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Stuttgart Wind Energy (SWE)
@ Institute of Aircraft Design

Evaluation of control methods for floating offshore wind turbines

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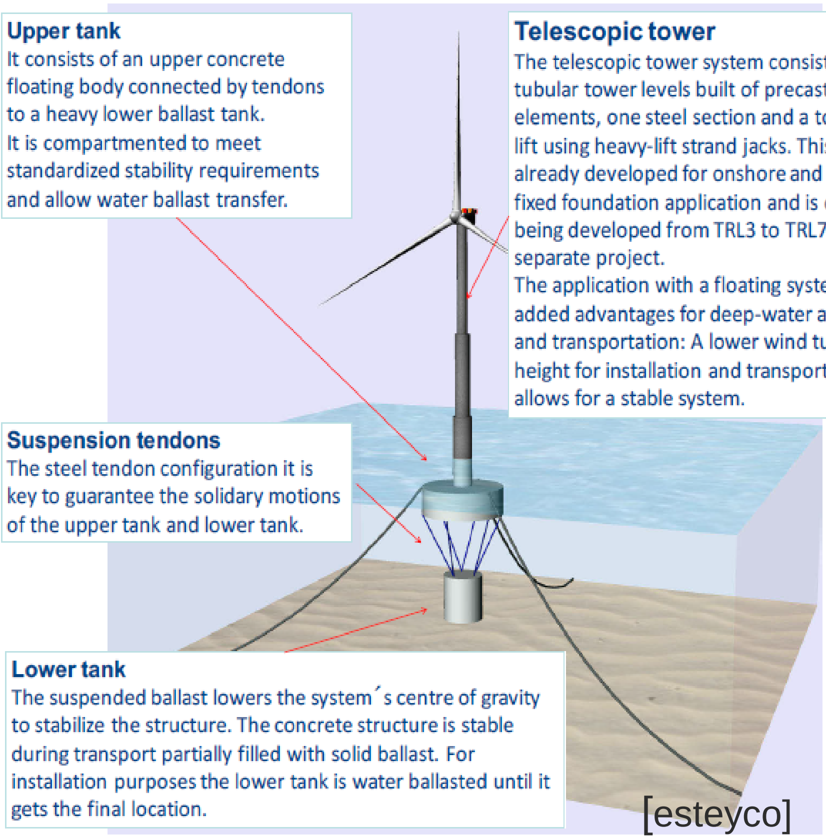
Background & Motivation



EU Horizon 2020 project: TELWIND

Cost reduction for floating offshore turbine

- Evolved spar concept
- Telescopic tower
- Local and low cost material usage: Concrete
- Simpler manufacturing and installation processes

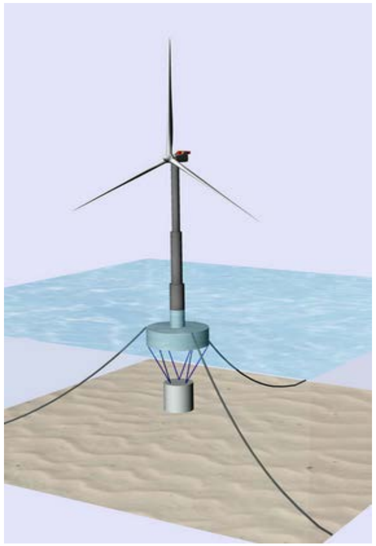
➢ How great is the impact of controller on FOWTs?

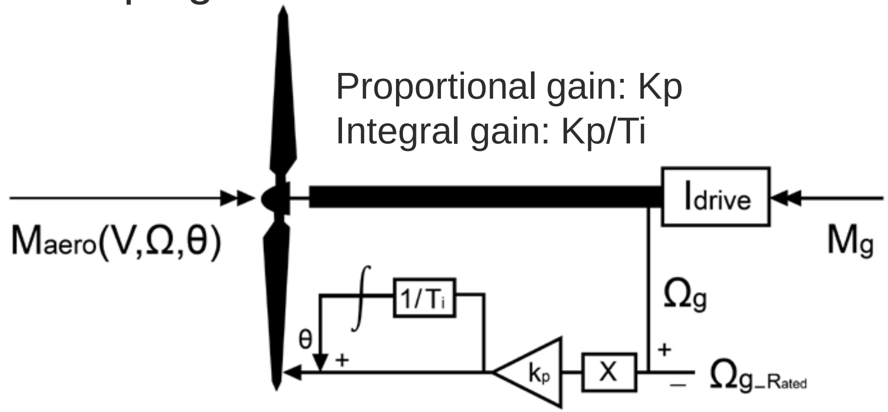
➢ What makes controlling FOWTs difficult ?

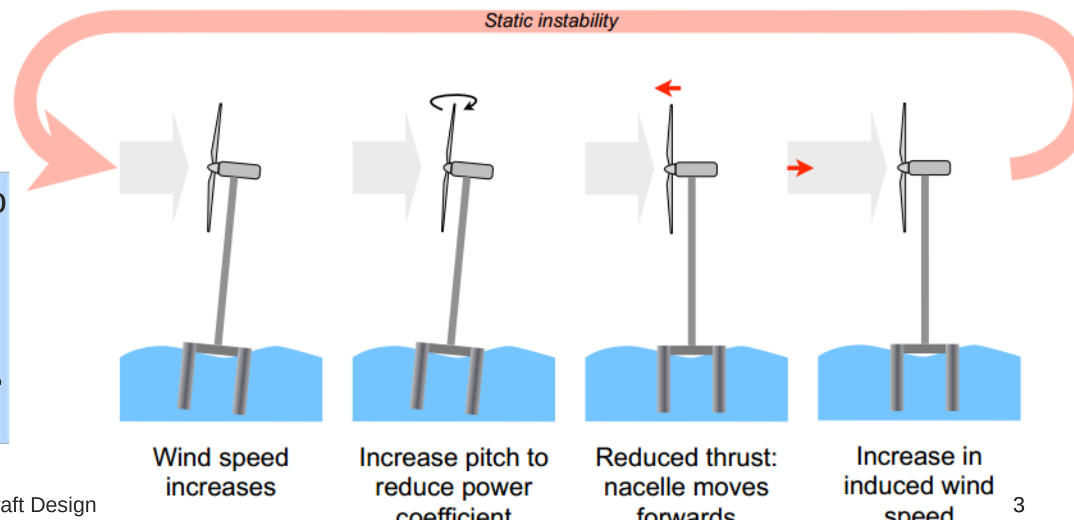
➢ How well do the state-of-art control methods work?

What makes controlling FOWTs difficult ?

Physical: Negative aerodynamic damping





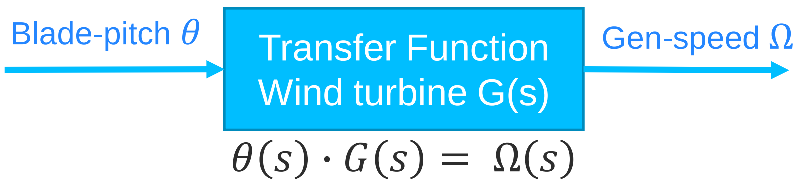


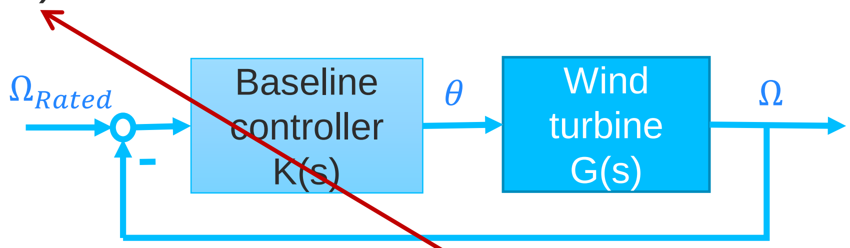
Applying conventional on-shore controller to FOWT leads to the instability problem

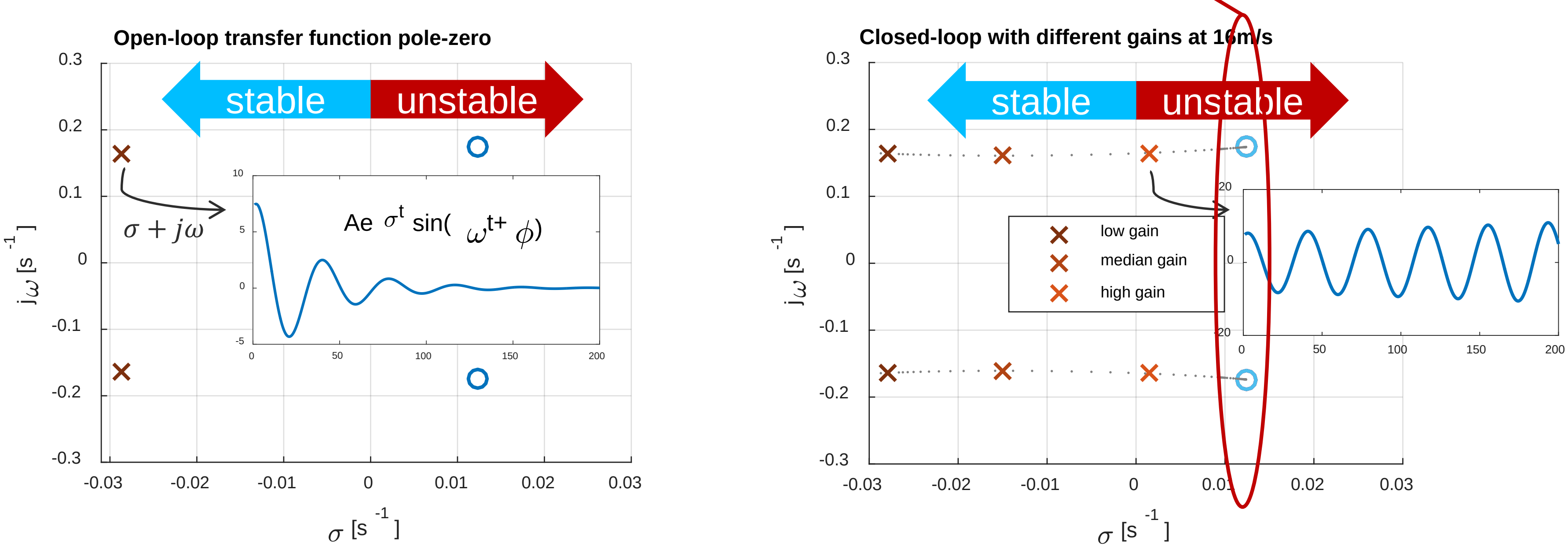
Larsen, T. J., and Hanson, T. D., 2007. “A method to avoid negative damped low frequent tower vibrations for a floating, pitch controlled wind turbine”. *Journal of Physics: Conference Series*, ***75***(1), p. 012073.

What makes controlling FOWTs difficult ?

Control theory: Right-half-plane-zero (RHPZ)







How good do the state-of-art controllers work?

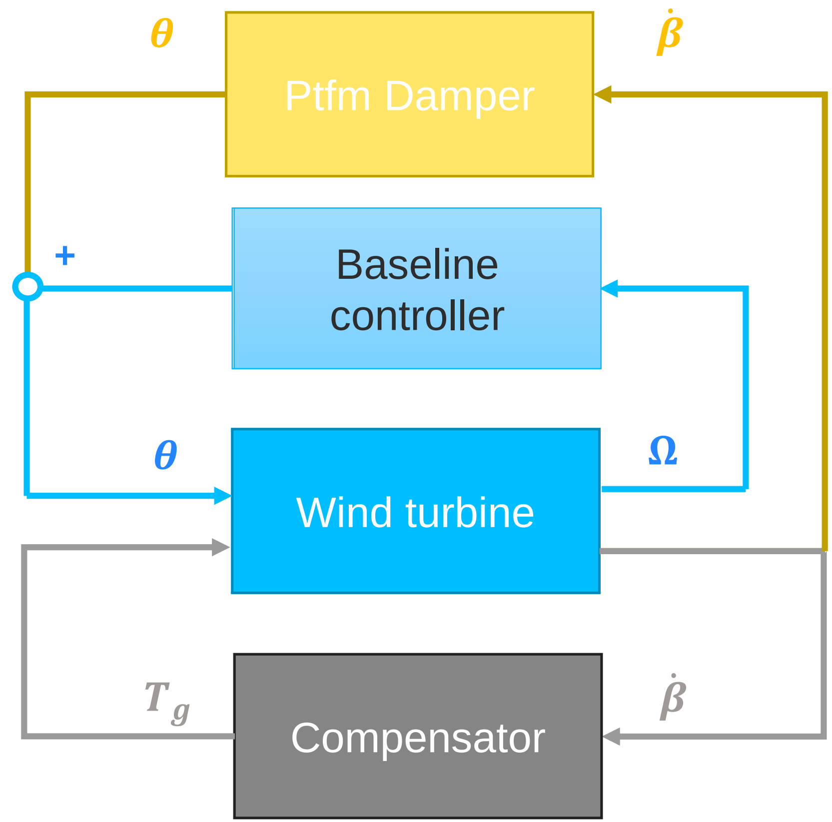
Selection of theoretical methods

Different control methods used for FOWT by modifing Baseline controller:

- Single-input-single-output (SISO):
  Detuning / scheduled detuning
- Multi-input-single-output (MISO):
  Ptfm damper - feedback of Ptfm-Pitch to Blade-Pitch
- Multi-input-single-output (MIMO):
  Compensator - feedback of Ptfm-Pitch to Generator torque

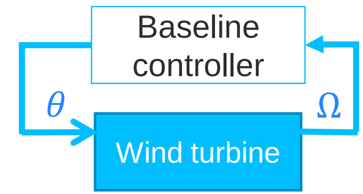
Evaluation tool:

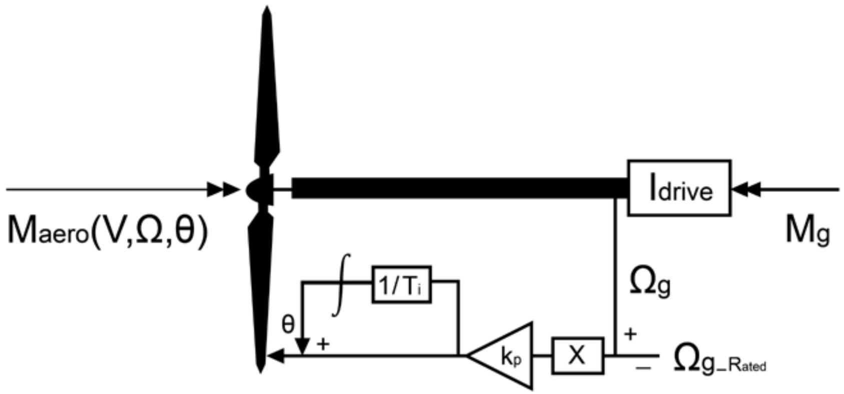
- Linear analysis: simplified linear mdoel with 5 DOF (SLOW)
- Coupled aero-hydro-servo-elastic nonlinear model (Bladed v4.7)



SISO: Detuning

Simple approach

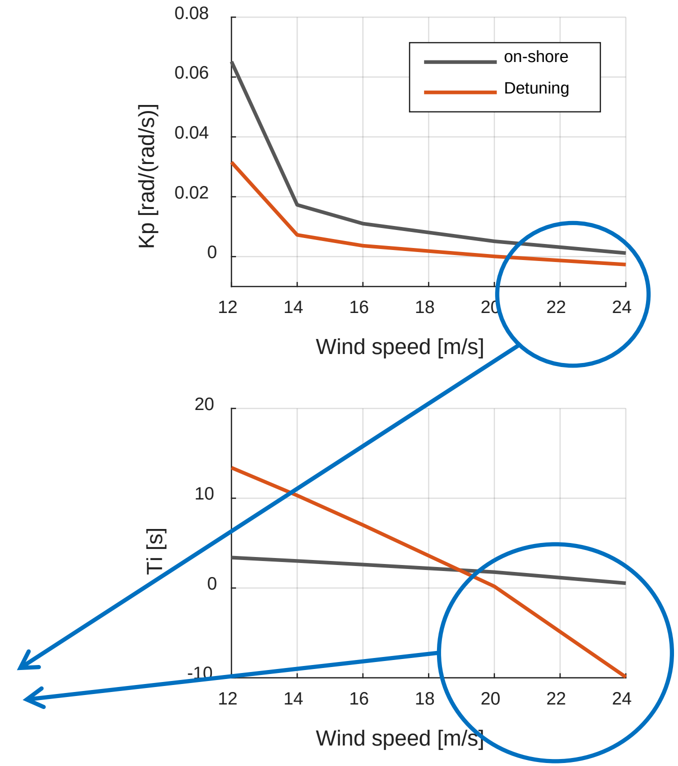




1DOF Drivetrain: second order differential system

$$I_{drive}\ddot{\varphi} + \left(-\frac{\partial M_{aero}}{\partial \theta}\right) K_P\, \dot{\varphi} + \left(-\frac{\partial M_{aero}}{\partial \theta}\right) \frac{K_P}{T_i} \varphi = 0$$

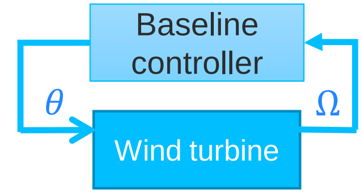
Eigen-frequency of the drivetrain motion should be lower than the Ptfm eigen-frequency

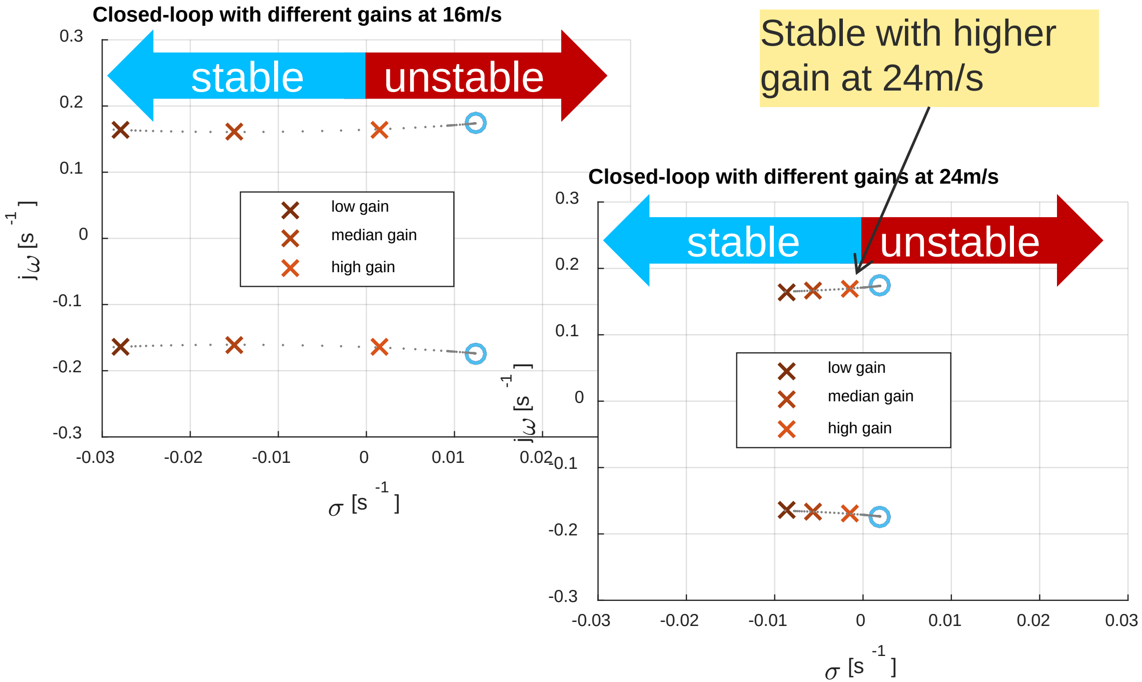


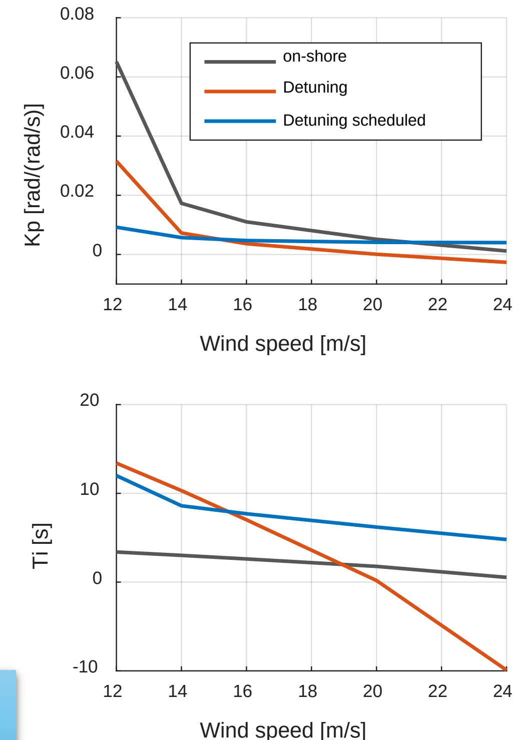
Detuning method could lead to negative gains at higher wind speed

SISO: Detuning

Scheduling at different wind speeds



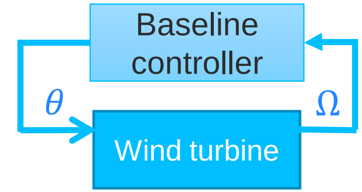


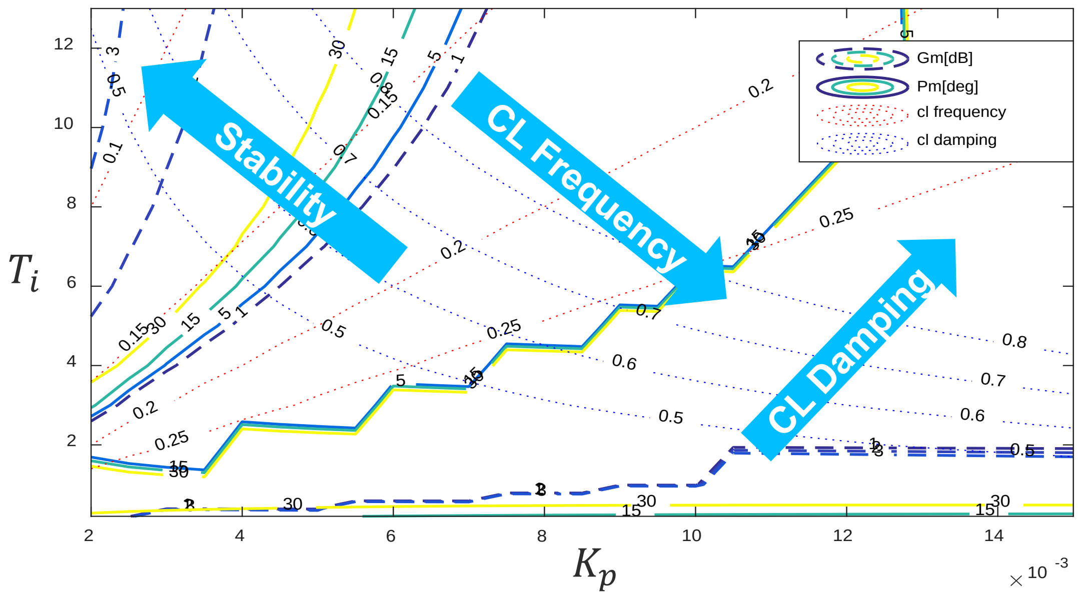


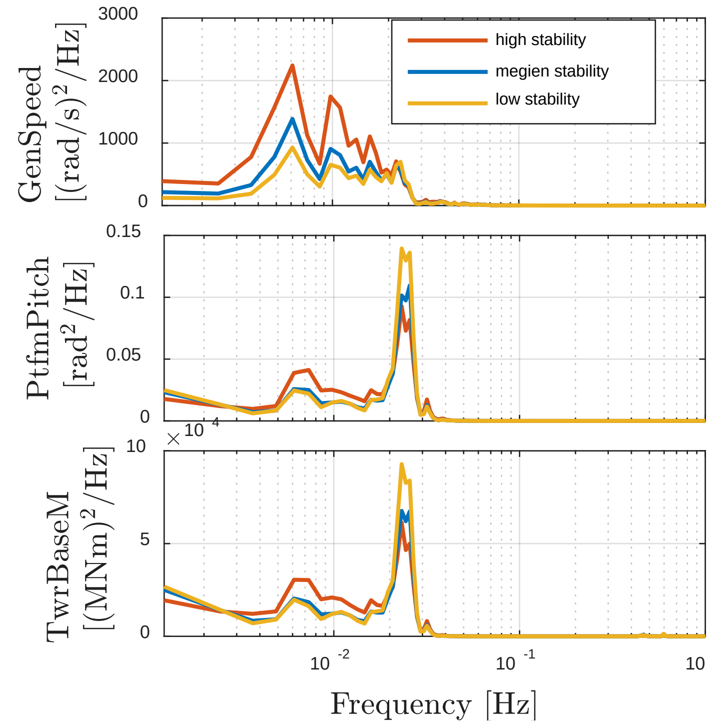
RHPZ problem differs from the operating wind speed, thus detuning should be applied according to the operating point

SISO: Detuning

Trade-off between system stability and control performance



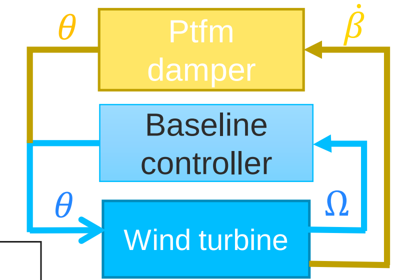


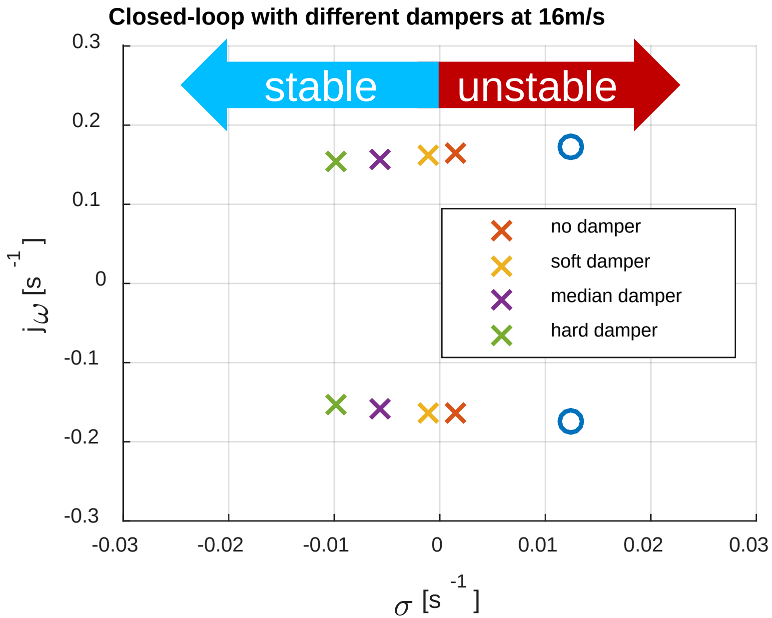


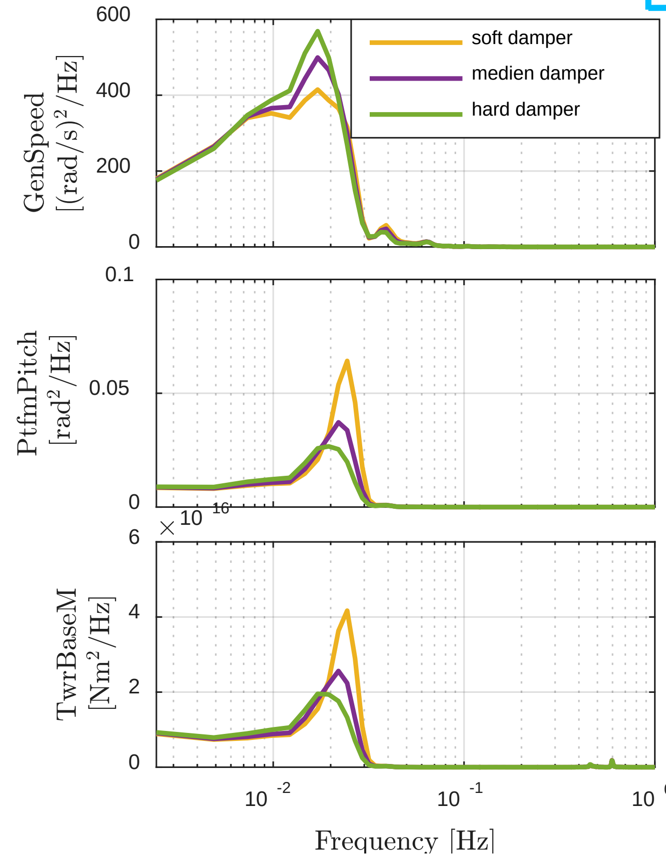
Higher stability is at the cost of the control performance.

MISO: Feedback of Ptfm-Pitch to Blade-pitch

How does it work?



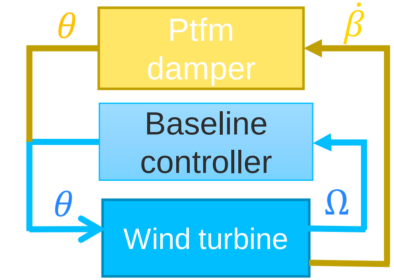


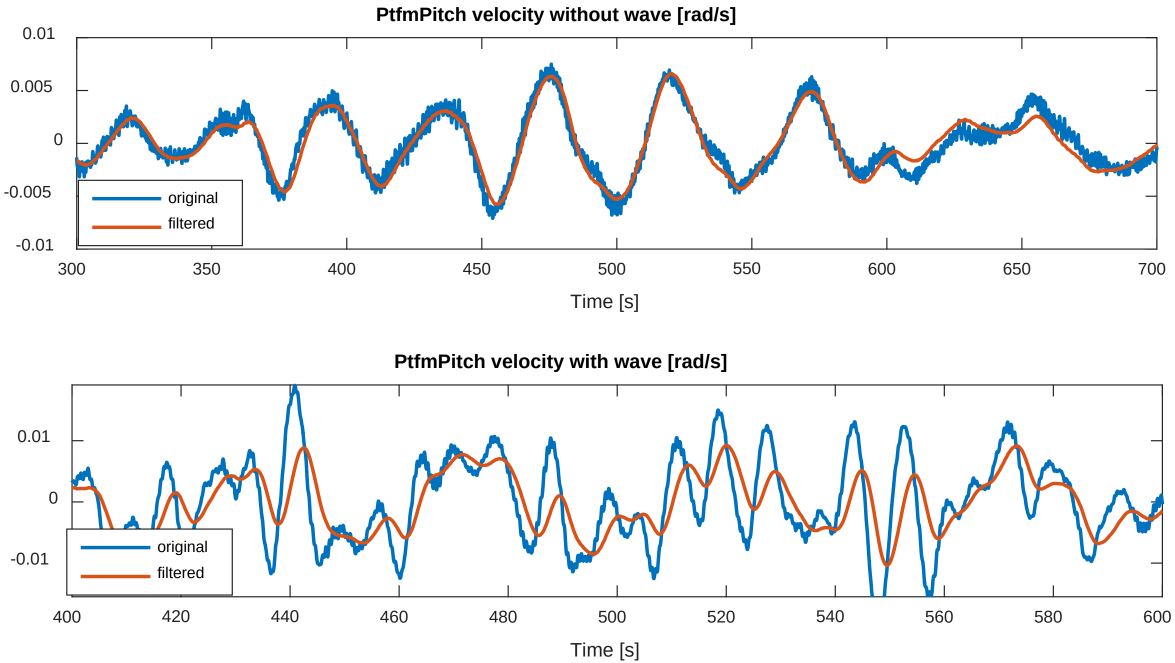


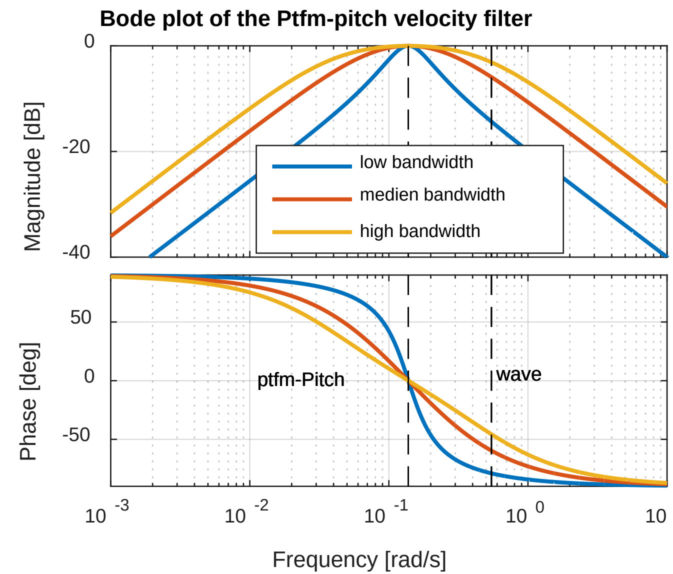
Ptfm-damper can increase the pitch stability, however the trade-off between stability and control performance still exist.

MISO: Feedback of Ptfm-Pitch to Blade-pitch

Problem with wave



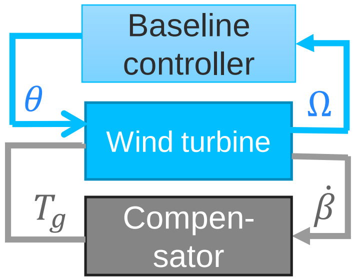


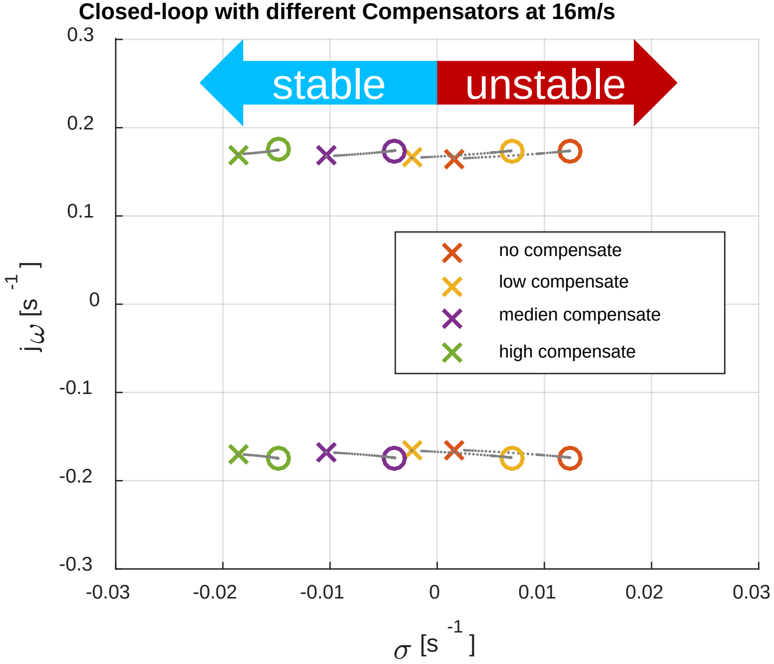


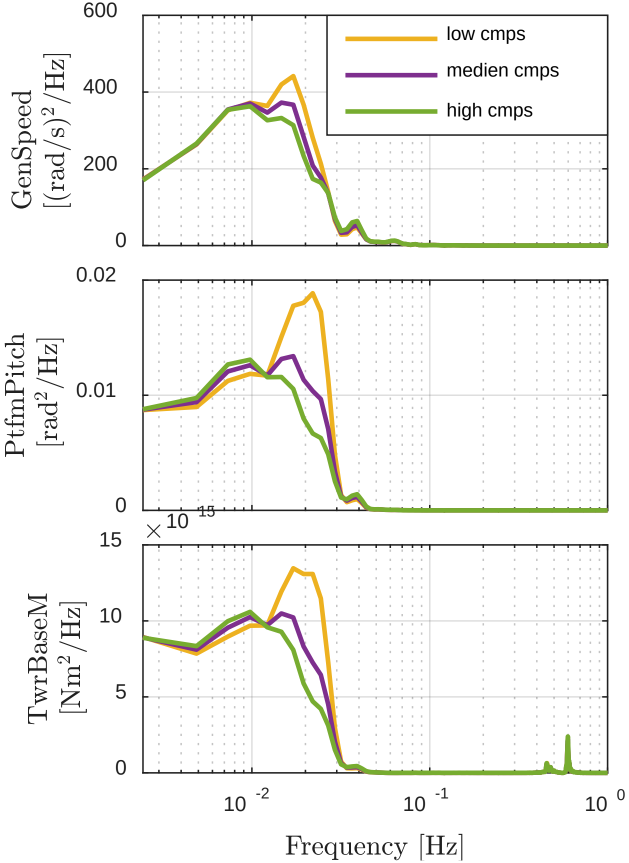
Due to the difficulty on filtering out the signal in wave frequencies, Ptfm Damper doesn‘t work well for Ptfms with pitch eigen-frequency close to the wave frequencies,

MIMO: Feedback of Ptfm Pitch to Gen Torque

How does it work?



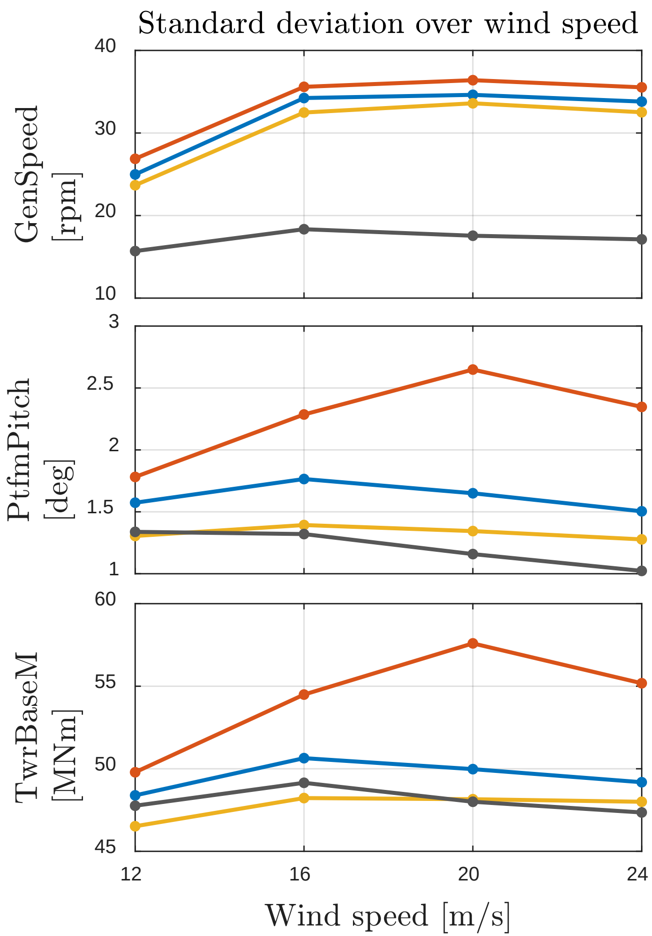


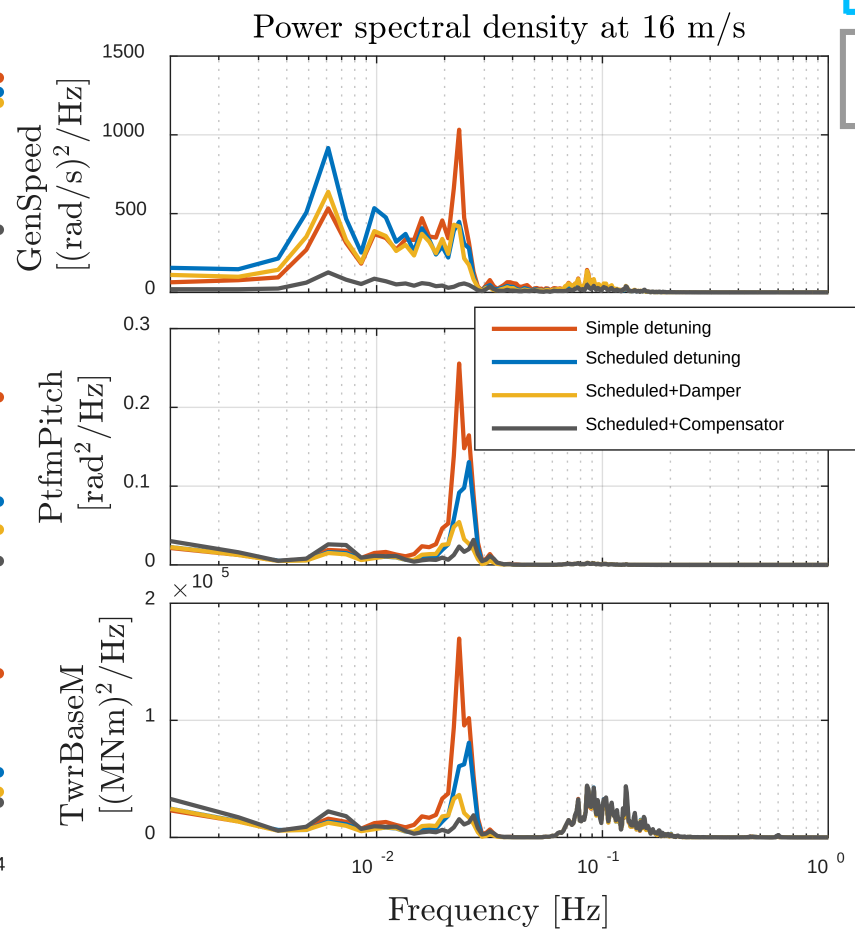


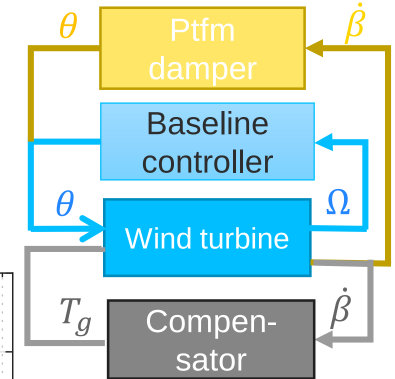
A RHPZ-Compensator can solve the trade-off problem by moving the positive zero to the left s-place, however will increase the maximum loads on the generator torque.

How great is the impact of controller on FOWTs?

Wind: [12, 16, 20, 24] m/s, IEC3-A class **Wave:** Hs 5.7 [m], Tp 11.5 [s]







Conclusion

- System motions and loads are strongly influenced by the controller. These can be significantly reduced by a well designed controller.

- Additional loops can improve the control performance. However, all of the state-of-art approaches have drawbacks.

- Improvement of control performance in wave frequency region is difficult with current sensor and actuators.

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Thank you!

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