Wind Farm Control

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Lecture #13
Controller Design for
Wind Turbines and Wind Farms

Schedule

02.09.	1	Controller Design Objectives and Modeling
03.09.	2	Baseline Generator Torque Controller
04.09.	3	Collective Pitch Controller
05.09.	4	Filter Design
06.09.	7	Wind Field Generation
09.09.	10	Lidar-Assisted Control I
10.09.	11	Lidar-Assisted Control II
11.09.	5	Tower Damper
12.09.	6	Advanced Torque Controller
12.09.	8	Steady State Calculations
16.09.	9	Individual Pitch Control
17.09.	12	Wind Farm Effects
18.09.	13	Wind Farm Control
19.09.	14	Floating Wind Control I
20.09.	15	Floating Wind Control II

Wind farms

Horns Rev wind farm.
Photo by C. Steiness.

"...a humid and warm air mass was advected from the southwest over cold sea and the dew-point temperature was such that cold-water advection fog formed in a shallow layer...The condensation appears to take place primarily in the wake regions with relatively high axial wind speed and high turbulent kinetic energy."[1]

Motivation wind farms

- Costs of the grid connection $\searrow$
- Maintenance costs $\searrow$
- Land pollution $\searrow$

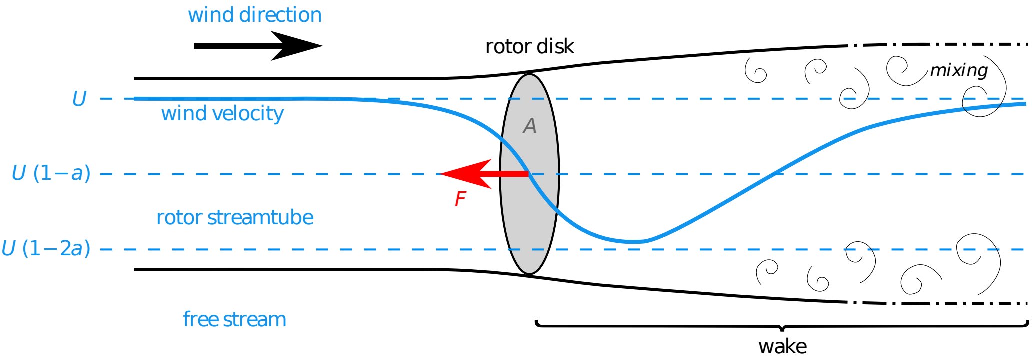
Motivation wind farm control

- Energy production $\nearrow$
- Structural loading $\searrow$
- Energy quality $\nearrow$

Main questions

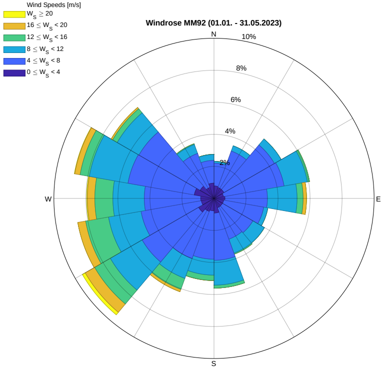
- How can we optimize wind farm operation?
- What are current challenges?

Wind turbine wakes



Simplified representation of a wake [2].

Yaw control



based on [Daniel Pereira (2022)]

Motivation yaw control

- Wind direction is usually not constant
- Upwind turbines usually better aerodynamics, no tower shadow
- Active yaw control is necessary

Main questions

- How is a yaw controller for wind turbines implemented?
- Can we improve yaw control with Lidar?

Learning objectives

After this lectures you should be able to...

- explain the measurement principle of different sensors for yaw control
- explain how yaw control works
- calculate the wake losses using the Jensen wake model
- name and explain the three main concepts of wind farm control
- explain the main challenges in wind farm control

Contents

Challenges

Horns Rev wind farm.

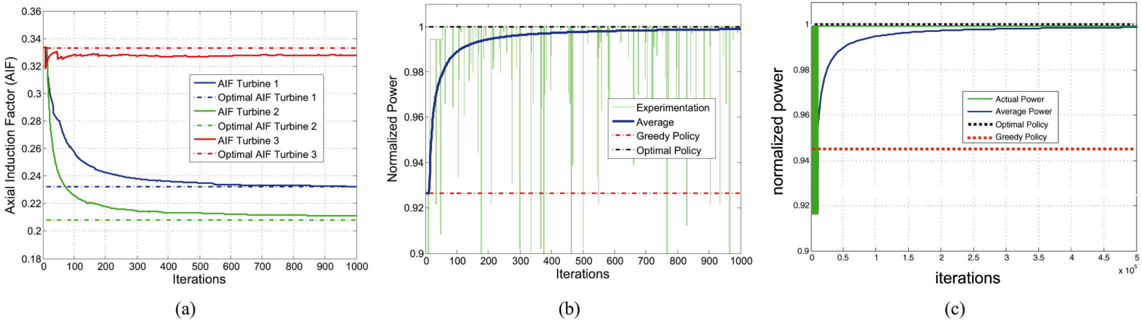
Wind speed dependency

Control inputs of turbine j: yaw misalignment γ_j, pitch angle θ_j, generator torque $M_{\mathsf{G},j}$

$$
\begin{aligned}
u_j &= [\theta_j, M_{\mathsf{G},j}, \gamma_j] \\
P_{\mathsf{a},j} &= \frac{1}{2}\rho\pi R^2 c_{\mathsf{P}}(u_j, v_{0,j}) v_{0,j}^3 \\
F_{\mathsf{a},j} &= \frac{1}{2}\rho\pi R^2 c_{\mathsf{T}}(u_j, v_{0,j}) v_{0,j}^2 \\
v_{0,j} &= f(u_1 \ldots u_i)
\end{aligned}
$$

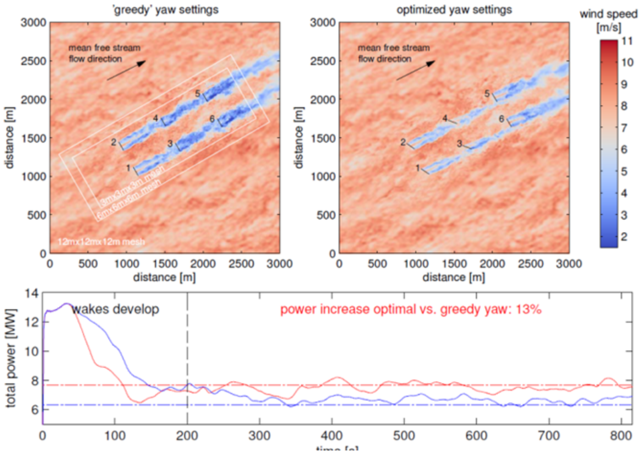
Wind input $v_{0,j}$ depends on control inputs from previous turbines (and undisturbed wind speed).

Axial Induction Control



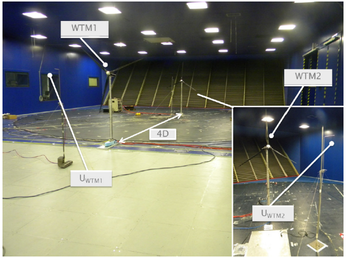
A model-free approach to wind farm control using game theoretic methods [3]

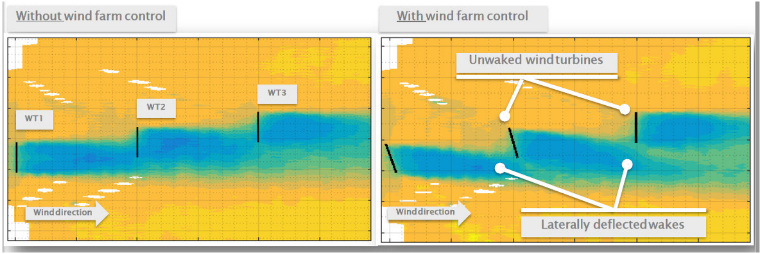
Wake Steering



Wind plant power optimization through yaw control using a parametric model for wake effects - a CFD simulation study[2]

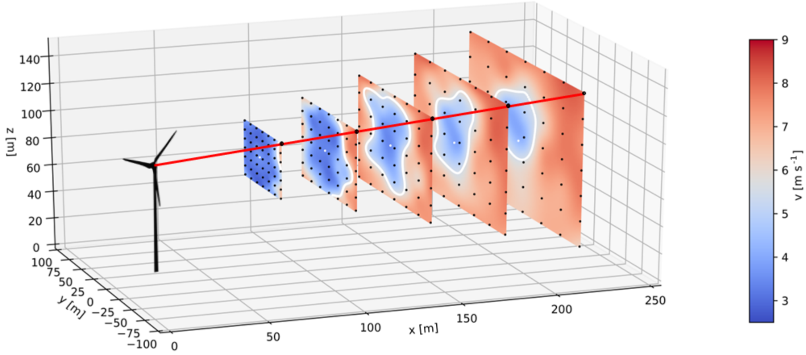
Wake Steering





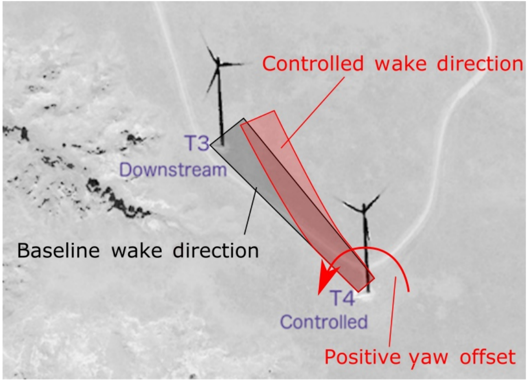
Wind tunnel testing of a closed-loop wake deflection controller for wind farm power maximization [4],[ZephIR]

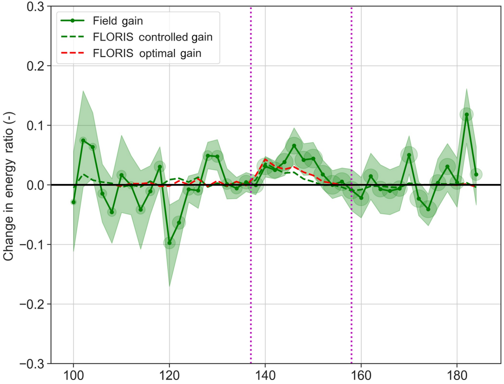
Wake Steering



Full-scale field test of wake steering [5] shows good agreement with control-oriented wake models in FLORIs.

Wake Steering on a Commercial Wind Farm





Initial results from a field campaign of wake steering applied at a commercial wind farm [6] confirms an approximate 4% increase in energy over a 10 deg sector.

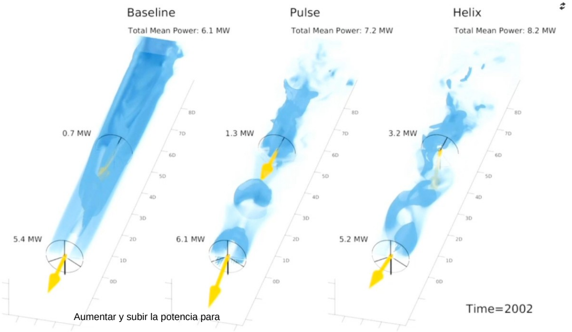
Commercial Wake Steering

[Video by Siemens Gamesa]

Siemens Gamesa Wake Adapt

Commercial controller by SGRE, claimed benefits: 1% more energy

Wake Mixing



DATA DRIVEN CONTROL

TUDelft

Aumentar y subir la potencia para

Disminuir el efecto de estela

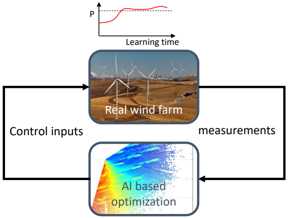
Utilizas IPC para generar una estela helicoidal

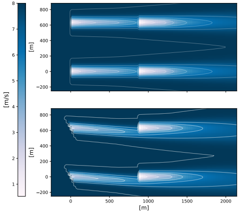
Generar pulsos en la potencia es complejo

The helix approach [7], Video

- Individual pitch control is used to enhance wake mixing in wind farms
- Higher wake turbulence, and subsequently faster wake recovery
- Downstream turbines experience higher wind speeds, thus increasing their energy yield

Lidar-Assisted Wind Farm Control in Complex Terrain





Wind farm control in complex terrain

- Goal: Optimize AEP and reduce loads
- Problem: Terrain interaction hard to model

Application of Lidar

- Lidar provides useful flow information
- Black box modeling and optimization
- Should combine wake steering and axial induction
- Master thesis by Felipe Novais at sowento

Conclusion

- How can we optimize wind farm operation?
- What are current challenges?

- three main concepts: axial induction control, wake steering, wake mixing
- control objective: power optimization, loading, active power control
- challenges: Choice of flow model, big data, use of sensors and actuators

References

[1] C. B. Hasager, N. G. Nygaard, P. J. H. Volker, I. Karagali, S. J. Andersen, and J. Badger. “Wind Farm Wake: The 2016 Horns Rev Photo Case”. In: *Energies* 10.3 (2017), p. 317. DOI: 10.3390/en10030317.

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Let's talk...

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