Report 2021
Task 44

Figure 1. Under dedicated meteorological conditions, the wakes are visible within a wind energy farm. Photo taken on 12 February 2008 at the offshore Horns Rev 1 wind farm, which has a minimum spacing of 7.5 rotor diameters. *Graphic courtesy of Vattenfall*

Flow Farm Control

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Wind farm control is an active and growing field of research in which the control actions of individual turbines in a wind power plant are co-ordinated to minimize wake interactions.

THESE INTERACTIONS ARE significant: each wind turbine produces a wake downstream (Fig. 1), which depends on the orientation of the turbine and/or its rotational speed. A wind turbine in the wake of another turbine experiences a wind field with a lower average wind speed and a higher turbulence intensity, causing significant power loss compared to turbines without wake interaction.

The International Energy Agency Wind Technology Collaboration Programme (IEA Wind) initiated Task 44, Flow Farm Control, to coordinate international research in the field of wind farm flow control. Wind farm control can:

- Increase energy production at existing wind farms by reducing wake losses and encouraging energy entrainment into the farm

Table 1. Task 44 Participants in 2021

	COUNTRY/SPONSOR
1	United States of America
2	United Kingdom
3	Finland
4	Ireland
5	Denmark
6	Germany
7	Norway
8	Japan
9	Netherlands

- Optimize the layout and maximize cost-effectiveness of new wind farms when incorporated into the design process
- Better realize existing turbine control strategies, such as maintaining alignment to the flow.

Task 44's goal is to provide guidance for the wind industry and researchers on current control algorithms, requirements, and impediments to adoption, future directions, and expected benefits of wind farm flow control. This goal will be accomplished by:

- Maximizing the value of wind energy in systems and markets by increasing the energy that can be produced from wind power plants
- Lowering the cost of land-based and offshore wind energy by reducing the wake-induced loading of the wind turbines
- Fostering collaborative research and the exchange of best practices and data by developing benchmarks and best practices for realistic wind farm flow control models and ensuring easy access to the most up-to-date knowledge, algorithms, and ideas within wind farm control.

Task 44 leverages resources and expertise from nine member countries (Table 1) and their extended networks to identify priority issues and synthesize information on the global state of wind farm flow control science.

Task 44 leads international efforts to advance promising wind farm control technologies from theory to practical application.

In addition to a management work package, Task 44 is divided into four work packages:

Work Package 1:
Research results collection

Work Package 2:
Uncertainty quantification

Work Package 3:
Overview of technology/algorithms

Work Package 4:
Interaction with other research entities.

Progress and achievements

Prior to the start of Task 44 in June 2021, several current Task participants held a Topical Experts meeting and two rounds of surveys among experts to gain a deeper understanding of the effectiveness of wind farm control and research gaps surrounding it.

The Topical Experts Meeting resulted in a September 2020 published article in the *Journal of Physics: Conference Series* for the Science of Making Torque from Wind (TORQUE 2020) conference. The "Expert Elicitation on Wind Farm Control" paper was written by Task 44 co-operating agents Jan-Willem van Wingerden and Paul Fleming, along with wind industry experts from Delft University of Technology, the National Renewable Energy Laboratory, Technical University of Denmark, Technical University of Munich, and SINTEF Energy Research. This work was also part of the European Union-funded Horizon 2020 FarmConners project, which is working to pave the way for wind farm control.

The research presented in this article prompted IEA Wind to establish Task 44.

A four-year effort, Task 44 kicked off in July 2021 with a virtual meeting. From July through December 2021, Task 44 participants began gathering ongoing research results and state-of-the-art industrial practices, creating an overview of control technologies agnd algorithms, and exploring how uncertainties affect the performance and potential for the adoption of wind farm control. The chief focus was on developing robust and/or adaptive solutions for dealing with uncertainty in real-world applications.

Work Package 1: Research Results Collection

Background

The overall goal of Work Package 1 is to identify state-of-the-art research and practice, best practices, and areas in need of research and development. Activities will focus on:

Photo: Tommy Kwak /Unsplash

- **Wind farm control terminology.** Task 44 will seek to determine the preferred language and develop consistent terms for use across the research and industrial communities.

- **Database of research results and algorithms.** An online database will be developed to collect, organize, and disseminate state-of-the-art results in wind farm control. Regular updates will provide an ongoing picture of the current state of the art in wind farm flow control.

- **Expert elicitations.** Several surveys of experts across research and industry will be conducted to develop consensus on wind farm control best practices, barriers to wide adoption, and needed research.

- **Recommendations and best practices.** Based on analysis of information collected, a set of recommendations and best practices for wind farm control design and deployment will be developed.

- **Workshops.** In support of the above activities, workshops will be arranged for discussion and dissemination of recent research.

2021 Results

The first expert elicitation, summarized in the *Journal of Physics: Conference Series* for the Science of Making Torque from Wind (TORQUE 2020) conference, helped establish the research focus for Task 44.

Work Package 2: Uncertainty quantification

Background

The goal of Work Package 2 is to provide the foundation and best practice for realistic evaluation of wind farm control and an uncertainty set to be used when developing and benchmarking wind farm control algorithms. This work package will characterize the different sources of uncertainties in wind farm flow control that contribute most to annual energy production calculation and structural load reduction potential:

- **Uncertain flow conditions.** The variability of wind is one of the main sources of uncertainty. The continuously changing inflow conditions are considered, as well as day-night changes in atmospheric conditions.

- **Model mismatch: Flow models.** Flow dynamics are described by the Navier-Stokes equations; however, reduced-order or control-oriented models are often used in wind farm control. This potential model inadequacy introduces a second important source of uncertainty.

- **Model mismatch: Turbine models.** Extracting the power from the wind is a complex task, and assumptions and simplifications are made that introduce uncertainty.

- **Actuators.** The transducers that are used to influence the flow within a wind farm (e.g., yaw position and pitch position) also bind the implementation by their physical constraints. Important aspects are bandwidth, accuracy, energy consumption, robustness, and resolution.

- **Sensors.** The transducer that is used to measure the effect of certain quantities within a wind farm (e.g., power measurement, strains, and flows) also binds the implementation by its physical constraints. Important aspects are bandwidth, reliability, availability, accuracy, robustness, and resolution.

For each of the sources, Task 44 aims to quantify the uncertainty range and provide realistic assumptions and methods of implementation for an overall uncertainty assessment.

2021 Results

The first Work Package 2 meeting was held in December 2021. Participants reviewed the work package objectives and deliverables and discussed modifications to the plan.

Work Package 3: Overview of technology/algorithms

Background

This work package will characterize and generate an overview of the required software/algorithms for wind farm control, focusing on the scalability and the complexity/performance trade-off. The wind farm control algorithm building blocks are:

- **Control technologies.** The control technology defines how the control algorithm interacts with the physical system (e.g., pitch actuation, yaw actuation, and lidar measurements). Important aspects are controllability, observability, loads, bandwidth, costs, and availability.

- **Objective function.** The (multi-)objective for which wind farm is employed (e.g., loads, power, and predictability) and how this can be mathematically quantified. Important aspects are convexity, constraints, scalability, and predictability.

- **Internal models.** The model used for decision making (e.g., engineering model and empirical model). Important aspects are accuracy, computational load, coding language, including physics, disturbance modeling, and fidelity.

- **Estimators.** The decision making typically depends on the fusion between models and data collected by the sensors. Algorithms have to be developed that bring these two together. Important aspects are accuracy, sampling time, sensors required, type of model, knowledge required, and convergence speed.

- **Optimizers.** The objective function conditioned by the internal model will be used to make decisions on how actuators are employed over time. The important aspects are reliability, convergence, convexity, adaptability, robustness, ability to work with uncertainty, and computational complexity.

2021 Results

Work Package 3 participants established a regular meeting schedule. In addition, they organized and planned an in-person meeting to be held in 2022.

Work Package 4: Interaction with other research entities

Background

The goal of Work Package 4 is to ensure that all relevant research and experience with wind farm flow control, both from the Task participants and from other efforts, are coordinated and captured to provide the most accurate overview for impactful research and accelerate further adoption of wind farm flow control. IEA Wind Tasks with which Task 44 will collaborate and coordinate include:

- **Task 31 Wakebench.** This task also focuses on wake interactions between turbines.

- **Task 32 Lidar.** Lidar measurements can become an integral part of wind farm control.

- **Task 37 Systems Engineering.** Having a robust wind farm flow control system can have a large impact on how a wind power plant acts as a system.

- **Task 36 Forecasting.** Wind farm control can impact forecasted wind power production by increasing the produced power and making it more predictable.

- **Task 42 Lifetime Extension.** Wind farm flow control has the potential to better balance wind turbine lifetime usage with minimal annual energy production downside.

- **Task 43 Digitalization.** Wind farm flow control is expected to make heavy use of wind energy digitalization and feed essential data back to other wind digitalization systems.

Collaboration is also sought with research efforts such as the European Union Horizon 2020 FarmConners project and the U.S. Department of Energy's Atmosphere to Electrons initiative and the American WAKE experimeNt (AWAKEN).

References

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