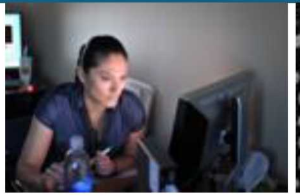
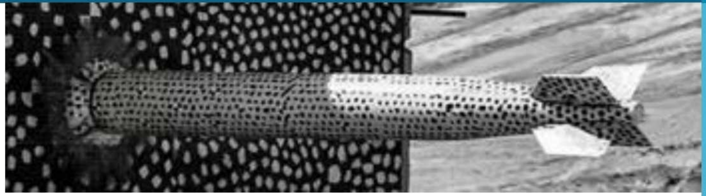
Sandia National Laboratories

SAND2019-0472C

Effects of Wind Turbine Generators on Inter-Area Oscillations and Damping Control Design





PRESENTED BY

Felipe Wilches-Bernal

The 52nd Hawaii International Conference on System Sciences (HICSS)

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Presentation Outline

- Introduction & Motivation
- Wind turbine generator (WTG) and Power System model used in this work
- Impact of WTG integration on inter-area oscillations
- Design of an inter-area oscillations damping controller using a WTG
  - Design methodology
  - Simulation results
- Conclusions

Project Team

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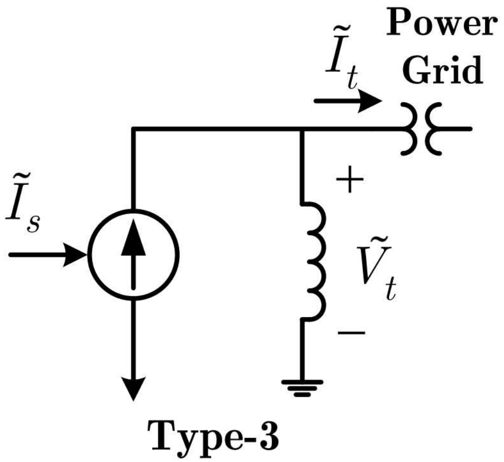
- Christoph Lackner and Joe H. Chow, **Rensselaer Polytechnic Institute**
- Juan J. Sanchez-Gasca, **GE Energy Consulting**

Introduction & Motivation

- Future grid is expected to accommodate higher levels of penetration of inverter-interfaced generation (wind and solar)
- The dynamics of inverter-interfaced generation is different from those of "conventional" generation (rotating machines)
- Increased penetration of inverter-interfaced generation affects the overall dynamics of the system
- This work analyzes how small signal stability of power systems is affected in the face of increased wind penetration
  - Uses a small power system representative of a power transfer
  - Studies the effect of location of wind integration
- Proposes two different controllers to damp inter-area oscillations using WTGs
  - Active power
  - Reactive power

Wind Turbine Generator Model

- **Dynamic Model:** positive sequence model suitable for transient stability time domain simulations (for bulk power system planning studies).
- The model are observed from the **grid** as a **controlled current source**:



- Active and reactive current outputs are controlled independently

$$I_t = \left(I_p - j\frac{E_{fd}}{L_{pp}} \right) (\cos(\gamma) + j\sin(\gamma)) + j\frac{\tilde{V}_t}{L_{pp}}$$

Output of the WTG active power control

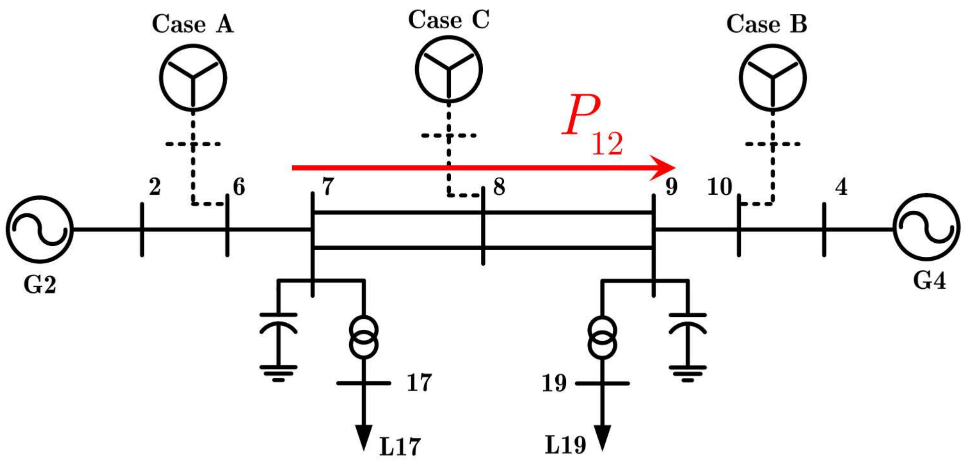
Output of the WTG reactive power control

γ is a state representing the PLL action

$$\dot{\gamma} = k_{pllp}[V_{tim}\cos(\gamma) - V_{tre}\sin(\gamma)]$$

Power System Model

- **Test system:** 2-machine, 2-area system with a **dominant inter-area oscillation.**



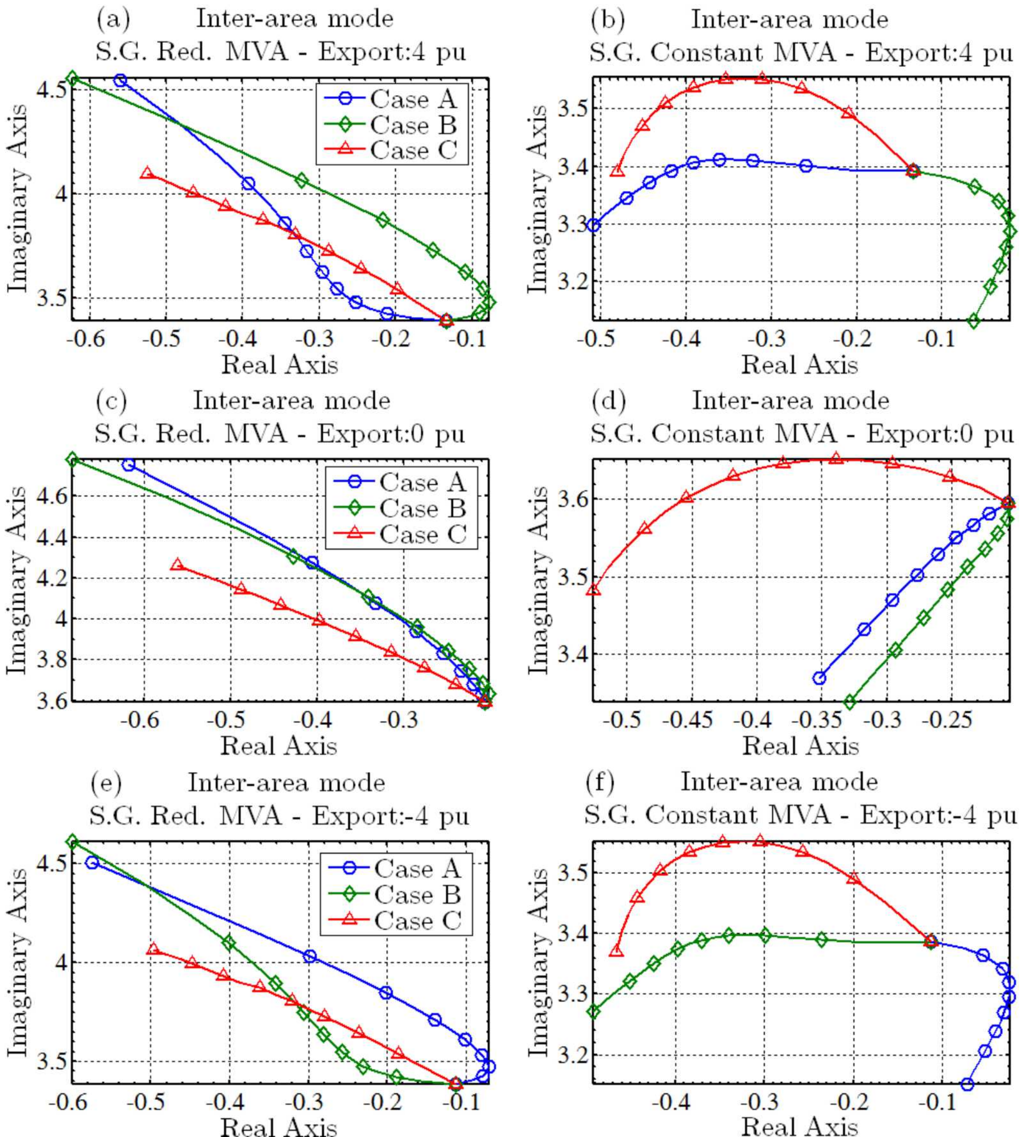
Import: P12 is negative

Export: P12 is positive

- **Objective:** Study the impact that integrating wind generation has on the inter-area oscillation of the test system. 3 Cases of WTG positioning were considered:
  - **Case A:** wind generation performed in Area 1.
  - **Case B:** wind generation performed in Area 2.
  - **Case C:** wind generation performed in the middle of the transfer path

- Two scenarios regarding how the displacement of conventional generation is achieved are considered:
  - **Scenario 1:** reduction on the MVA of the displaced conventional generator
  - **Scenario 2:** constant MVA and only power level reduction on the displaced conventional generator

Inter-area Mode Variations with Increased Wind Penetration



- Wind penetration was varied from 0% to 43% (86% of the corresponding area).
- Analysis was carried out for the two displacement scenarios and the three cases of WTG positioning. Additionally, three different loading conditions were considered, one importing, one exporting and no power transfer.
- Overall trend in the cases where MVA is reduced is for the inter-area mode to move upwards (less inertia) and leftward (more stable).
- In cases where MVA is constant generally the inter-area mode moves towards the LHP. However, the inter-area mode initially moves towards instability (rightward) when the WTG is installed in the area that imports power.

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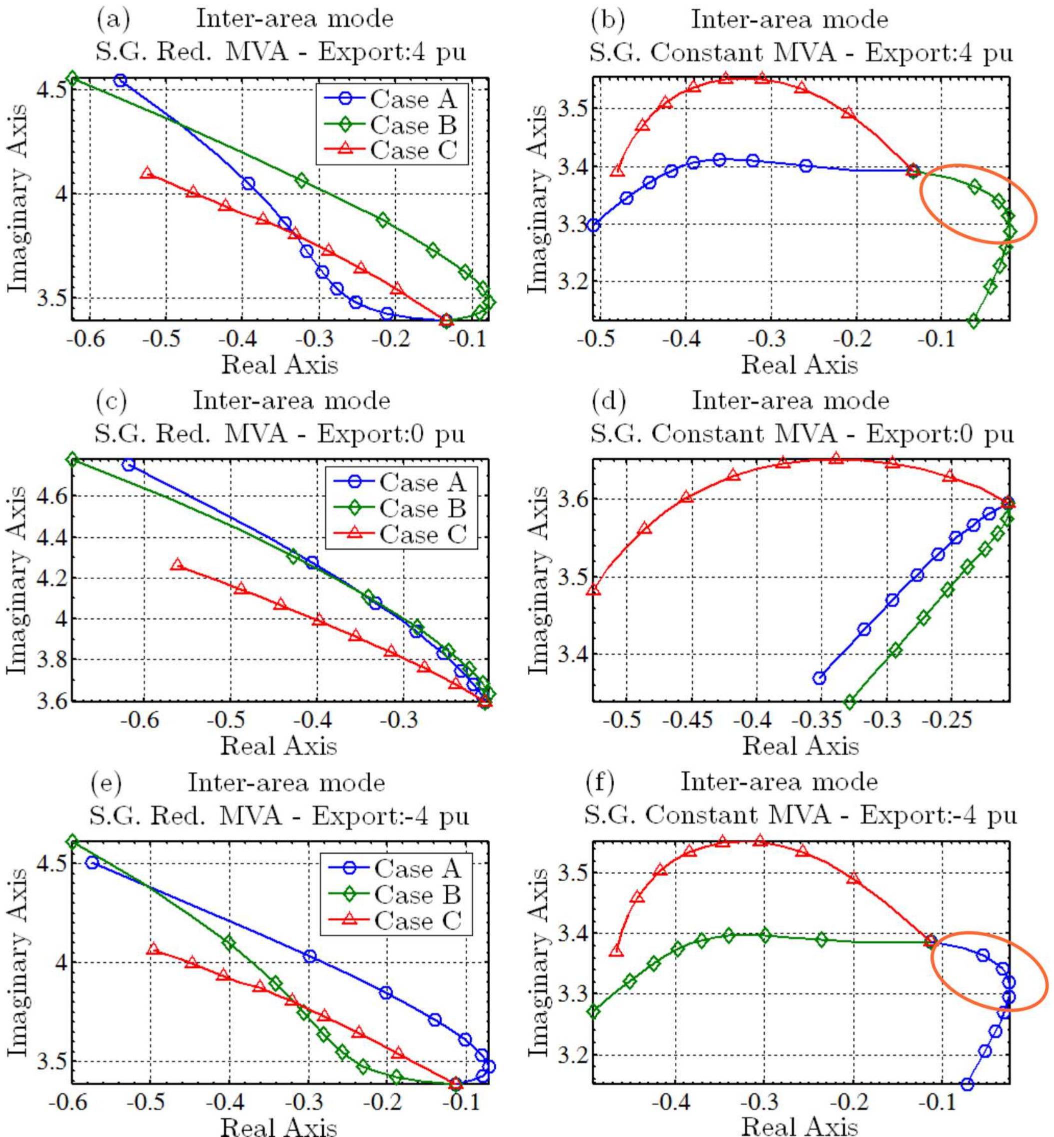

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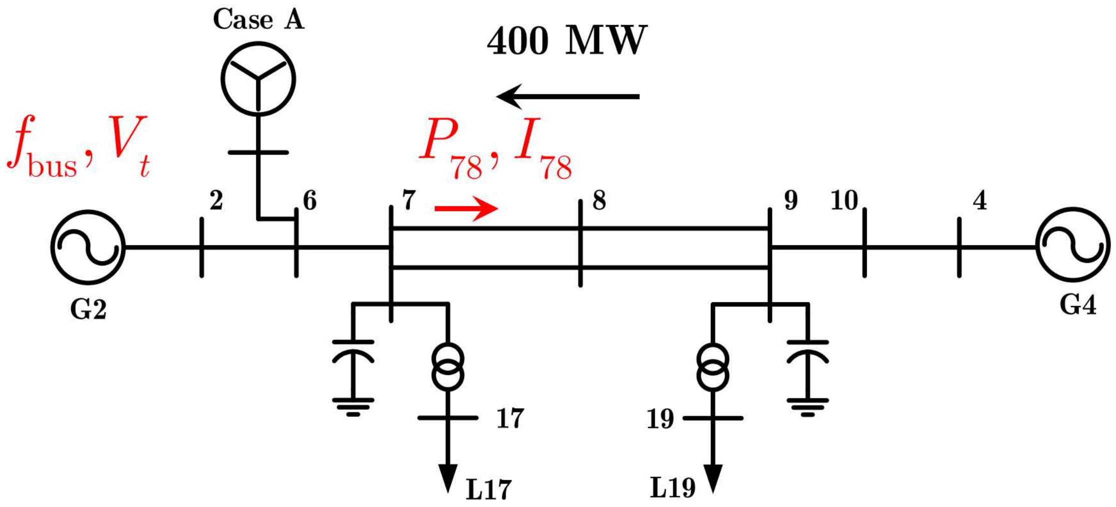
WTG Damping Control Design

- **Result:** integrating wind affects the inter-area oscillation. When wind integration is performed in an area that is importing power it creates a destabilizing effect.
- **Approach:** Just as some conventional generation is required to damp inter-area oscillations by adding a Power System Stabilizer (PSS) to its voltage regulation, this work investigates the capability of wind generation to perform this damping task.
- Investigation carried out in the 2-area, 2-machine test system.

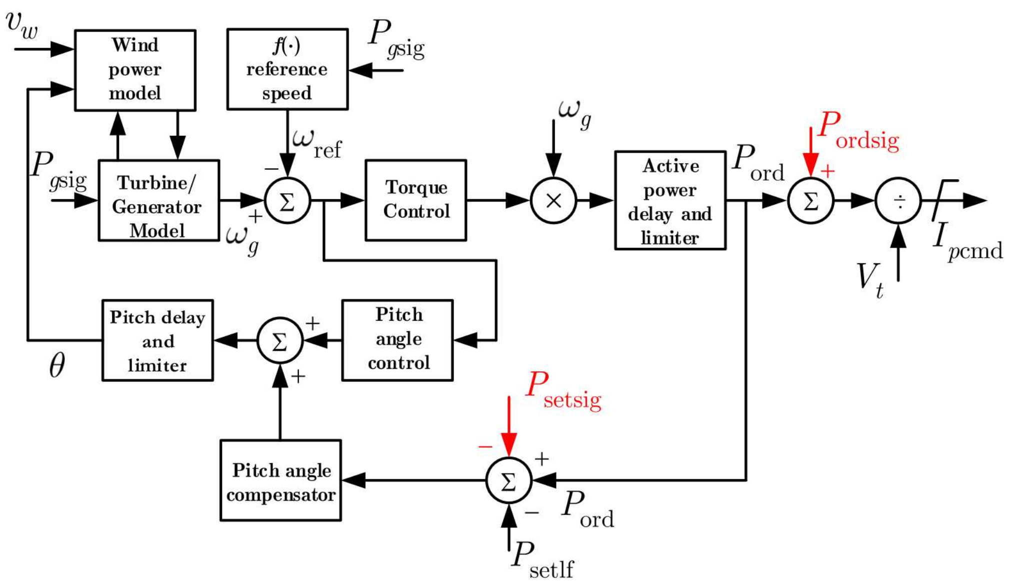


WTG Damping Control Design

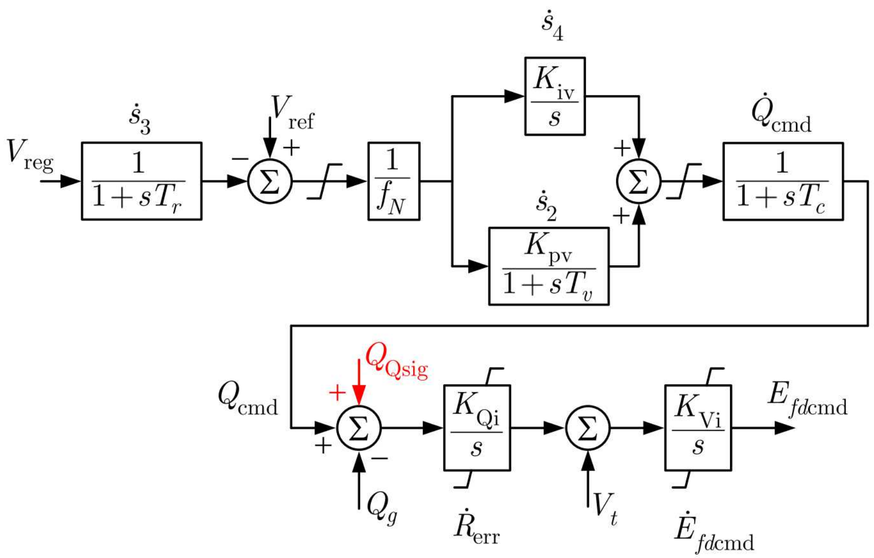
- Analyze the best combination of input and output signals for control design.

- **(1)** analyze a set of signals to determine the most suitable one to be used as an feedback input for the controller:
  - **Bus frequency**
  - **Voltage Magnitude**
  - **Power transfer between the areas**
  - **Current magnitude between the areas**
- **(2)** evaluates the proper place to integrate the controller within the WTG.

Active power control diagram:



Reactive power control diagram:



WTG Damping Control Design

- System was linearized
- Linear system has 47 states

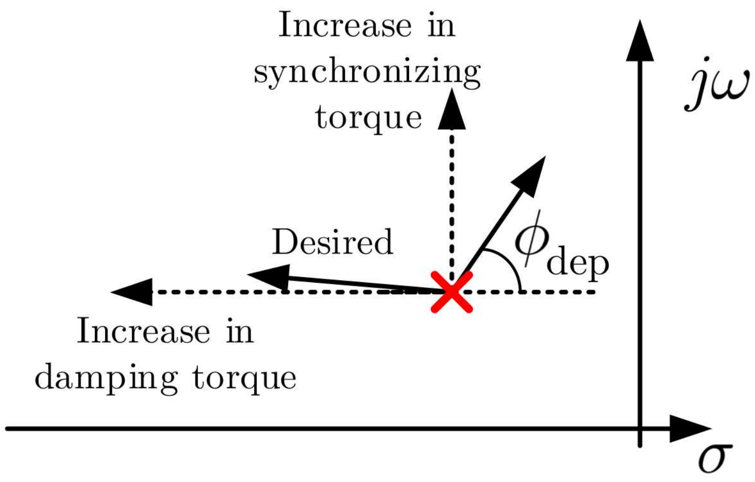
$$\dot{x} = Ax + B_{zz}u$$
$$y = C_{xx}x$$

Input matrices (***B***) according to controller location

Output matrices (***C***) according to feedback signal

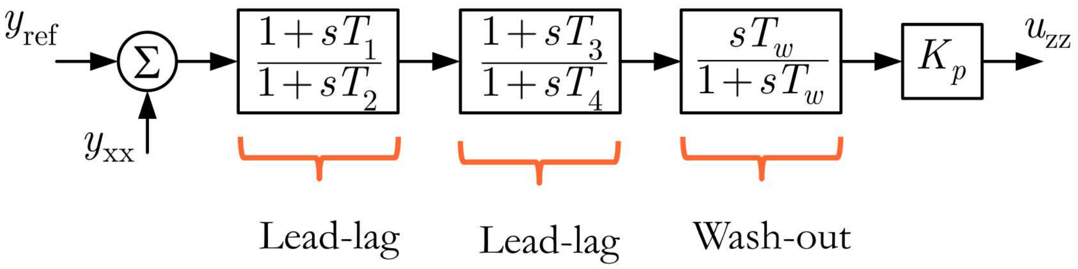
- 12 systems to analyze (SISO)

Control Objective



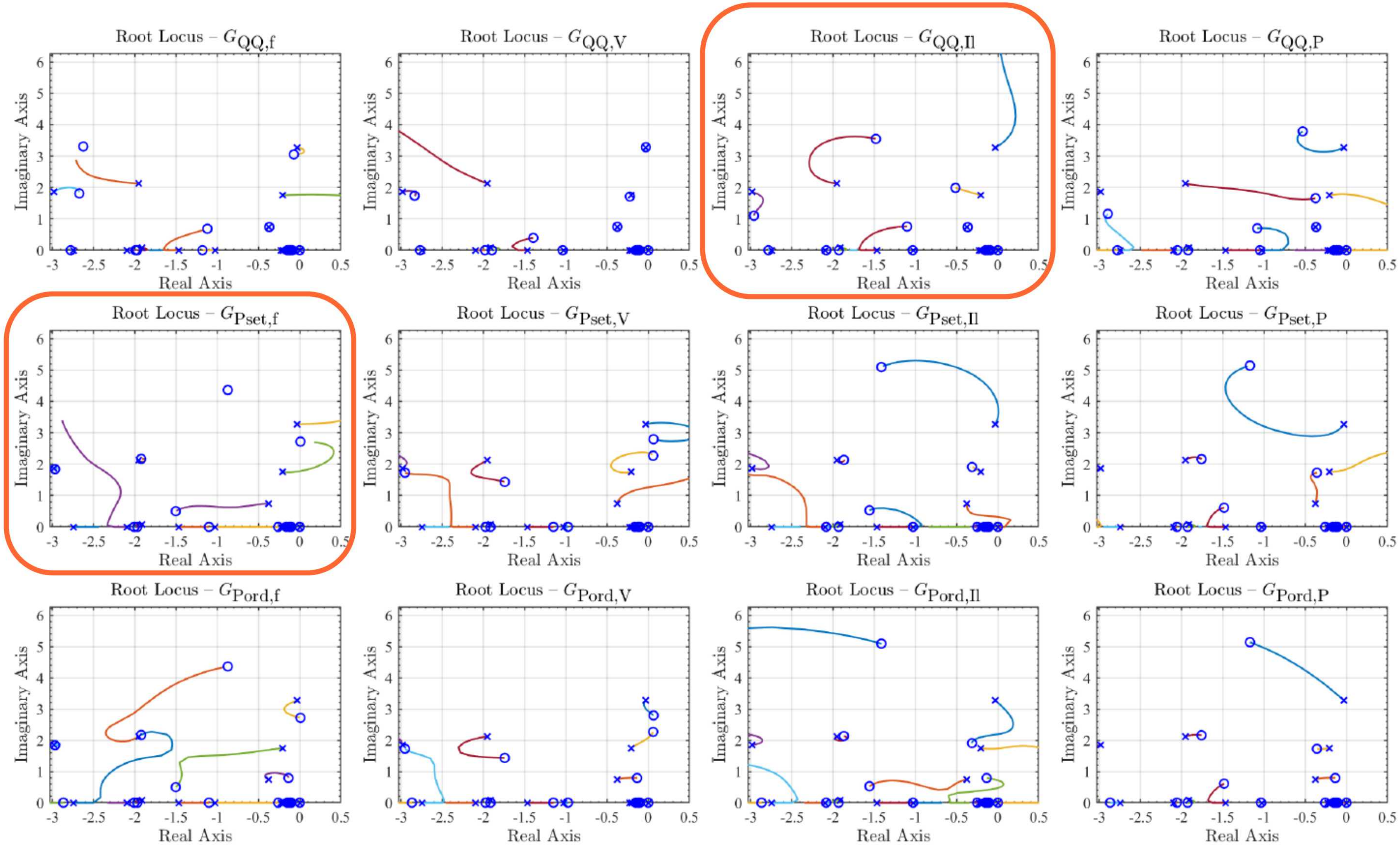
Design approach: increase the damping torque by modifying the angle of departure (use of root locus).

Controller structure:



WTG Damping Control Design

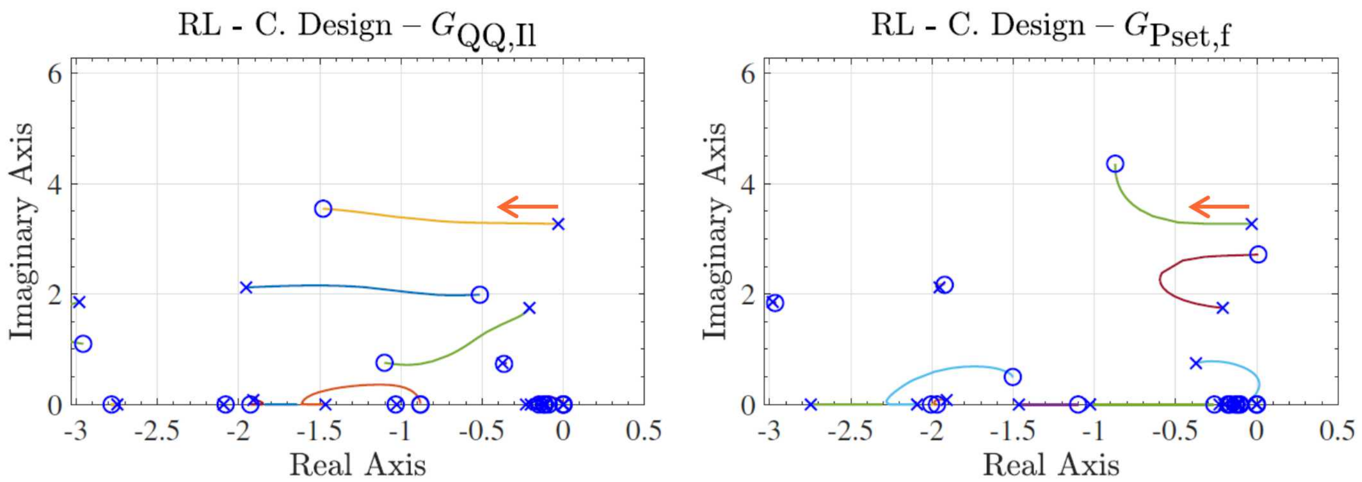
- Root locus plots (washout action included)



- Note the presence of zeros make some combinations unsuitable for control

WTG Damping Control Design

- By determining the angle of departure of the angle the time constants of the lead-lag compensator were determined. The constant was determined with the use of the root-locus plot.

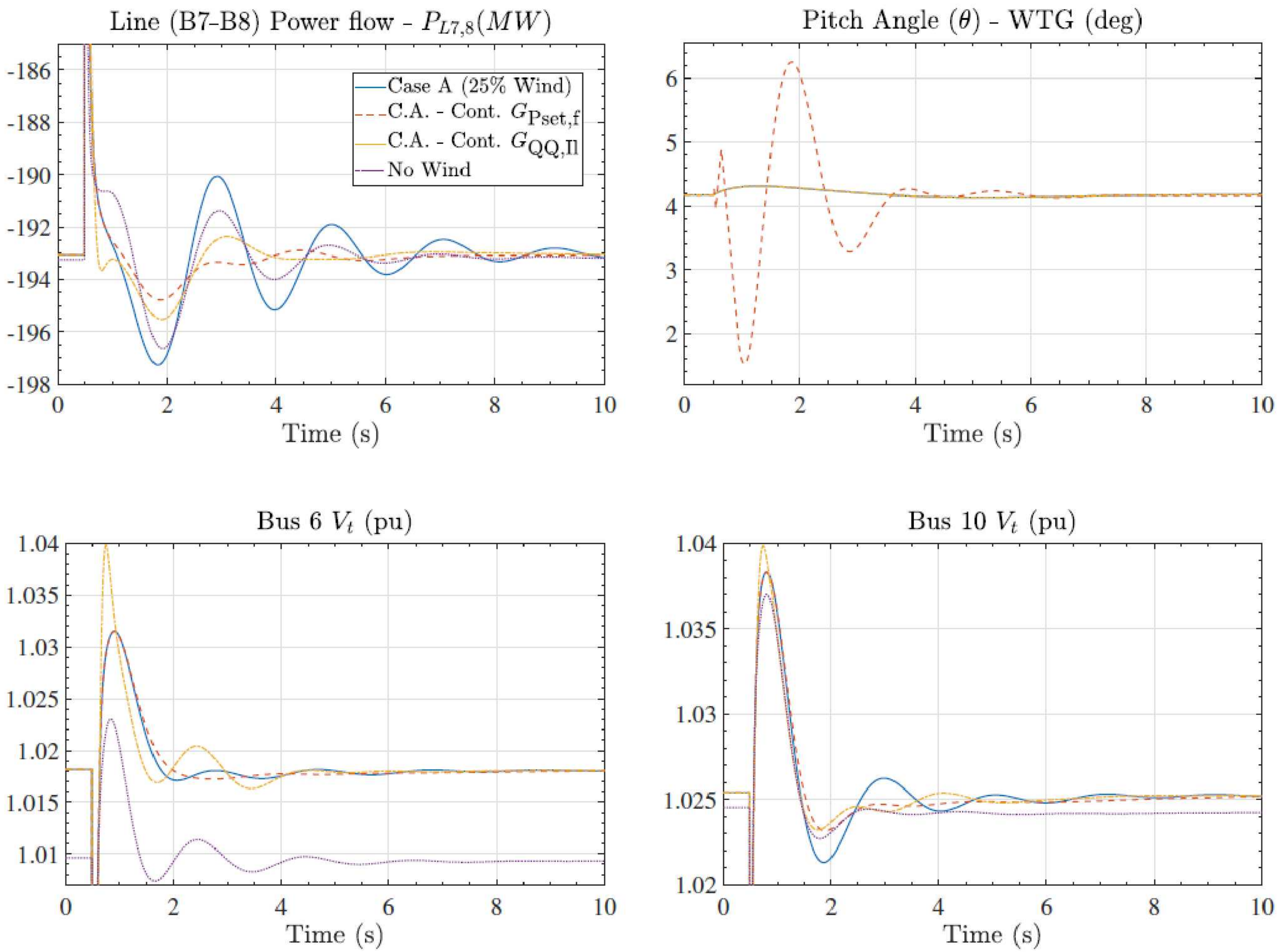


- The gain was selected with the help of the root locus plots

Controller	T_1 [s]	T_2 [s]	K_p $\frac{pu}{pu}$
$G_{QQ,Il}$	1.1358	0.0824	0.4
$G_{Pset,f}$	5.6613	0.0165	18

Simulation Results

- System i**mporting 4 pu of power in Area 1** where the WTG is integrated
- 4 cases considered:
  - No Wind Case
  - WTG with no additional control
  - WTG with active power control
  - WTG with reactive power control
- Including wind **lowers** the damping of the inter-area mode
- Both controllers are effective in damping the oscillation
- Active power control makes use of the pitch angle (potentially undesirable)
- Reactive power control causes more variations in the voltage



WTG Damping Control Design

- Controller also tested at a operating point where the **system exporting 4 pu** of power to **Area 2**

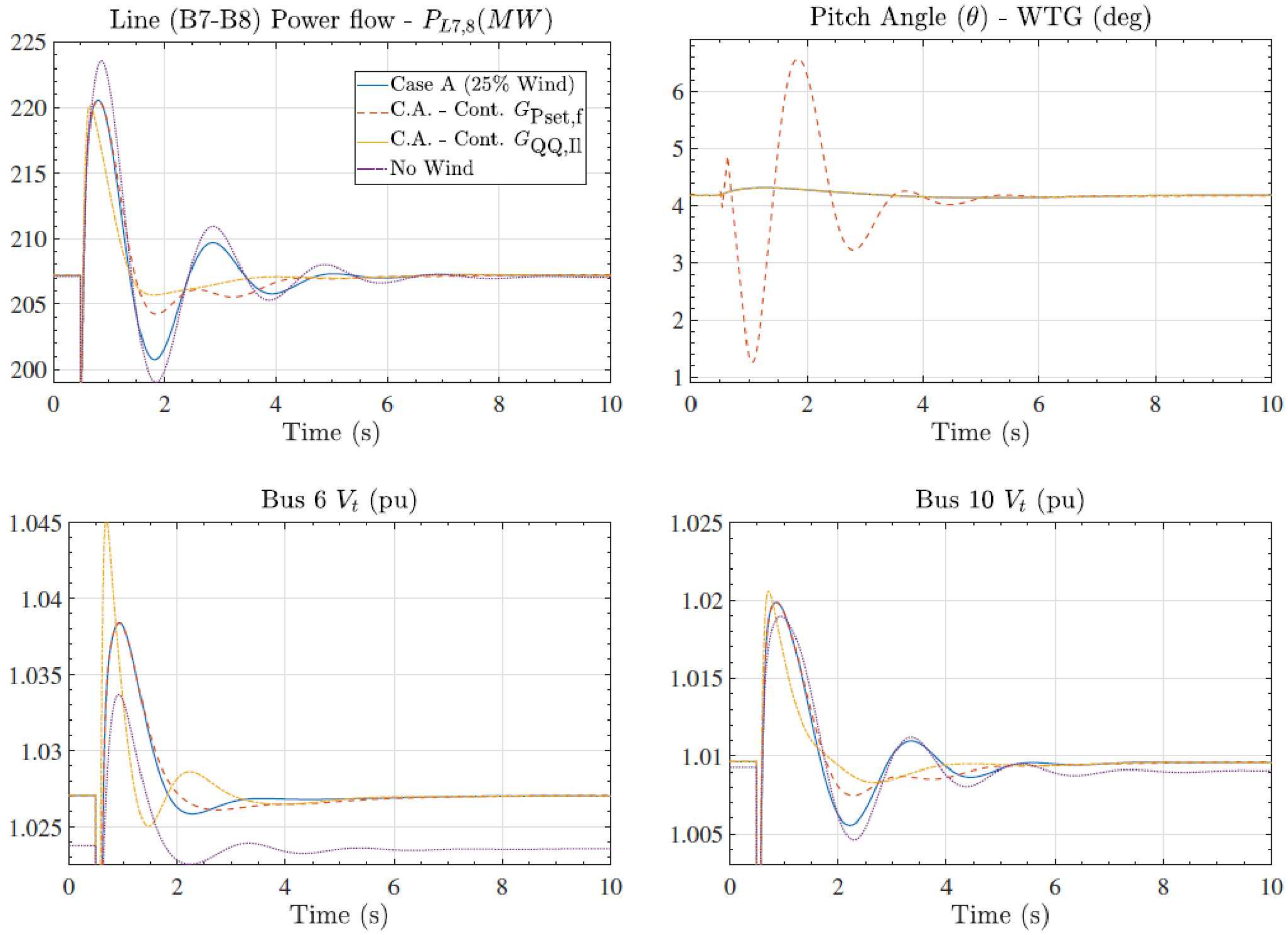
- Same 4 cases considered:
  - No Wind Case
  - WTG with no additional control
  - WTG with active power control
  - WTG with reactive power control

- Including wind **increases** the damping of the inter-area mode

- Both controllers are effective in damping the oscillation

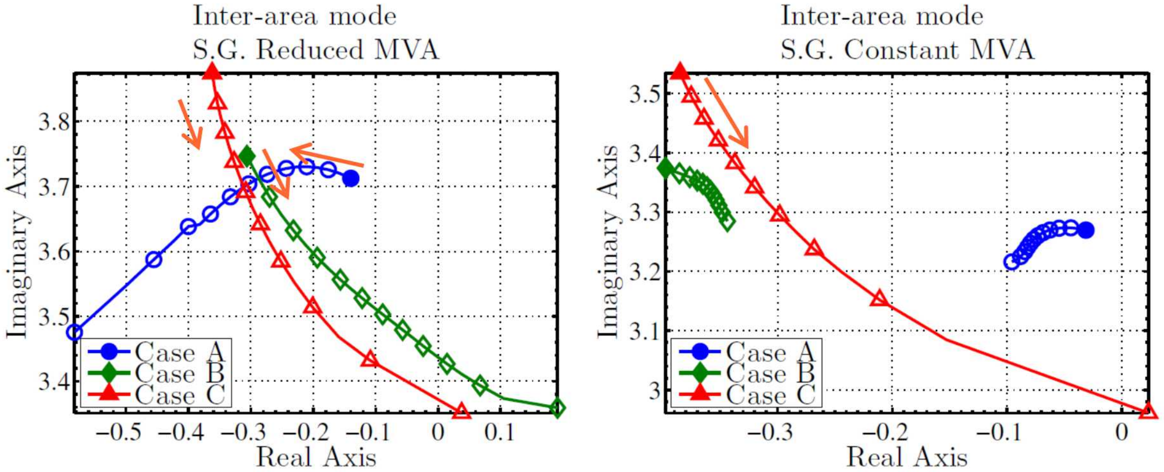
- Active power control makes use of the pitch angle (potentially undesirable)

- Reactive power control causes more variations in the voltage



Inter-area Mode Variations with Connecting WTG TX Line

- An study on how the length of the transmission line that connects the WTG to the system was performed. The three cases of WTG positioning and the two scenarios of conventional generation displacement were considered.



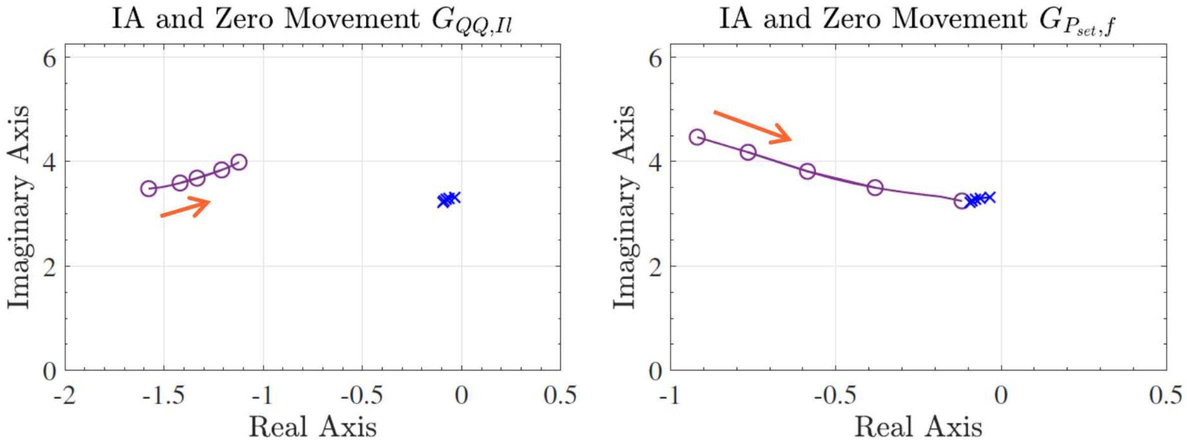
- The reactance was varied from 0 to 0.11 pu (0 to 110 Km equivalent). The loading condition was 400 MW importing.

- In the reduced MVA scenario, **the synchronizing torque is decreased as the connecting reactance is increased.**

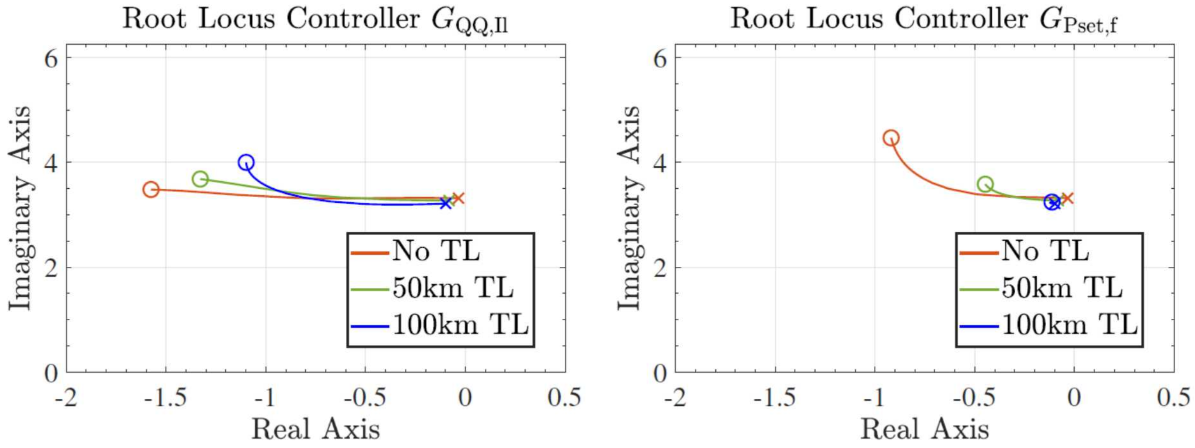
- In the constant MVA scenario, for cases A and B there is a reduced effect on how the mode is affected by the increase in the TL reactance. However the trend of synchronizing torque reduction is preserved.

WTG Damping Control Design

- When increasing the transmission line connecting the WTG to the system the zeroes of the system are mostly affected while the poles move slightly in comparison



- The root locus (dominant mode and zero) for different transmission line lengths



Conclusions

- It determined the conditions for which wind integration causes instabilities in the inter-area oscillation.
- It demonstrated that WTGs can be an effective means to damp the inter-area oscillation of a test power system.
- It showed that different combinations of input/output signals can used to implement the damping controller. In particular it demonstrated both the active and reactive power controller to be possible places to implement the damping control.
- It showed that increases in the transmission line connecting the WTG affect mostly the zeros and not the poles of the system

Acknowledgment

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Thank You!

Questions?

WTG Damping Control Design

- Controller also when the WTG TX line is 100 Km (case 4 pu importing)
- Same 4 cases considered:
  - No Wind Case
  - WTG with no additional control
  - WTG with active power control
  - WTG with reactive power control
- Controllers are still effective damping inter-area oscillations but not as much as in the case of no long TX line