Consequences of load mitigation control strategies for a floating wind turbine

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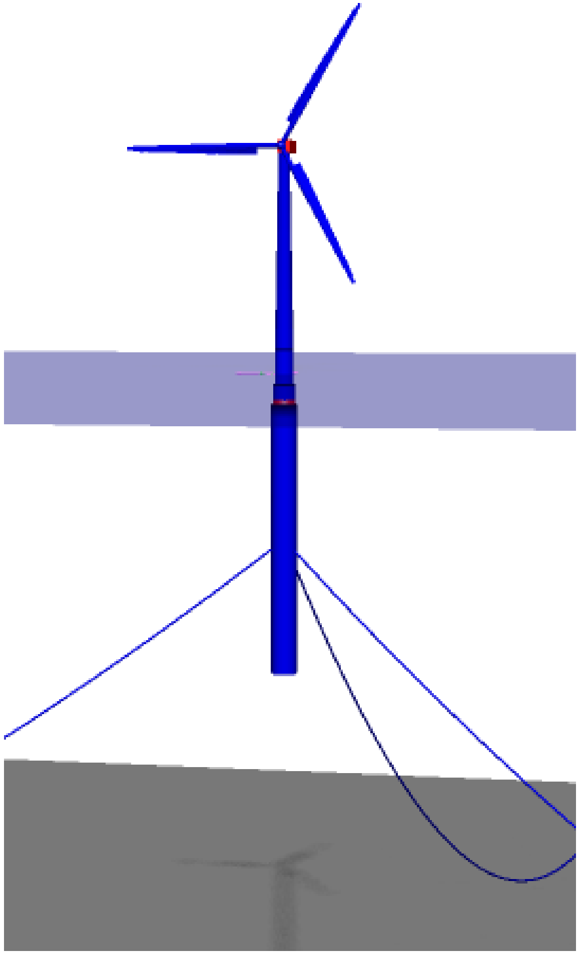

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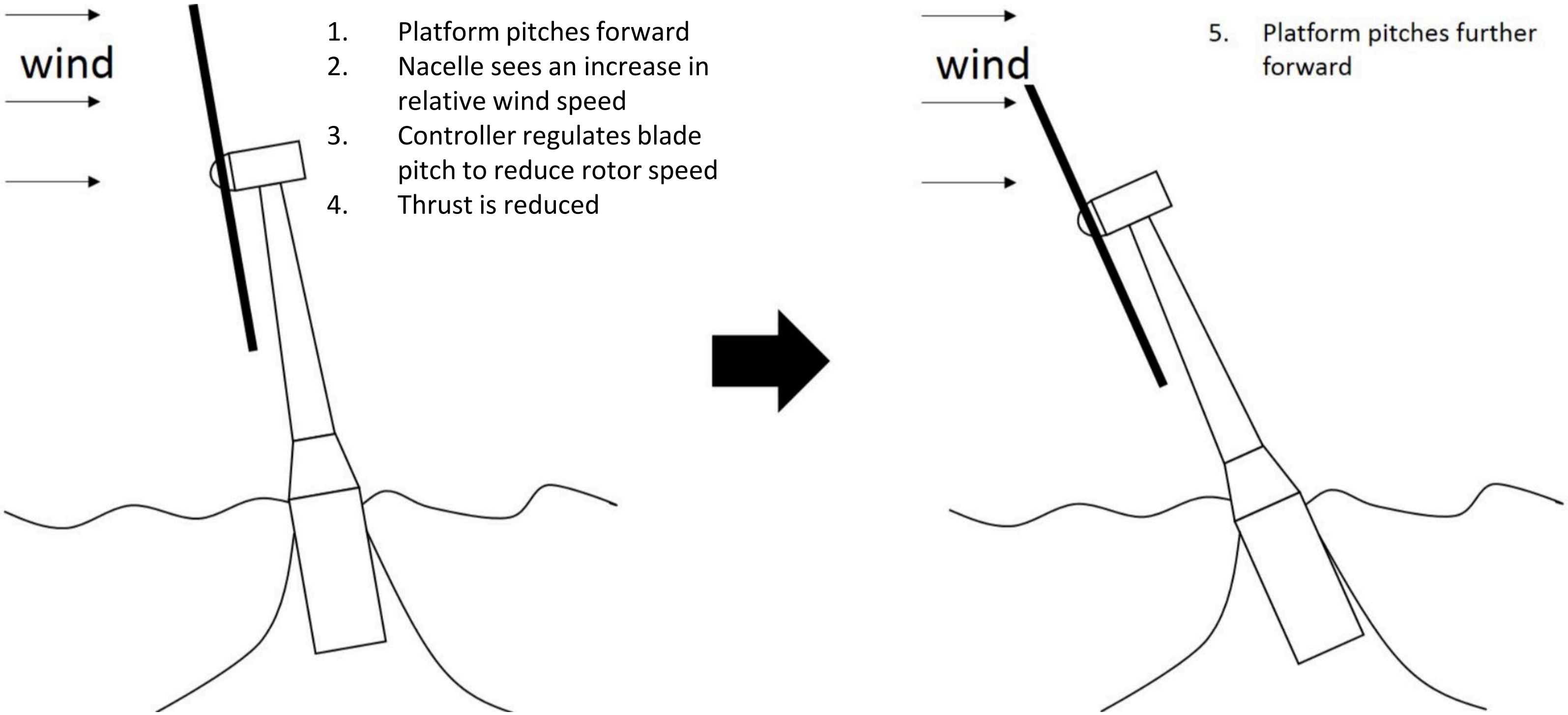
Control-induced resonance

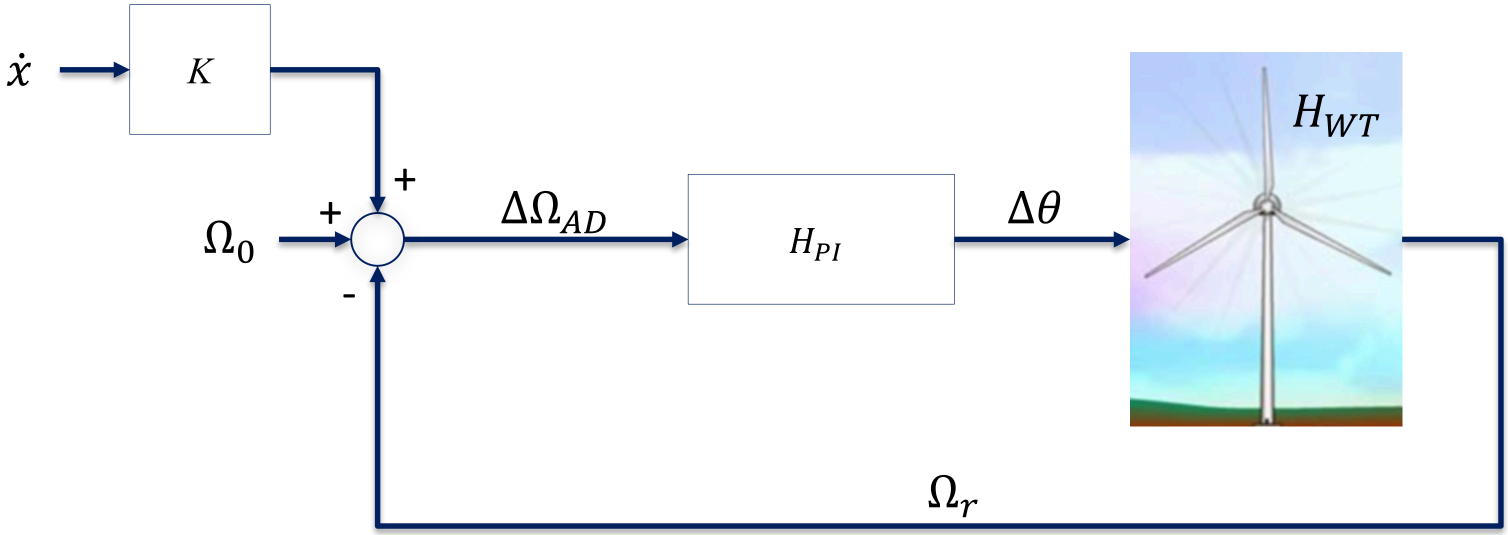


1. Platform pitches forward
2. Nacelle sees an increase in relative wind speed
3. Controller regulates blade pitch to reduce rotor speed
4. Thrust is reduced

5. Platform pitches further forward

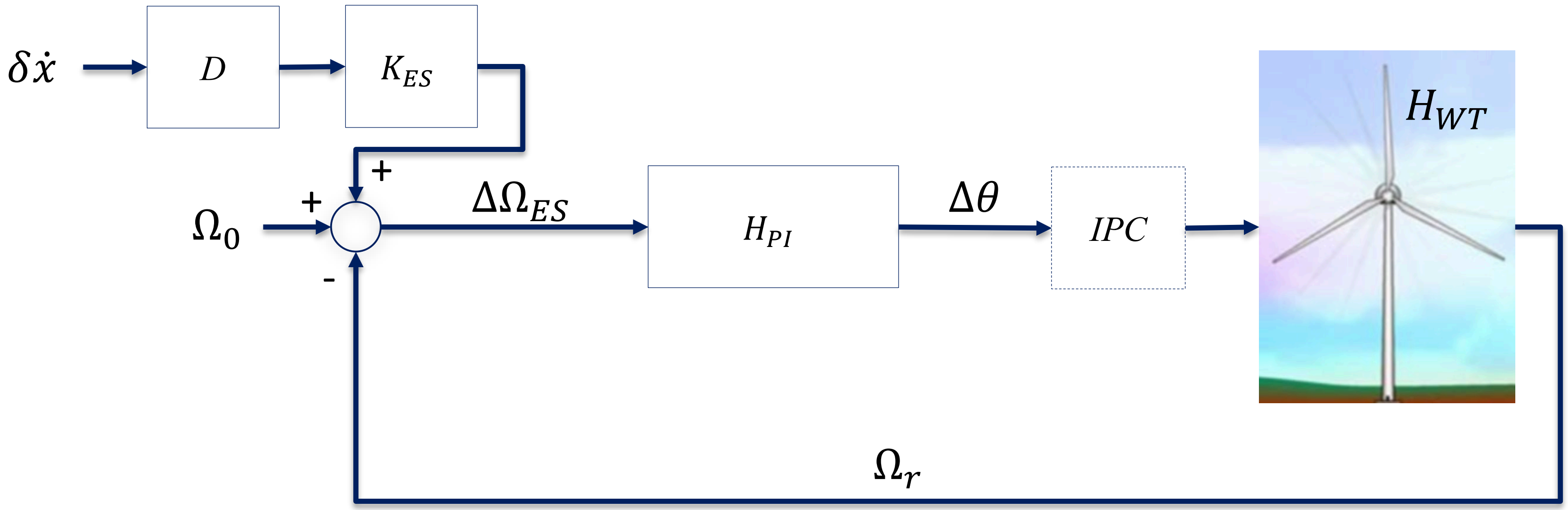
Load-mitigation control strategies for FWTs

- AD: Nacelle velocity feedback (added damping)
  - Lackner, 2007
  - Modify rotor speed reference with nacelle velocity measurement



Load-mitigation control strategies for FWTs

- ES: Energy shaping controller
  - Pedersen, 2017
  - Modify rotor speed reference using the deviation of nacelle velocity from its value in equilibrium



Load-mitigation control strategies for FWTs

- AD: Nacelle velocity feedback (added damping)
  - Lackner, 2007
  - Modify rotor speed reference with nacelle velocity measurement
- ES w/o IPC: Energy shaping controller
  - Pedersen, 2017
- ES w/IPC: Energy shaping controller with IPC
  - Try to reduce individual blade root bending moments
  - IPC follows Lackner and van Kuik, 2009

Known consequences of load-mitigating control strategies

- AD: reduction in pitch motion, increased variations in power and rotor speed
- ES: stable control, expected reductions in pitch motions
- IPC: reduce blade root bending moments, increase pitch actuator use

What about the drivetrain?

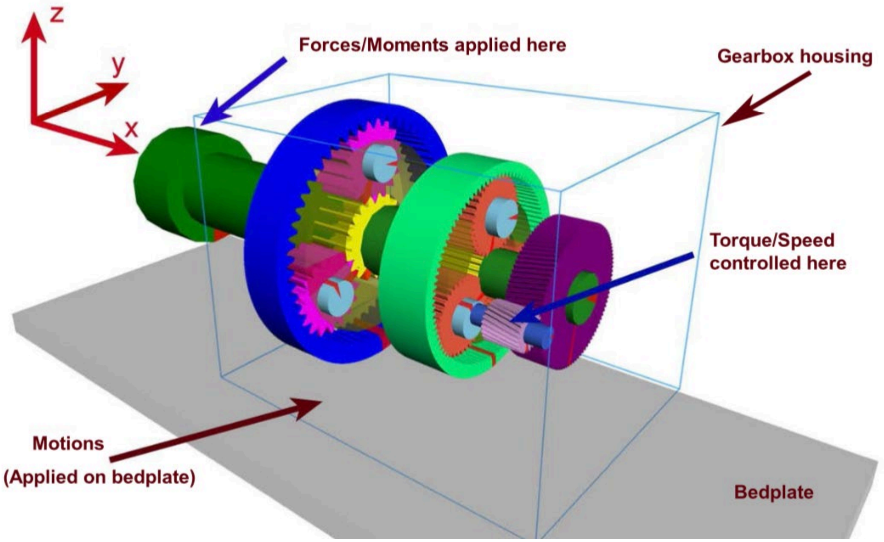


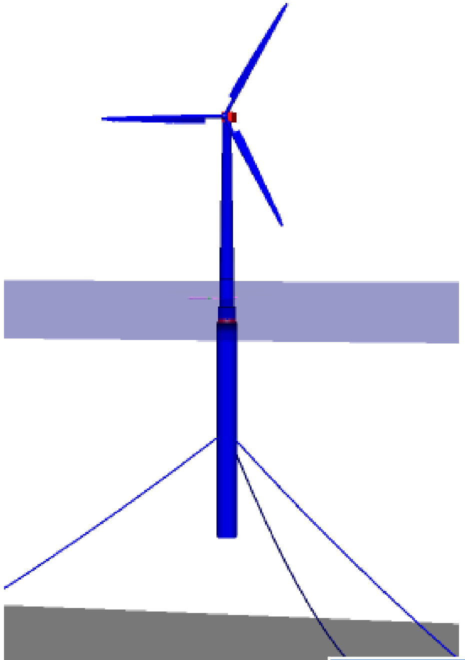
Image: Nejad et al., 2016

Outline

- Methodology
- Global analysis results
- Drivetrain loads
- Conclusions

Methodology: Decoupled simulations

Global analysis: SIMA



6x1hr

Drivetrain analysis: SIMPACK

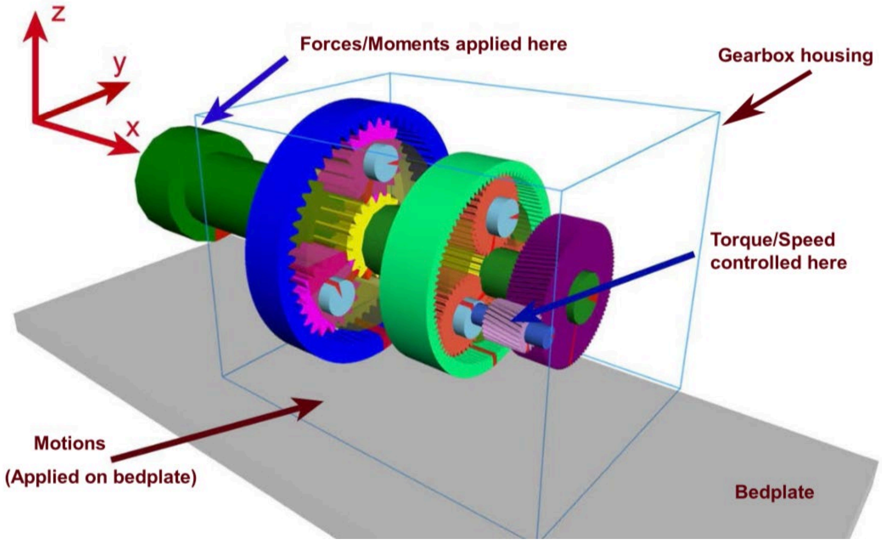


Image: Nejad et al., 2016

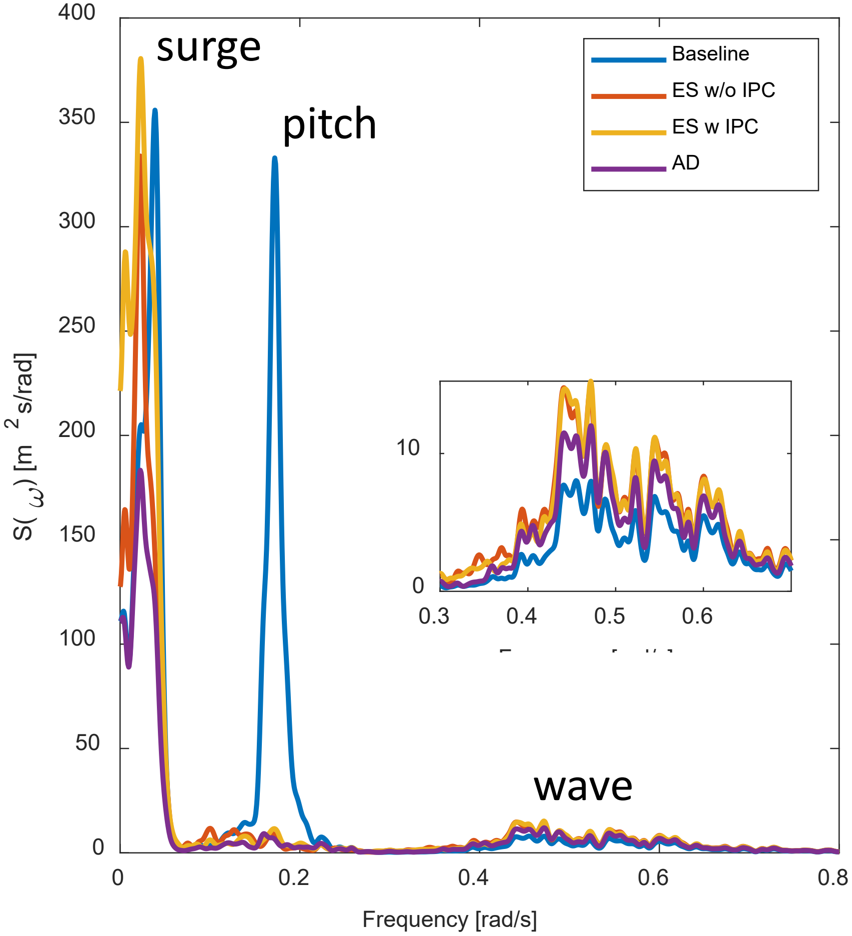
1x1hr

	EC 1	EC 2	EC 3
Significant wave height, H_s [m]	5.0	4.0	5.5
Peak period, T_p [s]	12.0	10.0	14.0
Mean wind speed, U [m/s]	12.0	14.0	20.0
Turbulence intensity, I [-]	0.15	0.14	0.12

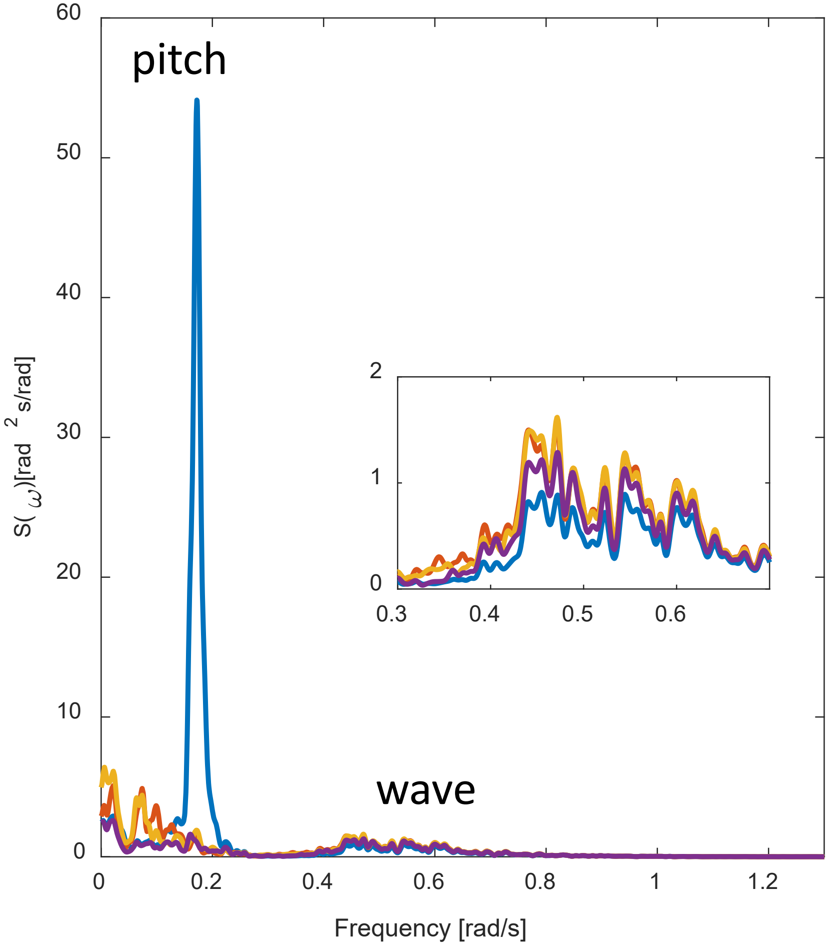
Performance indicators

- Tower base 1-hr fatigue damage
  - Stresses from global analysis, rainflow counting, SN curve, Miner’s rule
- Gear root 1-hr fatigue damage
  - Forces from MBS analysis, load duration distribution method
- Bearing 1-hr fatigue damage
  - Forces from MBS analysis, load duration distribution method
- Standard deviation of power output
  - Direct result from global analysis

Global motions, EC1

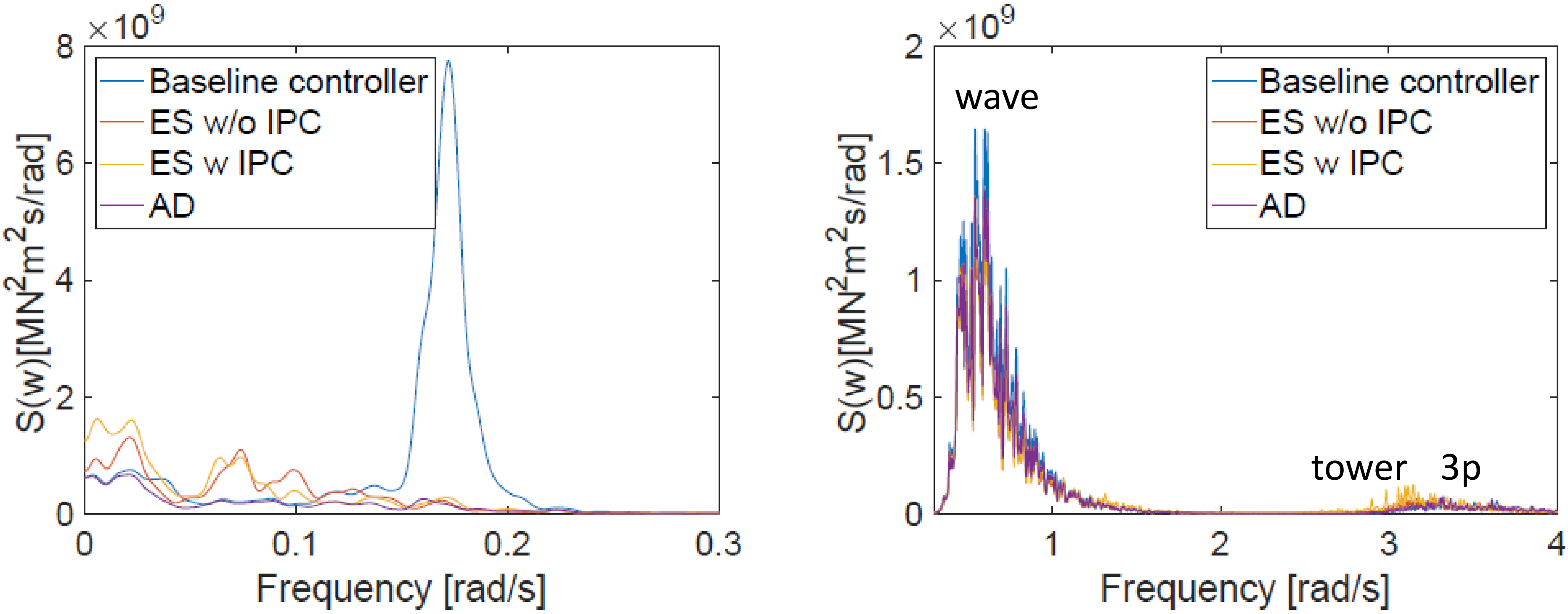


Surge



Pitch

Tower base fore-aft bending moments



Gearbox topology

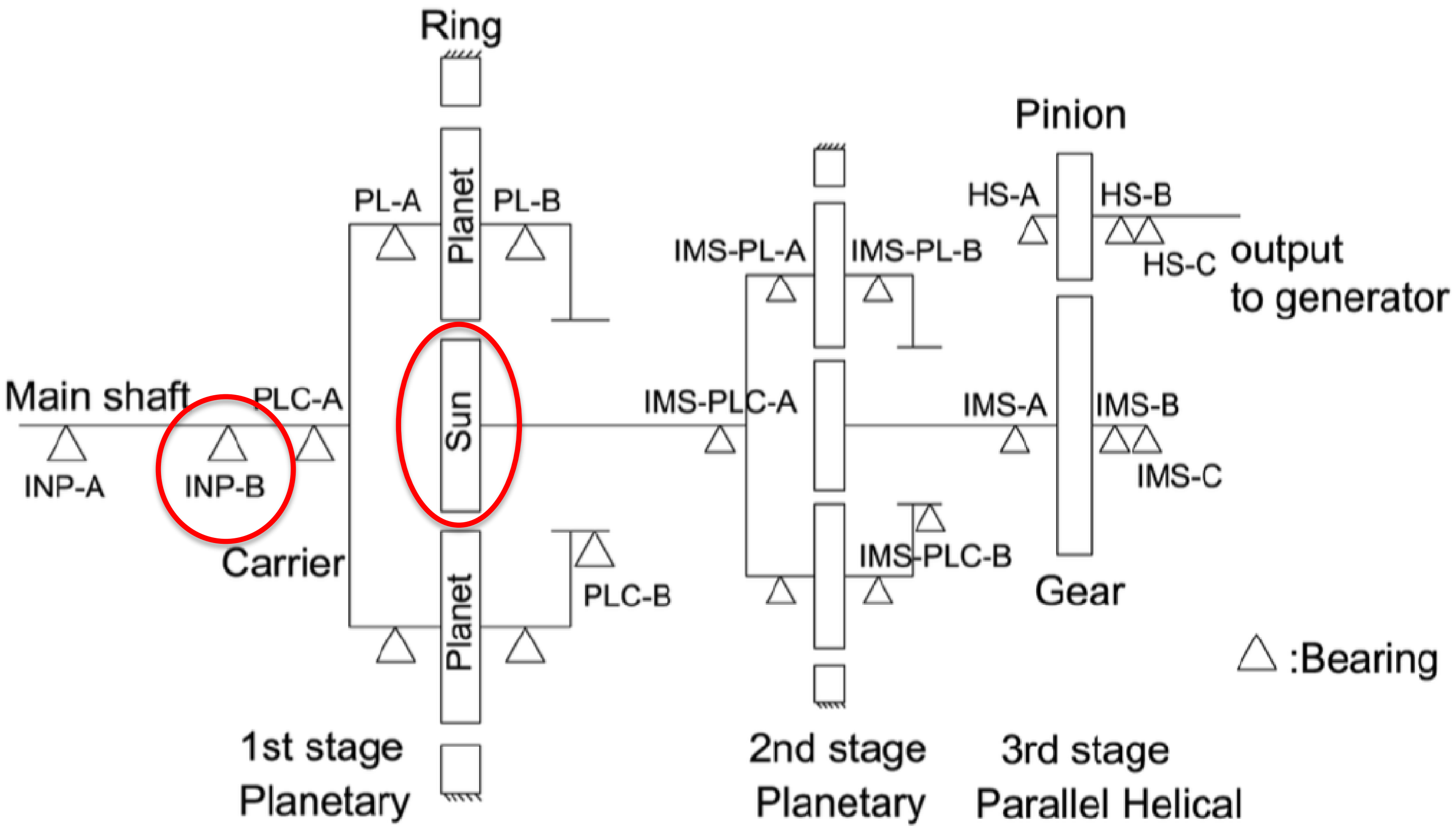
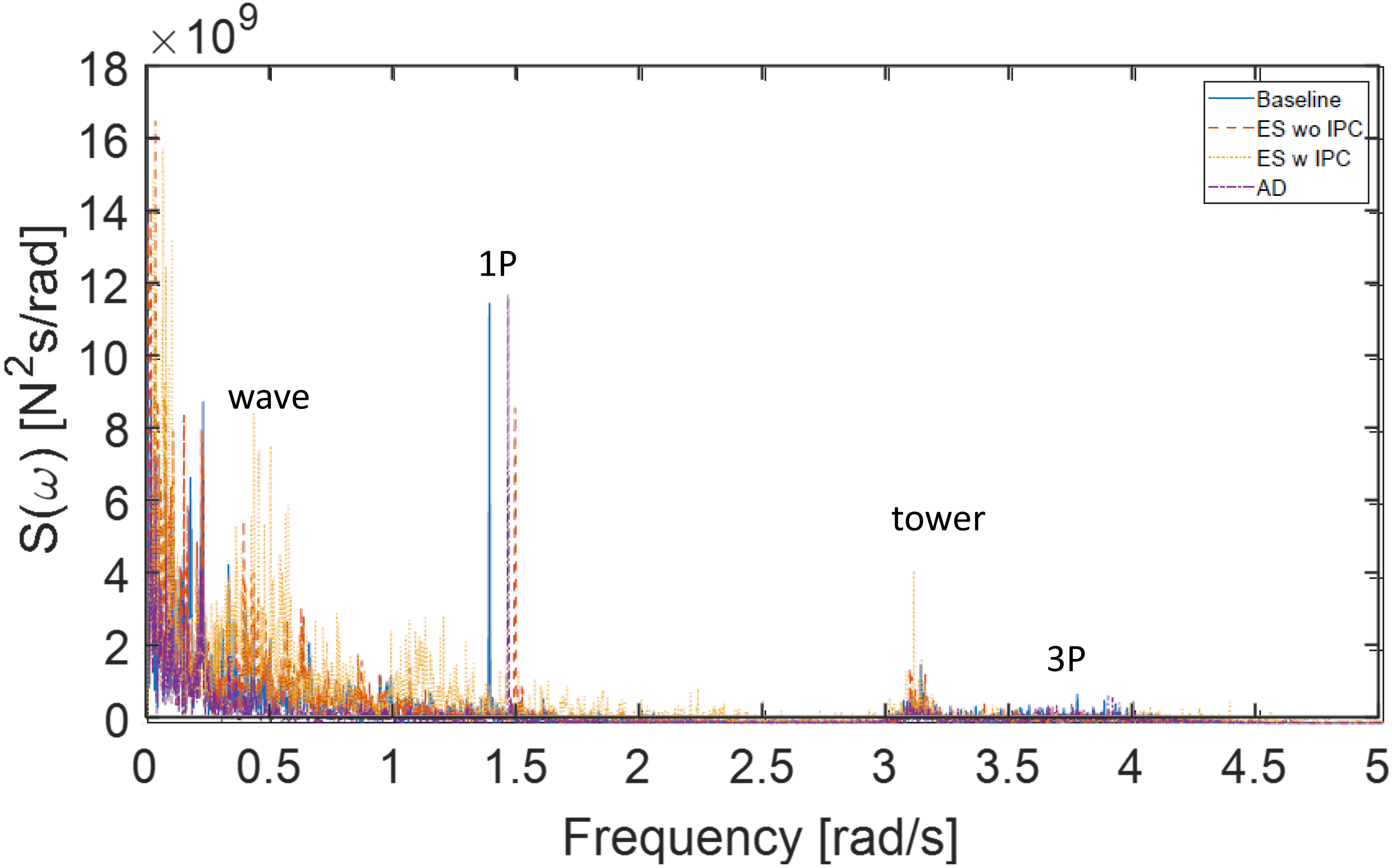
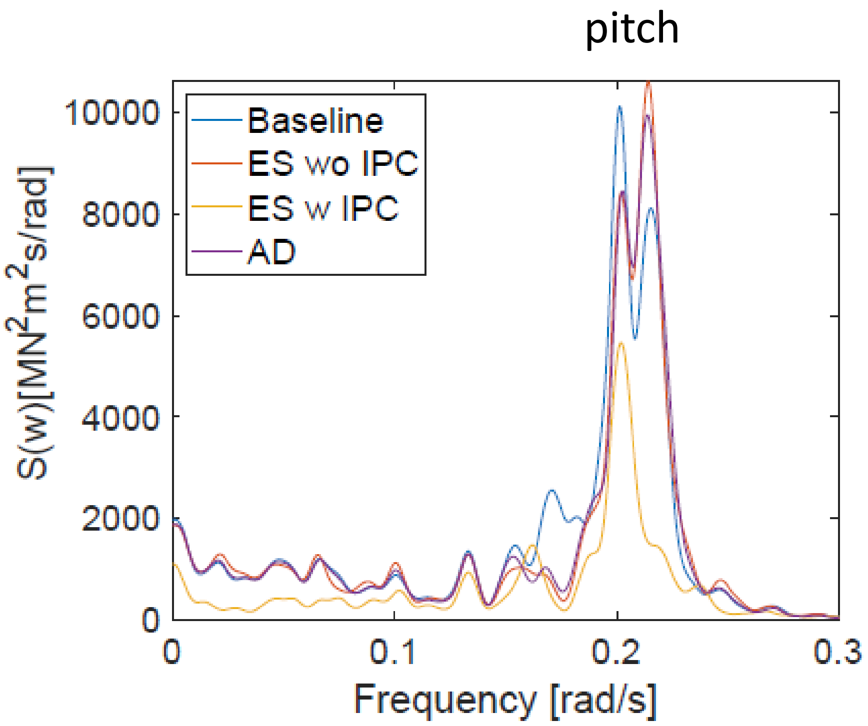


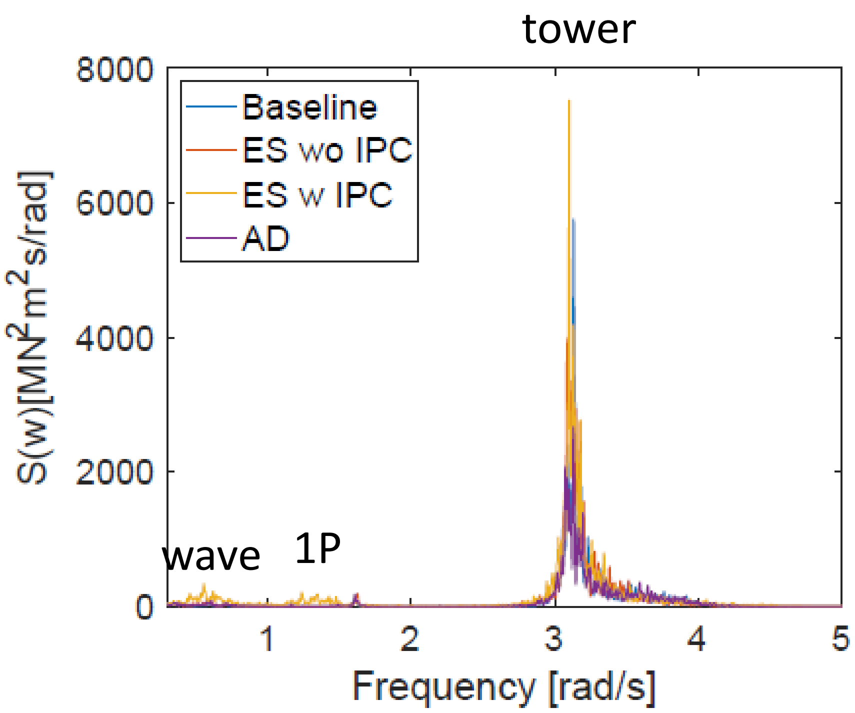
Image: Nejad et al., 2016

Sun gear circumferential force



Tower top side-side force


pitch

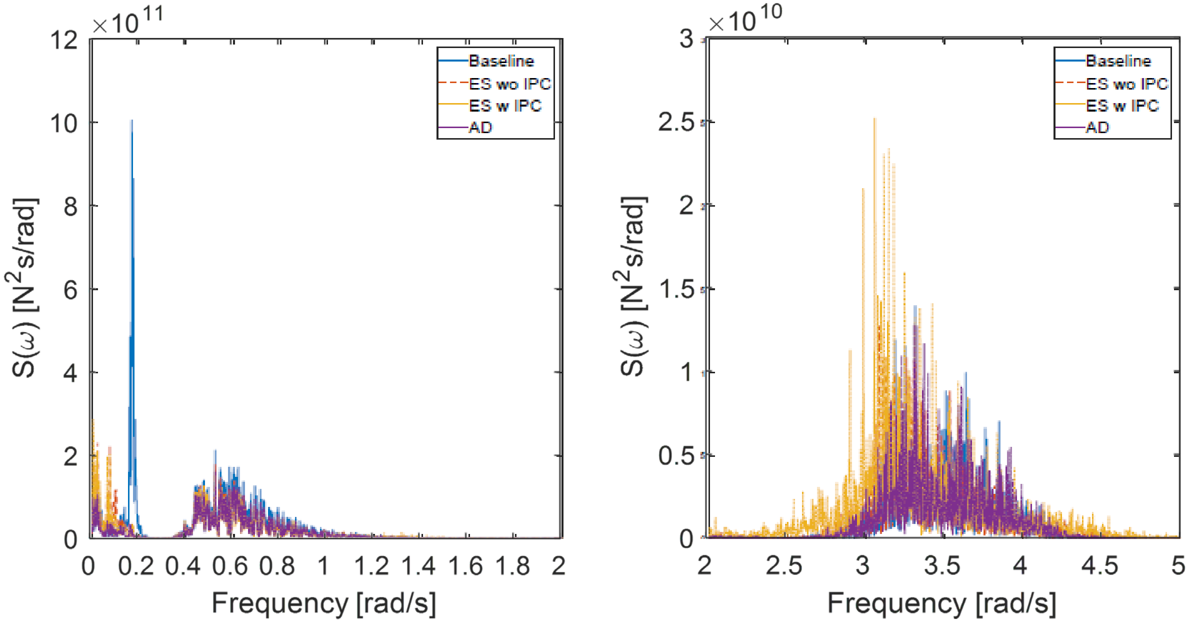

tower

wave

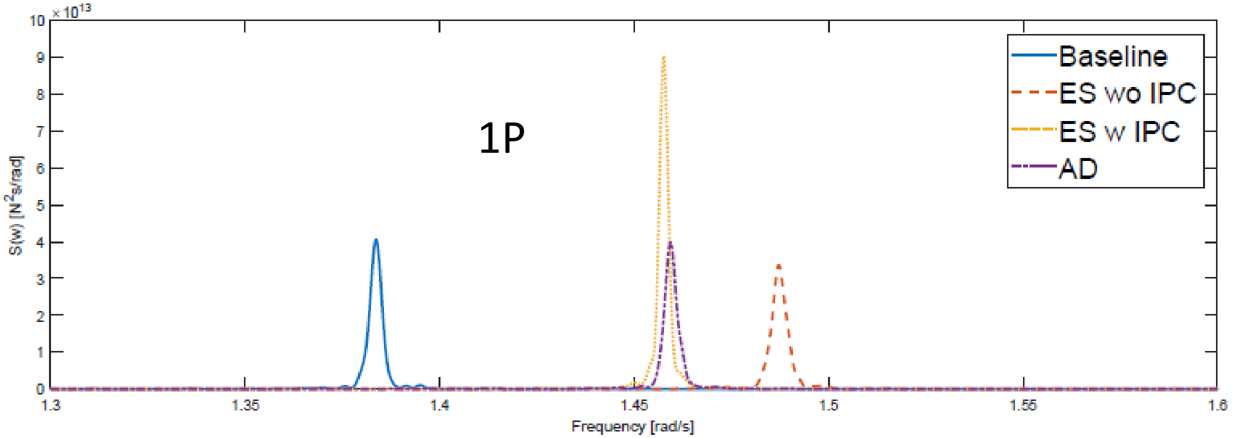
1P

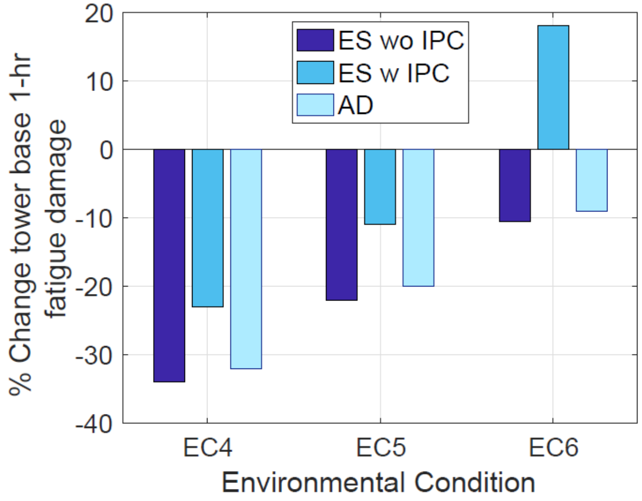
Bearing INPB

axial

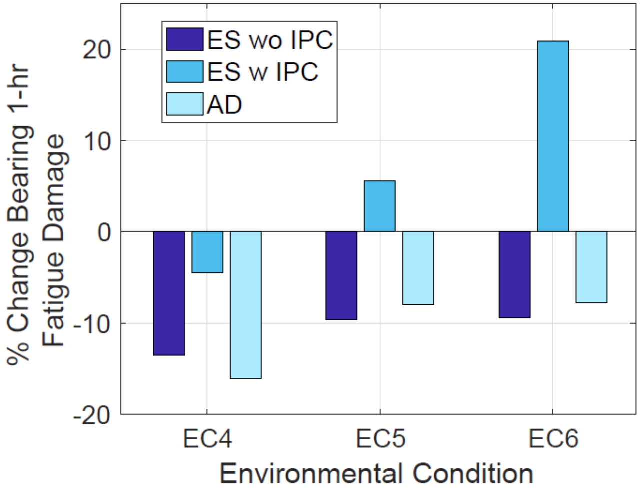


radial

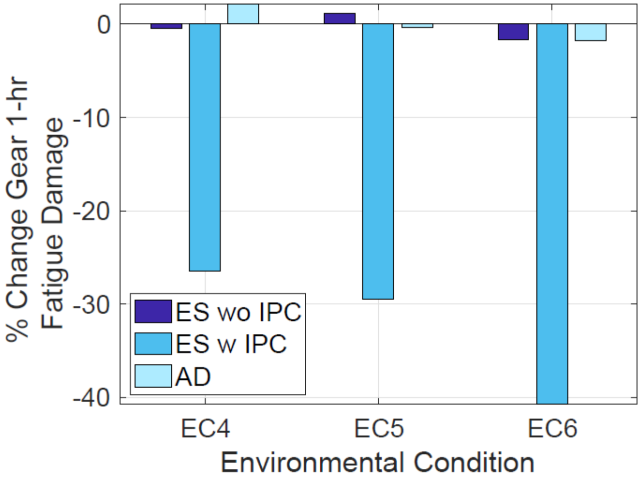




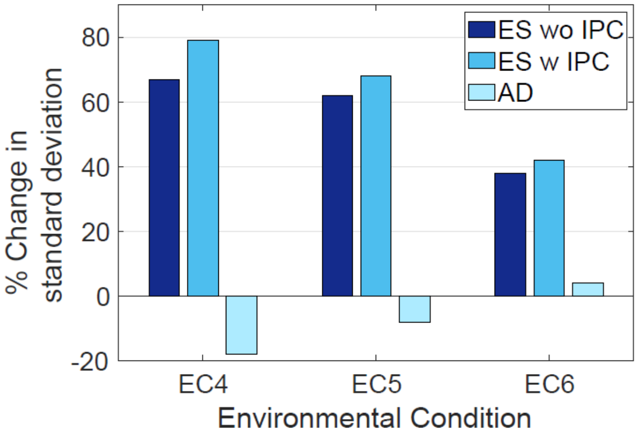
(a) $\chi_{D_{TowerBase}}$



(b) $\chi_{D_{bearing}}$



(c) $\chi_{D_{gear}}$



(d) $\chi_{\sigma_{power}}$

Conclusions

- Global and drivetrain responses of a spar floating wind turbine
- Three control modifications
  - active damping (AD)
  - energy shaping control (ES w/o IPC),
  - energy shaping control with individual blade pitch (ES w/IPC).
- Improved platform motion responses in surge and pitch
- ES adds some responses at i.e. wave frequency
- IPC reduces blade root flap-wise bending, but introduces excitation of tower top shear force at rotor frequency.
- The reduced blade root moment therefore comes with a cost of increased radial load resonance in drivetrain gears and bearings.
- Drivetrain should be considered when assessing control performance