Steady States Calculations

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21.11.2022

Lecture #8 of Course
"Controller Design for Wind Turbines and Wind Farms"

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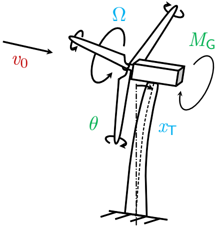
Schedule

19.09. 1 Controller Design Objectives and Modeling
26.09. 2 Baseline Generator Torque Controller (online)
10.10. 3 Collective Pitch Controller (online)
17.10. 4 Filter Design (online)
24.10. 5 Tower Damper
07.11. 6 Advanced Torque Controller
14.11. 7 Wind Field Generation
21.11. 8 Steady State Calculations
28.11. 10 Lidar-Assisted Control I
05.12. 11 Lidar-Assisted Control II
12.12. 12 Wind Farm Effects
19.12. 13 Wind Farm Control
09.01. 14 Floating Wind Control ???

Steady States Calculations



Motivation

- Controller design impacts steady states of wind turbine
- Steady states impact controller design
- Steady states are handy to initialize simulations
- Steady states are important for rest of wind turbine design
- Example: Optimus LE: What is the rated wind speed?

→ To know how to calculate steady states is important!

Main questions

- How can we calculated steady states for a reduced order turbine model?
- How can we get the steady states for a full aero-elastic model?

Content

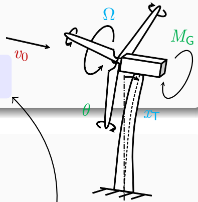
1. Steady States Calculations SLOW
2. Conclusion and Learning Objectives

Reduced Model for Controller Design

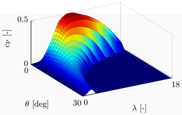
Structural dynamics

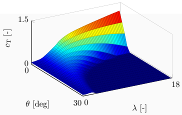
rotor motion: $J\dot{\Omega} = \boxed{M_\mathsf{a}} - M_\mathsf{G}$

tower motion: $m\ddot{x}_\mathsf{T} + c\dot{x}_\mathsf{T} + k(x_\mathsf{T} - x_{\mathsf{T}0}) = \boxed{F_\mathsf{a}}$



Aerodynamics





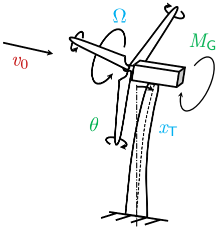
torque: $\boxed{M_\mathsf{a} = \frac{1}{2}\rho\pi R^2 \frac{c_\mathsf{P}(\lambda,\theta)}{\Omega} v_\mathsf{rel}^3}$ thrust: $\boxed{F_\mathsf{a} = \frac{1}{2}\rho\pi R^2 c_\mathsf{T}(\lambda,\theta) v_\mathsf{rel}^2}$

with tip speed ratio $\lambda = \frac{\Omega R}{v_\mathsf{rel}}$ and relative wind speed $v_\mathsf{rel} = v_0 - \dot{x}_\mathsf{T}$

Steady States

- Calculated by setting $\dot{\Omega} = \ddot{x}_\mathsf{T} = \dot{x}_\mathsf{T} = 0$ for each v_0 including controller.
- Since x_T is not impacting Ω, calculate Ω first, then x_T.

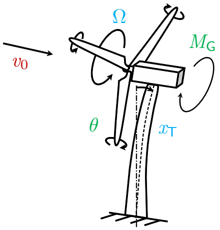
General Procedure to Calculate Steady States



Steps

1. Find v_{rated}
2. Calculate steady states below rated wind speed
   (a) If baseline torque-controller, calculate all together
   (b) If PI torque-controller, calculate separately for Region 1, 1.5, 2, and 2.5.
3. Calculate steady states above rated wind speed

How to find rated wind speed?



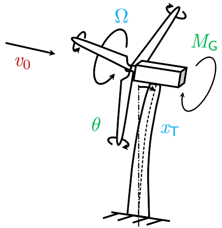
Minimization Problem

$$\min_{v_0} \left(M_a(v_0, \Omega, \theta) - M_G\right)^2$$

Find v_0, set other values to the corresponding values

- $\Omega = \Omega_{rated}$
- $M_G = M_{G,rated}$
- $\theta = \theta_{min}$

Below rated wind speed - Baseline torque controller



Minimization Problem

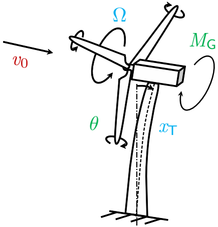
For every wind speed v_0, the free variable is Ω:

$$\min_{\Omega} \left(M_a(v_0, \Omega, \theta) - M_G\right)^2$$

Find Ω, set other values to the corresponding values

- v_0 from $v_{\text{cut-in}}$ to v_{rated}
- $M_G = M_G(\Omega)$
- $\theta = \theta_{\min}$

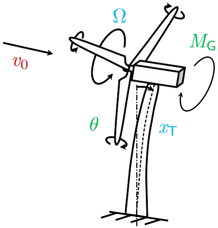
Below rated wind speed - PI torque controller



Steps

1. Find $v_{1\text{to}1.5}, v_{1.5\text{to}2}, v_{2\text{to}2.5}$ similar to v_{rated}
2. Calculate steady states for every v_0 solving minimization problem ($\theta = \theta_{\text{min}}$):
   (a) In region 1 and 2: Ω free, M_G either 0 or $M_G = k\Omega_G^2$
   (b) In region 1.5 and 2.5: M_G free, Ω either $\Omega_{1.5}$ or $\Omega_{2.5} = \Omega_{\text{rated}}$

Above rated wind speed



Minimization Problem

For every wind speed v_0, the free variable is θ:

$$\min_{\theta} \left(M_\mathsf{a}(v_0, \Omega, \theta) - M_\mathsf{G}\right)^2$$

Find θ, set other values to the corresponding values

- v_0 from v_rated to $v_\mathsf{cut\text{-}out}$
- $M_\mathsf{G} = M_\mathsf{G,rated}$
- $\Omega = \Omega_\mathsf{rated}$

Conclusion

Main questions

- How can we calculated steady states for a reduced order turbine model?
- How can we get the steady states for a full aero-elastic model?

Set ODEs to zero

- Separate into regions by finding rated wind speed
- Find always free variable, solve minimization problem

Run simulations with constant wind

- Steady states from SLOW can be used to initialize for first time
- Average over couple of full revolutions

Quick check on learning objectives

After this lectures you should be able to...

- calculate steady states for a simplified wind turbine model
- calculate steady states with FAST

Please use our mobile phone and go to kahoot.it

- use game pin displayed on screen
- and type in your nickname

Purpose: Access the learning effect and obtain feedback!

Please let me know if you have further questions!

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