Impacts of Dynamic Pitch Control on Aerodynamic Performance of Wind Turbines

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INTRODUCTION

- Wind farms have become an increasingly important part of global power production
- Turbines in farms can experience losses as upstream turbines generate wakes that interact with downstream turbines, reducing power production by 10% to 25%.[1]

OBJECTIVES

- Explore different turbine blade pitch control strategies to maximize overall farm power output while minimizing load impact
- The pitch control methods examined are a baseline case, DIC, and the Helix.

CONTROL METHODOLOGIES

Greedy Control (Baseline)

- Static control, blades are positioned for optimal steady-state power extraction

Dynamic Induction Control (DIC)

- A sinusoidal signal is superimposed over the baseline collective blade pitch

Dynamic Individual Pitch Control (Helix)

- The sinusoidal signal on each blade has a phase shift, offsetting each blade's pitch.

$$\begin{bmatrix}\theta_1(t)\\ \theta_2(t)\\ \theta_3(t)\end{bmatrix} = \begin{bmatrix}1 & \cos(\psi_1) & \sin(\psi_1)\\ 1 & \cos(\psi_2) & \sin(\psi_2)\\ 1 & \cos(\psi_2) & \sin(\psi_3)\end{bmatrix}\begin{bmatrix}\theta_0(t)\\ \theta_{tilt}(t)\\ \theta_{yaw}(t)\end{bmatrix}$$

$$\theta_b(t) = \sin\left[2\pi(f_r + f_e)t + \psi_{0,b}\right]$$

Fig. 1: Inverse multiblade coordinate (MBC) transformation and its simplified form.

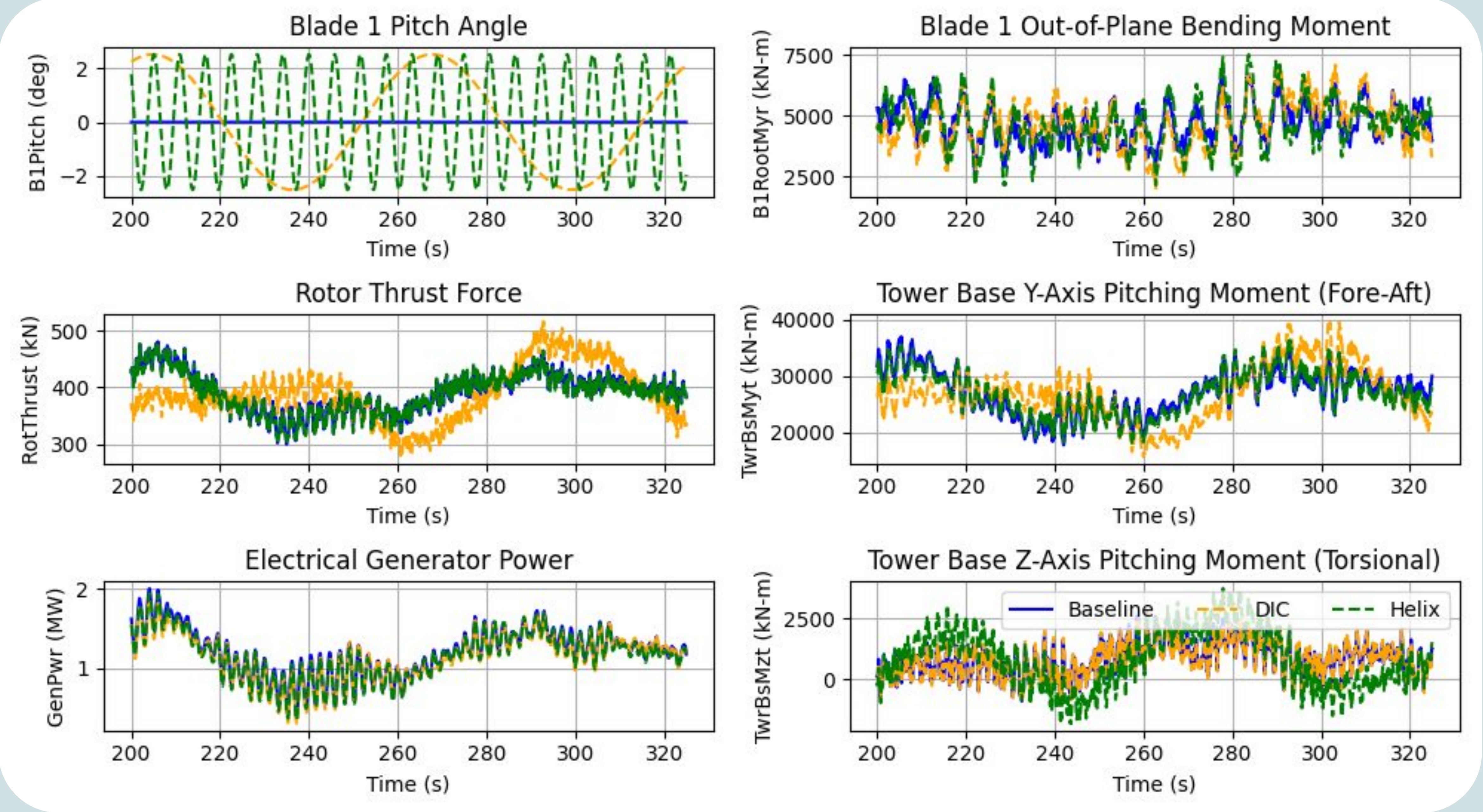

Fig. 2: Comparison of the Baseline (blue), DIC (orange), and Helix (green) pitch control methodologies. Graphs show the pitch of blade 1, blade 1 out-of-plane moment, rotor thrust force, tower base y-axis pitching moment, electrical generator power, and tower base z-axis pitching moment vs time.

- Under DIC control, the rotor thrust force shows periodicity, though it does not significantly impact generator power
- Both DIC and Helix control increase the blade's out-of-plane bending moment compared to the baseline, suggesting a reduction in turbine blade lifespan
- DIC control results in an increased tower base y-axis moment, while Helix and the baseline control show comparable levels.

$$St = \frac{f_e D}{U_\infty}$$

Fig 3: The DIC and Helix control pitch excitation signal frequency is found using the Strouhal number equation, with the optimal number assumed to be 0.25

OPENFAST ARCHITECTURE

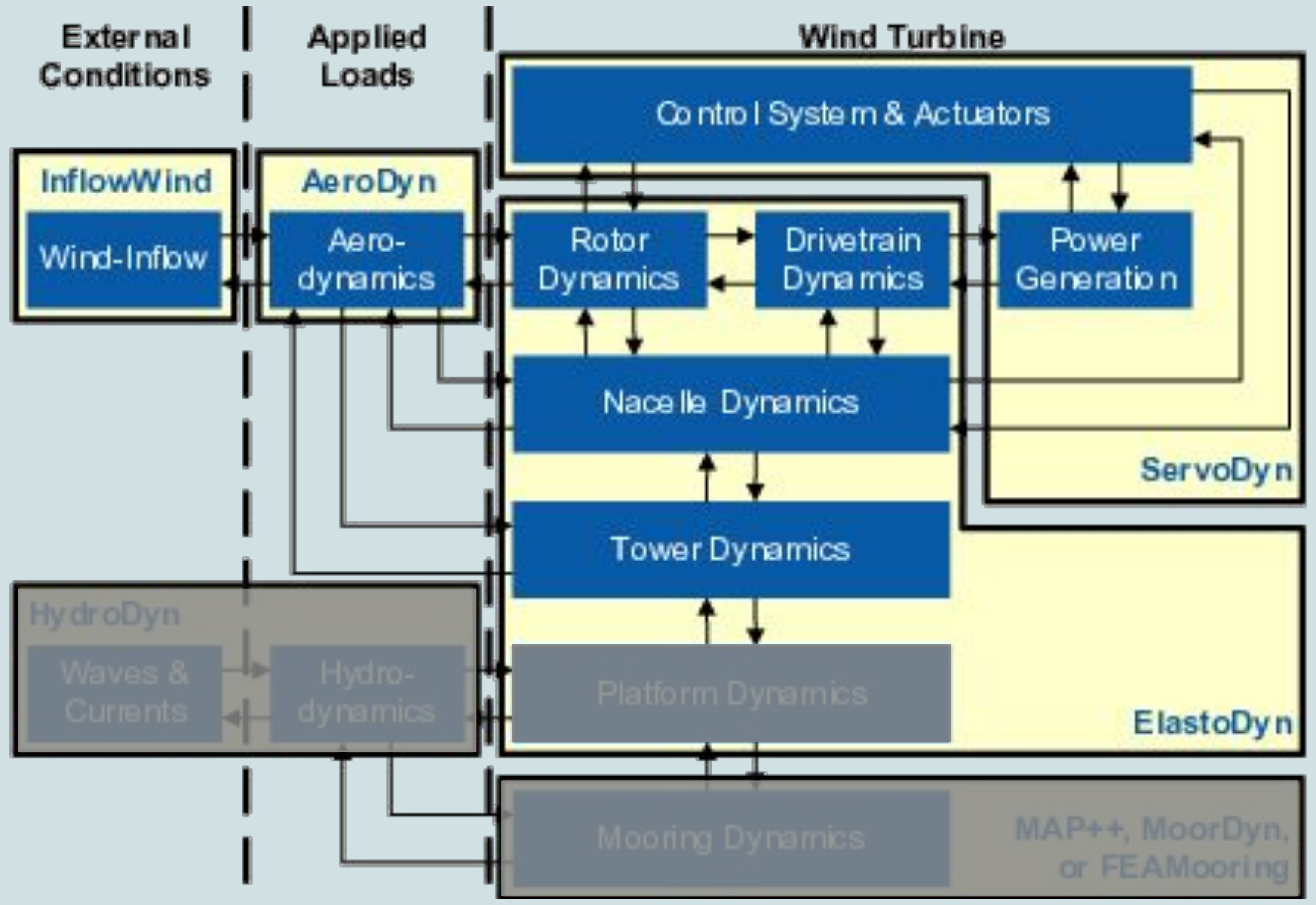

Fig. 4: Schematic illustrating the architecture of OpenFAST, an open-source multi-physics simulation tool for wind turbines.

FUTURE WORK

- An optimal Strouhal number of 0.25 is assumed to find the excitation signal's frequency in *Fig 2.*[2] This number was found experimentally for land-based turbines, but more research is needed to validate that it is optimal for floating turbines as well
- Large-scale simulations across a broader parameter space – including variations in wind speed, turbulence intensity, and comparisons between floating and offshore turbines – will provide a comprehensive view of the underlying dynamics.

REFERENCES

1. Barthelmie, R. J., et al. (2009). Modelling and measuring flow and wind turbine wakes in large wind farms offshore. Wind Energy, 12, 431–444. https://doi.org/10.1002/we.348
2. Frederik, J. A., et al. (2020). The helix approach: Using dynamic individual pitch control to enhance wake mixing in wind farms. Wind Energy, 23, 1739–1751. https://doi.org/10.1002/we.2513.