**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 3) 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 referenc 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 ∆Pref adjusts the power reference Pref using feedback of the total wind farm tracking error eTot.
- **CLD-Pi:** The power set-point of ∆Pref adjusts the power demand Pref of the i-th turbine using local feedback of the load-based tracking error ei from the turbine-averaged loading of the wind farm at each time instant.
- Each turbine has its own local feedback control system to realize Pref and the wind farm control objectives in a cooperative manner.

**RESULTS: Numerical validation**

**PALM simulation setup**

![Image](https://via.placeholder.com/150)

<table>
<thead>
<tr>
<th>Number of turbine Nr</th>
<th>6</th>
<th>8</th>
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<tr>
<td>Wind turbine control</td>
<td>126 m</td>
<td>90 m</td>
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<tr>
<td>Induction factor</td>
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<td>1.25</td>
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**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)

**RESULTS: Experimental validation**

**Wind tunnel experiment setup**

![Image](https://via.placeholder.com/150)

- **Wind tunnel model:** 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
- 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**

![Image](https://via.placeholder.com/150)

- Closed loop APC shows a good power tracking performance.

**Compensation of wind turbine failures**

![Image](https://via.placeholder.com/150)

- 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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