### Closed-loop control of wind farms

#### Real-time wind field estimation & model calibration using SCADA data

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## INTRODUCTION



#### The problem in wind farms: wake interaction





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#### Axial induction control for wind farms





#### Wake redirection control in wind farms





#### Wake redirection control in wind farms





#### Wind farm control: current practice in existing farms





Wind farm control: state of the art – open-loop wind farm control





Wind farm control: bleeding edge - closed-loop wind farm control





Wind farm control: bleeding edge - closed-loop wind farm control





## OUR RESEARCH



An estimator for a dynamic surrogate wind farm model





WindFarmSimulator (WFSim)<sup>1,2</sup>

- 3D LES model simplified to 2D (assumption of axisymmetry)
- Nonlinear, medium-fidelity dynamical wind farm model
- Mixing length turbulence model with spatial variations
- Validated to high-fidelity LES data in 2-turbine and 3 x 3-turbine case





- 1. Boersma, S., Doekemeijer, B., Vali, M., Meyers, J., and van Wingerden, J.-W.: A control-oriented dynamic wind farm model: WFSim, Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2017-44, in review, 2017.
- 2. WFSim is publically available on Github: https://github.com/TUDelft-DataDrivenControl/WFSim

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*How far can we push the accuracy of a wind farm model while maintaining computational tractability?* 



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WindFarmObserver (WFObs)<sup>1,2</sup>

- Employs an Ensemble Kalman filter for state and parameter estimation
- Follows a power inversion rule to estimate the freestream wind speed
- Computationally superior to state of the art in the literature





- 1. B. M. Doekemeijer, S. Boersma, L. Y. Pao and J. W. van Wingerden, "Ensemble Kalman filtering for wind field estimation in wind farms," 2017 American Control Conference (ACC), Seattle, WA, 2017, pp. 19-24.
- 2. WFObs is publically available on Github: https://github.com/TUDelft-DataDrivenControl/WFObs

## SIMULATIONS



#### Results

Calibration of 2D flow field,  $TI_\infty$  and  $U_\infty$ 

- WFSim meshed at approx. 12000 states
- WFSim initialized with poor  $TI_\infty$  and  $U_\infty$
- Measurements exclusively SCADA data
- Reality modelled by LES with ALM rotor models
- Extremely low computational cost
- Accuracy comparable to the best in the literature (UKF)







**ŤU**Delft

## CONCLUSIONS



### Conclusions

- Real-time calibration of a dynamic wind farm model
  - Freestream wind speed and turbulence intensity
  - Modeling errors within the wind farm
- High accuracy at very low computational cost
  - Comparable accuracy to the Unscented Kalman filter
  - Two orders of magnitude lower computational cost
- Using only SCADA data
- Ongoing work: optimization using the calibrated model



# Thank you!



