Controller Design Objectives and Modeling

Exercise to Lecture #1
Controller Design for Wind Turbines and Wind Farms

David Schlipf

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1 Uncontrolled Wind Turbine

A 5 MW wind turbine is operating below rated wind conditions. With a reduced model (Figure 1), the motion of the rotor speed Ω and the generator can be described by:

$$J\dot{\Omega} = M_\mathrm{a} - M_\mathrm{G} r_\mathrm{GB} \tag{1}$$

$$P_\mathrm{el} = M_\mathrm{G} \Omega r_\mathrm{GB} \eta_\mathrm{el}. \tag{2}$$

The gearbox with the ratio r_GB is assumed loss-free. Further, J is the sum of the moments of inertia about the rotation axis and η_el is the efficiency of the generator. The aerodynamic torque acting on the rotor with the radius R at a wind speed v_0 is

$$M_\mathrm{a} = \frac{1}{2}\rho\pi R^2 \frac{c_\mathrm{P}(\lambda,\theta)}{\Omega} v_0^3, \tag{3}$$

where c_P is the effective power coefficient, ρ is the air density, and λ is the tip speed ratio defined as:

$$\lambda = \frac{\Omega R}{v_0}. \tag{4}$$

Suddenly, the turbine loses the connection to the grid due to a broken cable (generator torque becomes 0 Nm). Unfortunately, the control engineer forgot to implement a safety system and the blade pitch remains at 0 deg. Please answer following questions:

a) Find the missing values in Table 1 (see below) by downloading and searching in [1].
b) Which tip-speed-ratio will the turbine approach in the uncontrolled case?
c) At which wind speed the blade tips would break the sound barrier in the uncontrolled case? This question is of course academic: Blades will most probably break before reaching supersonic speed.

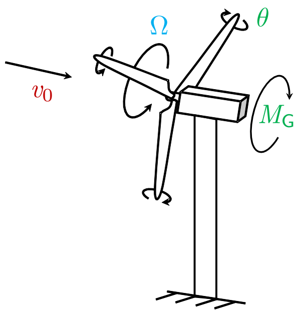

Figure 1: Reduced nonlinear model.

Table 1: Specification of the NREL 5 MW wind turbine model [1].

Rotor radius	R	
Gear box ratio	r_{GB}	
Generator efficiency	η_{el}	
Air density	ρ	
Rated rotor speed	Ω_{rated}	

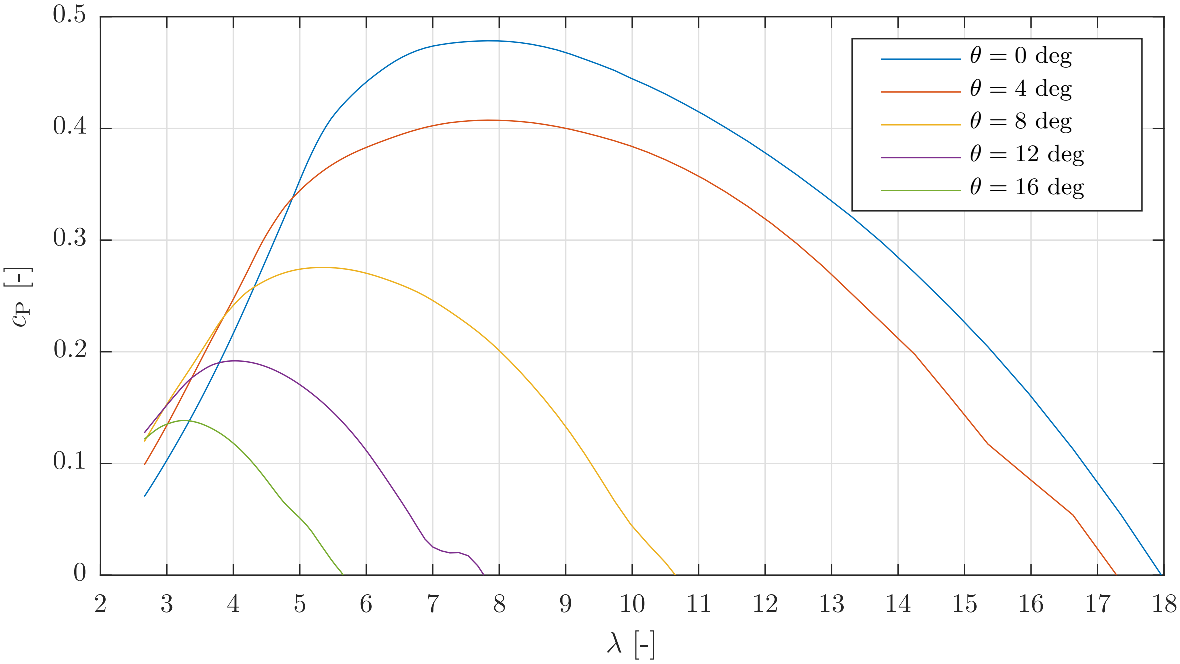

Figure 2: Power coefficient $c_{\mathrm{P}}(\lambda, \theta)$ of the NREL 5 MW wind turbine model.

Hints:

- The power coefficient is plotted in Figure 2.
- For objects traveling in dry air of a temperature of 20 °C at sea level, the speed of sound is approximately 343 m/s.

2 Controlled Wind Turbine

Another 5 MW wind turbine is operating in above rated wind conditions.

a) What will be the rated generator torque?
b) Which pitch angle will be reached at 16 m/s?

3 Simulation Exercise

Here, a wind turbine is controlled manually in open loop at 16 m/s. For the SLOW model, see [2]. For the FAST turbine, only the rotor motion is enabled. Please perform the following tasks:

a) Download the files and get familiar with the code.
b) Adjust the file NREL5MWDefaultParameter_SLOW1DOF.m. Here, the parameter of the SLOW model should be loaded in the preprocessing step. Add the missing paramters and calculate the inertia J.
c) Adjust the file Exercise01.m by finding useful values for pitch and torque to keep the turbine at rated rotor speed and rated electrical power. You can define and use the variable `P_el_rated` and `Omega_g_rated` for it. Add the calculation of the electrical power in the postprocessing section.
d) Adjust the FAST and SLOW simulation to 20 m/s to keep the turbine at rated rotor speed and rated electrical power. Best would be to make a copy of all FAST input files and of Exercise01.m, so you can still run both.

References

[1] J. Jonkman, S. Butterfield, W. Musial, and G. Scott. *Definition of a 5-MW Reference Wind Turbine for Offshore System Development*. Tech. rep. TP-500-38060. NREL, 2009. DOI: `10.2172/947422`.

[2] D. Schlipf. "Lidar-Assisted Control Concepts for Wind Turbines". PhD thesis. University of Stuttgart, 2015. DOI: `10.18419/opus-8796`.