

Controller Design Objectives and Modeling

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

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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:

$$J\dot{\Omega} = M_a - \frac{M_G}{i_{GB}} \quad (1)$$

$$P_{el} = M_G \frac{\Omega}{i_{GB}} \eta_{el}. \quad (2)$$

The gearbox with the ratio i_{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

$$M_a = \frac{1}{2} \rho \pi R^2 \frac{c_P(\lambda, \theta)}{\Omega} v_0^3, \quad (3)$$

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

$$\lambda = \frac{\Omega R}{v_0}. \quad (4)$$

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:

- Find the missing values in Table 1 (see below) by downloading and searching in [1].
- Which tip-speed-ratio will the turbine approach in the uncontrolled case?
- 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.

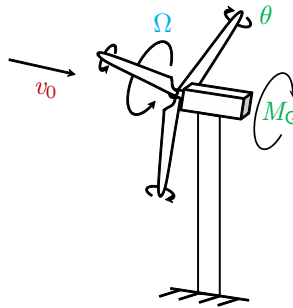


Figure 1: Reduced nonlinear model.

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

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

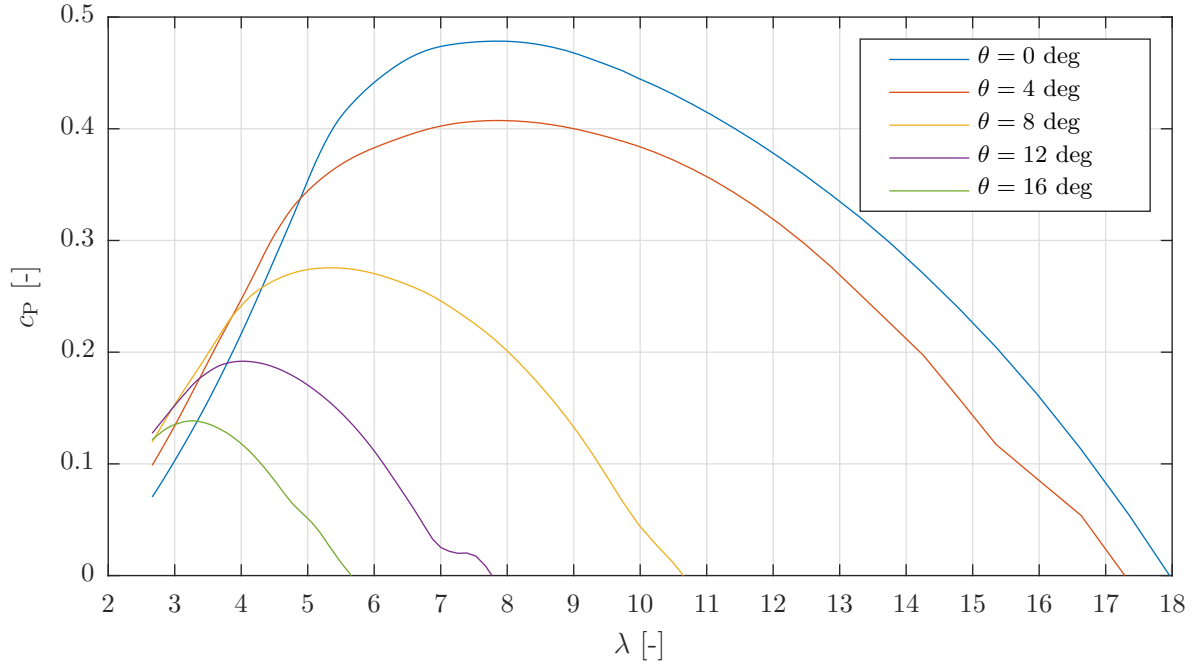


Figure 2: Power coefficient $c_p(\lambda, \theta)$ of the NREL 5 MW wind turbine model.

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.

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

3 Simulation Exercise

Here, a wind turbine is controlled manually in open loop. 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 parameters 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](#).