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Numerical and experimental validation of wind farm active power control

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ABSTRACT

- A closed-loop wind farm control framework is studied for active power control (APC) with a simultaneous coordination of structural loadings of the wind turbines.
- The applicability of the closed-loop APC approach is investigated using large-eddy simulations and wind tunnel experiments.

INTRODUCTION

- Wake interactions make wind farm control challenging:
  1) Velocity deficits lowering the total power production
  2) Higher dynamic loading of the downwind turbines
- Future wind farms should contribute to the stabilization of the grid frequency through control of their power production
- **Active power control (APC):** Regulating the power productions of the individual turbines while their total production follows a power reference, demanded by the transmission system operator (TSO).
- **Open-loop approach:** The wind farm power reference is evenly distributed among turbines.
- **Closed-loop APC:** The power reference tracking is improved using the feedback of the accumulated wake-induced power tracking error [1].

OBJECTIVES

1) A new closed-loop control approach, exploiting the non-unique solutions of APC to find a control solution, which reduces structural loadings of the wind turbines.
2) The applicability of the closed loop APC validated using the large eddy simulations (LES) and wind tunnel experiments.

APPROACH: Active power control architecture

The control architecture of the closed-loop APC with a coordinated load distribution (CLD) law (see Fig. 1):

- **APC-PI:** The control signal ΔP^{ref} adjusts the power reference P^{ref} using feedback of the total wind farm tracking error e^{P}_{total}.
- **CLD-PI:** The power set-point of $\propto_i$ adjusts the power demand P_i^{dem} of the i^{th} turbine using local feedback of the load-based tracking error e_i^T from the turbine-averaged loading of the wind farm at each time instant.
- Each turbine has its own local feedback control system to realize P_i^{dem} and the wind farm control objectives in a cooperative manner.

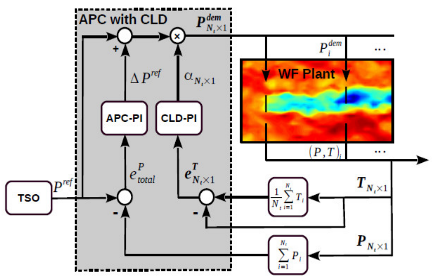

Fig. 1: Schematic illustration of the proposed APC of wind farms with coordinated load distribution (CLD) [2].

APPROACH: Active power control validation

Two validation approaches are conducted to verify the applicability of the closed-loop APC:

1) **Numerical validation:** Parallelized LES Model (PALM) coupled with actuator disc models, in a developed neutral boundary layer [2].
2) **Experimental validation:** Wind tunnel experiments with scaled wind turbine models [3].

RESULTS: Numerical validation

PALM simulation setup

Tab. 1: The key parameters of the PALM simulation.

Number of turbine N_T	6	Rotor diameter D	126 m
Wind turbine control	Induction factor	Hub height	90 m
Effective wind speed at hub height			8 m/s
Longitudinal turbulence intensity of ambient wind			≈ 5%
Longitudinal turbulence intensity of wakes			≈ 15%

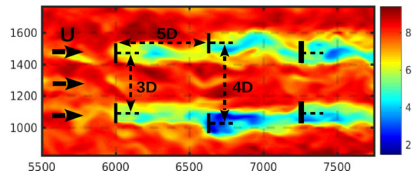

Fig.2: The instantaneous field of the u-component of the 2×3 wind farm flow at the hub height of wind turbines.

APC with coordinated load distribution (CLD)

Three control approach are investigated:

1) An open-loop power distribution (dashed green lines)
2) A closed-loop APC (dashed blue lines)
3) The APC with CLD (red lines)

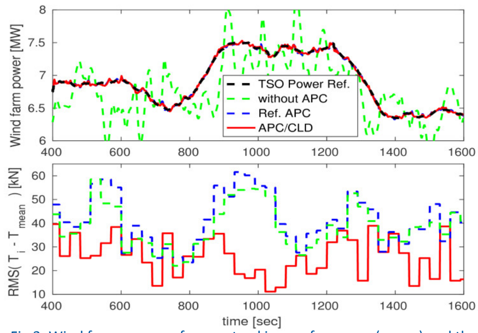

Fig.3: Wind farm power reference tracking performance (upper) and the root mean square (RMS) of the errors across all wind turbines between the applied thrust forces and their turbine-averaged value (lower). In the lower plot, the signals are averaged over 30 s periods.

- The open-loop approach suffers from the accumulated wake-induced power losses (dashed green lines).
- The wind farm power tracking performance is improved using the closed-loop APC (dashed blue lines).
- The APC with CLD (red lines) is capable of regulating the wind turbine power productions with the same accuracy of the Ref. APC. However, the RMS of the defined thrust-based error is reduced over time, meaning that the wind turbines are loaded more evenly.

RESULTS: Experimental validation

Wind tunnel experiment setup

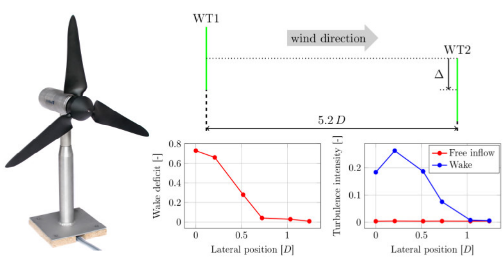

Fig.4: Wind turbine model (left), wind tunnel layout (top right), and the inflow conditions for the downwind turbine (down right).

- Wind tunnel with dimensions 3 x 3 x 30 m^3
- Active grid can be used for generation of realistic inflows
- Pitch and torque controlled wind turbine models (ø 0.6 m)

RESULTS: Experimental validation

Power tracking performance

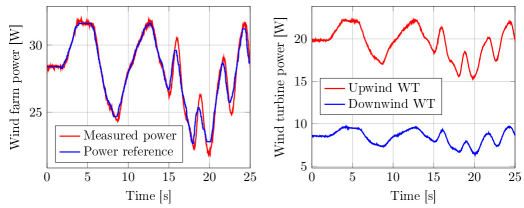

Fig.5: The wind farm response to dynamic changes of the wind farm power reference.

- Closed loop APC shows a good power tracking performance.

Compensation of wind turbine failures

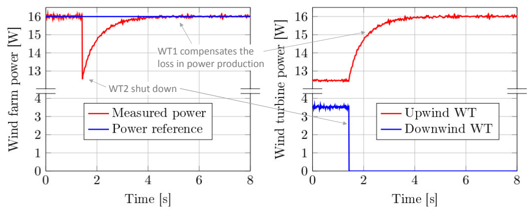

Fig.6: The wind farm response to a sudden shut-down of the downwind wind turbine.

- A sudden shut-down of the downwind turbine compensated by the closed-loop APC by shifting power production to the upwind turbine.

CONCLUSIONS

- Both numerical and experimental results show good power tracking possibilities of the closed-loop APC concepts.
- Detailed comparisons with the open-loop approach are performed, including situations with insufficient available power, wind turbine failures, and turbulent conditions.
- Since there exist multiple solutions for the APC problem with respect to the distribution of individual power, a solution with mitigated structural loading should be possible.

OUTLOOK

- Investigating the effects of changes in wind farm operating condition, e.g., different levels of power reference, and changes in atmospheric conditions, e.g., different wind directions, on the performance of APC with CLD.
- Examining APC with CLD from more reliable and practical perspectives. e.g., fatigue load and lifetime analyses.

REFERENCES

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