IPID4all Doctorate Research Exchange with Carl von Ossietzky Universitat Oldenburg

Feedback report

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Exchange topic – Linear Parameter Varying Control

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Introduction

Since my arrival in Oldenburg, Germany on August 8th, 2017 I have been working in conjunction with the controls group here at ForWind, as well as, continuing work on the Segmented Ultra-light Morphing Rotor (SUMR) project. For research directly related to projects in progress here at ForWind, I have been working closely with Fredrik Berger, David Onnen, and Vlao Petrovik on data analysis and modelling of the FW-18 wind turbine. For continuing research related to the SUMR project, I have been compiling previous research conducted into a paper and working to implement a Linear Parameters Varying (LPV) torque controller for the SUMR-13i turbine.

Research Undertaken

i. *FW-18 FASTv8 Modelling and Experimental Data Analysis*

Upon arriving at ForWind, the FW-18 scaled wind turbine FASTv8/AeroDynv14 model currently working for only two DOF, and a single wind speed. I was able to update the aerodynamic definition files to be compatible with aerodynv15, and estimate various turbine parameters for improved model performance. Using the FASTv8 input files, I have characterized the rotor in terms of maximum power coefficient, optimal tip speed ratio and fine pitch angle for optimal aerodynamic efficiency using both aerodynv15 and aerodynv14.

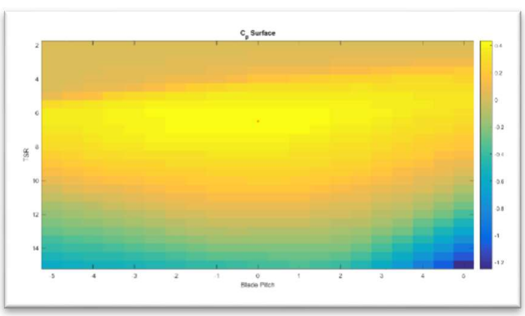

Figure 1 - AeroDynv14 Cp Surface

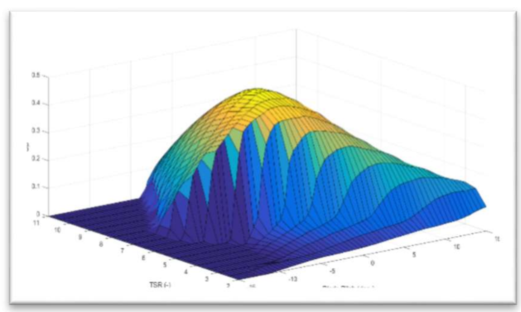

Figure 2 - AeroDynv15 Cp Surface

Using the linearization capability of FASTv8/Aerodynv15, I computed the jacobian of rotor power to pitch angle, for the tuning of the baseline PI gain scheduled pitch controller.

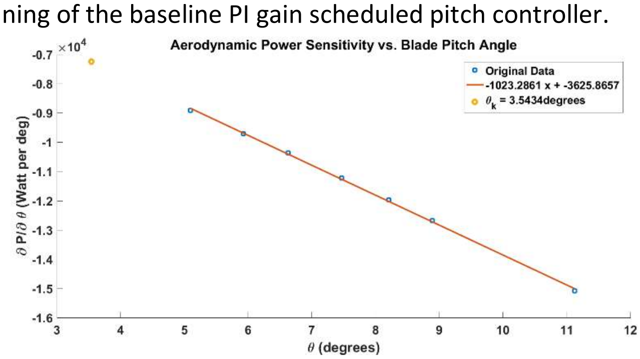

Figure 3 - Rotor Power Sensitivity for the FW-18 FASTv8 model

With the torque look-up table and PI-gain scheduled pitch controller tuned, I ran the FW-18 wind turbine through a series of turbulent wind inflow conditions ranging from cut-in to cut-out wind speed and performed power spectral density load analysis to be used for model ID and controller performance comparison. I also received test data from Fredrik Berger as collected during FW-18 experimental rotor performance characterization, and visualized the data to be compared with values obtained from FASTv8 simulations and rotor characterizations.

ii. *SUMR-13i LPV Torque Controller for load Reduction*

My area of research is focused on LPV modelling and control for wind turbines. During my exchange, I was able to synthesize and implement an LMI based LPV torque controller with the aim of reducing tower base FA bending moments using concepts and algorithms presented in [1] and [2]. The model used in the synthesis is given below.

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}\rho_1(\theta) & -\rho_2(\theta)\\ \rho_4(\theta) & -\frac{1}{M_t}B_t - \rho_5(\theta)\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}\frac{\partial Q_g}{\partial \Omega}\\ 0\end{bmatrix}\tau_{gen} + \begin{bmatrix}\rho_2(\theta)\\ 0\end{bmatrix}V_\infty$$

$$[z] = \begin{bmatrix}c_{z1} & c_{z2}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + [0]\tau_{gen} + [0]V_\infty$$

$$\begin{bmatrix}y_1\\ y_2\end{bmatrix} = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ 0\end{bmatrix}\tau_{gen} + \begin{bmatrix}0\\ 0\end{bmatrix}V_\infty$$

With $\dot{x}_1 = \dot{\Omega}$ and $\dot{x}_2 = \ddot{q}$ and the basis functions used for the model are the aerodynamic torque, Q_a, and thrust, T_a, sensitivities.

$$\rho_1(\theta) \coloneqq \frac{1}{J_r}\frac{\partial Q_a}{\partial \Omega}_{\overline{V}},\ \rho_2(\theta) \coloneqq \frac{1}{J_r}\frac{\partial Q_a}{\partial V}_{\overline{V}},\ \rho_3(\theta) \coloneqq \frac{1}{J_r}\frac{\partial Q_a}{\partial \beta}_{\overline{V}},$$

$$\rho_4(\theta) \coloneqq \frac{1}{M_t}\frac{\partial T_a}{\partial \Omega}_{\overline{V}},\ \rho_5(\theta) \coloneqq \frac{1}{M_t}\frac{\partial T_a}{\partial V}_{\overline{V}},\ \rho_6(\theta) \coloneqq \frac{1}{M_t}\frac{\partial T_a}{\partial \beta}_{\overline{V}}$$

Once the model had been implemented, the LMI was constructed and the optimization process was completed following the algorithm in [2]. With the controller matrices in hand, the closed-loop system was constructed and implemented in MATLAB/Simulink and simulated using FAST for Normal Turbulence Model (NTM) inflow. Figure 4 shows a time-series plot of the baseline torque look-up table as compared with the LPV tower damper.

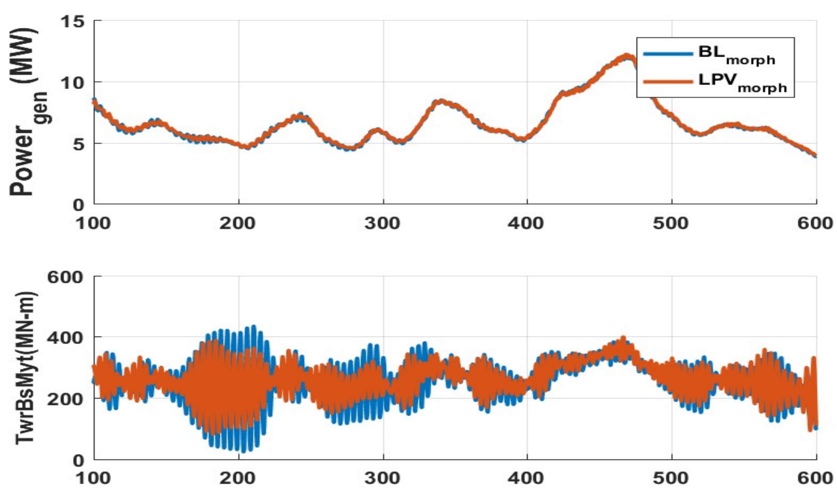

Figure 4 -Time-series of turbine power and Tower Base FA bending moment comparison between baseline TLUT and advanced LPV torque control

From these results, it can be seen that the LPV torque controller is able to capture the same amount of power for an identical turbulent inflow, while resulting in lower tower base fore-aft bending moments.

iii. *FW-18 LPV Torque Controller for load Reduction*

Using the FW-18 FAST model, the turbine was simulated using NTM inflow conditions for wind speeds ranging from cut-in to cut-out (~4 m/s to 12 m/s), and performance was compared between the two architectures.

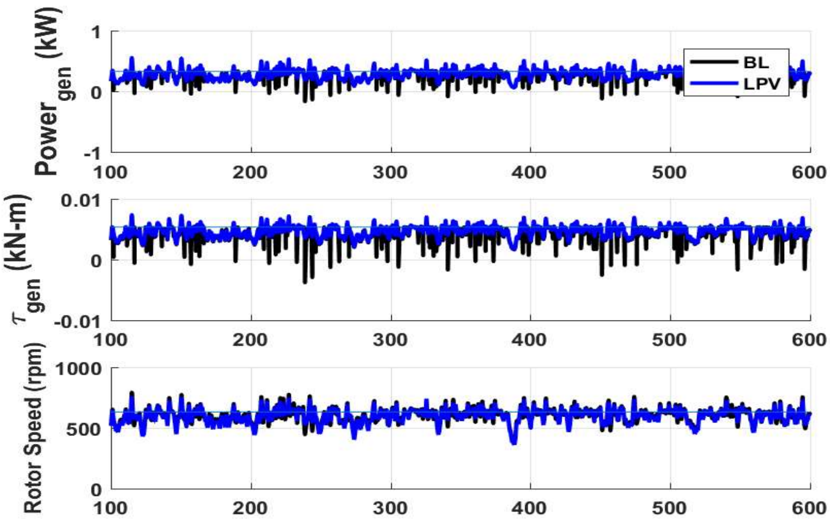

Figure 5 – Time series plot showing metrics for the FW-18 turbine during an NTM inflow condition with a mean wind speed of 8 m/s (rated wind speed).

Personal Experience

During my time here in Oldenburg, I have been in contact with many different people from many different backgrounds. The lab at ForWind is one of the most culturally diverse offices I have ever worked in, and has provided insights and interactions with people from all corners of the world.

I live with a group of students (mostly native to Germany), whom have all been kind, patient, helpful, and fun to be around. They have taught me about the culture and language of Germany, and helped me settle to a comfortable living situation.

Overall, it has been a pleasant and stimulating personal experience.

Conclusions

The work conducted so far has allowed for an initial characterization of the FW-18 rotor and some identification of model parameters, such as blade and tower natural harmonics which can be used for load reduction control schemes. Baseline simulations have provided a standard to compare future advanced control architectures.

Outlook

Upon returning to the United States, I plan to compile the work I have accomplished during my IPID4all exchange into 1-2 papers to be submitted to either journals or conferences. I also plan to further develop the optimization portion of the LPV controller synthesis process, and fine tune the model used for less online tuning.

References

[1] J. Mohammadpour and C.W. Scherer, Control of Linear Parameter Varying Systems with Applications. Springer, 1st edition. New York, New York, 2012.

[2] P. Zhao and R. Nagamune. *Switching LPV controller design under uncertain scheduling parameters*. Automatica. vol. 76, 2017.

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