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Wind Turbine Structural Load Reduction with Pitch Sensor Fault Compensation

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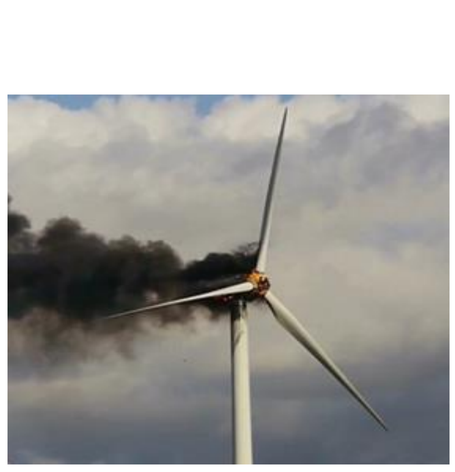
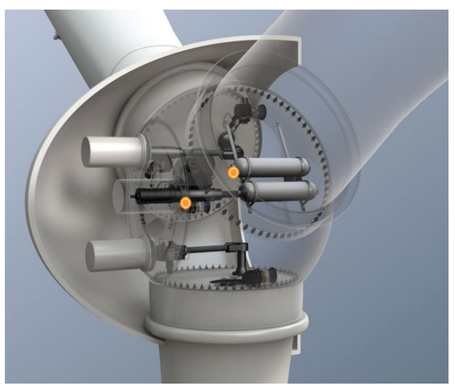
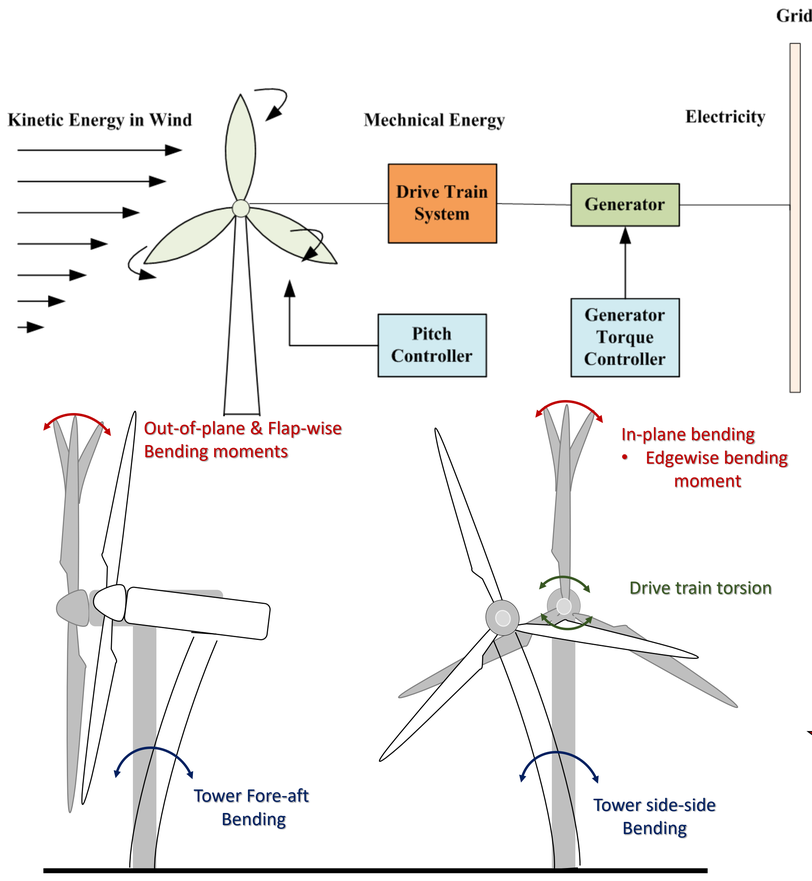
Introduction: **Wind turbine dynamic loads caused by rotational sampling of turbulence, tower shadow and wind shear affect the life and performance of wind turbines. Individual Pitch Control (IPC) is an effective way to overcome this problem. However, pitch sensor faults affect the IPC performance in reality. It is valuable to consider pitch sensor fault compensation in wind turbine load mitigation control.**

Background







- Blades suffer from asymmetric loads due to non-uniform incoming winds, further affecting non-rotating turbine structures including hub, nacelle, tower etc.
- Couplings between blade & tower loads, require multivariable control-based IPC system.
- Hydraulic pitch systems play significant role in power output regulation & load mitigation by IPC under high wind conditions (e.g. 11.4-25m/s).
- Pitch sensor faults deteriorate IPC performance, enhancing demand on reliability of proposed control system.

★ **Research Objective: Mitigate blade & tower loads together by LQR-based IPC with pitch sensor faults compensation by unknown input observer (UIO).**

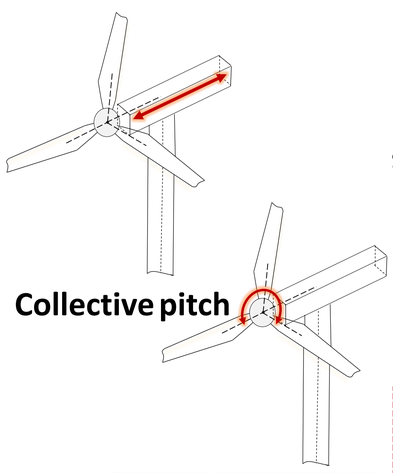
Work Overview

A. LQR-based IPC for blade & tower load reduction

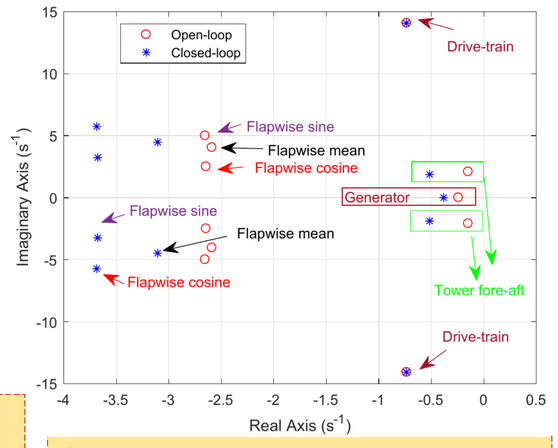
- **Different controlled variant for structural load mitigation**

Controlled Variant	Blade Flapwise	Tower Fore-aft	Tower Side-side
Collective Pitch Angle	×	√	×
Individual Pitch Angle	√	√	√
Generator Torque	×	×	√

- **Linear model from FAST Linearization with 6 DOFs.**



❖ Effective force/moments on tower top



❖ Open & Closed-loop (with proposed LQR) pole locations

B. UIO based pitch sensor faults estimation & compensation

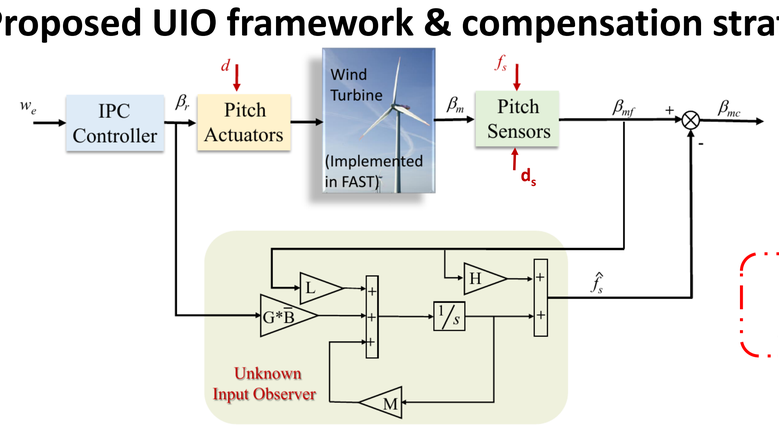
- **Pitch actuator systems modelling (4 pitch sensor faults considered)**

$$\dot{x}(t) = Ax(t) + Bu(t) + Dd(t) \quad \text{(disturbance)}$$
$$y(t) = Cx(t) + F_s f_s(t) + E_s d_s(t) \quad \text{(Measurement noise)}$$

sensor faults

$$f_s(t) = \begin{cases} \beta_{bias}, & \text{Biased Fault} \\ -\beta(t) + \beta_{fixed}, & \text{Fixed Output} \\ -\beta(t), & \text{Total failure} \\ (f-1)\beta(t), & \text{Multiplicative fault} \end{cases}$$

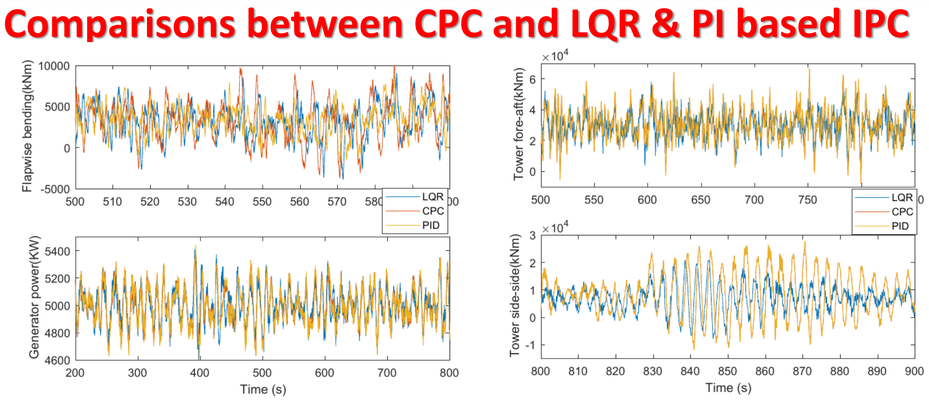
- **Proposed UIO framework & compensation strategy:**



$$\bar{z} = Mz + G\bar{B}u + Ly$$
$$\hat{\bar{x}} = z + Hy$$

Simulation Results

A. Comparisons between CPC and LQR & PI based IPC



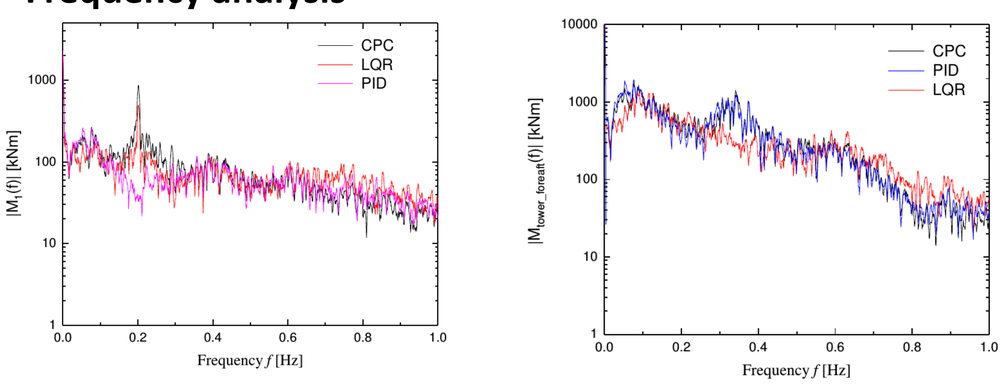
- **Time-domain analysis with mean wind speed (23m/s)**

RMS

Case	Genpower	Pitchrate	Bending	Tower_foreaft	Tower_side
CPC	133.5	0.0084	2733.4	10628	7234.9
PID	142.0	0.0619	1832.9	10858	7801.3
LQR	119.2	0.0893	2128.4	8879.6	7179.3

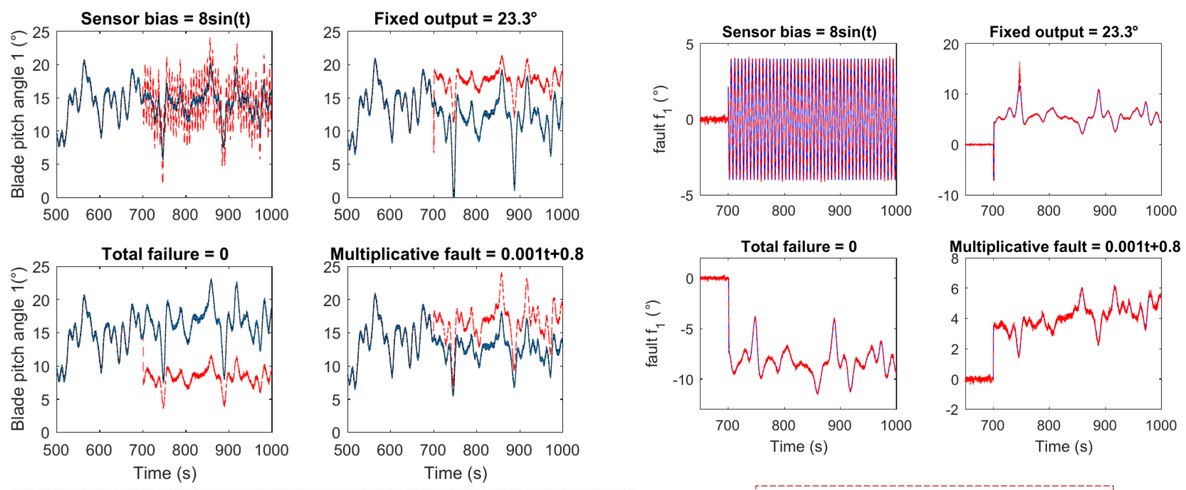
❖ LQR can reduce flapwise bending (1P 0.2Hz) & tower fore-aft bending (0.3Hz) together without enhancement of generator power & tower side-side bending at cost of pitch travel.

- **Frequency analysis**



B. Sensor Fault estimation & compensation

- **Pitch sensor 1 suffers from one of the considered 4 faults**



Three pitch system measurement outputs

Sensor fault estimation

Conclusions

- Designed UIO estimate 4 faults in 3 different pitch control cases.
- Verified the robustness & effectiveness of proposed UIO.
- According to sensor fault estimation, the fault hiding strategy used to compensate fault effects.
- Important to consider performance of designed load reduction controller in faulty cases to have better comprehensive evaluation of proposed controllers, here LQR based IPC better than PI-based IPC.