Technische Universität München
Wind Energy Institute

Improved Wind Farm Operation

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Motivation–Problem statement

Power extraction from wind is usually organized in clusters of wind turbines → **wind farms**

This is necessary due to:

- Commissioning\Decommisioning cost
- Installation and Maintenance cost
- Grid connection cost

Wind Turbines in a wind farm operate in a "**greedy**" mode → they try to maximize the power capture **individually**

This is **not** optimum! **Upstream** machines naturally disturb the flow severely, resulting in **lower power capture** and **higher loads** for the **downstream** machines

- Wind farm modelling for Wind Farm control
- Implementation and augmentation of wind farm models
- Validation capabilities
- Conclusions & Outlook

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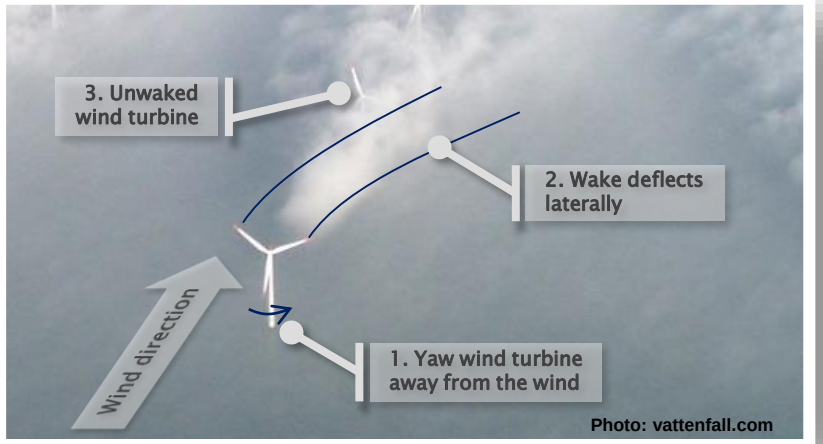
Wind Farm Control

Which is the answer?

- We can make the wind turbines work as a **team** by introducing a wind farm controller.
- The purpose is to optimize the **wind farm power capture** instead of each wind turbine separately



How does this work?

- The physical explanation behind this is wake deflection
- Yawing the upstream machine(s) the wake is pushed out of the rotor of the downstream machines.
- Upstream machine captures less power but overall there can be significant gain

Wind Farm Modelling

Sounds easy, but it is not!

- Wind is constantly changing→ the same should happen with the optimum yaw setting of each wind turbine
- It is mandatory to have an accurate enough reduced order model of the wind farm
- Such a model can be used in a model predictive wind farm controller

→Wind farm modelling for wind farm control is one of the hottest topics within the wind energy research community

At **TU Munich** we work on this topic on several fronts:

1. **Implementation** of such models

2. **Augmentation** of these models with information coming from the rotor

3. Numerical and **experimental** validation of the models

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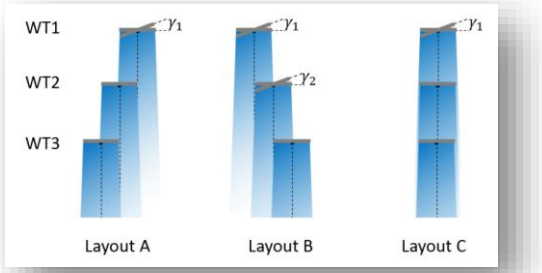
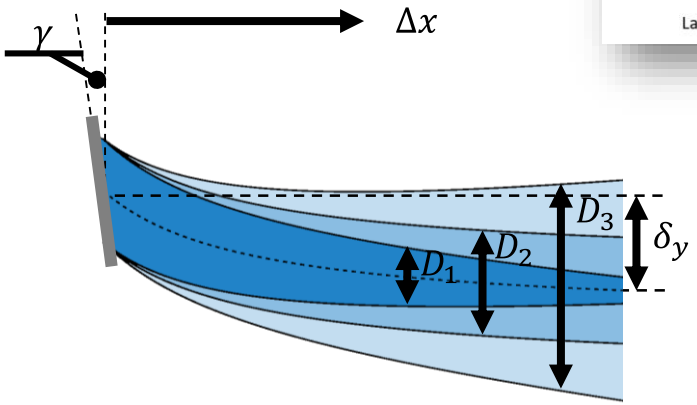
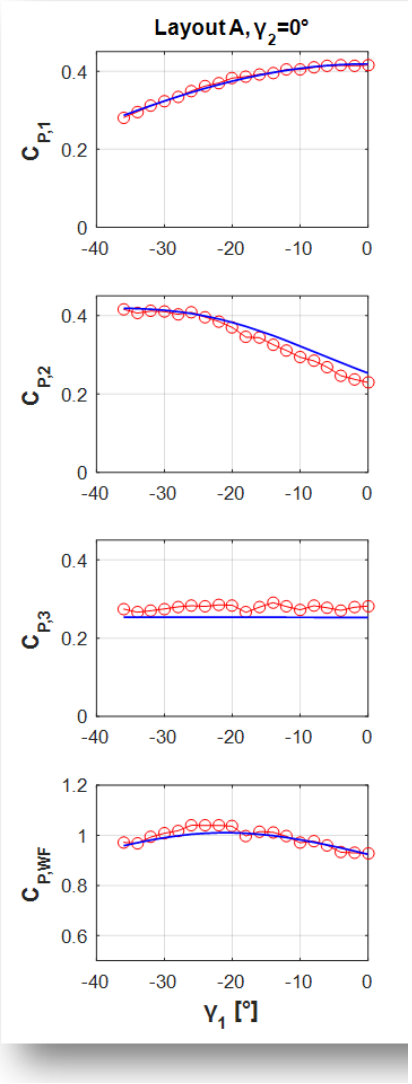
Implementation





Schematic representation of FLORIS[1] model.



This model is based on conservation of momentum for estimating:

Wake **expansion**

Wake **deflection**

Velocity **deficit**

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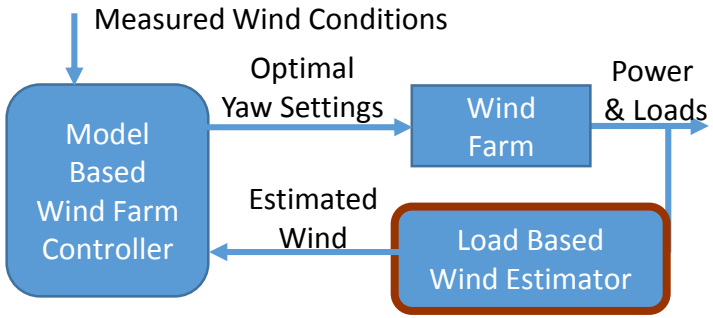
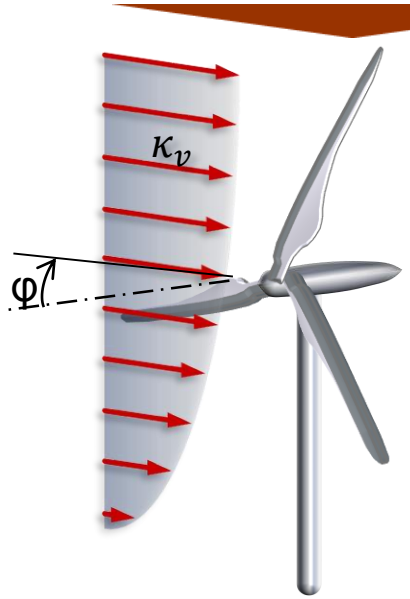
[1] P. M. Gebraad, F.W. Teeuwisse, J.W. van Wingerden, P. A. Fleming, S. D. Ruben, J. R. Marden, and L. Y. Pao, "A data-driven model for wind plant power optimization by yaw control," 2014.

Augmentation

- Flow is highly **non uniform** within the rotor area → Point measurements (anemometers) can mask the complex reality
- Uncertainty in model input and/or disturbance can lead to poor control performance
- **Rotor is the best anemometer**

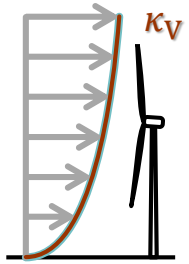




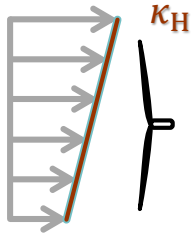
- in and out-of plane blade moments m;
- azimuth angle;
- rotor speed;
- wind speed;
- air density.

$$\mathbf{m} = \mathbf{F}\begin{Bmatrix}\phi\\ \kappa_v\\ \chi\\ \kappa_h\end{Bmatrix} + \boldsymbol{m_0}$$

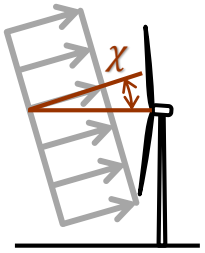
Vertical shear layer



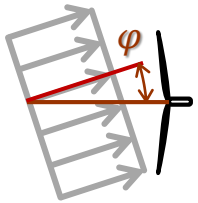
Horizontal shear layer



Upflow angle



Yaw misalignment



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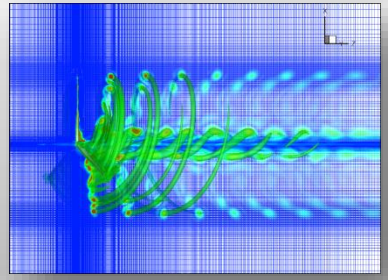
Validation Capabilities

Importance of experimental validation:

Field (full-scale) testing

Validated mathematical models



Wind tunnel (scaled) testing

Wind tunnel testing:

– Cons:

Usually impossible to exactly match all relevant physics due to scaling

+ Pros:

Better control/knowledge of conditions/errors/disturbances

Much lower costs

Does not replace simulation nor field testing, but works in **synergy** with them

Validation Capabilities

TUM possesses a family of scaled models:

G06

G1

G2

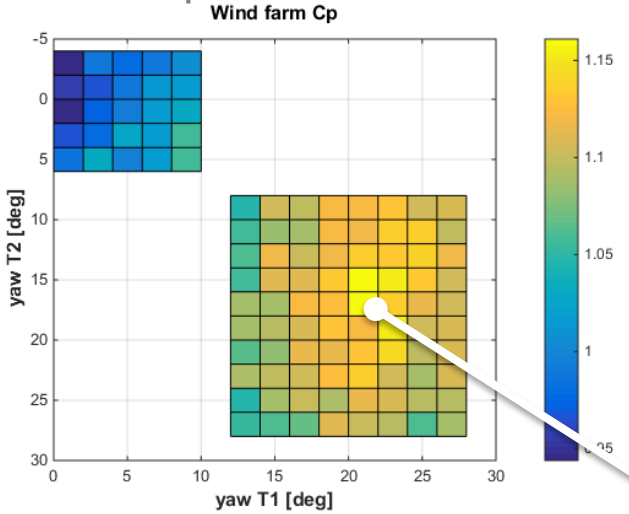
All:

- Real-time individual blade pitch, torque and yaw control
- Fully sensorized: shaft & blade loads, shaft torque, tower loads, blade pitch & rotor azimuth

From **single WT** analysis to **multiple wake interactions** and **complex terrains**

Some results

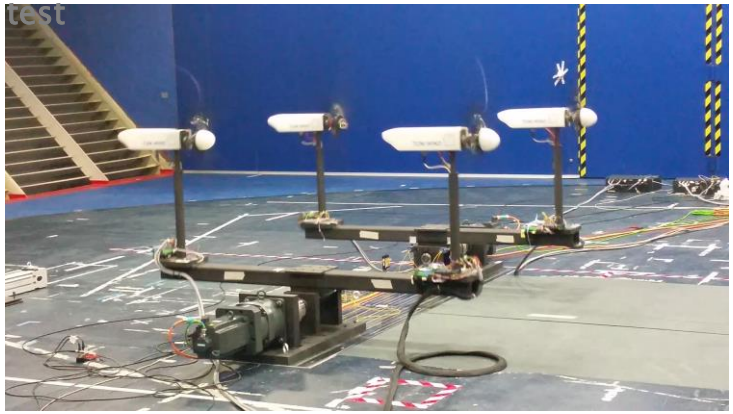
1.Closed-loop wake deflection control



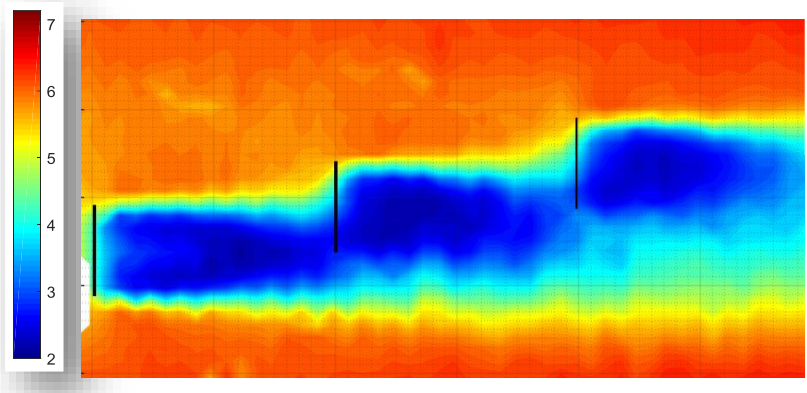
Wind Farm collective Cp for various yaw angles of first two wind turbines

Potential power increase

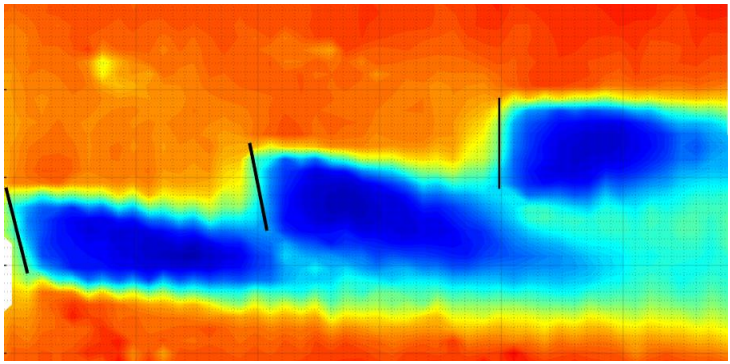
2. Floating platform for offshore applications



3. Wake visualization with DTU scanning LiDARs[1]



Flow without wind farm control



Flow with wind farm control

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[1] Marijn van Dooren: "Demonstration of synchronised scanning lidar measurements of 2D velocity fields in a boundary-layer wind tunnel", Prandtl Hall, Thursday, 14.10-14.30

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Conclusions:

- **Wind farm control can play important role in the future operation of wind farms**
- Key for this is proper wind farm modelling
- Wind tunnel is a cost effective way of validating these techniques

Outlook:

- Put together wind farm models and wind farm control algorithms and test them in the wind tunnel
- Extend the tests to deep array wind farm configurations and complex terrain environments.

Thank you for your attention!

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