U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

NREL Transforming ENERGY

T19 - Advanced Flow Control Science for Wind Plants

Technology RD&T and Resource Characterization – Atmosphere to Electrons (A2e)

Paul Fleming
NREL

August 4, 2021

FY21 Peer Review - Project Overview

Project Summary:

- Wind farm controls seeks to optimize the value of wind farms by coordinating the control of individual turbines.
- Methods such as wake steering reduce wake losses, increase energy production, reduce loads, increase lifetime and reduce costs.
- These methods can be applied at existing onshore farms value increases for offshore farms and if the layout can be optimized about this approach to control.
- Project is a world leader in the development and validation of wind farm control and has produced much of the public validation.
- Project further produces important turbine controllers for floating offshore turbines, or turbine system design research.

Project Objective(s) 2019-2020:

- Develop the models, methods, validation and analysis of wind farm control to yield wide scale deployment and realization of benefits.
- Advance the state of the art in physical understanding of wind farm control and best practices for application.

Overall Project Objectives (life of project):

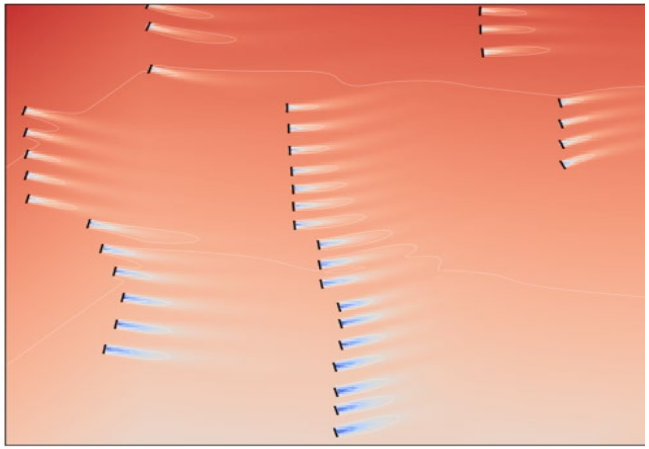
- Research and develop wind farm control and partner with industry to enable wide scale deployment and transformation.

Project Start Year: FY19
Expected Completion Year: FF23
Total expected duration: 5 years

FY19 - FY20 Budget: $2,670,416

Key Project Personnel:
Paul Fleming, NREL
Jennifer King, NREL

Key DOE Personnel:
Michael Derby, Ben Hallissy



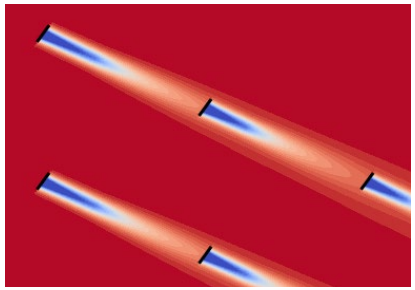
FLORIS simulation of a large wind farm with heterogenous inflow

Project Impact

- Wind Farm Controls has the potential to radically reshape the way wind farms are operated, and designed.
- **Wind farm control applied to existing plants has the potential to:**
  - Increase Annualized Energy Production (AEP)
  - Reduce turbine loading
  - Increase project lifetime
  - Decrease maintenance
- **Applied to new plants can be even more impactful by enabling the plant to be optimized for use of the technology.**

Project Impact

FLORIS

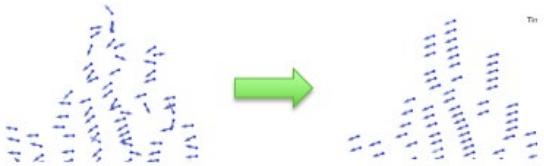


FLORIS is a de-facto standard wind farm control software framework (modeling and design) worldwide

ROSCO

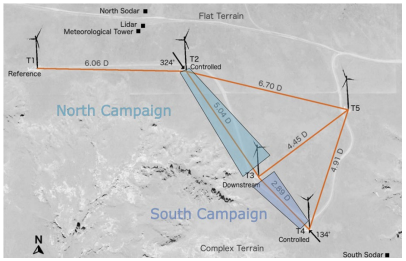
ROSCO provides auto-tuned turbine control across scales, floating or fixed, and is adopted in many important projects

Consensus Control



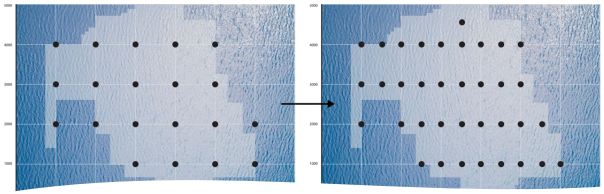
Consensus control enables real-time collective control and is subject to patent and commercialization project

Validation



In partnership with industry, conduct numerous experiments to validate control models and controller performance

Layout Optimization



Develop new means to design wind farms which exploit the benefit of wind farm control to maximize wind farm value

IEA Task 44

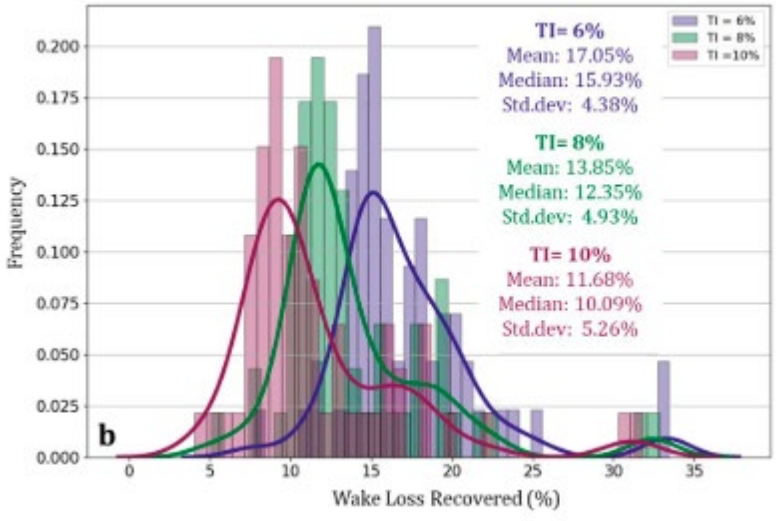
iea wind

Lead new IEA task to work across industry stakeholders to achieve bankability and deployment of wind farm control

Program Performance – Scope, Schedule, Execution

All milestones delivered on time and all important research findings published in journal articles, results from some key milestones:

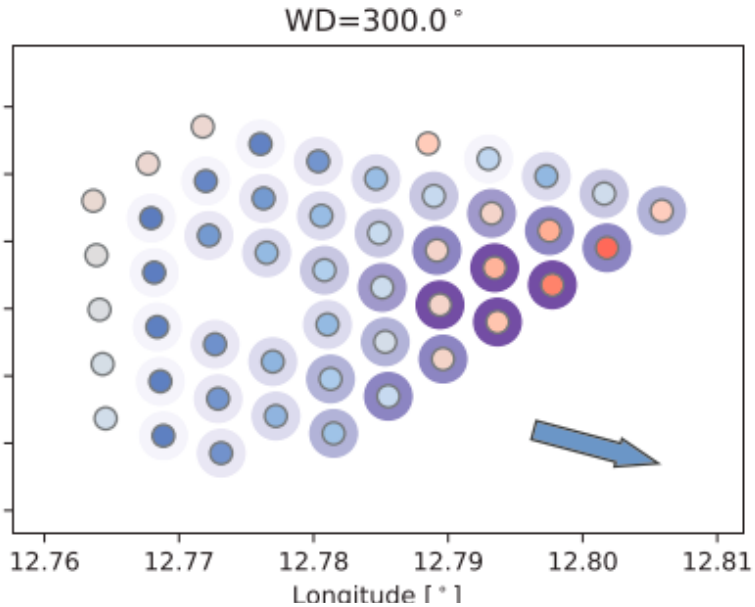
Used FLORIS to complete a study across a variety of US wind farms to show the expected range in wake loss reduction from wind farm control and its dependence on atmospheric conditions and wind farm layout.



Evaluation of the Potential for Wake Steering for U.S. Land-Based Wind Power Plants

D. Bensason,[1, a)] E. Simley,[1] O. Roberts,[1] P. Fleming,[1] M. Debnath,[1] J. King,[1] C. Bay,[1] and R. Mudafort[1]
National Wind Technology Center, National Renewable Energy Laboratory, Golden, CO, 80401, USA

Another study compared the performance of the wake modeling modules within FLORIS to SCADA data from an offshore wind.



Comparison of modular analytical wake models to the Lillgrund wind plant

Cite as: J. Renewable Sustainable Energy **12**, 053311 (2020); https://doi.org/10.1063/5.0018695
Submitted: 17 June 2020 . Accepted: 22 September 2020 . Published Online: 30 October 2020

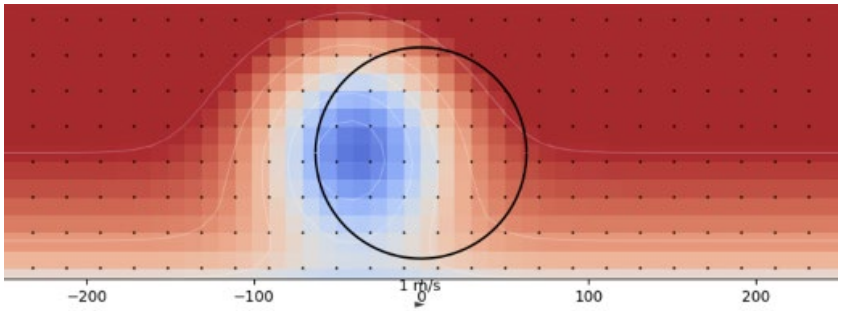
Nicholas Hamilton, Christopher J. Bay, Paul Fleming, Jennifer King, and Luis A. Martínez-Tossas

Program Performance – Accomplishments & Progress

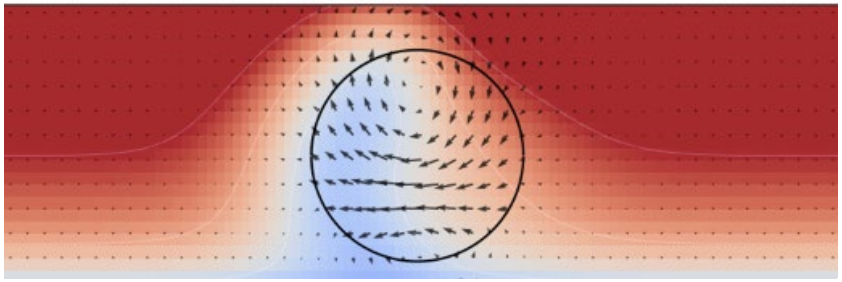
Improvement of physical models of wake steering produces better control strategies

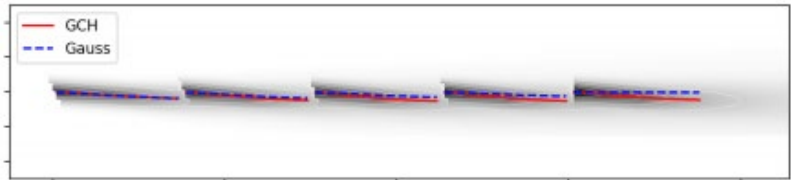
Developed the new curl, and gauss-curl hybrid models of wake steering which substantially improve accuracy for arrays of multiple turbines by accounting for counter-rotating vortices

Deflection Model

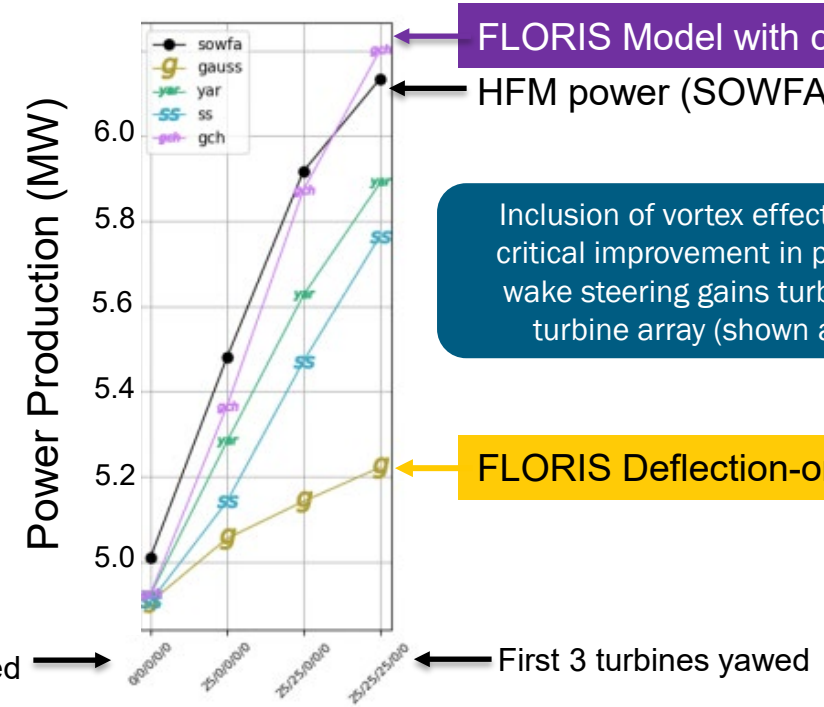


Curl Model





Combined 5-turbine Power



FLORIS Model with curl

HFM power (SOWFA)

Inclusion of vortex effects makes critical improvement in predicting wake steering gains turbine five-turbine array (shown above)

FLORIS Deflection-only model

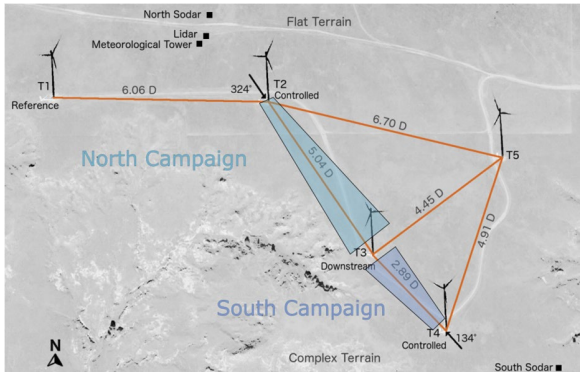
All turbines aligned

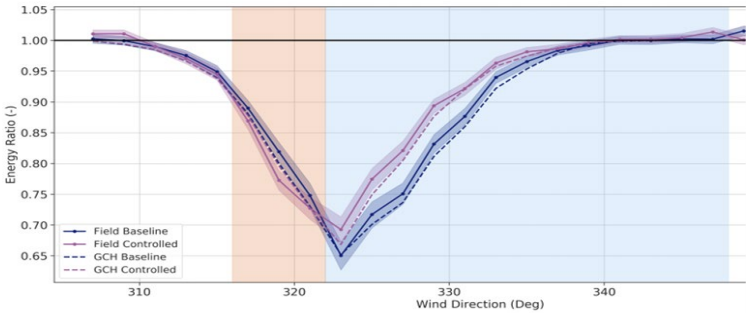
First 3 turbines yawed

Program Performance – Accomplishments & Progress

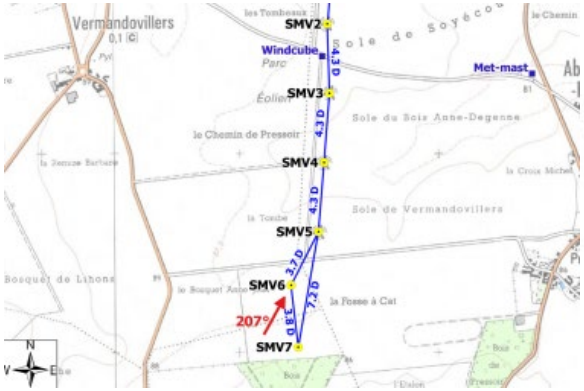
- Expert survey identified validation as key need for wide-scale adoption of wake steering.
- Completed critical public validation of wind farm control at commercial wind farms.
- More campaigns currently underway.

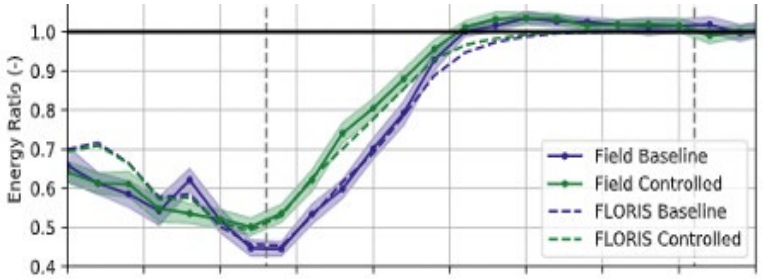
Partner: Nextera





Partner: Engie

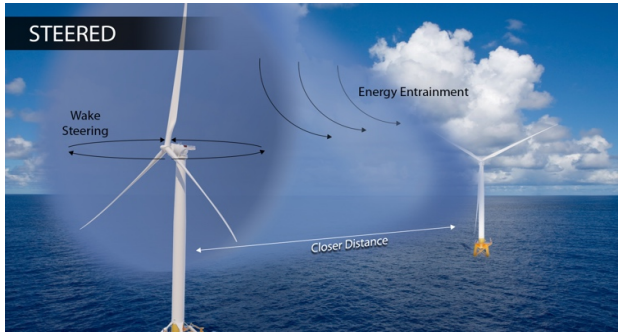




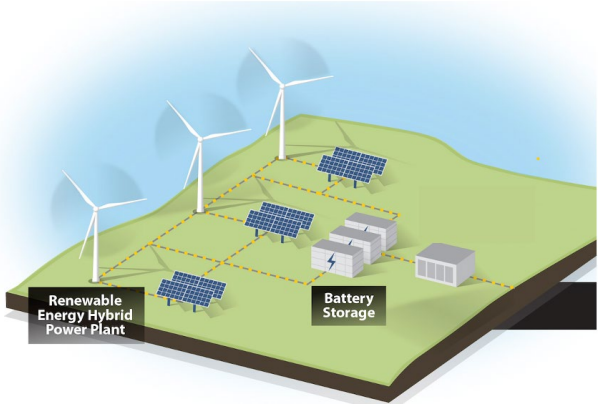
Comparing relative energy production in baseline control (blue both plots) and wake steering (magenta, green) shows a clear gain from wake steering, and good agreement with FLORIS predictions (dashed lines) from observations (solid).

Project Performance - Upcoming Activities

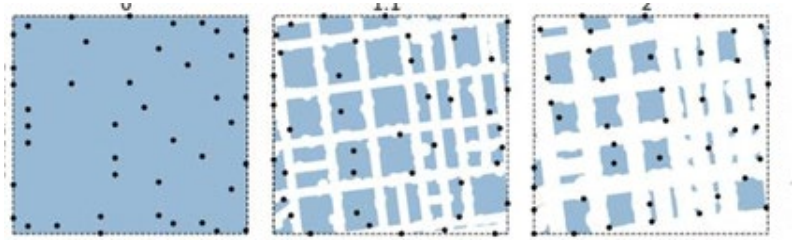
Development of models of wind farm control for large and offshore turbines, large arrays of turbines, offshore atmospheric conditions.



Development of engineering and control models of hybrid power plants.



Farm optimization with wind farm control, design for high constraints.



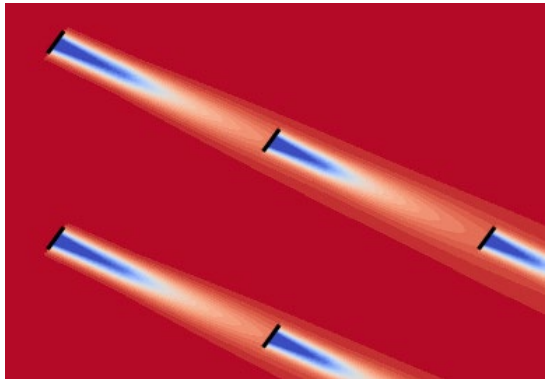
Update automatic tuning of ROSCO for floating turbines.

Stakeholder Engagement & Information Sharing

- Organized IEA Topical Experts Meeting in wind farm control in 2019.
- Successfully proposed new IEA task 44 on wind farm control in 2020.
- NREL will lead the task with TU Delft and will focus on quicky achieving **bankability** and **wide-scale deployment** of wind farm control.

Stakeholder Engagement & Information Sharing

Extensive use of open-source tools **FLORIS** and **ROSCO** in external research and industry.



Continuous collaboration with industry across a range of projects. Partners include turbine OEMs, wind farm developers, and wind energy consultancies.

NATIONAL OFFSHORE WIND
RESEARCH & DEVELOPMENT CONSORTIUM

<u>Strong track record of publication</u>

4 out of 10 most downloaded articles in Wind Energy Science journal authored or co-authored by members of wind farm control project.

Initial results from a field campaign of wake steering applied at a commercial wind farm – Part 1

Paul Fleming[1], Jennifer King[1], Katherine Dykes[1], Eric Simley[1], Jason Roadman[1], Andrew Scholbrock[1], Patrick Murphy[1,3], Julie K. Lundquist[1,3], Patrick Moriarty[1], Katherine Fleming[1], Jeroen van Dam[1], Christopher Bay[1], Rafael Mudafort[1], Hector Lopez[2], Jason Skopek[2], Michael Scott[2], Brady Ryan[2], Charles Guernsey[2], and Dan Brake[2]
[1]National Wind Technology Center, National Renewable Energy Laboratory, Golden, CO 80401, USA
[2]NextEra Energy Resources, 700 Universe Blvd, Juno Beach, FL 33408
[3]Dept. Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, CO 80303, USA

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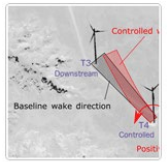

Currently engaged on technology commercialization project of consensus control.