Active Tip Deflection Control For Wind Turbines

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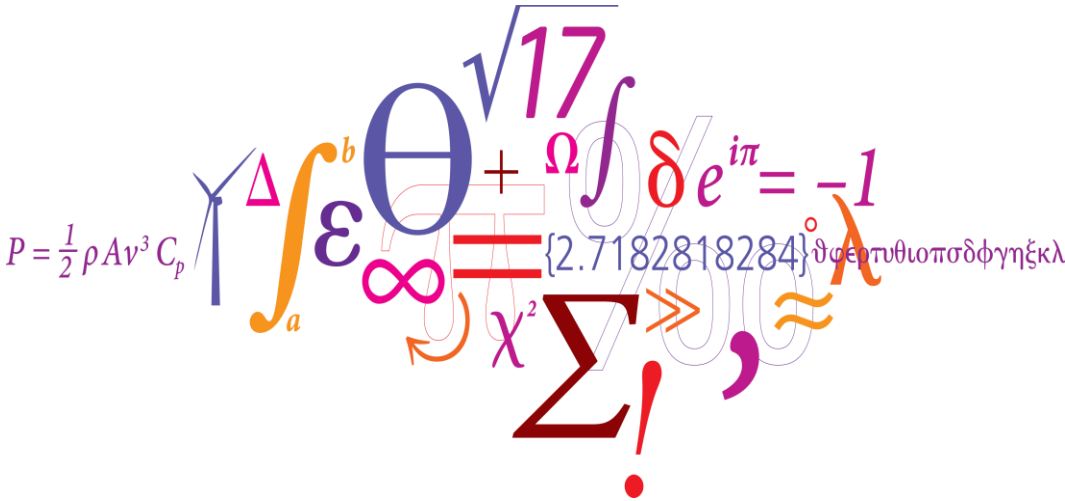

DTU Wind Energy
Department of Wind Energy

Thesis Goals

- Develop an **Individual Pitch Control (IPC)** system for wind turbines using **flapwise tip deflection measurements**.
- Investigate **fatigue load reductions** in rotating and non-rotating turbine components using IPC.
- Investigate **increasing blade-tower clearance** using IPC.

Motivation

- The increasing size of wind turbines causes large differential loads over the rotor plane.
- Load fluctuations lead to increased fatigue damage in components.
- IPC is able to reduce differential loads and fatigue loads.
- IPC studies typically use strain gauges sensors and rarely investigate alternative sensors.
- IPC studies focus on load reduction rather than increasing tower clearance.

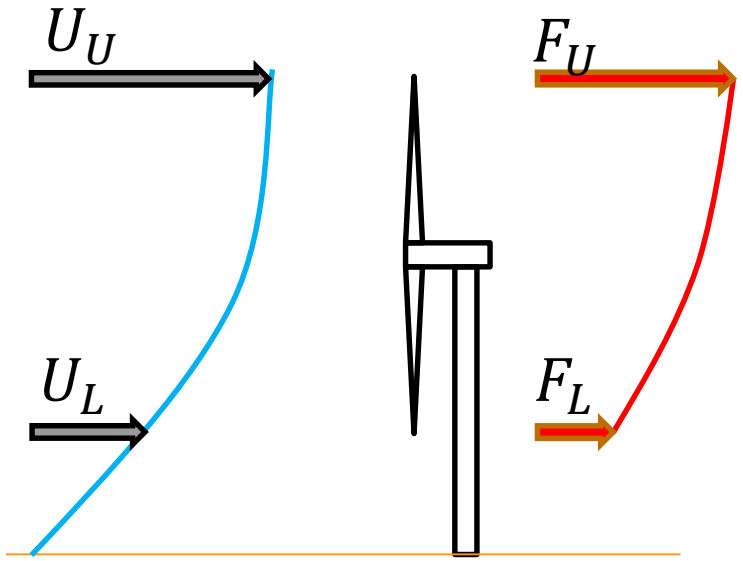

Fig 1: Without IPC

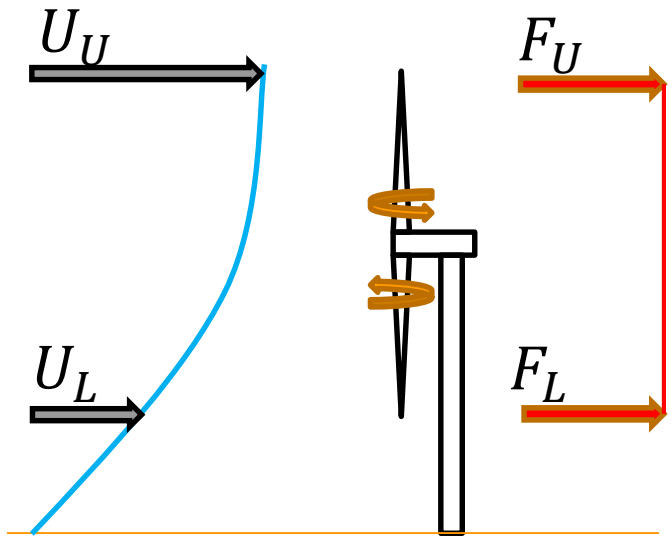

Fig 2: With IPC

IPC Controller Frequency Response

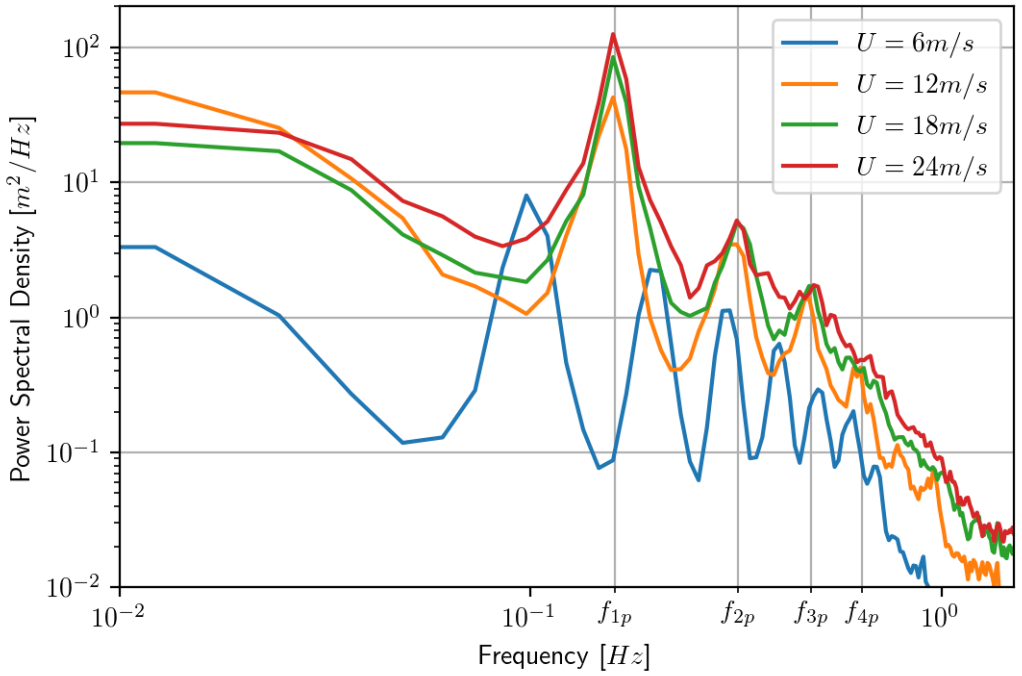

Fig 3: Tip deflection power spectral density.

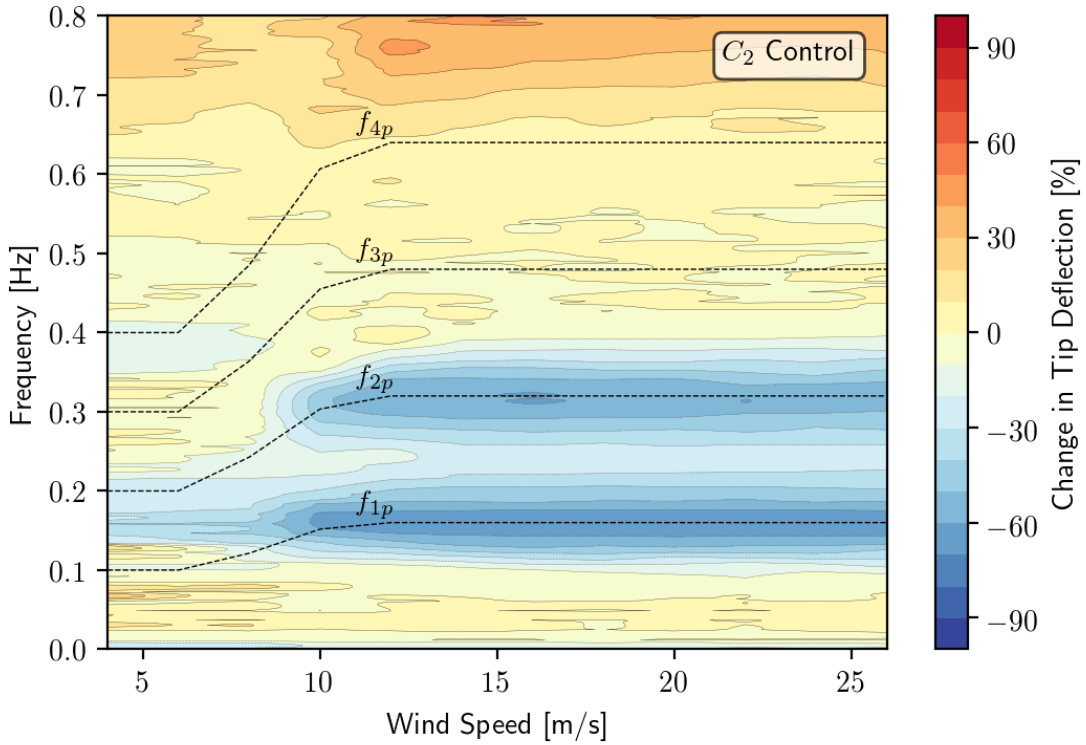

Fig 4: Frequency sensitivity contour for IPC controller.

Load Reductions Using IPC

- **25.10%** reduction in lifetime equivalent load in blades
- **13.19%** reduction in main bearing lifetime equivalent loads (tilt)
- **17.88%** reduction main bearing lifetime equivalent loads (yaw)

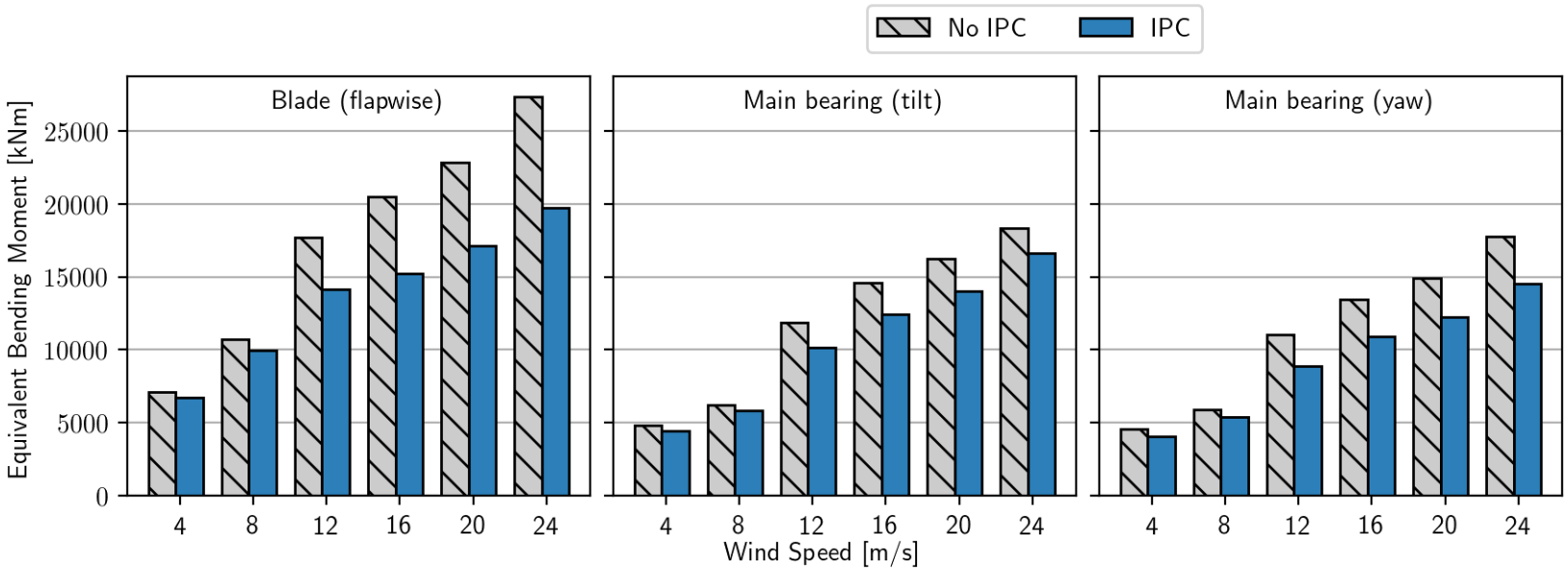

Fig 5: 1Hz equivalent loads

Blade Tip Tracking

IPC controller can successfully guide blade tips along sinusoidal trajectories (out of plane).

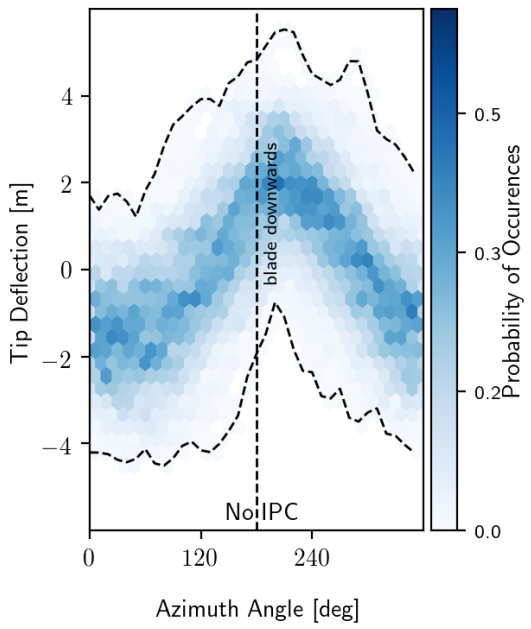

Fig 6: Tip deflection Perturbation **without IPC** (Blade 1, U=18m/s, NTM)

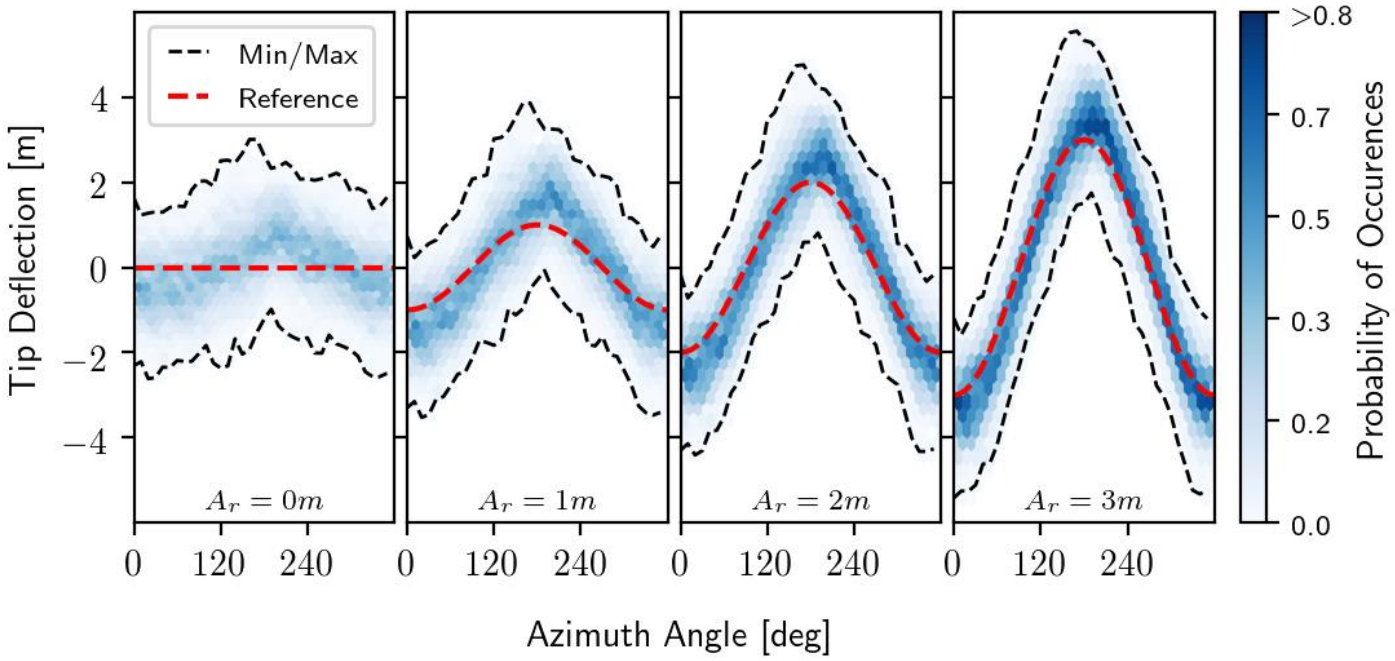

Fig 7: Tip deflection Perturbation **with IPC** (Blade 1, U=18m/s, NTM)

Effect of Tip Tracking on Tower Clearance

- Exact distance between blade tips and tower surface is measured in HAWC2.

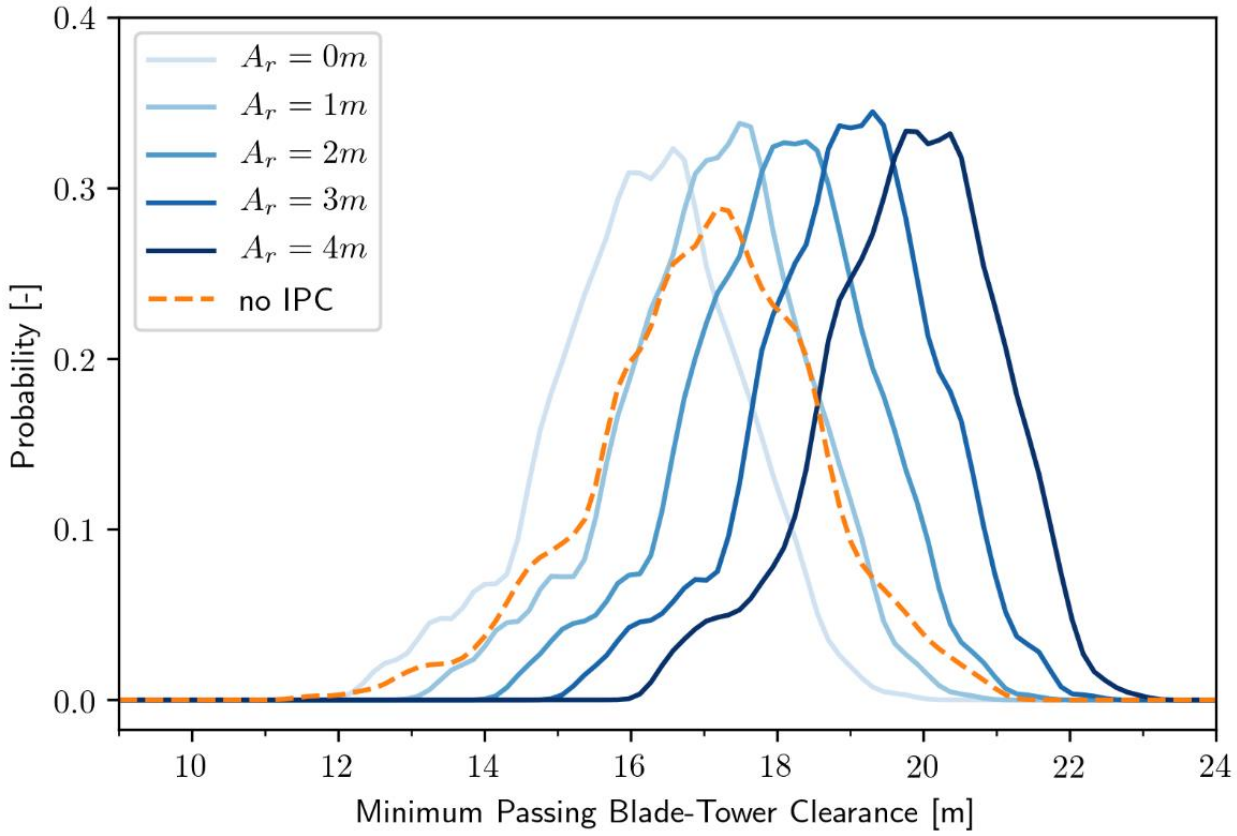

Fig 8: Probability distribution of minimum passing blade-tower clearance (**Normal shear**, U=18m/s)

Effect of Tip Tracking on Equivalent Loads

- Negligible influence on bearing loads.
- Blade loads increase with reference amplitude.

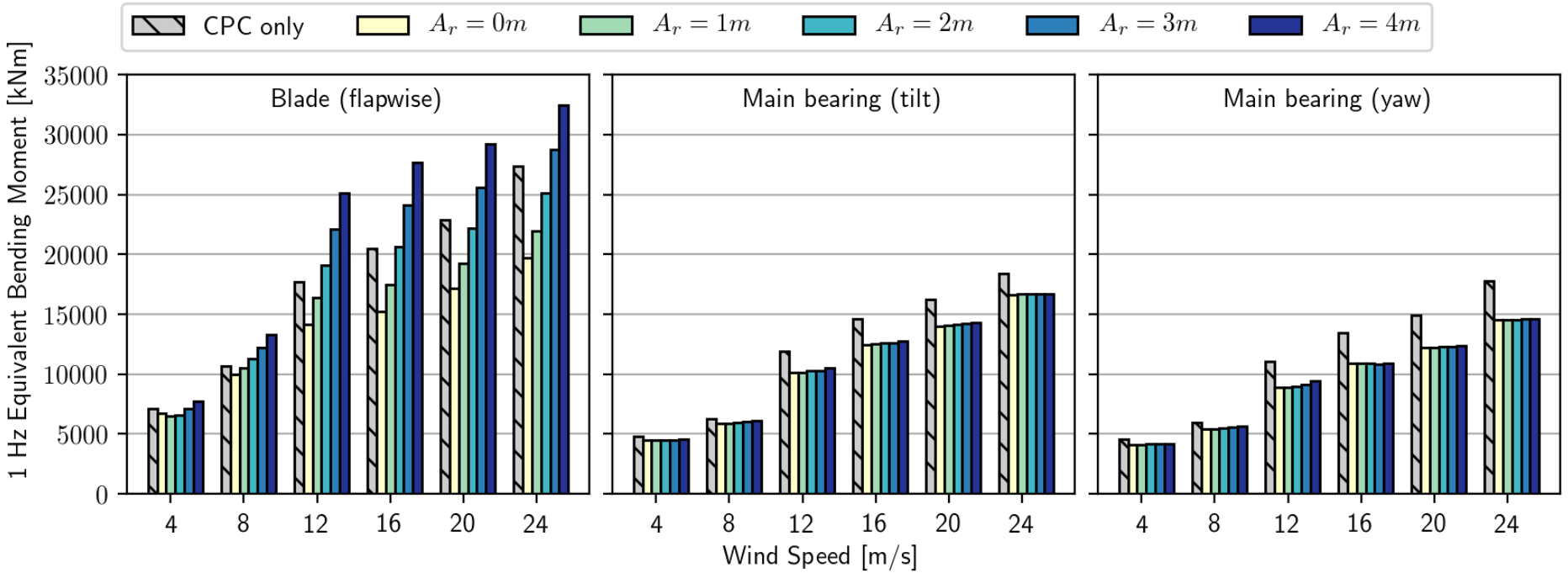

Fig 35: 1Hz short term equivalent loads

Are pitch rate limits exceeded?

- Pitch rate limit of 10 °/s is suggested by Bossanyi, 2000.
- Pitch rate remains within limits **99.86%** of simulation time (A_r = 4m, U=18m/s).

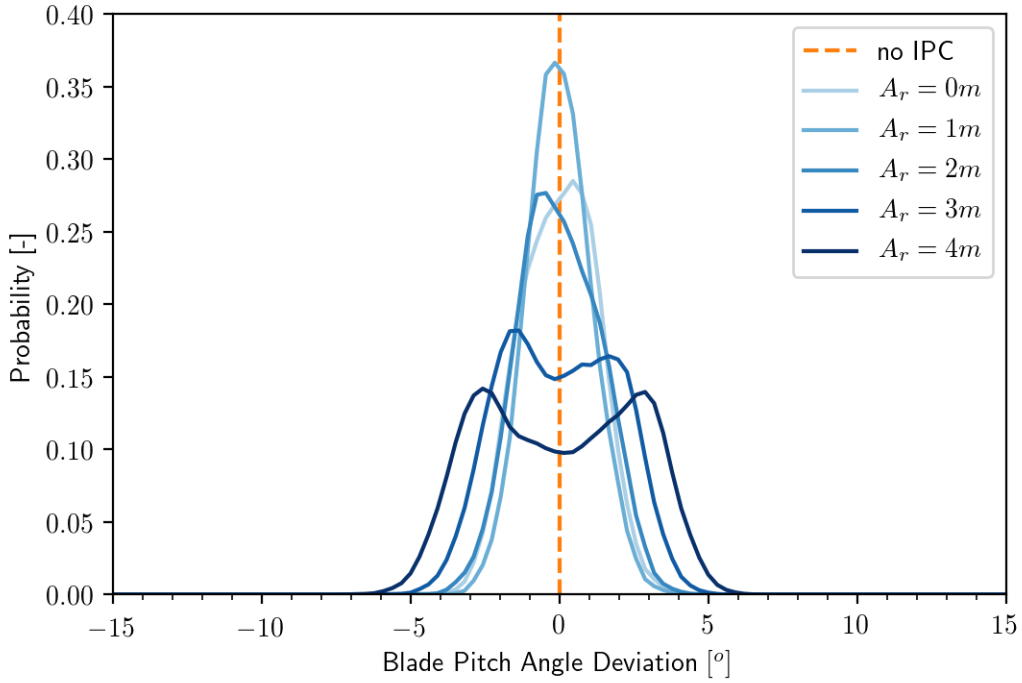

Fig 36: **Normal shear** pitch rate distribution

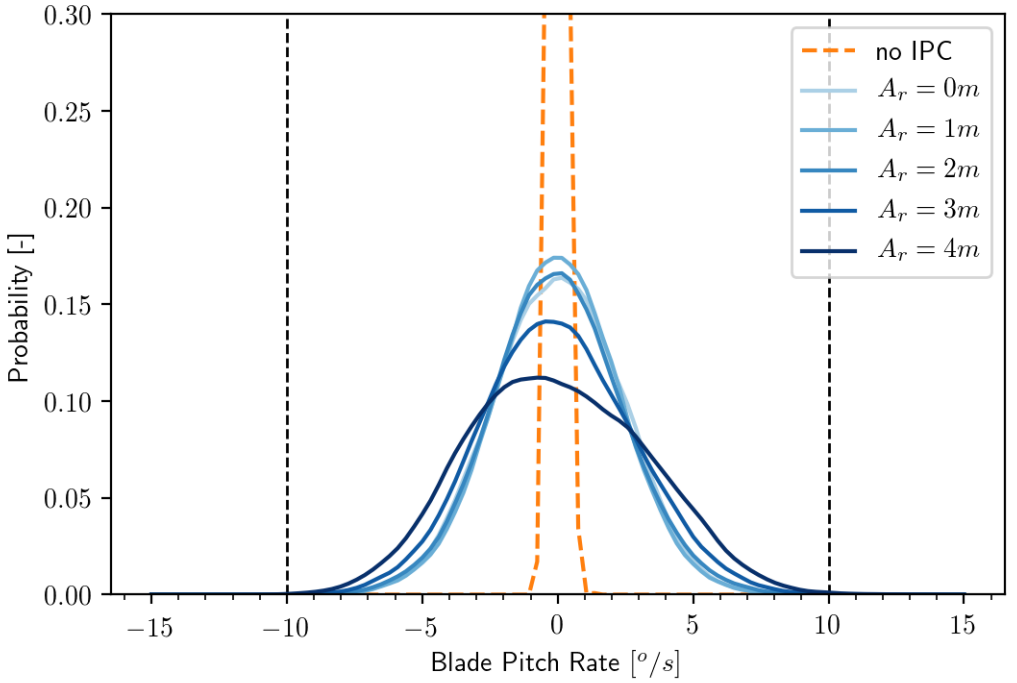

Fig 37: **Inverse shear** pitch rate distribution

Effect on power output

- Negligible influence on power output due to the decoupling of IPC and CPC.

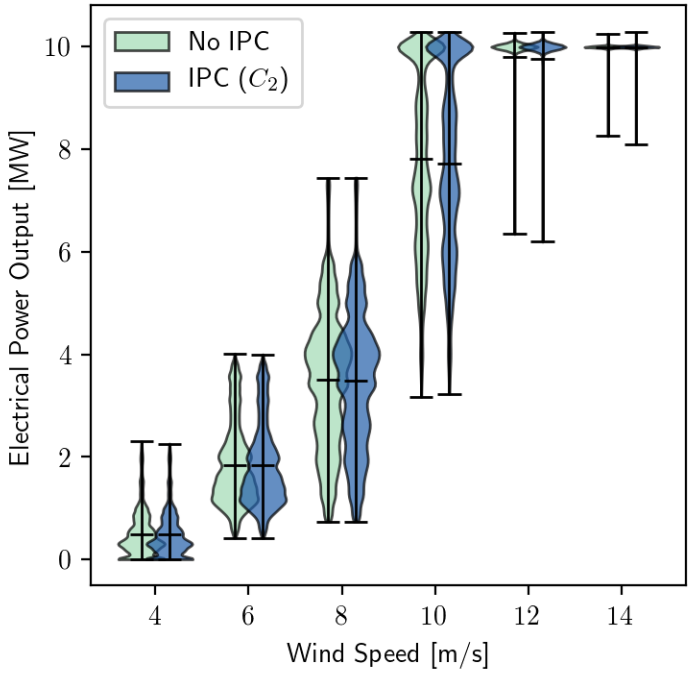

Fig 22: Below rated electrical power output distribution.

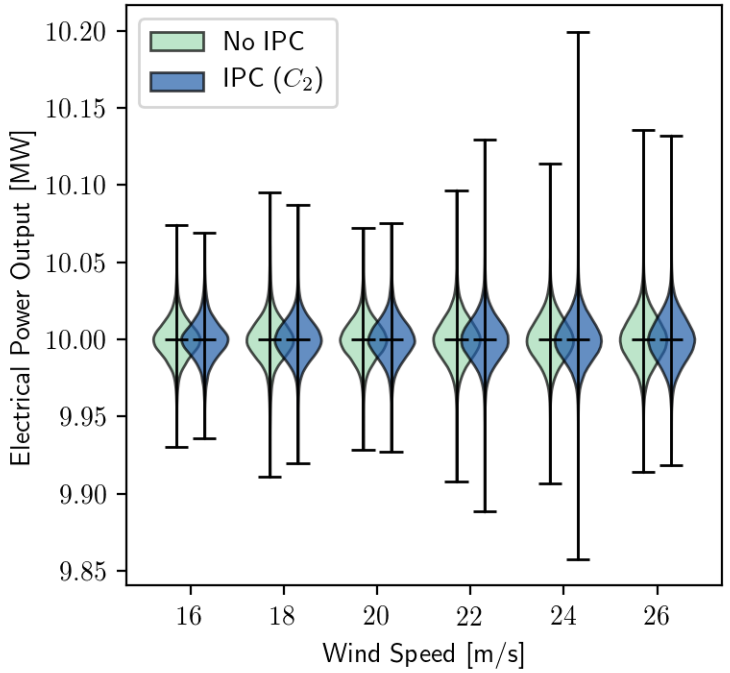

Fig 23: Above rated electrical power output distribution.

Summary

An individual pitch controller was presented which is able to achieve:

- Load reductions in rotating and non-rotating components
- Increased blade-tower clearance
- Negligible effect on power output
- Blade pitch activity within reasonable operating ranges