Mitigating Turbine Mechanical Loads Using Engineering Model Predictive Wind Farm Controller

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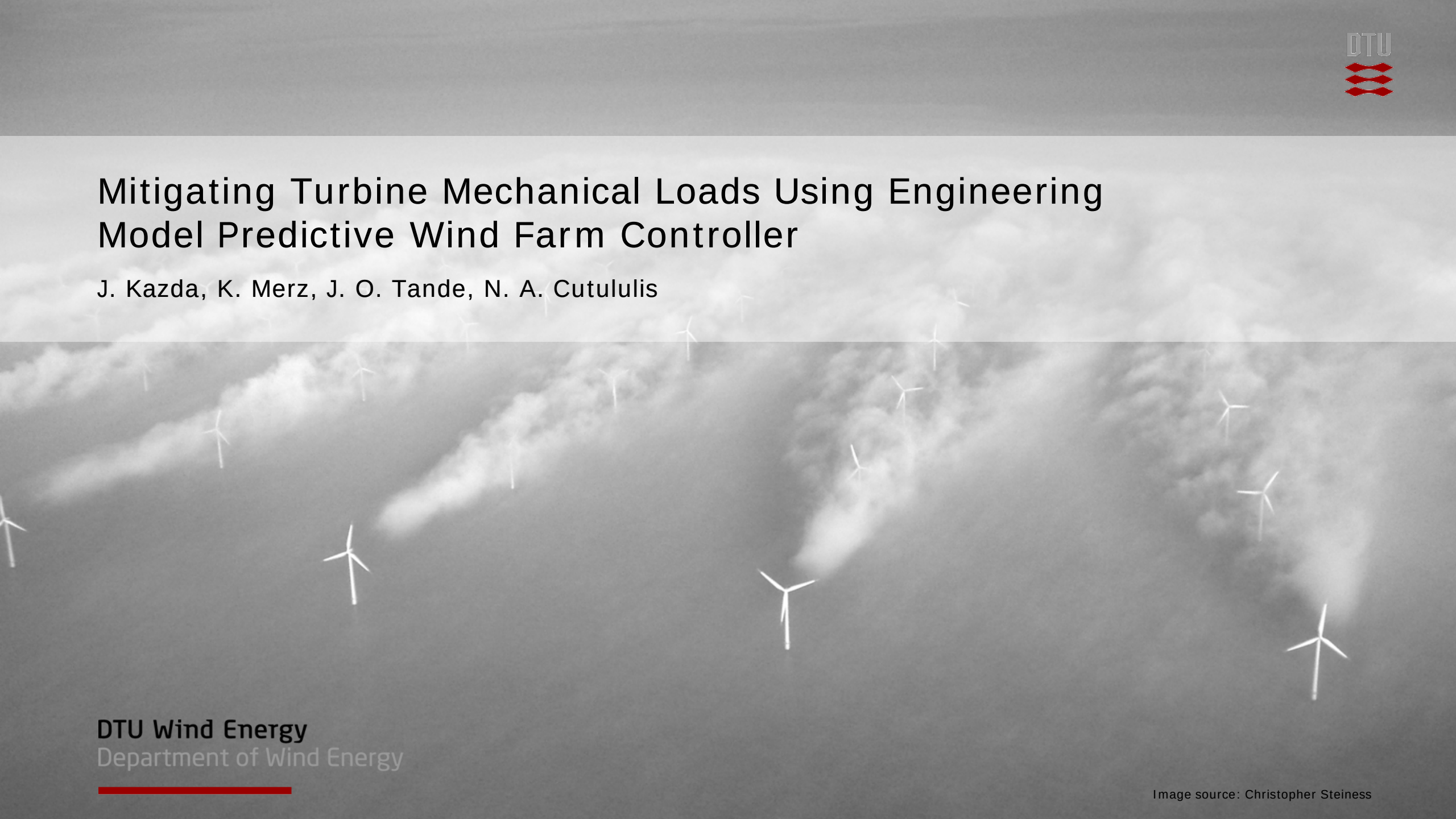

Image source: Christopher Steiness

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- Motivation and objectives
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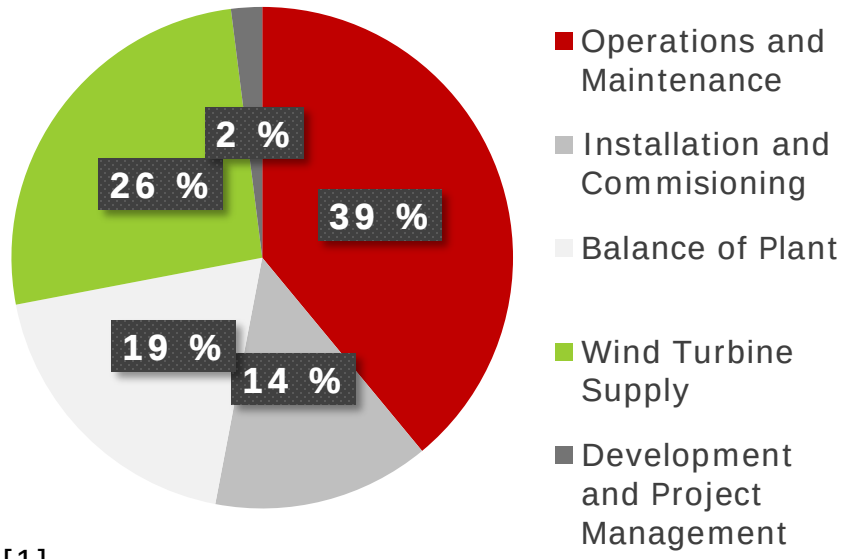
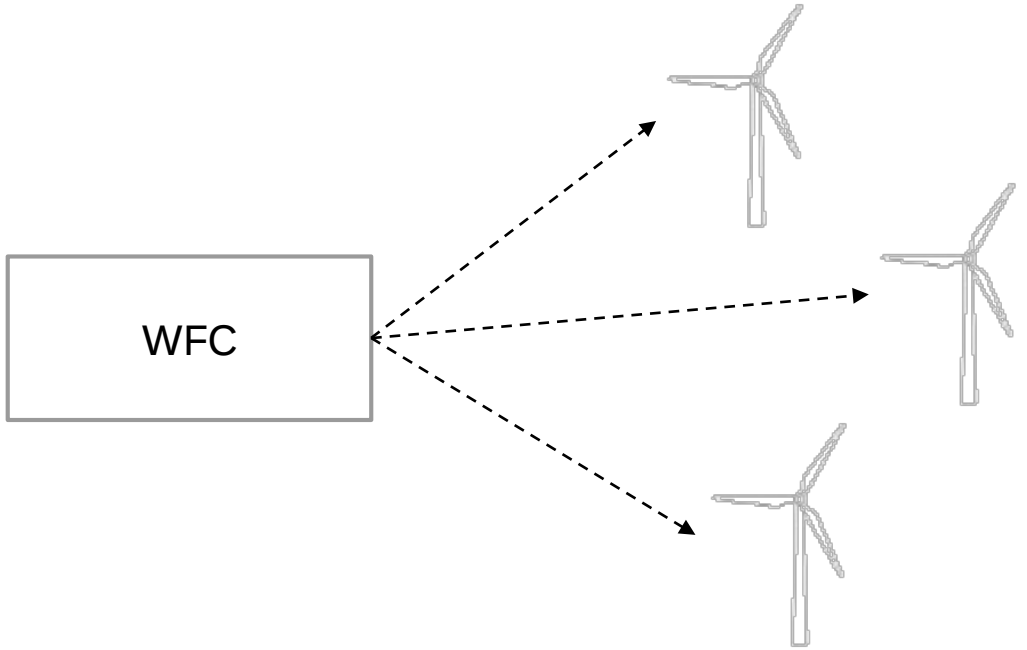
Motivation

- Interaction of wakes with downstream turbines causes up to 80% higher fatigue loads
- O&M costs amount for large share of offshore wind farm lifetime costs



[1]

- Wake-induced fatigue loads can be reduced using optimal wind farm controller (WFC)



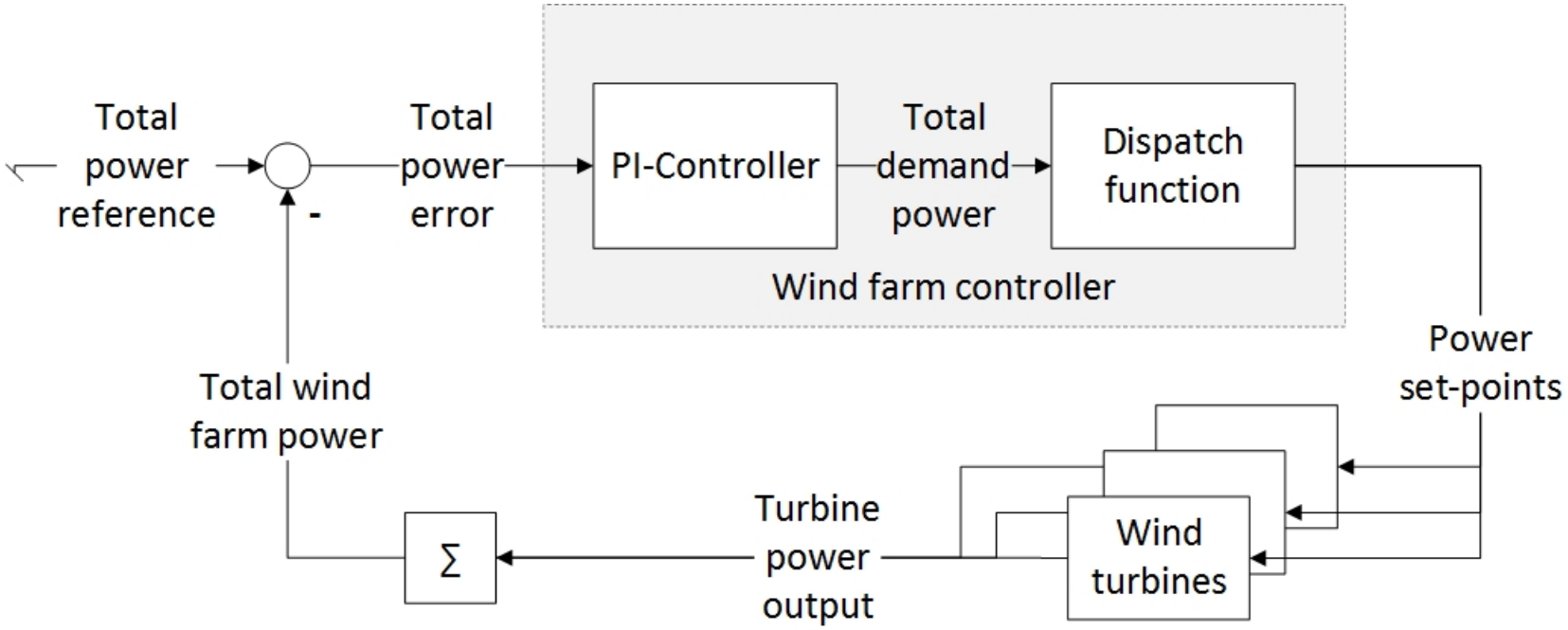
[1] "Wind Energy Update", 2015. [Online]. Available: http://analysis.windenergyupdate.com/

Objectives

Reduce wind turbine fatigue loads during wind farm ancillary services

- Develop model predictive wind farm controller (MPC) for this operational objective
- Compare performance of MPC with other commonly used wind farm controllers

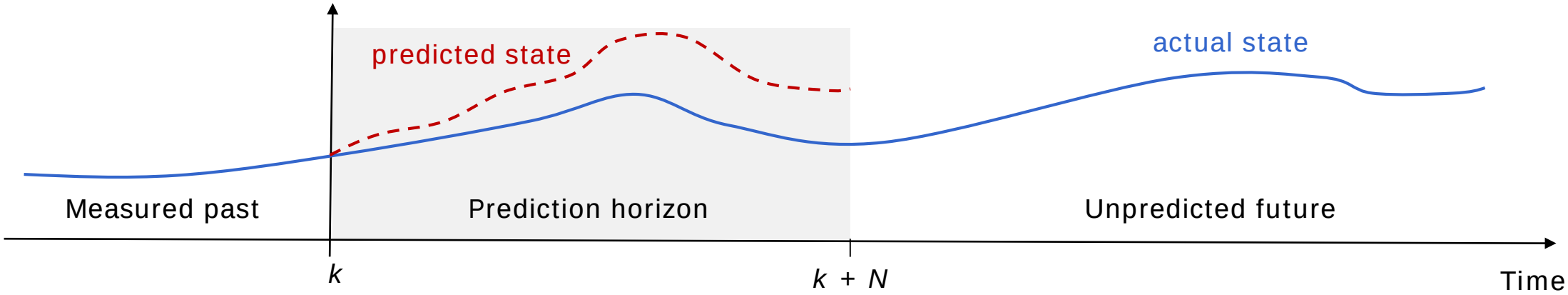
Wind Farm Controllers: PI-Controller



- Dispatch function sets distribution of total demanded power to individual turbines

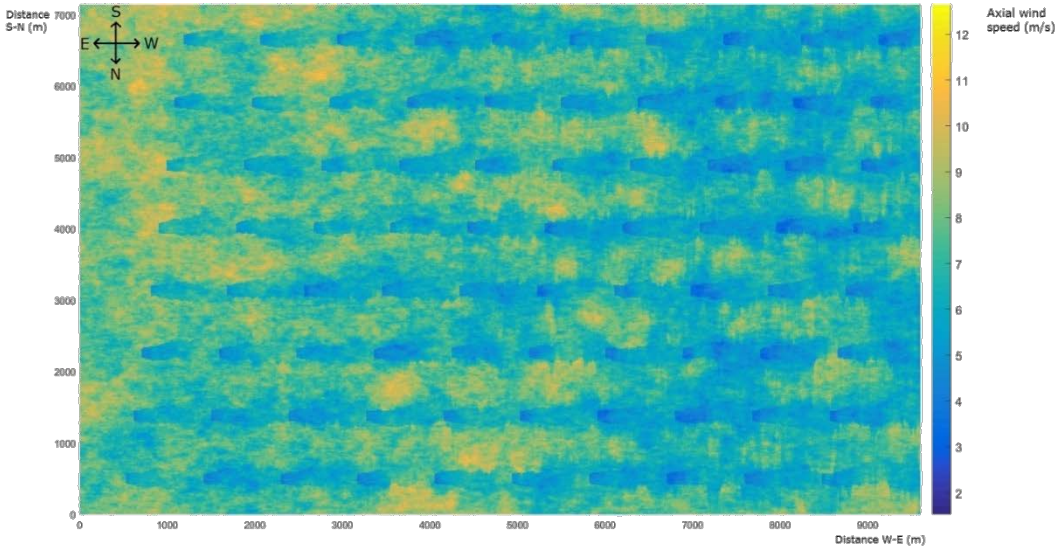
Wind Farm Controllers: Engineering Model Predictive Controller

- MPC cost function objectives are to
  - follow total wind farm power reference
  - follow optimum turbine operation point derived from statistical fatigue load models
  - reduce gust-driven mechanical loads
- Model predictive controller estimates wind farm operation using
  - linear, dynamic wind farm flow model
  - statistical and deterministic turbine load model



Controllers Tested in SimWindFarm Simulation Tool

- SimWindFarm can perform simultaneous, dynamic simulations of
  - wind turbines
  - wind farm controller
  - aerodynamic interaction of wind turbines
- Controllers are tested through DTU Wind Farm Control framework
- All simulations use wind conditions of
  - mean wind speed of 8m/s
  - turbulence intensity of 6%
  - constant wind direction along turbine row



Design of Linear Dynamic Wind Farm Operation Model

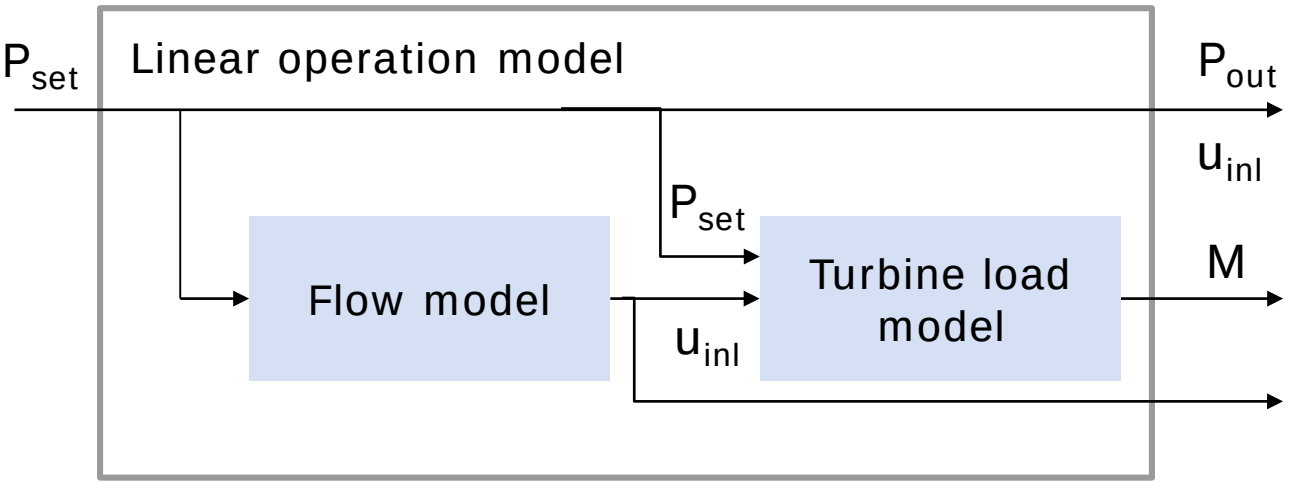
- Inlet wind speed at downstream turbine is obtained as

$$u_{inl,i} = u_\infty - \sum_{j=1}^{N} \delta\widetilde{u_j}$$

- Wind speed deficit from upstream turbine is calculated as

$$\delta\widetilde{u_j} = \delta u_{j,0} + \frac{\partial \delta u_j}{\partial u}_{x_0} \Delta u + \frac{\partial \delta u_j}{\partial P}_{x_0} \Delta P$$

- State space delay model is used to account for duration of wake propagation



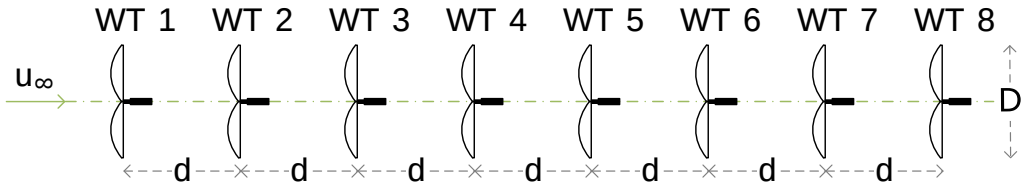
- Resulting total system description of flow model is

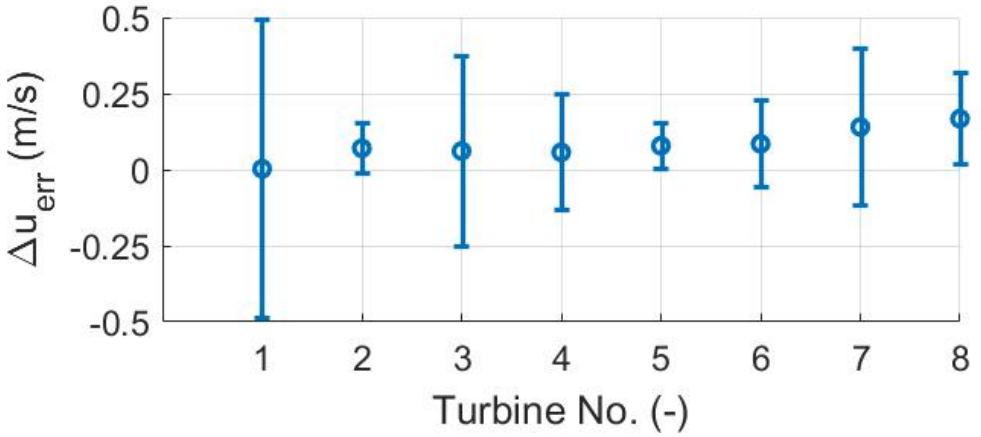
$$\begin{bmatrix} \underline{u}_{del,all} \\ \underline{u}_0 \end{bmatrix}[n+1] = \begin{bmatrix} \underline{\underline{A}}_{del,all} + \underline{\underline{B}}_{u,inl}\underline{\underline{C}}_{u,inl} & \underline{\underline{B}}_{u_0} \\ 0 & I \end{bmatrix} \begin{bmatrix} \underline{u}_{del,all} \\ \underline{u}_0 \end{bmatrix}[n] + \begin{bmatrix} \underline{\underline{B}}_{\Delta P} \\ 0 \end{bmatrix} \underline{\Delta P}[n]$$

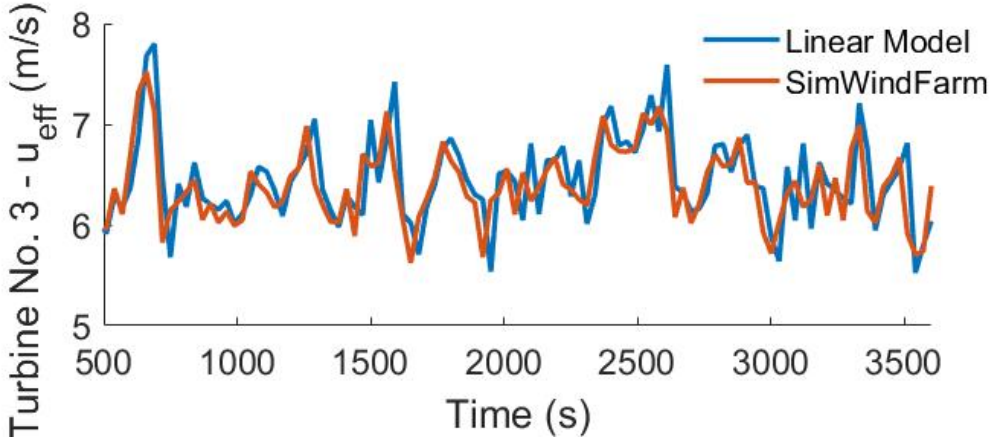
Successful Validation of Linear Operation Model

- Linear operation model compares well with SimWindFarm

- Comparison is conducted on array of 8 turbines

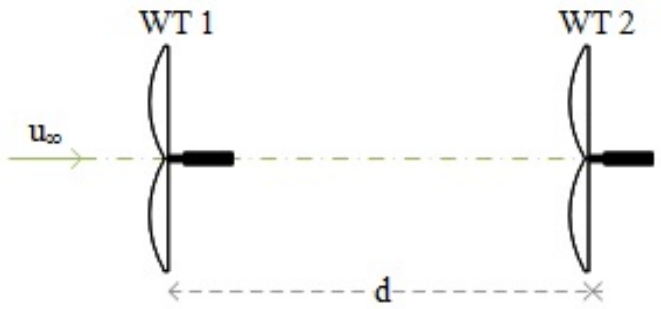




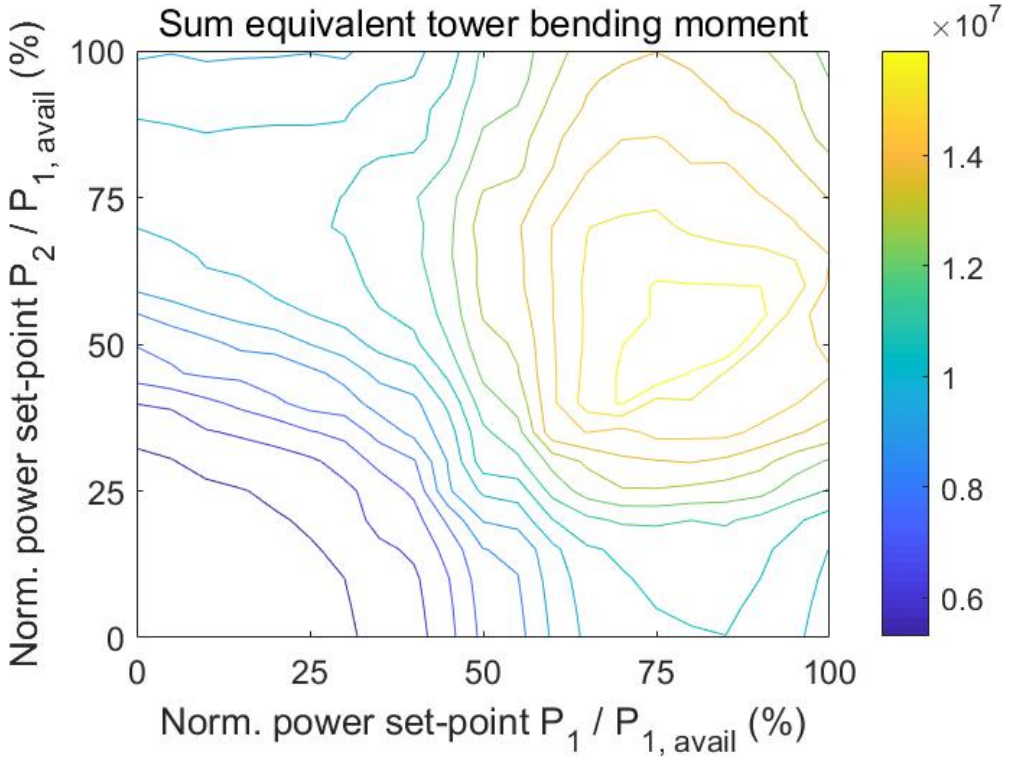


Turbine Fatigue Load Model Developed

- Turbine tower fatigue load model is derived from SimWindFarm simulations of two turbine array

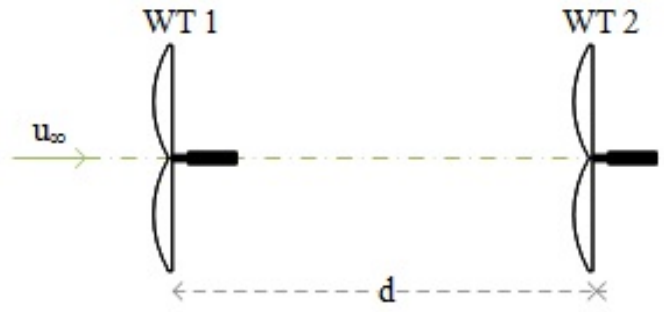


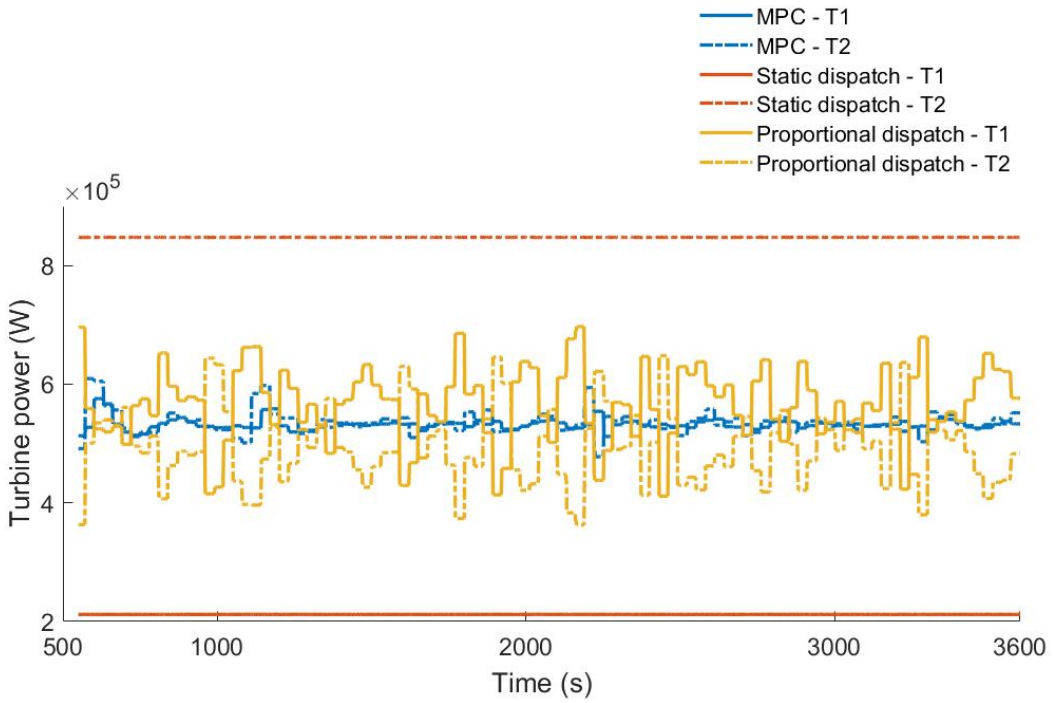
- MPC uses optimum operation point determined from fatigue load model



Two-Turbine Case Study

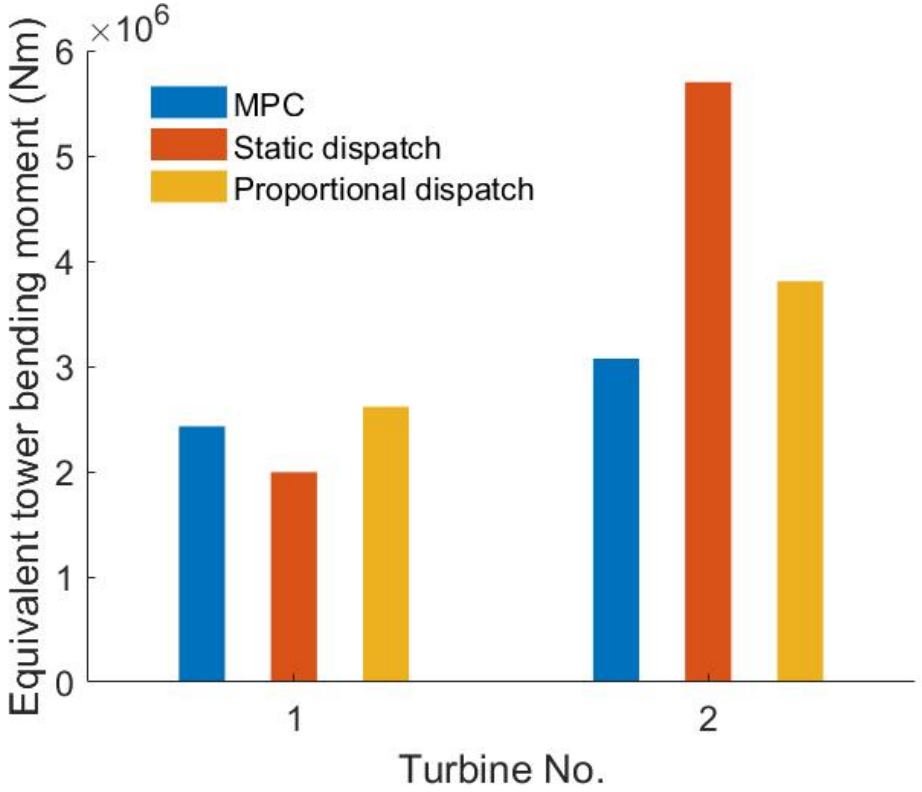
- Performance of MPC and PI-controller are compared in simulations of two turbine array

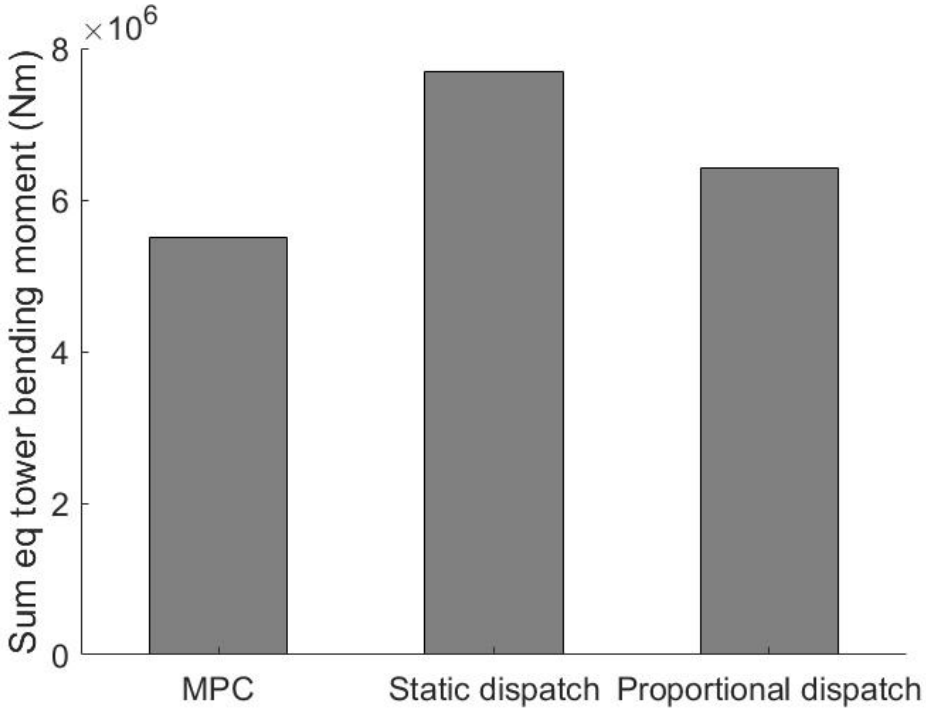




- Dispatch functions used in PI-controller are
  - static dispatch (WT1: 20%, WT2: 80 %)
  - proportional dispatch

Two-Turbine Case Study: Results

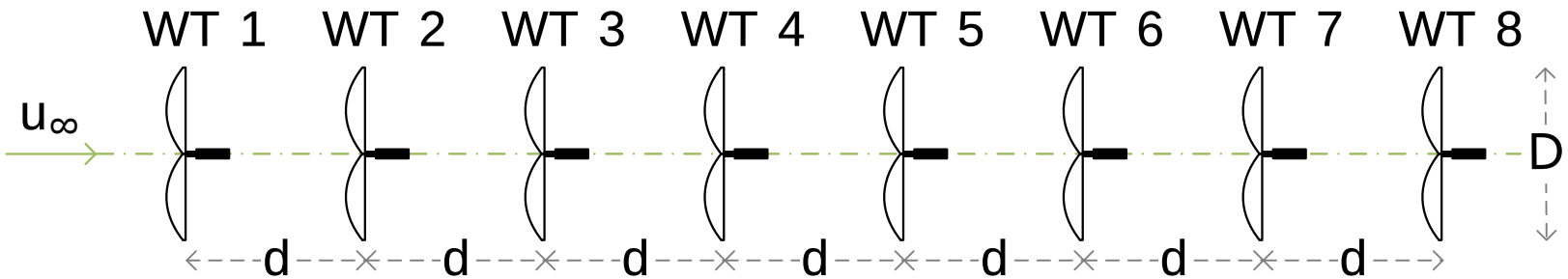




- Model-predictive control approach reduces total turbine fatigue loads by up to 28% in this case study

Eight-Turbine Case Study: Set-up

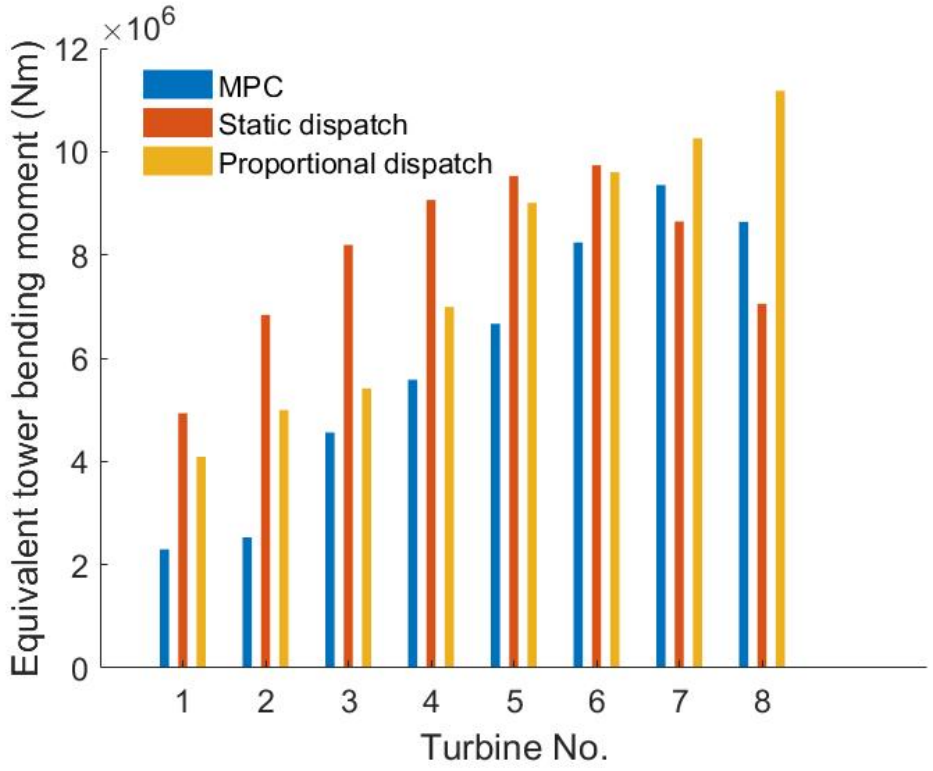
- Performance of MPC and PI-controller are compared in simulations of eight turbine array

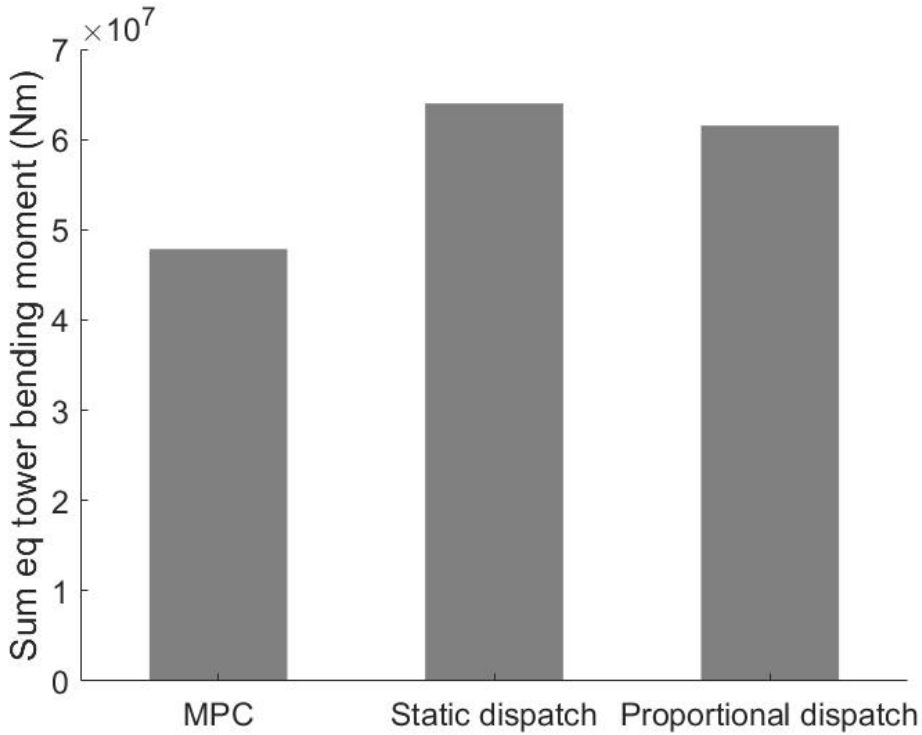


- Eight turbine array configuration is representative of common offshore wind farms

- Dispatch functions used in PI-controller are
  - static dispatch
  - proportional dispatch

Eight-Turbine Case Study: Results





- Model-predictive control approach reduces total turbine fatigue loads by up to 25% in this case study

Conclusions

- Developed linear wind farm operation model is successfully validated against SimWindFarm
- Developed turbine fatigue load model can be used in total power reference following WFC to reduce turbine fatigue
- Simulations of developed model predictive controller show up to 28% lower fatigue loads than with other commonly used wind farm controllers

Acknowledgements

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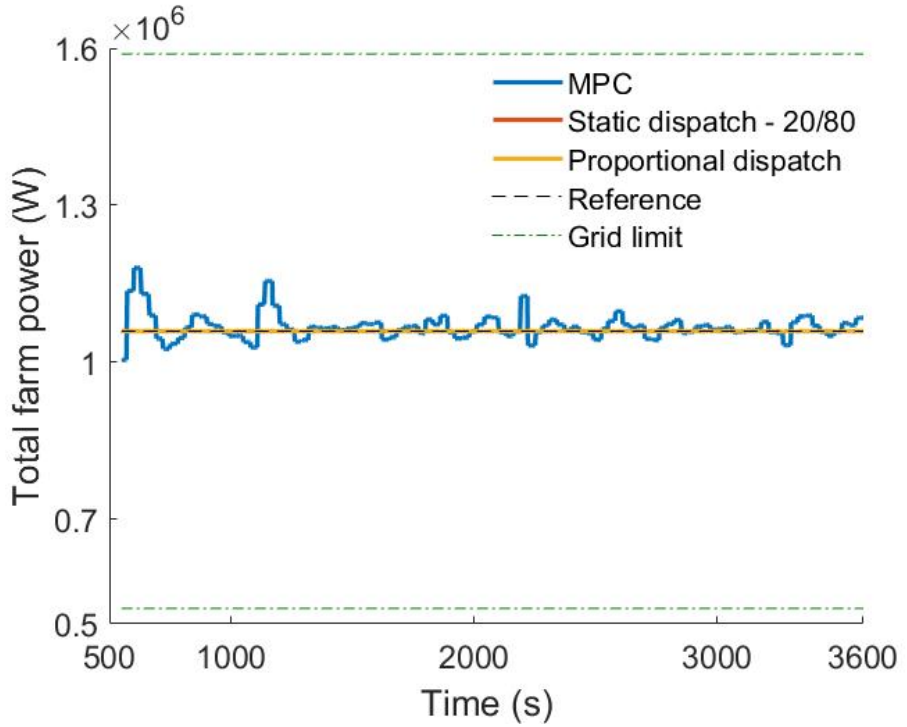
- OPWIND project funded by Research Council of Norway, Statoil, Vattenfall and Vestas

Backup

Two Turbine Case Study



- Variations of total power are within Danish grid code limits
- Danish grid code specifies limit of 5% of rated wind farm power as maximum deviation from total power reference