REMS
RENEWABLE ENERGY MARINE STRUCTURES

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Load Mitigation through Advanced Controls for an Active Pitch to Stall Operated Floating Wind Turbine

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EPSRC
Engineering and Physical Sciences Research Council

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1. Context and Problem Statement
2. Aims, Objectives & Approach
3. Results
4. Conclusions
5. Q & A

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1. Context and Problem Statement

- Usual to utilize offshore turbines designed for a fixed base on floating platforms

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1. Context and Problem Statement

- Usual to utilize offshore turbines designed for a fixed base on floating platforms
- FOWT experience increased tower base for-aft moments due to platform motion
- All pitch-to-feather HAWTs experience 'negative damping' which can cause tower fore-aft oscillations that increase the loads on the tower

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1. Context and Problem Statement

- Advanced control strategies can reduce the platform motion and hence loads on the tower

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- Advanced control strategies can reduce the platform motion and hence loads on the tower
- Blades that pitch-to-stall cause a drag force which increases with wind speed, therefore avoid undesirable 'negative damping' effects.

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2. Aim, Objectives & Approach

The aim is to assess whether pitching the turbine blades actively to stall in Region III, using advanced control strategies, could aid in reducing the loads on the tower of a turbine coupled to a semi-submersible platform design.

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2. Aim, Objectives & Approach

- DeepCwind semisubmersible model coupled to the three bladed NREL 5MW HAWT.

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- Fast provides an inbuilt interface with Simulink.
- Identify fatigue reduction benefits available from different control strategies.

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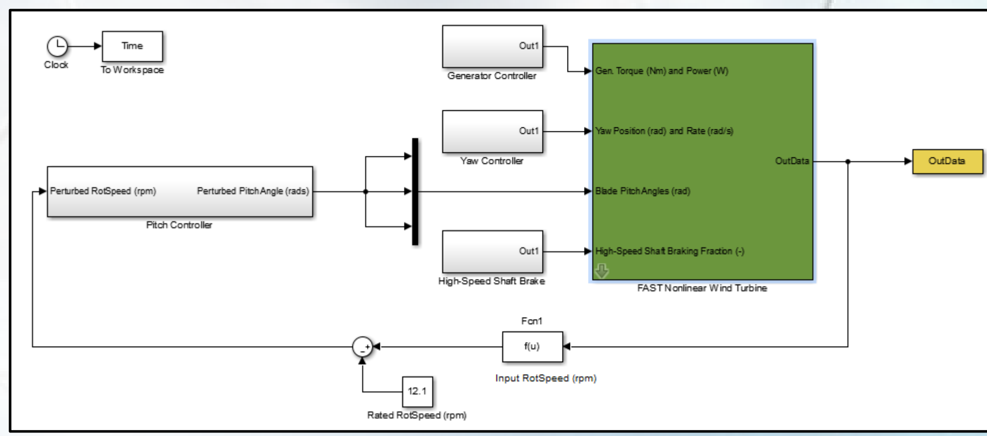
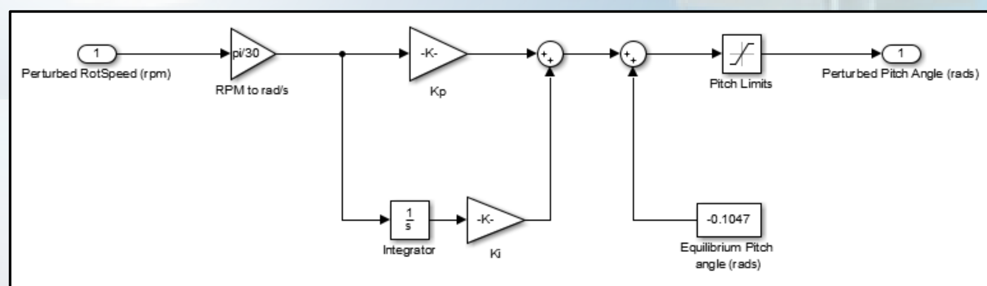
3. Results – Baseline pitch-to-stall controller

- Constant gain, closed-loop, feedback PI pitch controller
- Input = Error
  (the difference between the set-point (rated) and the actual rotor speed)
- Output = the summed results after K_P & K_I are applied & added to the equilibrium pitch value





3. Results – Periodic steady wind responses

- Initially unstable and would not converge
- K_P & K_I gains increased

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- Initially unstable and would not converge
- K_P & K_I gains increased
- Excessive blade deflections - striking the tower
- Blade flapwise stiffness increased
- A realistic active stall designed blade would be preferable

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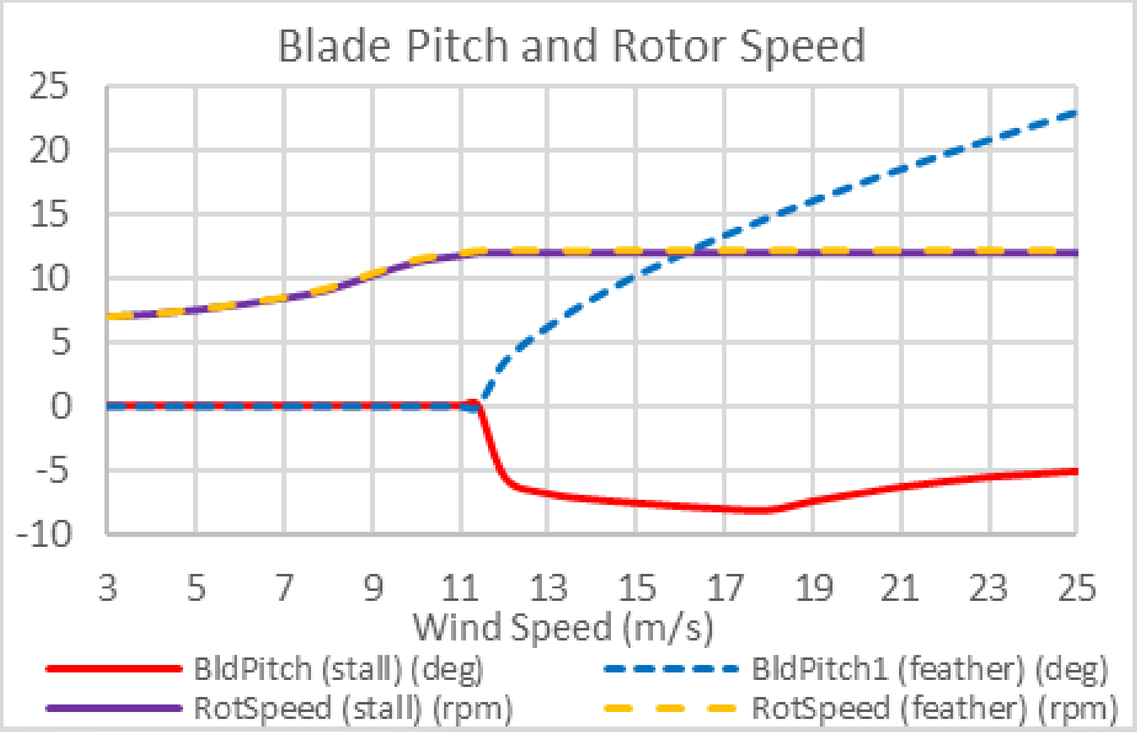
3. Results – Periodic steady wind responses

- Reduction in blade pitch angle in stall
  (-8.1˚ compared to 22.9˚)



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3. Results – Periodic steady wind responses

- Reduction in blade pitch angle in stall
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- Positive thrust force
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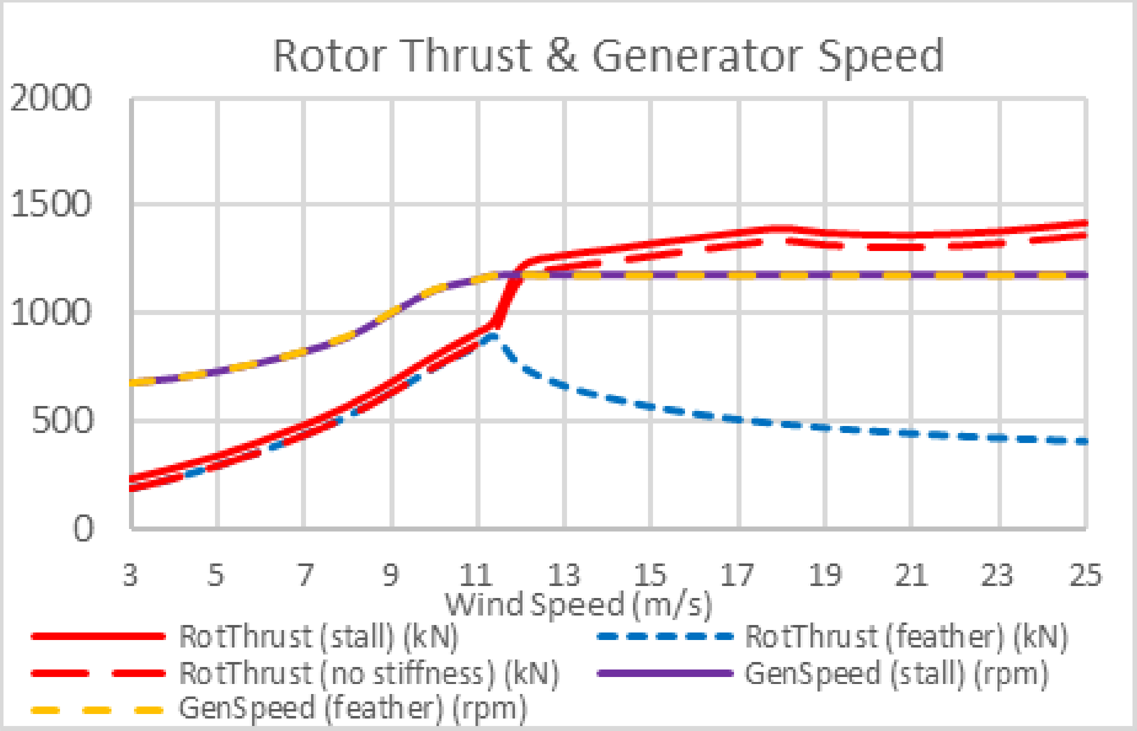
  (891kN to 1361kN stall)
  (891kN to 402kN feather)



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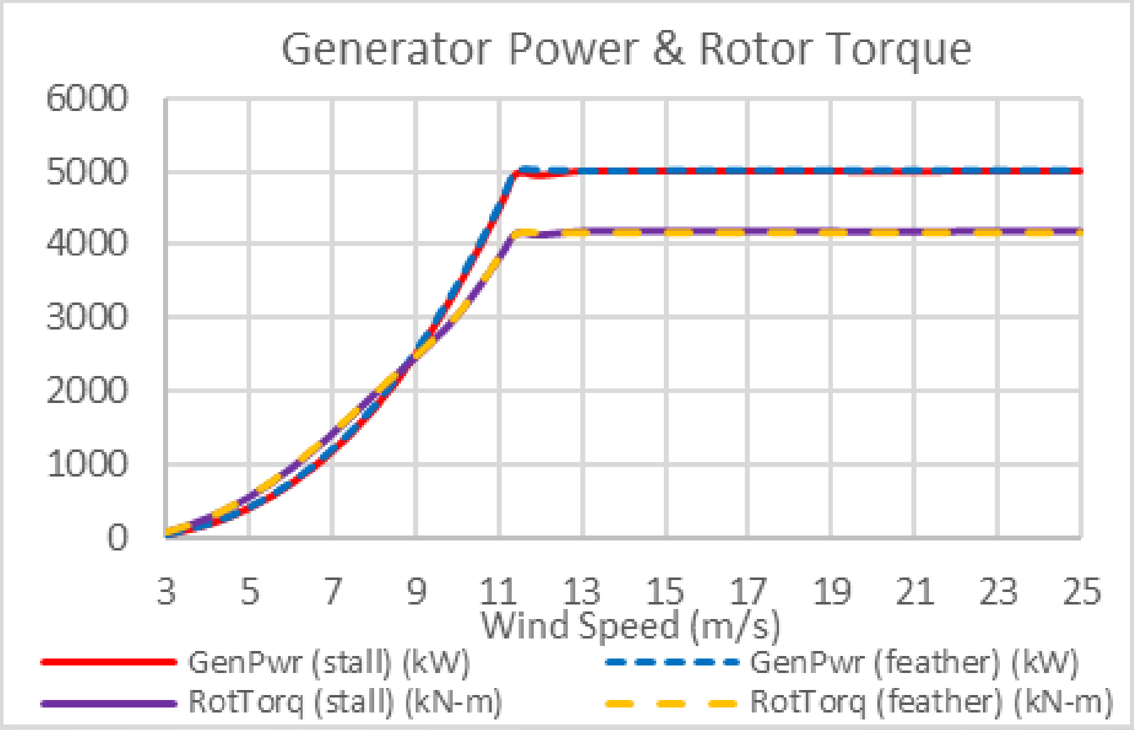

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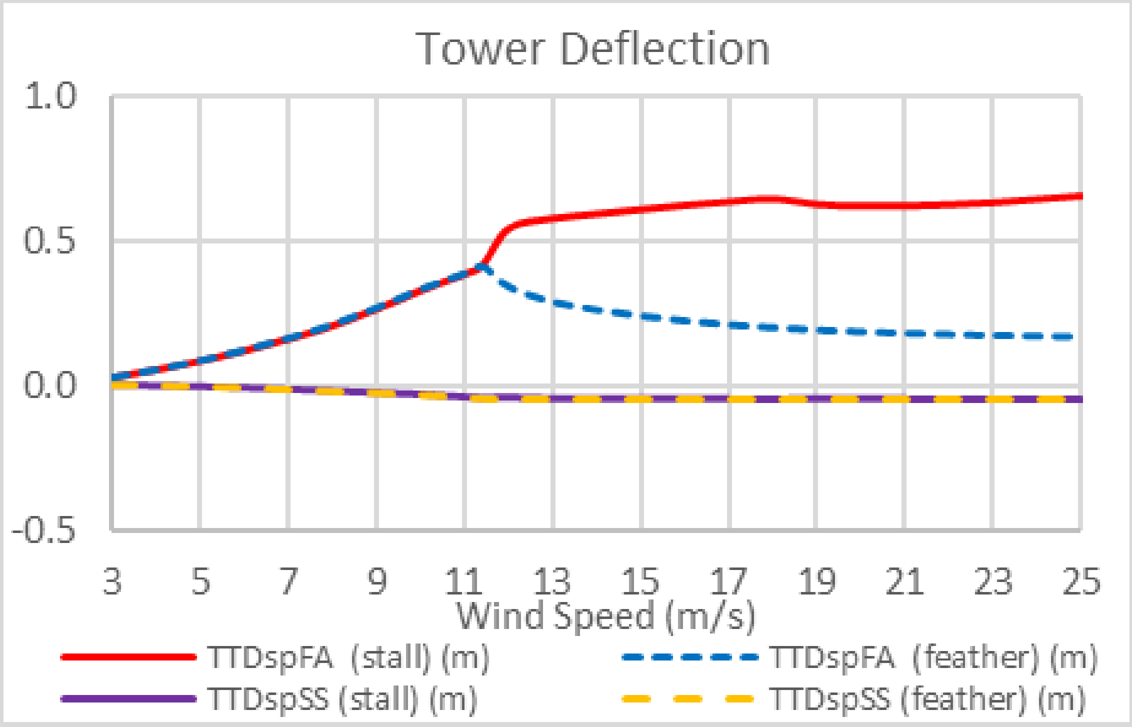
- Performance equal
- Increase in tower deflection



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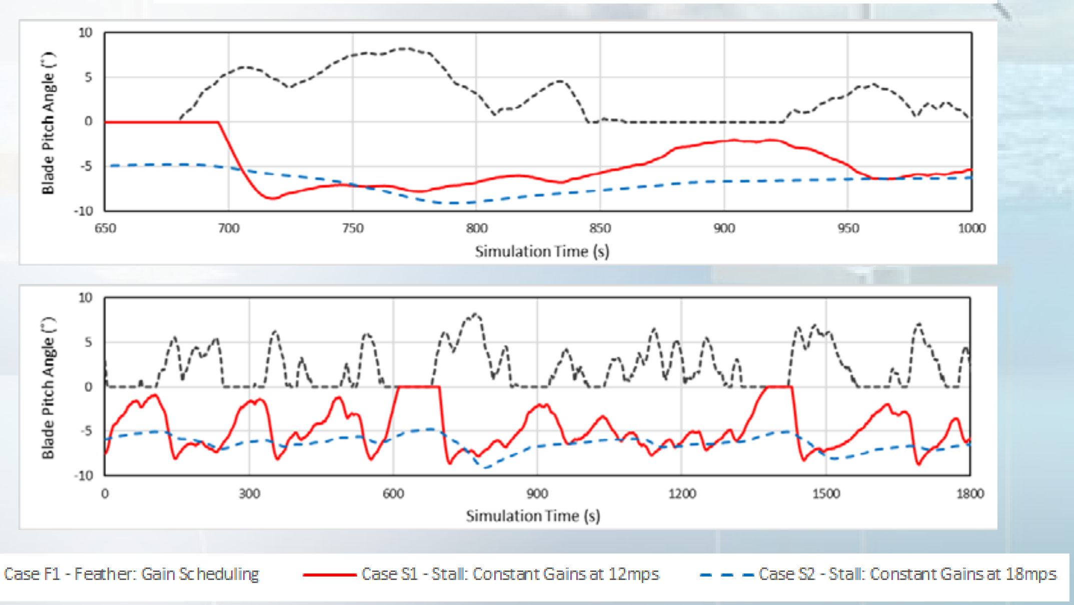
3. Results – Gain scheduling benefits

- 12mps mean turbulent winds irregular waves Hs 2m, Tp 7s
- Gain scheduling more complex in stall, may require 2 controller schedules

+ Faster response

Case ID	Control Regime	Natural Frequency, $W_{\varphi n}$ (rad/s)	Damping Ratio, ξ_{φ}	Proportional Gain, Kp (s)	Integral Gain, Ki
Case F1	Feather: Gain Scheduling	0.2*	0.7*	0.006275604*	0.000896515*
Case S1	Stall: Constant Gains at 12mps	0.6	0.7	-0.08555923	-0.03666824
Case S2	Stall: Constant Gains at 18mps	0.6	0.7	-0.00772205	-0.00330945

* at minimum pitch setting, Ref: Robertson A et al, 2014, Definition of the Semisubmersible Floating System for Phase II of OC4, NREL/TP-5000-60601



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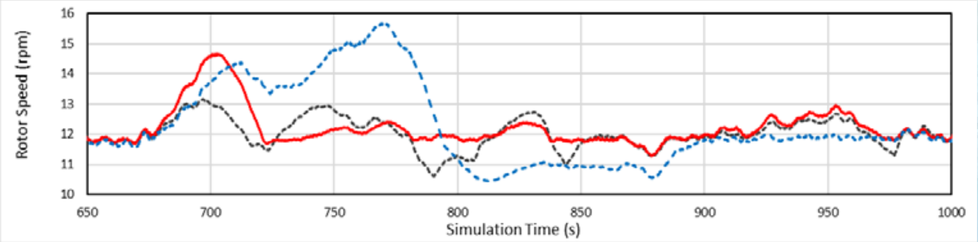

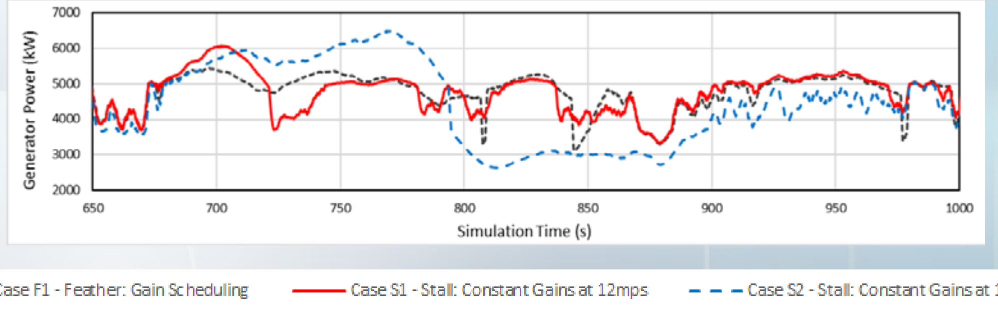

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\+ Loads & motion reduced

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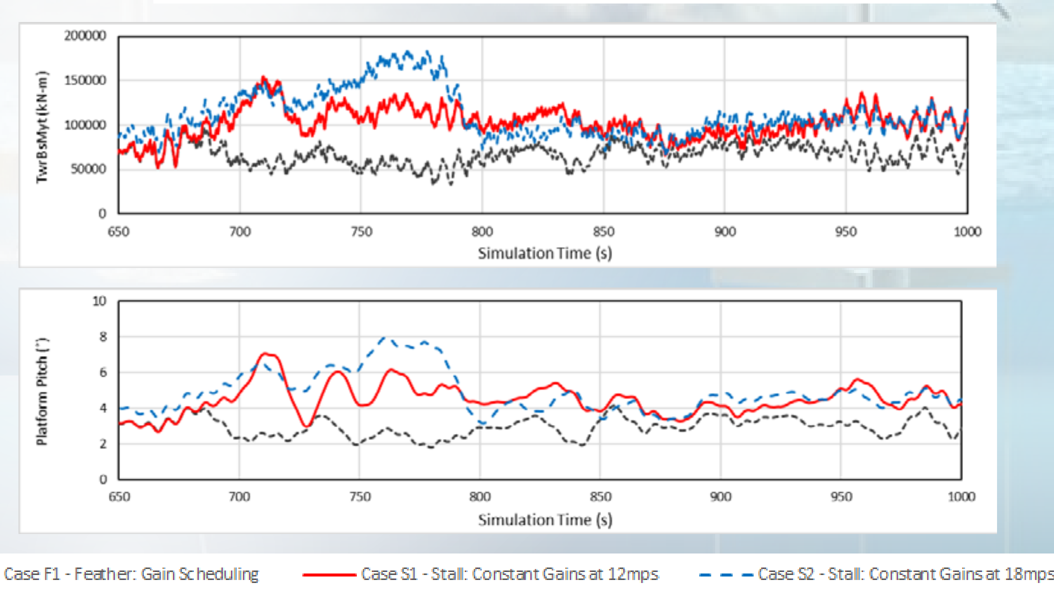

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3. Results – Tower base fore-aft load mitigation

- 18mps mean turbulent winds irregular waves Hs 4m, Tp 10s

- Response too slow with calculated gains
  ∴ proportional gain too low

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Case F2	Feather: Constant Gains at 18mps	0.2	0.7	0.0019216	0.0002745
Case S3	Stall: Constant Gains at 18mps	0.6	0.7	-0.0077221	-0.0033095
Case S4	Stall Constant Gains at 18mps x 10			-0.0772205	-0.0330945
Case S5	Stall:Constant Gains at 18mps x 100			-0.7722050	-0.3309450

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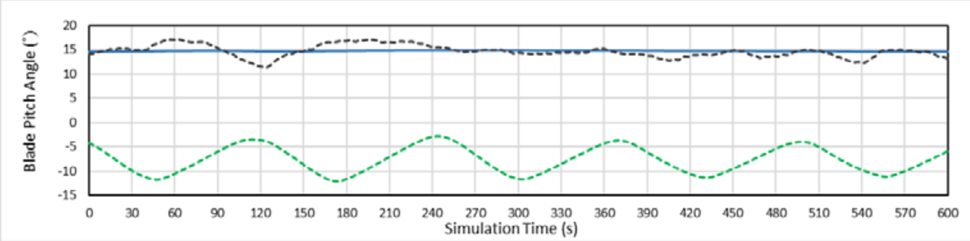

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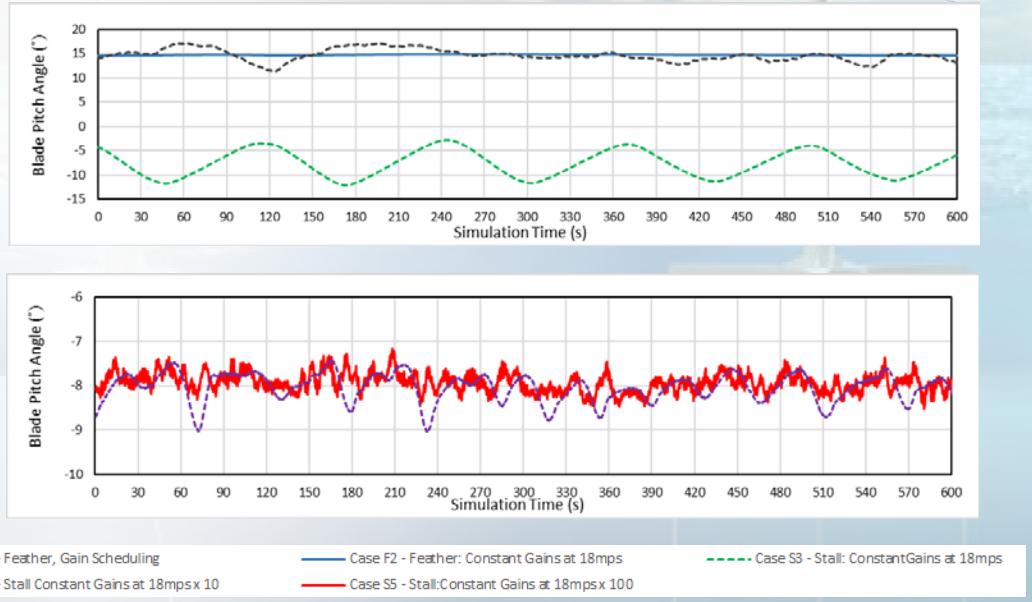

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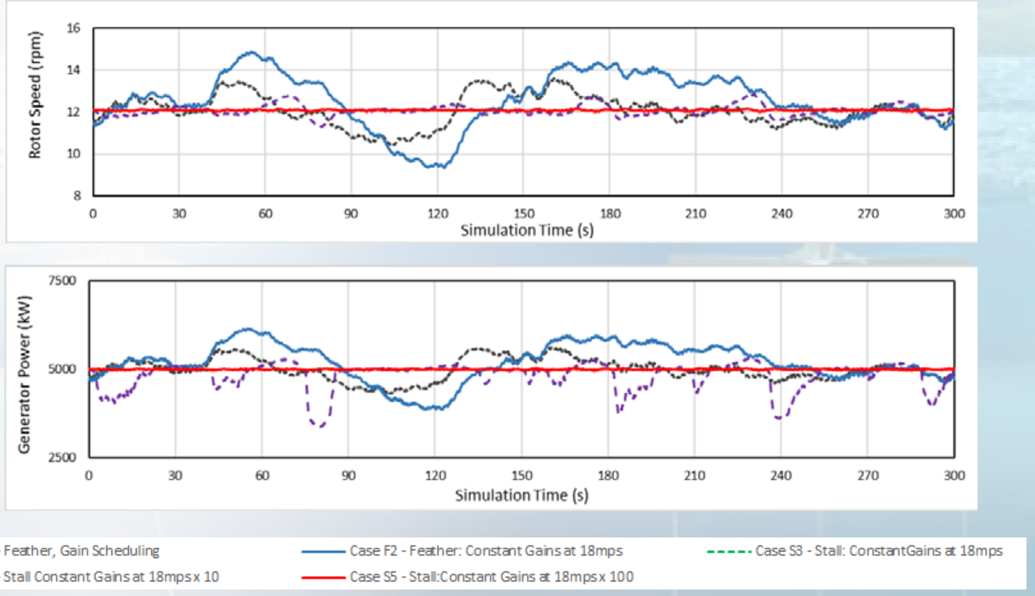

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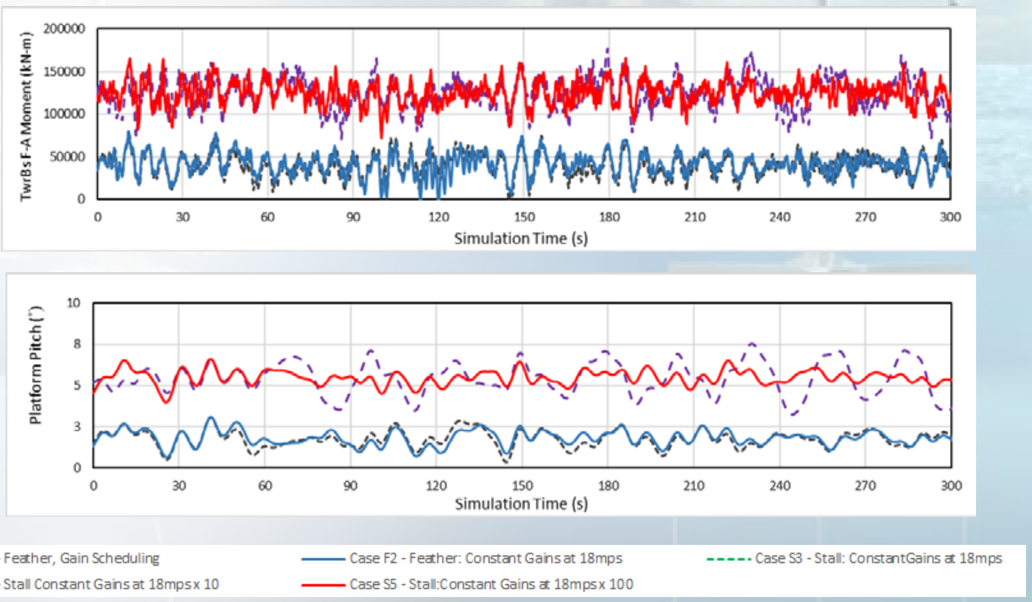
- Tower base fore-aft moment range & StD lower than F2



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- A robust control system with gain scheduling for stall operation could be further enhanced when coupled to other advanced control strategies.
- Increasing the gains gave improved performance and reductions in the tower base fore-aft moment range
- The increase in positive mean of the platform pitch and tower fore-aft motions compared to feather indicate that this platform's stability would need increasing, for a pitch to stall operating regime.

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Thank you for your time

Questions and Advice welcome

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