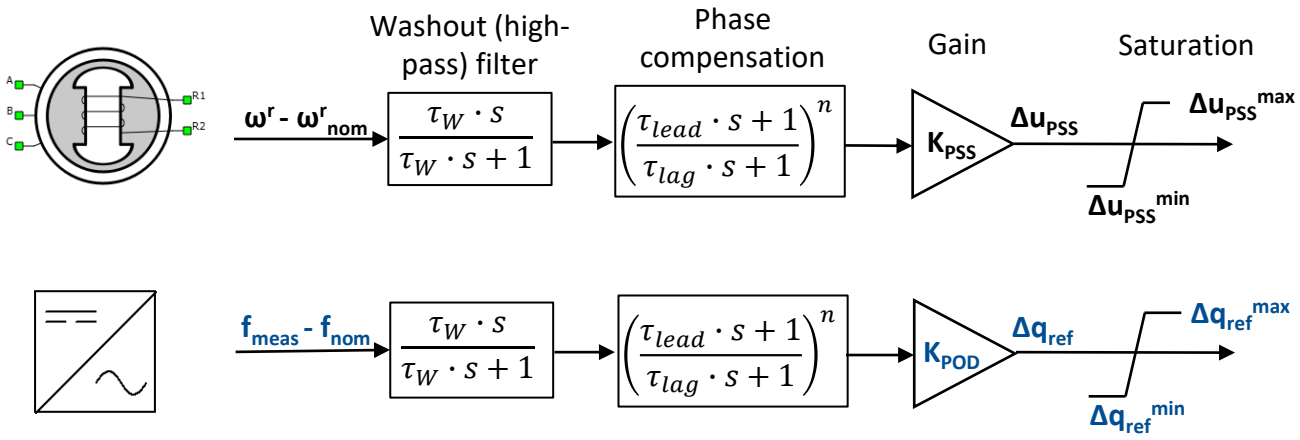
Equipment	Control
SG	PSS
Inverter	POD (HVDC & FACTS)
	POD (RES & storage)

PAST
PRESENT
FUTURE

State-of-the-art POD (RES & storage)

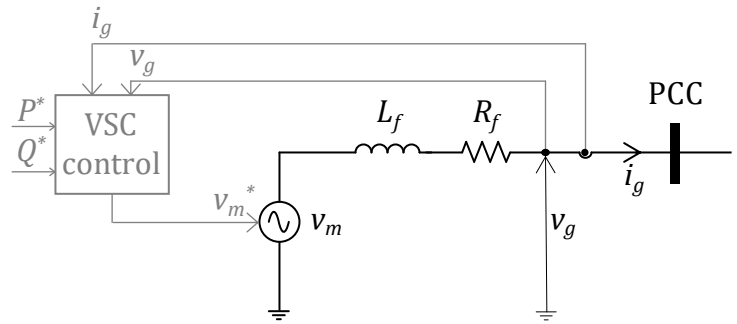
- **Grid-following** (GFL) or grid-forming (GFM)
- Modification of power reference: P* and/or **Q***
- Input signal: **local** or remote measurement
- Adaptative or **non-adaptative** tuning
- State representation: estimation or **conventional calculation**

PSS and **POD** topology:

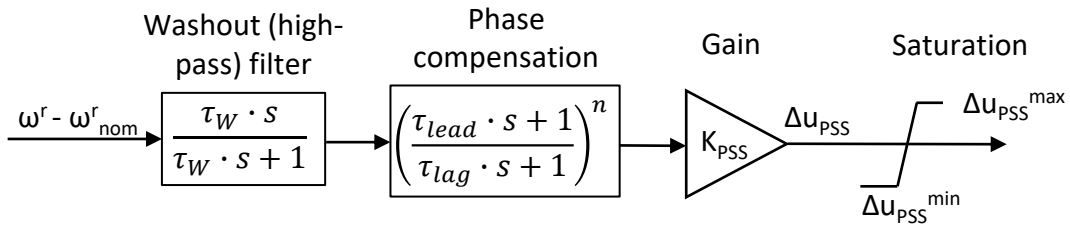


Tuning based on modal analysis

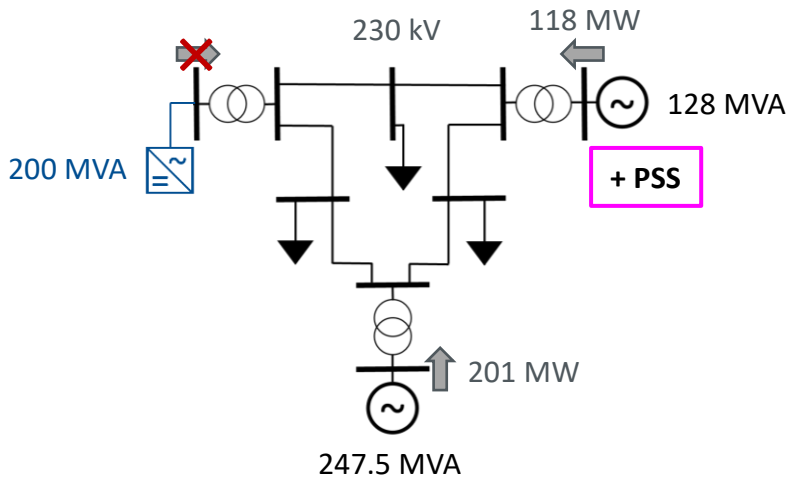
1. Phase compensation
2. Lead filter parameters

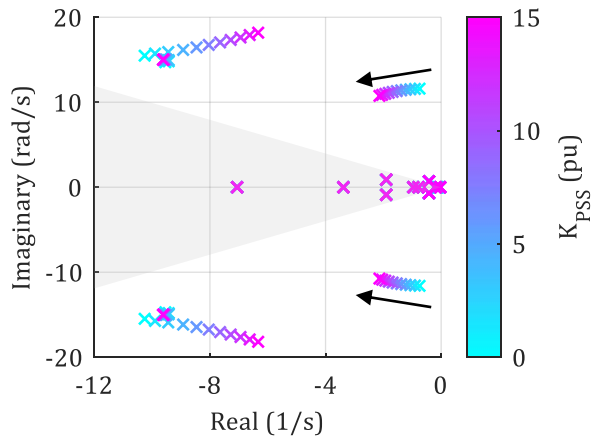


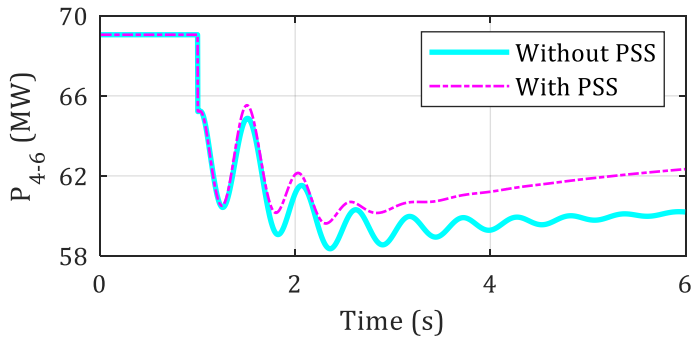
Results (1/3)
Traditional solution: PSS

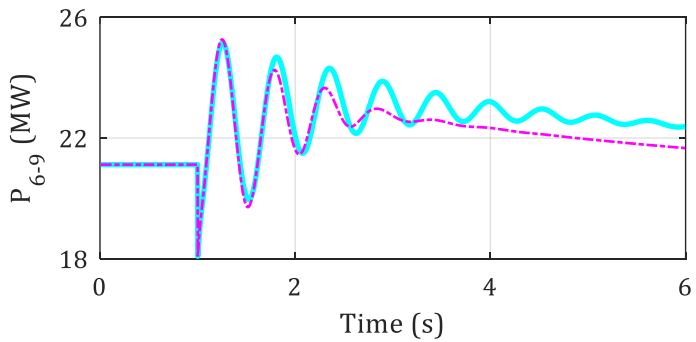


PSS parameters	
$\tau_{HPF}(s)$	10
K_{PSS} (pu)	**15**
τ_{lead} (s)	0.2179
τ_{lag} (s)	0.0342
n	3
$\pm u_{PSS}$ (pu)	0.1

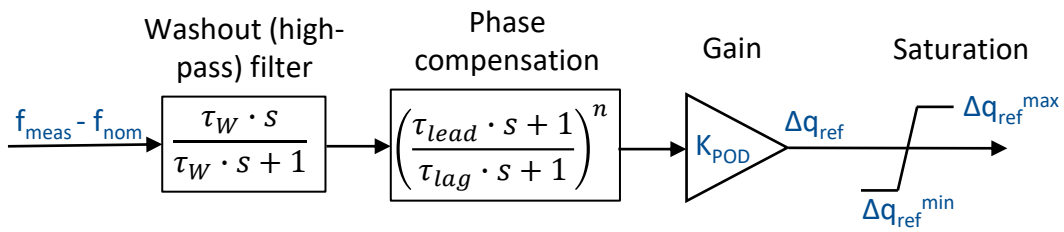




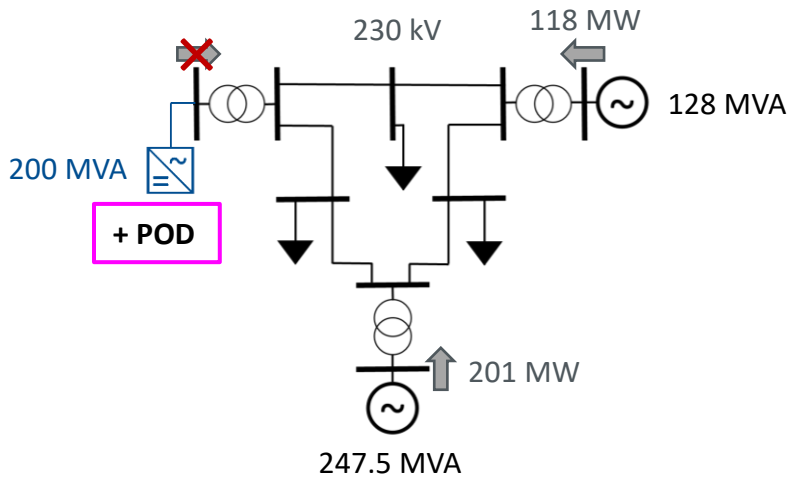


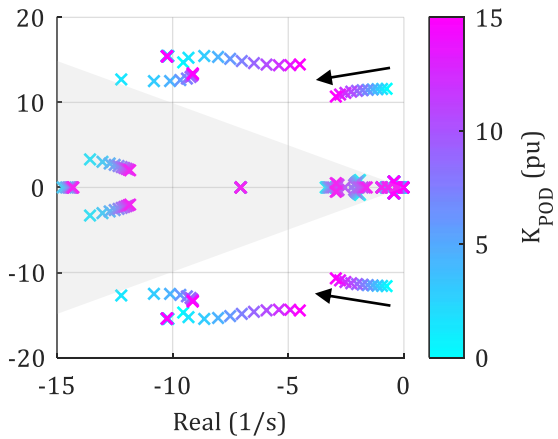


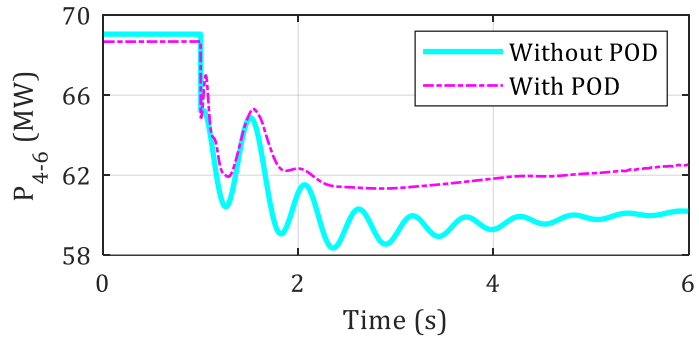
Results (2/3)
State-of-the-art solution: POD

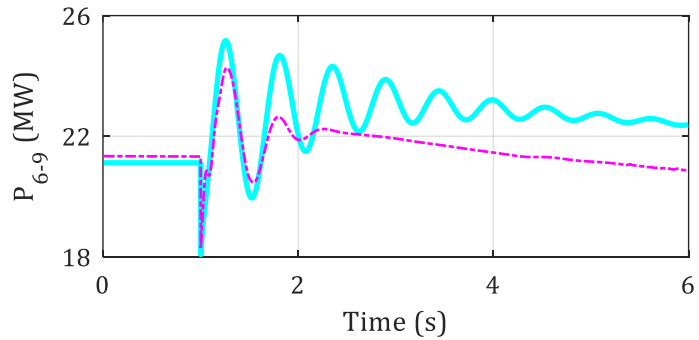


POD parameters	
$\tau_{HPF}(s)$	10
K_{POD} (pu)	**15**
τ_{lead} (s)	0.1960
τ_{lag} (s)	0.0379
n	2
$\pm u_{POD}$ (pu)	0.1









Results (2/3)
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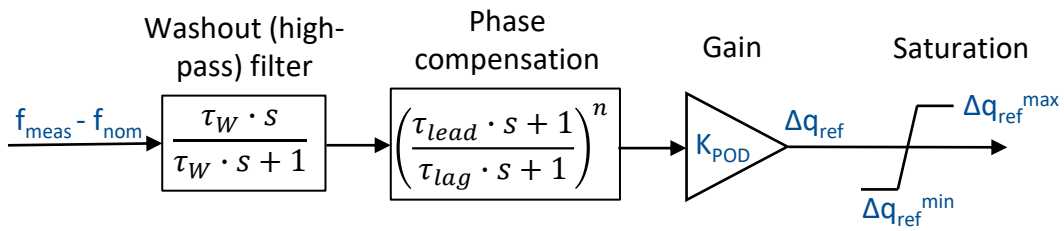

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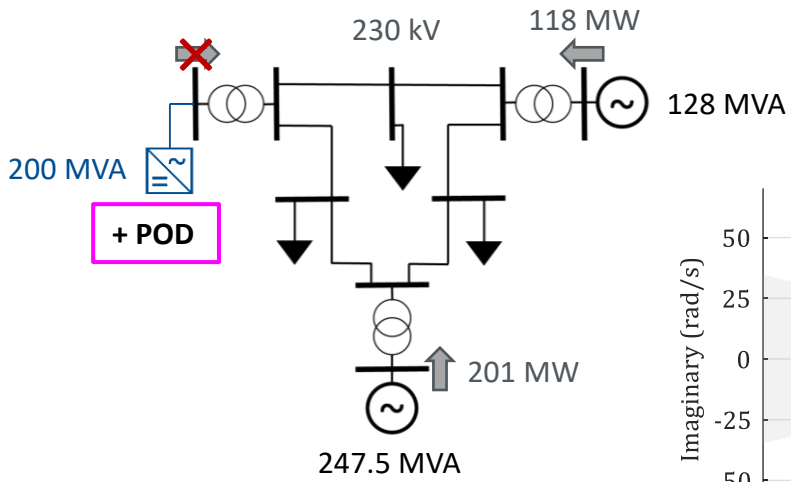
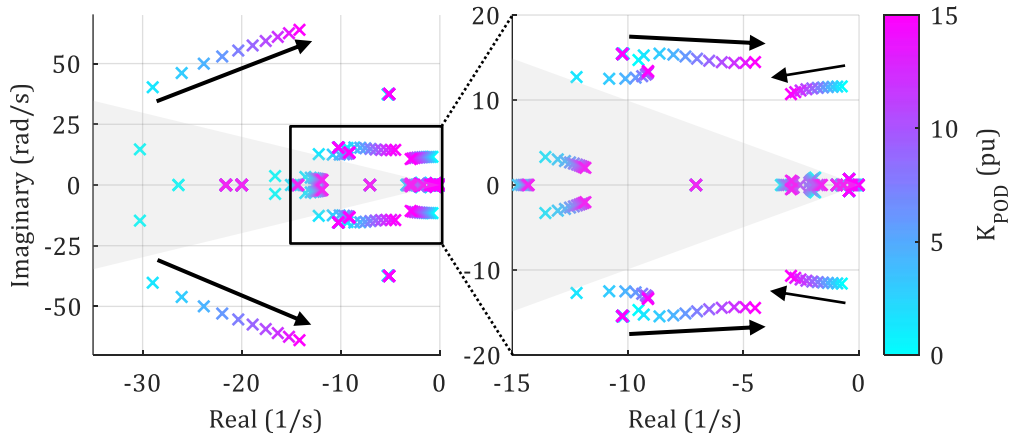
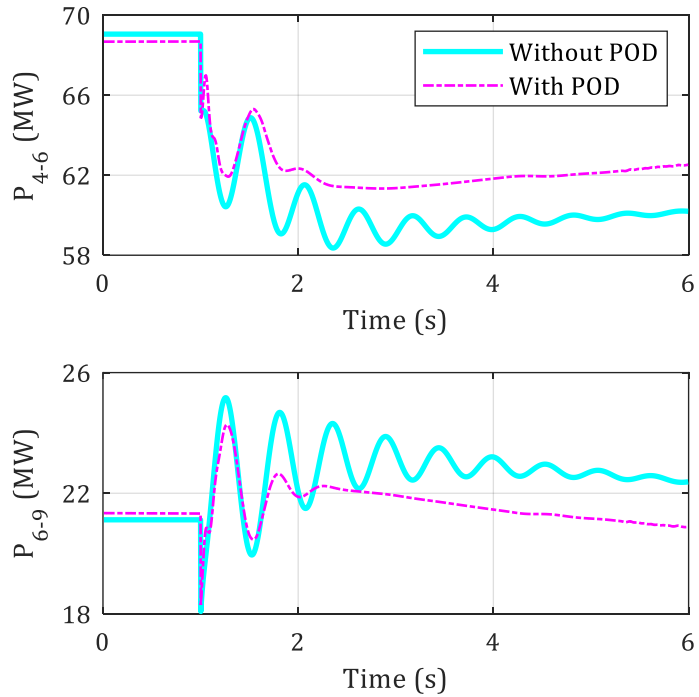
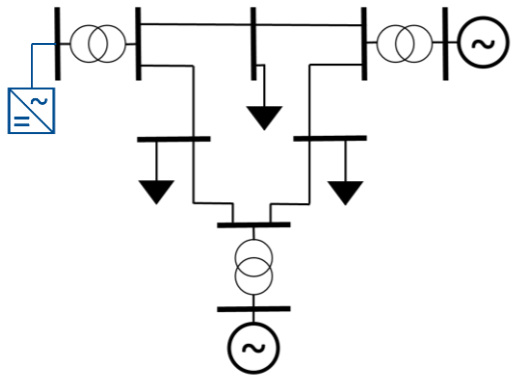






Results (3/3)
Overview

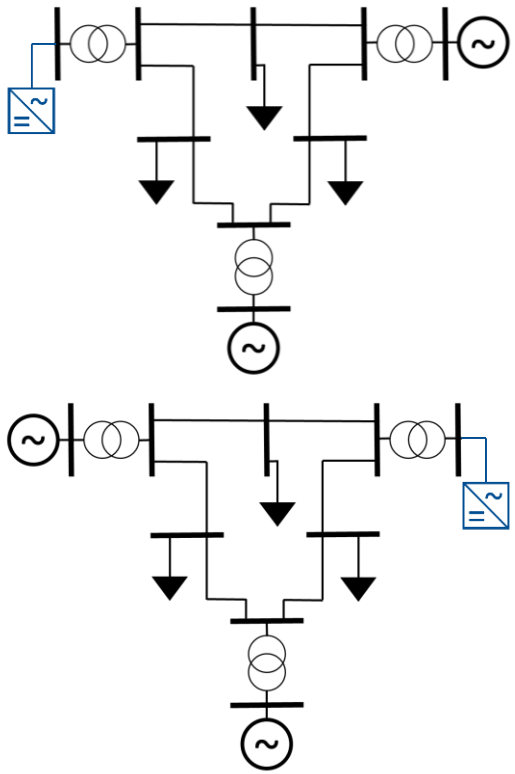


GFL-POD in generation bus

- **Result 1: GFL-POD capable of providing similar damping to SG-PSS** ----> [1]

[1] Marta Gomis-Domènech, Thai Phuong Do, and Raphaël Caire, « Contribution to power oscillations damping of inverter based resources », in CIRED Vienna Workshop 2024: Increasing Distribution Network Hosting Capacity, juin 2024.

Results (3/3)
Overview



GFL-POD in generation bus

- **Result 1: GFL-POD capable of providing similar damping to SG-PSS** [1]
- Result 2: **GFL-POD robustness** to load condition; inverter location, capacity, actual generation
- Result 3: Combined action of **GFL-POD and SG-PSS** [2]

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[2] Marta Gomis-Domènech, Thai Phuong Do, and Raphaël Caire, « Performance of IBR Power Oscillations Damper according to power system operating conditions », in 2024 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE), oct. 2024.

Results (3/3)
Overview

Simplifications:
- Network dynamics
- SG stator flux

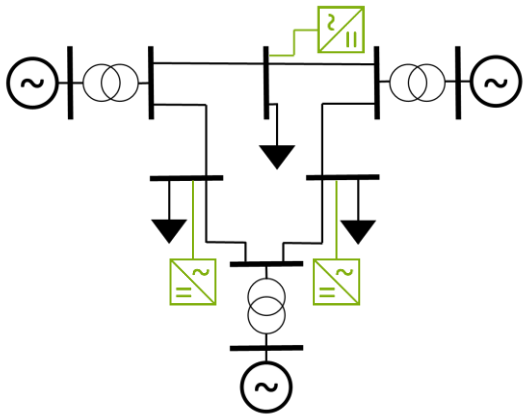
GFL-POD in generation bus

- Result 1: **GFL-POD** capable of providing **similar damping to SG-PSS** ----> [1]
- Result 2: **GFL-POD robustness** to load condition; inverter location, capacity, generation
- Result 3: Combined action of **GFL-POD and SG-PSS**

[2]

GFL-POD in load bus →

- Result 4: GFL-POD in distribution capable of providing damping to transmission ----> [3]



[1] Marta Gomis-Domènech, Thai Phuong Do, and Raphaël Caire, «Contribution to power oscillations damping of inverter based resources», in CIRED Vienna Workshop 2024: Increasing Distribution Network Hosting Capacity, june 2024.
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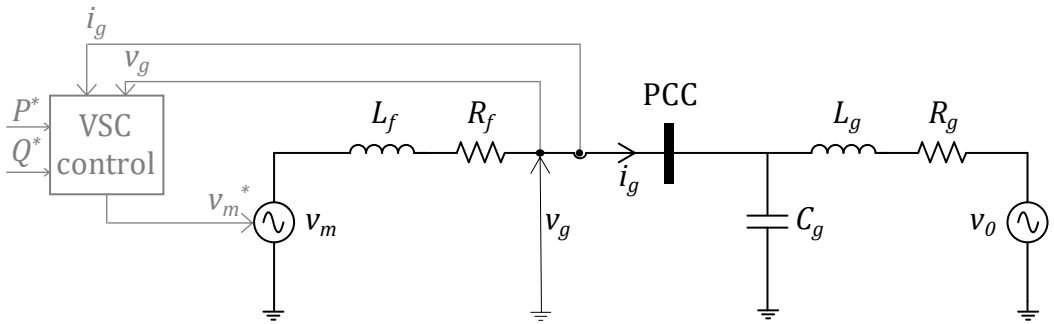
[3] (submitted) Marta Gomis-Domènech, Thai Phuong Do, and Raphaël Caire, «Damping Provision to Transmission System by POD Control in Distribution System», in 2025 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE), oct. 2025.

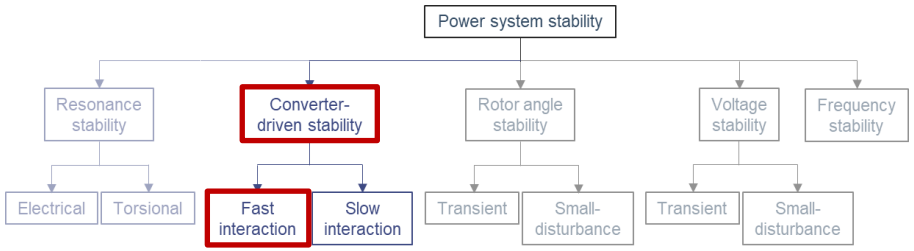
Consideration of rapid dynamics

Research collaboration

Simplifications:
- **Network dynamics**
  - SG stator flux

Small-signal stability tool by L2EP & Simulink





(To be published)

Key takeaways

Challenges regarding IBRs integration	Conclusions
Impact on power systems oscillatory behavior → case-specific	▪ The effect can be negative ▪ POD may be necessary ▪ POD effectively provides damping
Rapid and slow dynamics of power systems may not be decoupled anymore	Adverse converter-driven fast dynamic interaction → need to consider EMT dynamics

Merci beaucoup !

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CEA / G2Elab / ADEME

BACK-UP

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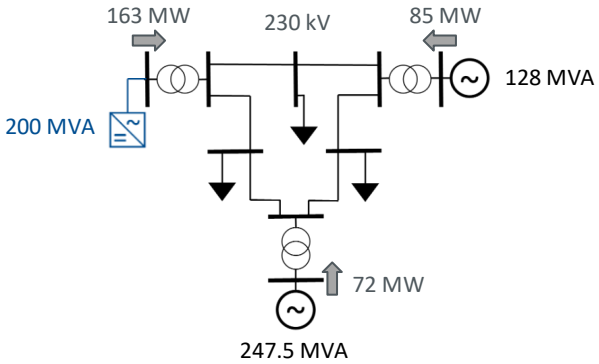
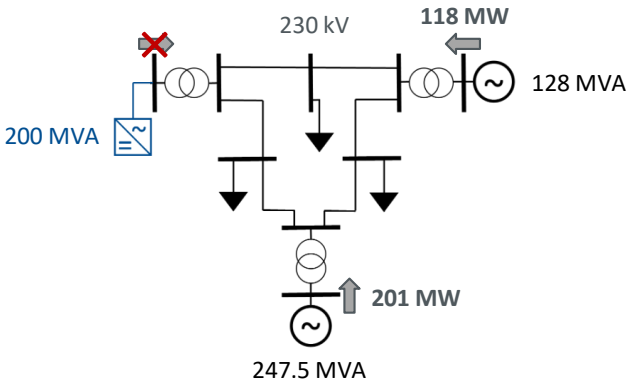
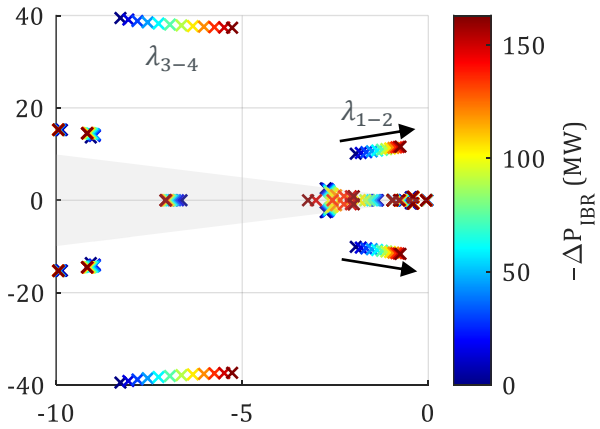
Eigenvalues: other dynamics & participation factors

Introduction (3/3)
Approach and objective





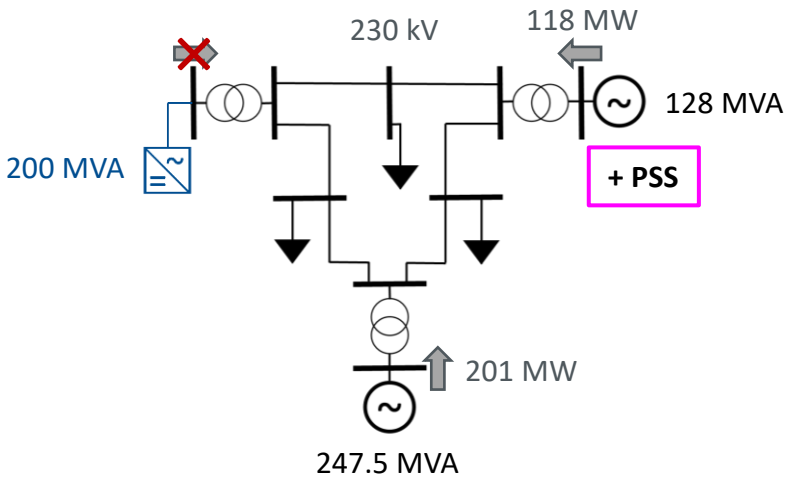
Modal analysis

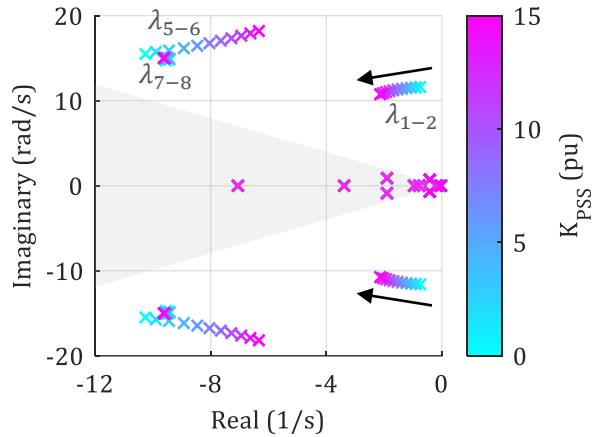


- Other dynamics within the $\zeta = 71\ \%$ area
- λ_{3-4} sensitive mode ~40 rad/s → PLL of the IBR

λ_{1-2}	Damping ratio ζ (%)	Frequency (Hz)
Initial	19.0	1.6
Final	6.4	1.8

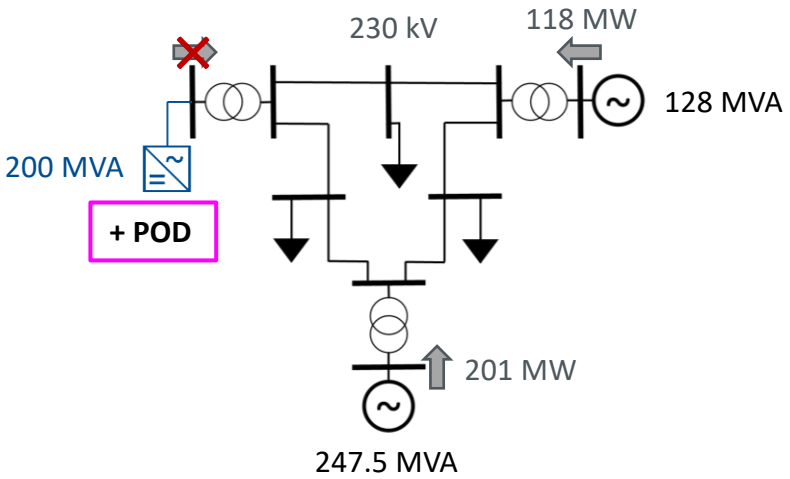
Results (1/3)
Traditional solution: PSS

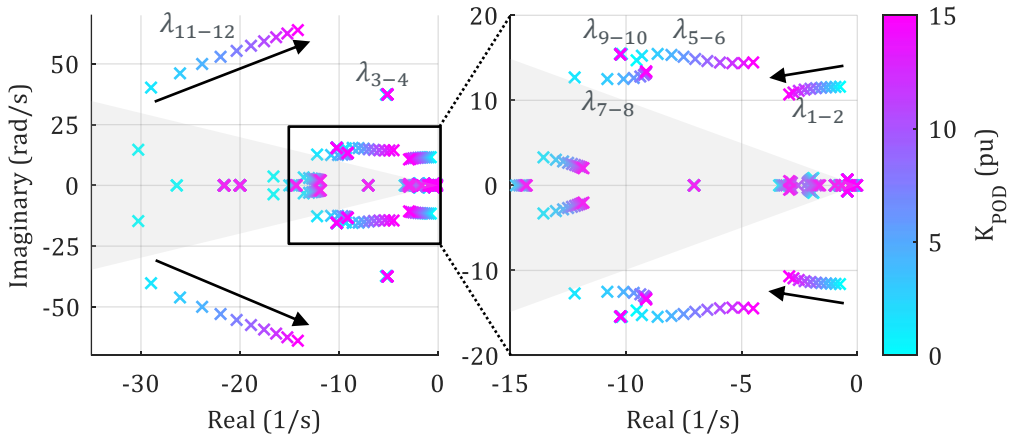




- Other dynamics:
  - (i) within the $\zeta = 71\ \%$ area
  - (ii) around 37 rad/s not sensitive (PLL)
- λ_{5-6} sensitive mode ~15 rad/s → AVR_1, PSS_3, ω_3
- λ_{7-8} non-sensitive mode ~15 rad/s → AVR_3

Results (2/3)
State-of-the-art solution: POD





- Other dynamics within the $\zeta = 71\ \%$ area
- Sensitive modes:
  - λ_{5-6} ~15 rad/s → $swing_3$, AVR_1, POD
  - λ_{7-8} ~12.5 rad/s → AVR_3, AVR_1
  - λ_{11-12} ~50 rad/s → Inverter inner control (voltage reference calculation)
- Not sensitive modes:
  - λ_{3-4} ~37 rad/s → PLL
  - λ_{9-10} ~15 rad/s → AVR_3, AVR_1

Comparison of solutions:

PSS vs. POD

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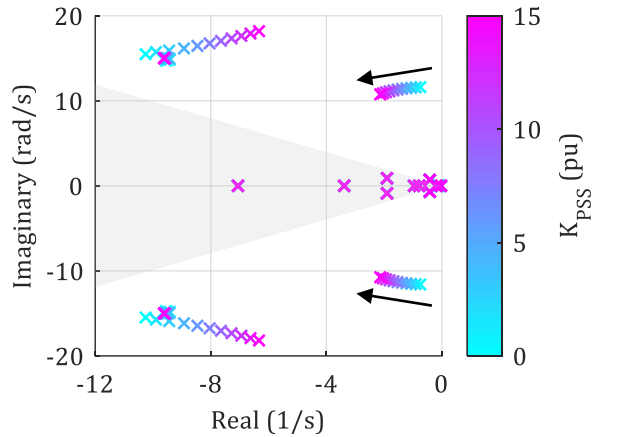
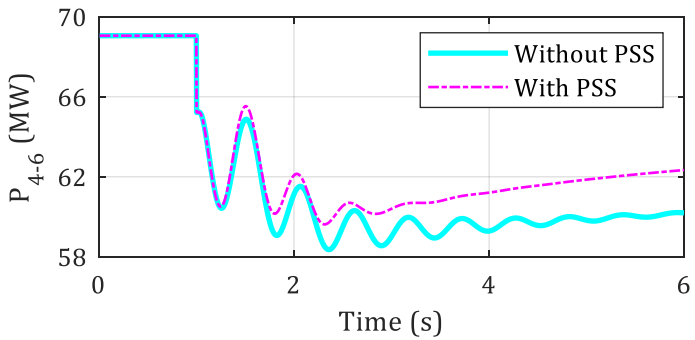
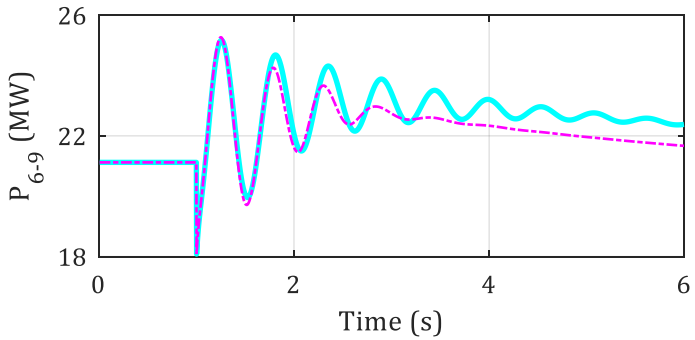
RESULTS - Comparison

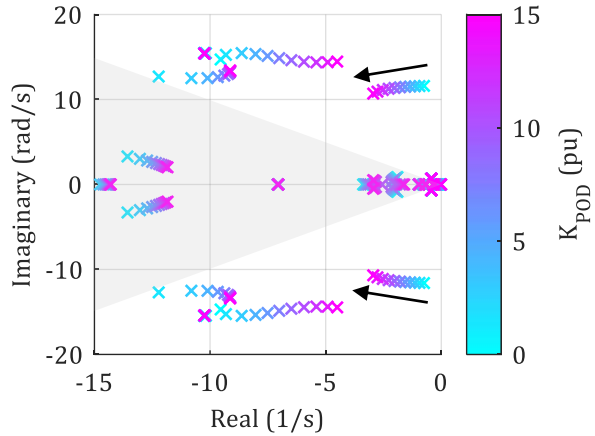
PSS

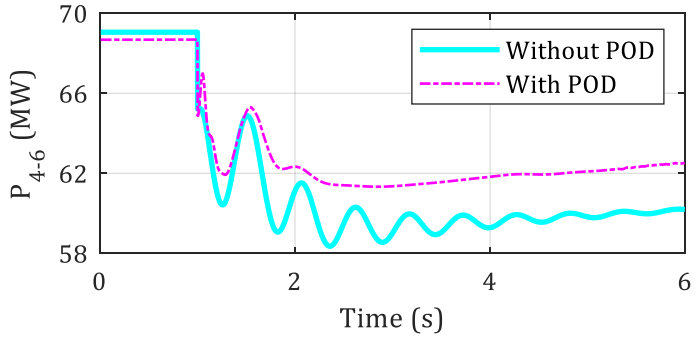


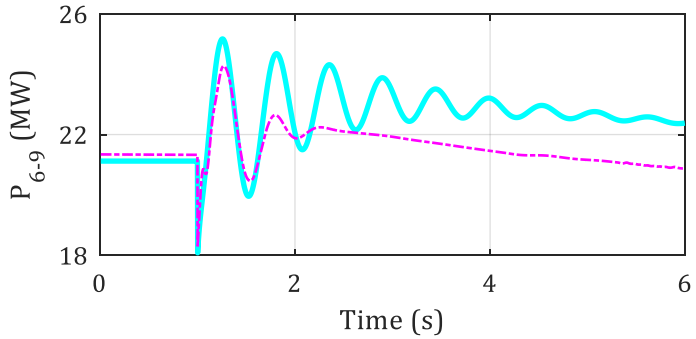




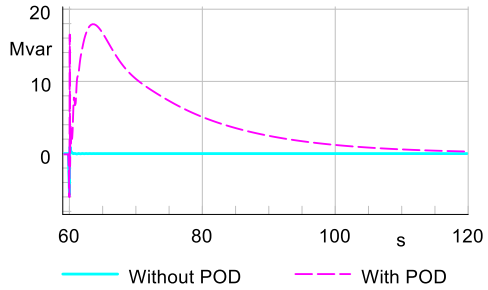
POD

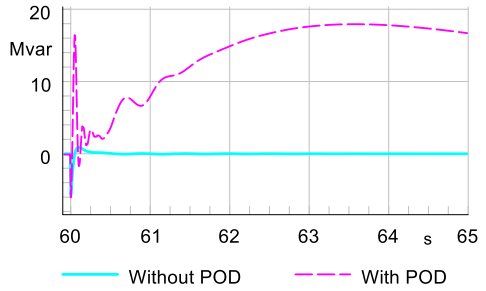


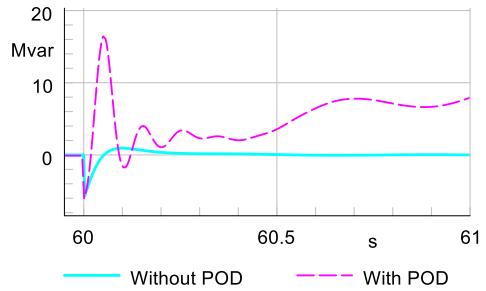




Q_{IBR}







Results POD (overview)

G2Elab Grenoble Génie Électrique Grenoble Electrical Engineering

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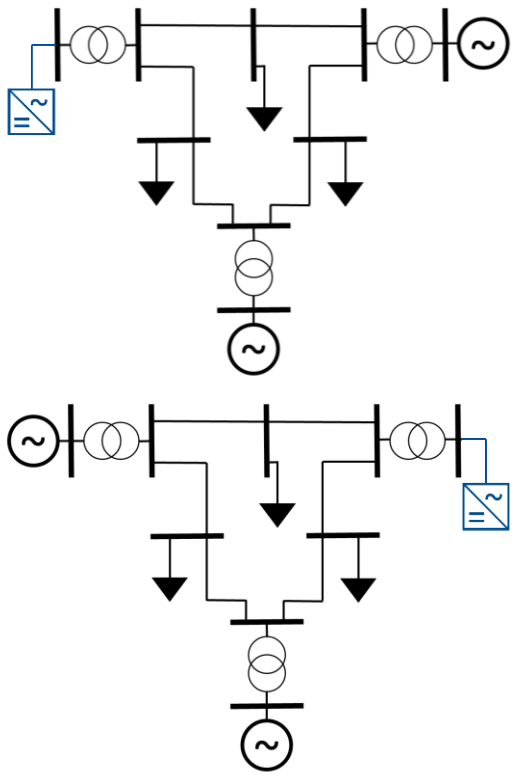
ADEME AGENCE DE LA TRANSITION ÉCOLOGIQUE

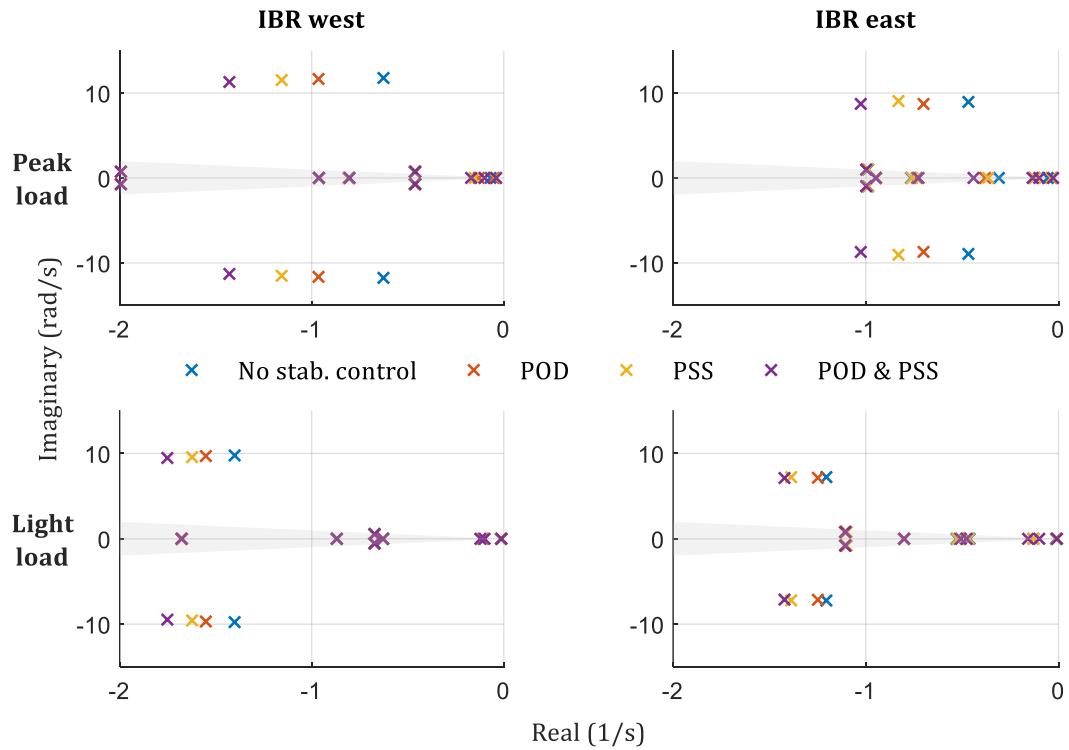
Results (3/3)
Overview



GFL-POD in generation bus

- Result 1: GFL-POD capable of providing similar damping to SG-PSS
- Result 2: **GFL-POD robustness** to **load condition**; **inverter location**, capacity, actual generation
- Result 3: **Combined action of GFL-POD and SG-PSS**

[2]



[2] Marta Gomis-Domènech, Thai Phuong Do, and Raphaël Caire, « Performance of IBR Power Oscillations Damper according to power system operating conditions », in 2024 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE), oct. 2024.