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A state-of-the-art controller for the 5MW UPWIND reference wind turbine

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Abstract summary

The UPWIND 5MW reference turbine is being used across the UPWIND project. It is a fictitious wind turbine typical of a modern state-of-the-art commercial turbine of this size. The original turbine definition included a fairly simple power production controller embodying collective blade pitch and generator torque control. Many commercial wind turbine controllers are now significantly more advanced than this. Since the controller plays a key role in determining the loading experienced by the turbine structure, which in turn is vital for the design of the various components, it is important that the reference turbine is equipped with a state-of-the-art controller as a starting point for further investigations.

This paper presents a new power production controller which has been designed for this purpose, making use of techniques which are currently considered to be at the forefront of commercial practice. The controller includes load reduction through enhanced damping of resonances and by compensating for asymmetrical wind loading using both first and second harmonic individual pitch control. Other features include avoidance of tower resonance at low rpm, and non-linear gust response to avoid overspeed trips in extreme conditions. The controller design uses a pragmatic combination of classical linear methods and detailed non-linear simulations, to achieve a realistic compromise between mathematical sophistication and practical usability.

Objectives

The objectives of the work are:

•To design a power production controller which achieves a good compromise between energy production and loads, with a realistic level of sophistication largely based on previous work [1]
•To test the controller under realistic conditions using detailed non-linear simulations
•To demonstrate the effect of particular features of the controller.

Methods

The new controller has the following principal features:

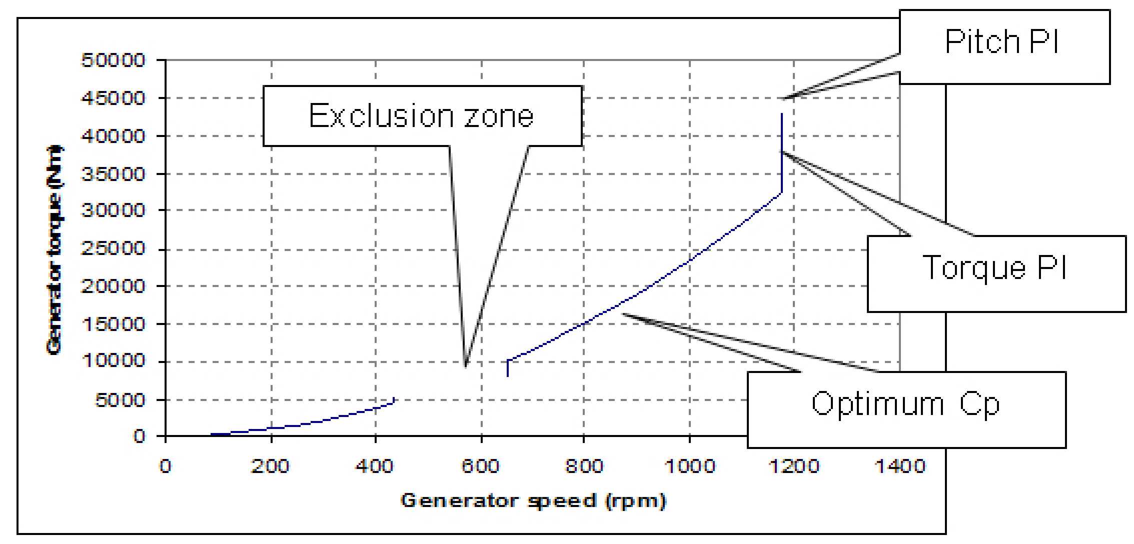
- Optimal power production over nominal speed range
- Exclusion zone to avoid tower resonance
- Speed regulation by interacting torque and collective pitch control, to ensure smooth transitions at rated and maximise energy capture
- Drive train damping filter in torque controller
- F/A tower damping by collective pitch control (small effect)
- Non-linear terms to improve gust response
- 1P individual pitch control to reduce fatigue on rotating parts
- 2P individual pitch control to reduce fatigue on non-rotating parts

For optimal power production, a static torque-speed relationship is used to maintain peak power coefficient without excessive power variation, provided the speed is within the allowable range, which incorporates an exclusion zone to prevent tower excitation at the blade passing frequency.
Speed regulation uses PI controllers with additional loop-shaping filters and gain scheduling where required. These and the other control loops are designed and tuned using classical methods such as root locus plots, Bode and step responses, ensuring adequate stability margins, cross-over frequency etc. Where the control loops are not fully decoupled, one or two iterations are required to achieve a good result.

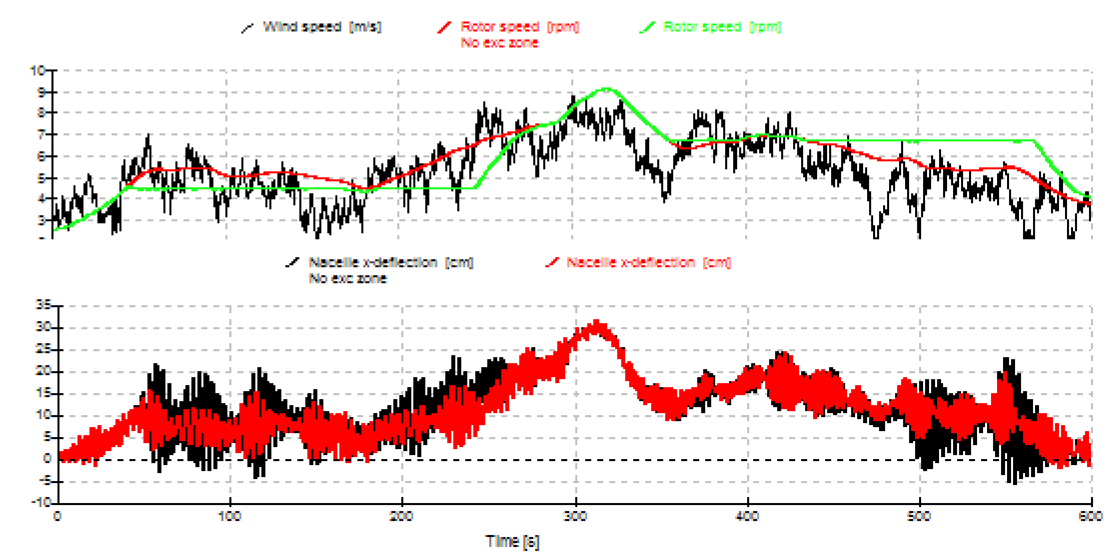
The individual pitching is based on rotational transformations into the non-rotating reference frame, where two orthogonal PI controllers are used.

Non-linear terms are adjusted using full non-linear simulations.

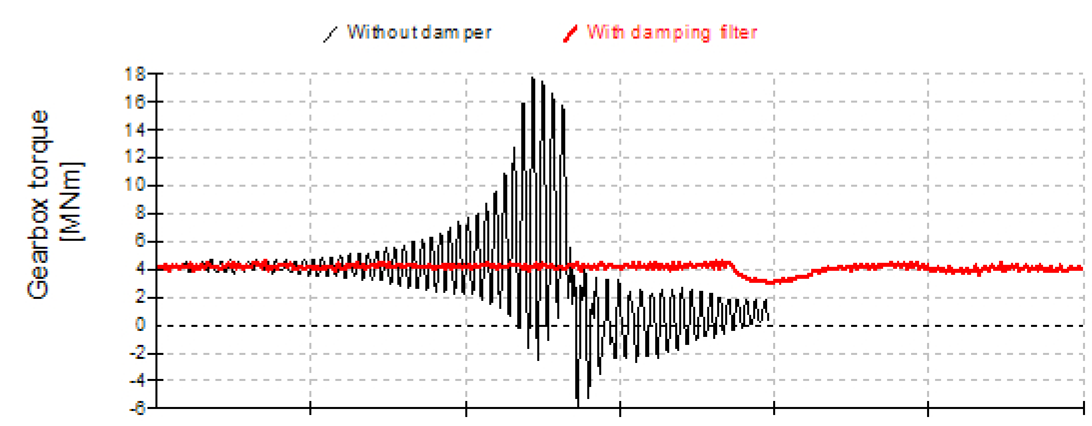
Results



This is the torque-speed curve, showing the exclusion zone for avoiding tower excitation caused by the blade passing frequency coinciding with the first tower mode.

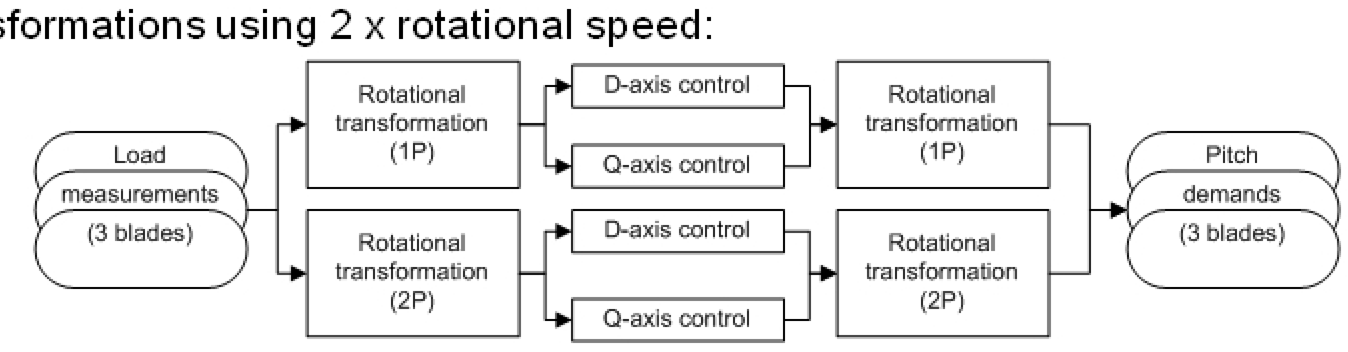


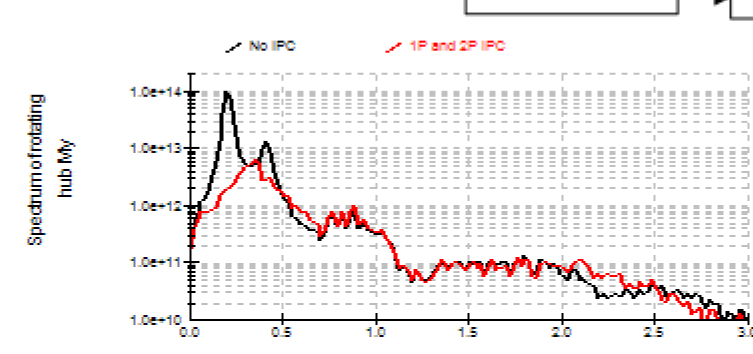
This simulation demonstrates the beneficial effect of the speed exclusion zone. Deviations from optimum Cp result in a small loss of energy.

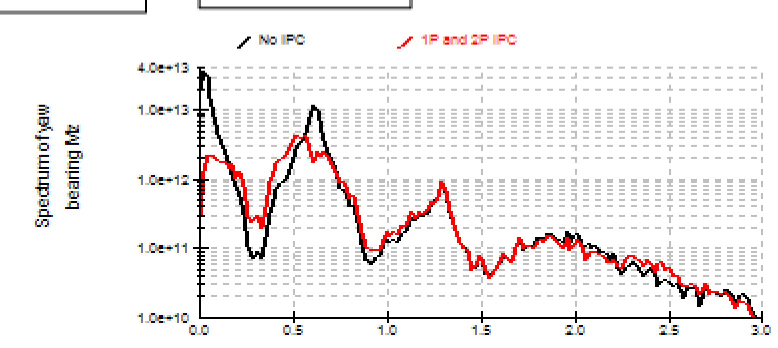


Without a drive train damper, the drive train would be completely unstable at some wind speeds.

1P individual pitch control (IPC) [2] is well established for reducing rotating fatigue loads. 2P IPC reduces non-rotating fatigue loads too, and the additional pitch action is not prohibitive. Just like the 1P IPC, PI control is used, but with rotational transformations using 2 x rotational speed:







Rotating loads reduced at:		Non-rotating loads reduced at:
• 1P	1^{st} harmonic IPC	• 0P (and 2P)
• 2P	2^{nd} harmonic IPC	• 3P (and 1P)

Conclusions

A controller is presented which can be used by the UPWIND community for further work using the 5MW reference turbine. The work demonstrates the applicability of state-of-the-art techniques to a representative 5MW turbine, and demonstrates significant load reductions due to the advanced features of the controller. Using this controller as a starting point, the reference turbine has already been used for further studies such as investigations of possible trade-offs between energy production and loading.

References

1. Wind Turbine Control For Load Reduction, E Bossanyi, *Wind Energy 2003 vol 6 pp 229-244.*
2. Developments in Individual Blade Pitch Control, E Bossanyi, *"The Science of making Torque from Wind" Delft University of Technology, The Netherlands, April 19-21 2004.*

Acknowledgements

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