UNIVERSITÀ DI TRENTO

DIPARTIMENTO DI

INGEGNERIA INDUSTRIALE

Assignment 1

Renewable Energy Conversion Systems

Giacomo Moretti, Elisabetta Tedeschi

A.Y. 2024-2025

UNIVERSITÀ DI TRENTO
Dipartimento di Ingegneria Industriale

Energy evaluation of an offshore wind turbine

We consider the DTU 10 MW reference wind turbine (see Lecture 6) and assume it is installed off the Danish island of Anholt. Meteorological data are available for the location (see .csv file) in the form of average wind speed measurements with 10-min resolution, recorded at a height of 116 m above sea level (i.e., roughly equal to the turbine hub height), for a period of approximately 2 years (source: Ørsted A/S).

The turbine has the features/dimensions listed below, and it generates electrical power using a direct-drive PMSG, with the features reported in the table below. Assume reasonable values (consistent with the problem context) for all missing data.

Turbine data

Number of blades	3	
Rotor orientation	Clockwise rotation - Upwind	
Control	Variable Speed, Collective Pitch	
Cut in wind speed	4	$[\mathrm{m\,s^{-1}}]$
Cut out wind speed	25	$[\mathrm{m\,s^{-1}}]$
Rotor diameter	178.3	[m]
Hub Height	119	[m]
Air density	1.225	$[\mathrm{kg\,m^{-3}}]$
Rated wind speed	11.4	[m/s]
Moment of inertia at the rotor	$1.56\cdot10^{8}$	$[\mathrm{kg\ m^2}]$
Rotor damping	$2\cdot10^{5}$	[N m s]

Generator data

Parameter	Value	
Inertia	4800	$[\mathrm{kg\,m^2}]$
Poles pairs	320	
q-*axis* inductance	1.8	[mH]
d-*axis* inductance	1.8	[mH]
Stator resistance	64	[mΩ]
Magnets flux	19.49	[Wb]
Inverter switching frequency	1	[kHz]

Tasks

Static analysis

- Generate a probability density function (yearly statistics) for the wind speed, and find the parameters of a best-fit Weibull distribution
- Consider two working scenarios: 1) stall regulated turbine (constant speed, no pitch control), and 2) pitch regulated turbine with variable speed. For the first case (stall-regulated), identify an appropriate target value for the (constant) angular speed.
  Neglecting all losses (damping, generator losses, etc.) and assuming that the turbine behaviour is ideal (i.e., the power produced at a certain wind speed can be read out of the theoretical power curve), calculate the average annual energy production for both scenarios. Compare the energy produced in the two cases (stall regulated vs. pitch regulated w. variable speed)
- Using the provided data, calculate the steady-state Joule losses (due to the windings resistances) and viscous losses (due to damping) as a function of the wind speed, and calculate the turbine average electromechanical efficiency over a year, for the case of pitch regulated variable speed turbine.

Tasks

Dynamic analysis

We now want to assess the dynamic behaviour of the turbine in the presence of variable wind speed. For this aim, we will build upon the *Simulink model* developed in class.

- Develop a new version of the Simulink model for the stall-regulated version of the turbine, using a closed-loop speed controller (to keep the speed nearly constant), and no pitch regulation.
- Expand the Simulink model of the pitch regulated variable speed turbine to include a limitation of the rate at which the pitch angle can be changed (e.g. $8°/s$).
- Considering a few significant wind speeds, generate realistic timeseries of the speed distribution (using a Kaimal distribution and a turbulence intensity on the order of 10%), calculate the power generated on a time window of consistent length by the two models, and compare the results. How does the power compare with the theoretical power curves at the considered average speeds?
- Assume now that the anemometer used in the pitch regulated variable speed model is noisy (assume a reasonable model and intensity for the noise). Evaluate the performance/robustness of the controller with simulations, and evaluate how/whether the power production (at different average speeds) is affected by the noise.
- <u>Optional</u>: Expand the pitch controlled variable speed turbine model to include the PMSG with inner current control loop (assume that i_d is constantly kept equal to 0 and model the q-axis only). How do the Joule losses in dynamic conditions compare with those estimated statically (at the same average speed)?