Adaptive MPC of wind turbine with aero-elastically tailored blades

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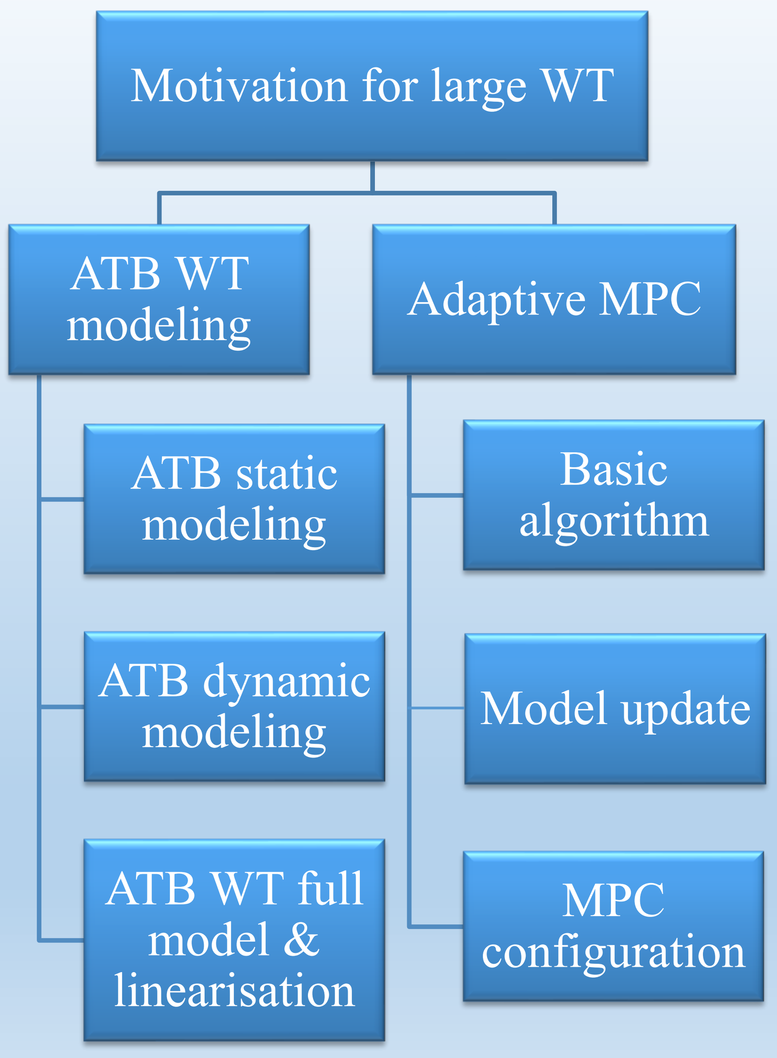
Abstract

The use of aero-elastically tailored blades (ATB) for large wind turbines has shown the benefit of mitigating blade loads with the design of bend twist coupling (BTC) along the blades. In this work, to include the ATB effect into the turbine model for control, a twofold modeling for ATB characteristics is proposed. First a static BTC distribution is added to the turbine aerodynamics to account for the blade's pre-bend-twist design, next a second order transfer function is introduced to approximate the blade structural dynamic response to wind speed variations. The nonlinear model of the whole ATB wind turbine is built up in Simulink, linearized and discretized into a state-space form. An adaptive model predictive controller (MPC) is developed, the control performance is compared to the gain-scheduling baseline controller.

Overview



ATB static modelling

- The blade is divided into a number of sections and each section may have different airfoil profiles. The bend and twisting deformation is represented by adding the twisting angles to each blade section. This modification is integrated with the baseline BEM modeling for all blade sections.
- The aerodynamic force and the moment for each section provide the lift force and the moment for the entire blade.
- This ATB model is developed in DNV Bladed and it gives the static effect to the rotor performance caused by ATB [1-3].

MPC of ATB WT

$$\min_{\Delta u(k)} J(k) = \sum_{i=1}^{n_y} e(k+i)^T Q e(k+i) + \sum_{i=0}^{n_u-1} \Delta u(k+i)^T R \Delta u(k+i)$$

$$s.t$$

$$x(k+1) = Ax(k) + Bu(k)\ ; u_{min} \le u(k) \le u_{max} ; \Delta u_{min} \le \Delta u(k) \le \Delta u_{max}$$

$$e(k) = y(k) - r(k)$$
$$\Delta u(k) = u(k) - u(k-1)$$

Adaptive MPC configuration

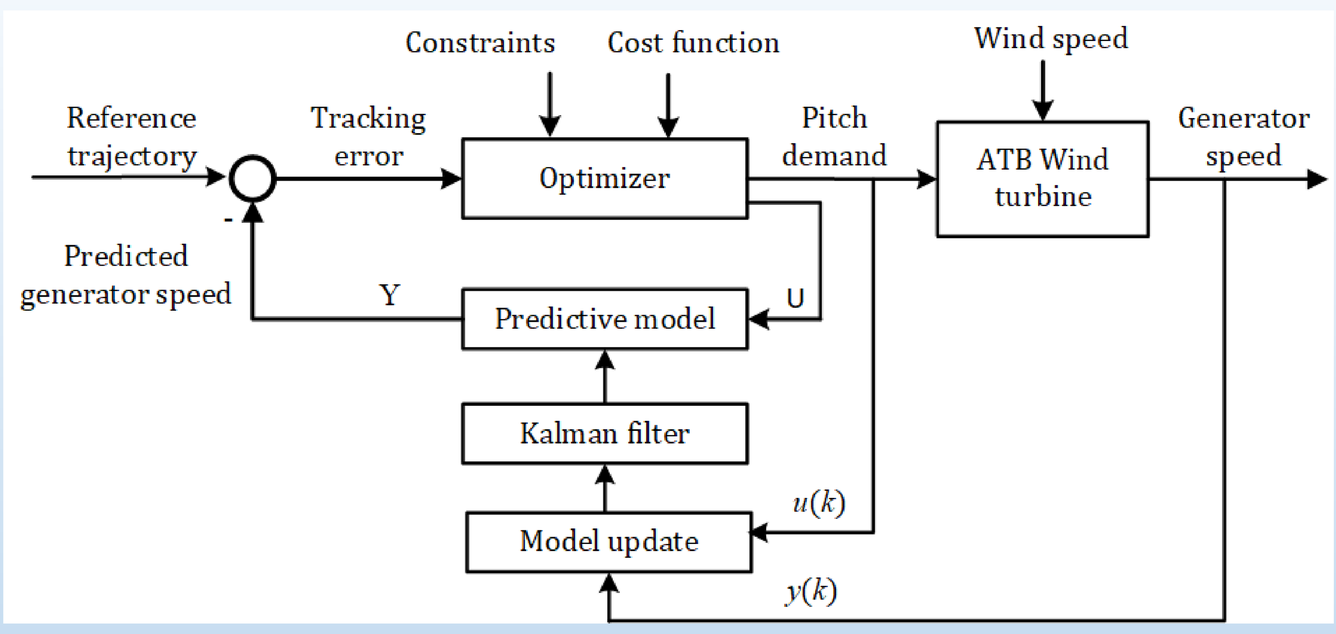


Figure 3 –Block diagram for ATB wind turbine with adaptive MPC

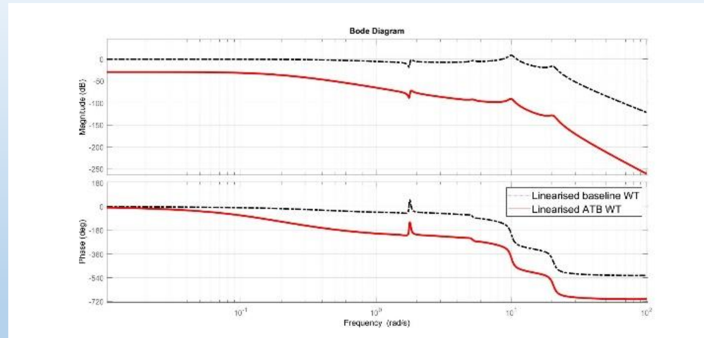
- At above rated wind speeds, adaptive MPC is required to compensate for the mismatch between the linearized model used in MPC and the nonlinear wind turbine model.
- Model update and Kalman filter are introduced to provide the adaptive feature.
- With the proposed scheme, the computational demand for real-time optimization is reduced compared to using nonlinear MPC, and the control performance is not compromised by the linear control.

Simulation parameters

Parameter	Value
Rated power	5MW
Rotor diameter	63m
Hub height	90m
Rated generator speed	120rad/s
Rated generator torque	46,372Nm

Parameter	Value
Sampling time	0.2s
Simulation time	600s
Prediction horizon	20
Control horizon	5
Pitch angle constraint	[0,0.3]rad
Pitch rate constraint	[-0.01,0.01]rad
MPC weightings	Q=1, R=2

ATB structural response approximation



$$G_{ATB}(s) = \frac{\alpha_{ATB}}{Js^2 + Ds + K}$$

K - spring stiffness, J - moment of inertia, D - damping factor, α_{ATB} - gain

Figure 1 - linearized baseline and ATB WT models

ATB WT & linearization model

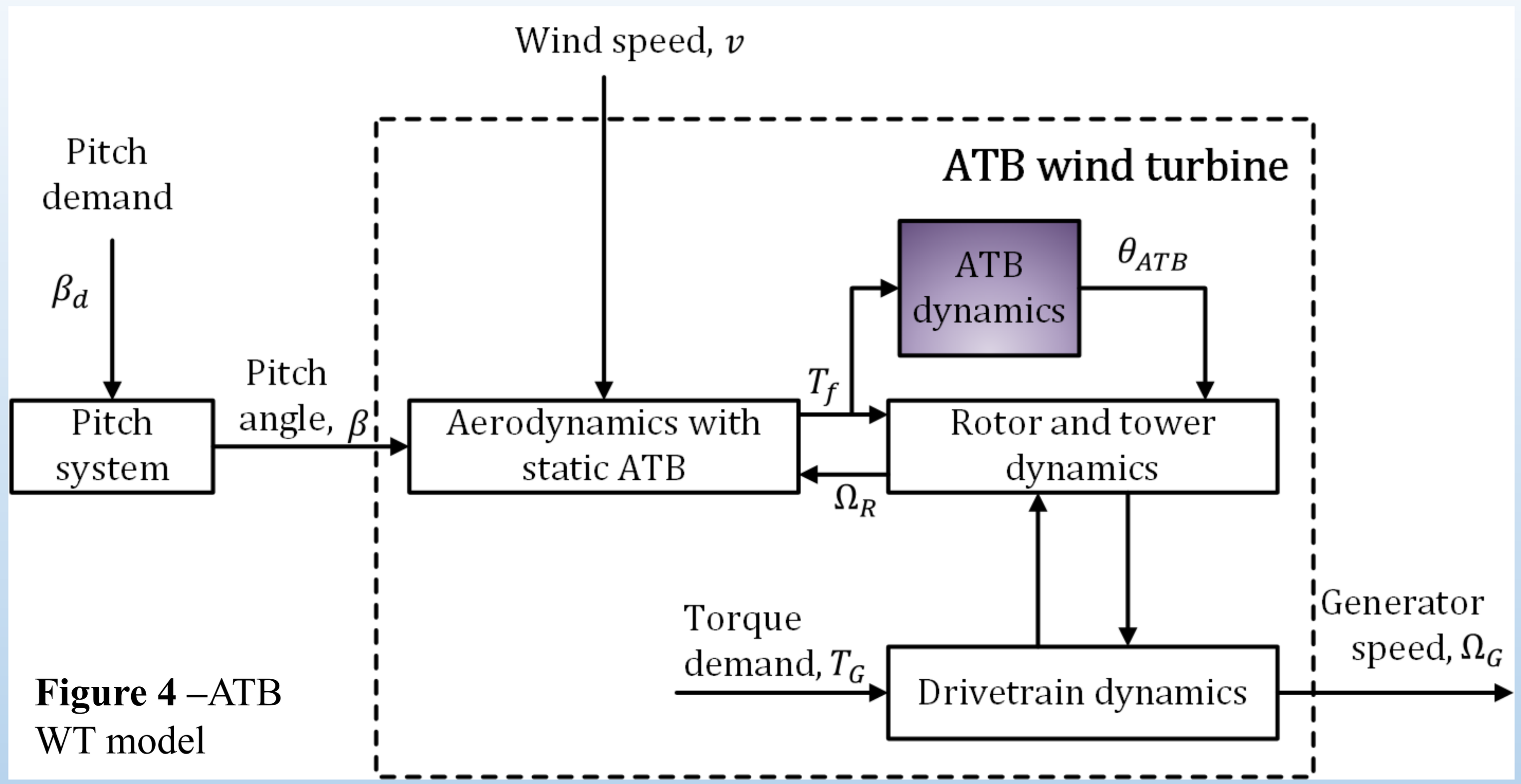


Figure 4 –ATB WT model

- Static ATB is included in the aerodynamics subsystem. The ATB structural response is supposed to act on the rotor dynamics by appropriately adjusting rotor in-plane displacement.
- The rotor is modelled by a single blade. Drivetrain subcomponents are approximated by linear spring-mass-damper models.

Results and conclusions

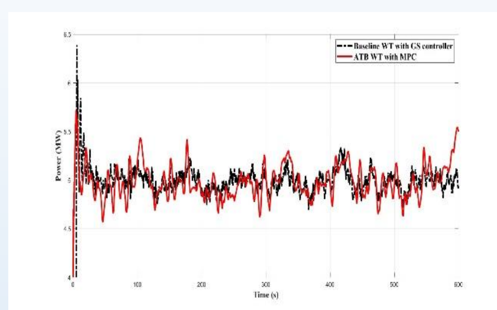


Figure 4 – Power

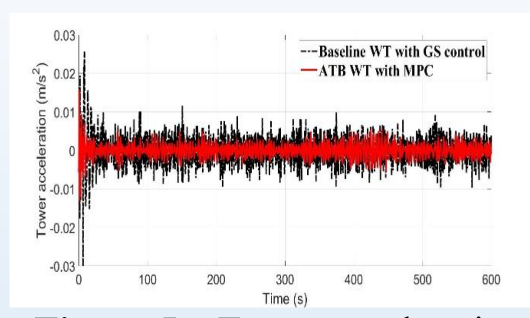


Figure 5 – Tower acceleration

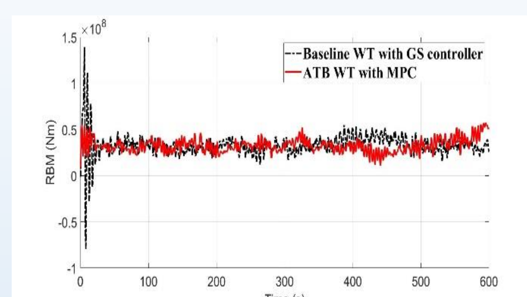


Figure 6 – RBM

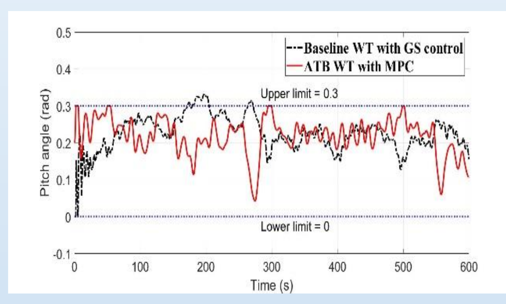


Figure 7 – Pitch angle

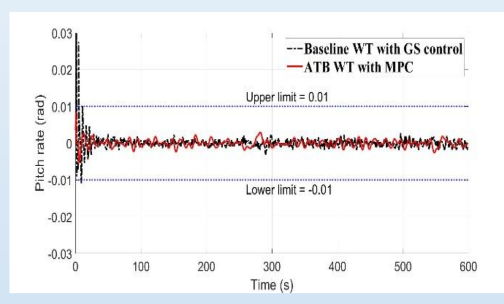


Figure 8 – Pitch rate

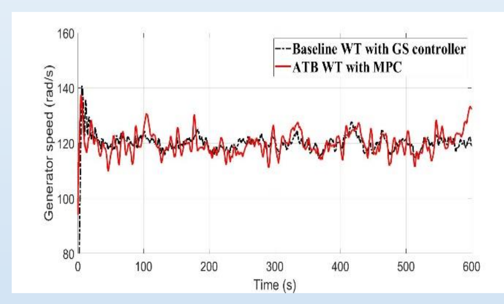


Figure 9 – Generator speed

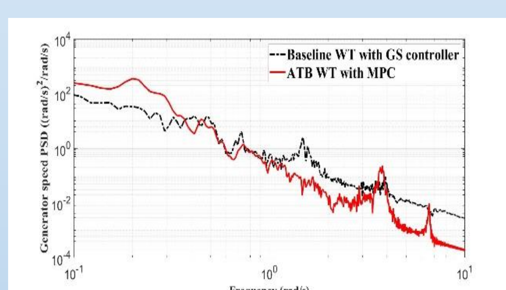


Figure 10 – Gen. speed PSD

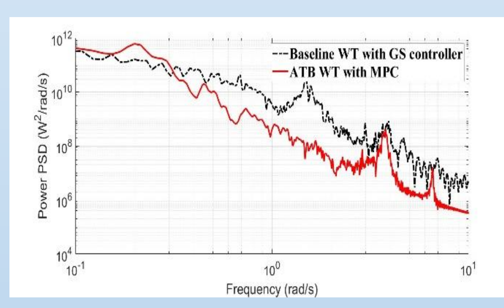


Figure 11 – Power PSD

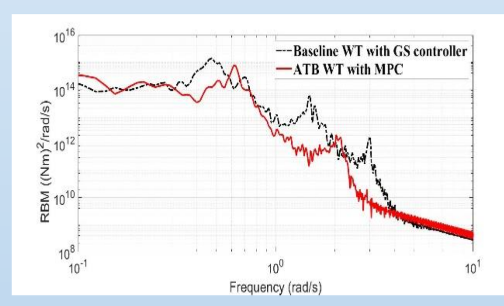


Figure 12 – RBM PSD

Comparisons are made between MPC for ATB WT and gain-scheduling control for baseline rigid-blade turbine. For ATB WT under MPC

- Load mitigation achieved, smaller variance in generator speed, power generation not compromised
- Constraints on pitch angle and pitching rate are satisfied.

References

[1] Hussain R, Yue H, Leithead W and Xiao Q 2017 *IFAC-PapersOnLine* **50** 10342–10347
[2] Capuzzi M, Pirrera A and Weaver P 2014 *Energy* **73** 15–24
[3] Capuzzi M, Pirrera A and Weaver P 2014 *Energy* **73** 25–32

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