Develop Wake Mitigation Strategy

Cooperative Research and Development Final Report

CRADA Number: CRD-17-00693

NREL Technical Contact: Paul Fleming

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/ TP-5000-79163
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Cooperative Research and Development Final Report

Report Date: February 10, 2021

In accordance with Requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: WindESCo, Inc.

CRADA number: CRD-17-00693

CRADA Title: Develop Wake Mitigation Strategy

Responsible Technical Contact at Alliance/NREL:

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DOE Program Office:

Small Business Voucher (SBV) Program; Office of Energy Efficiency and Renewable Energy (EERE), Wind Energy Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$200,000.00
TOTALS	$200,000.00

Executive Summary of CRADA Work:

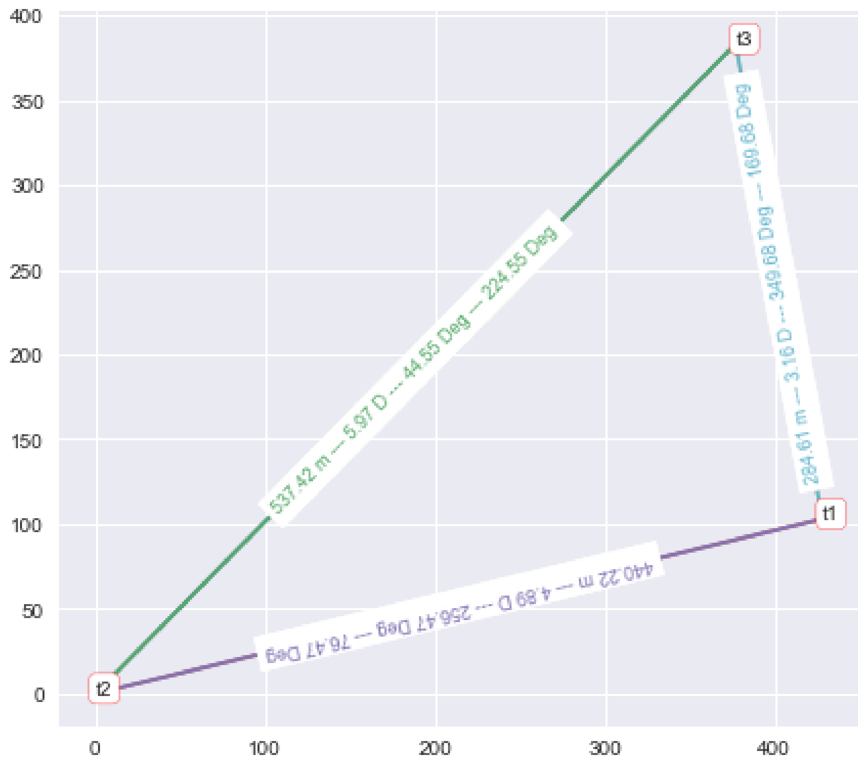
Wind turbines in a wind farm typically operate individually to maximize their own performance and do not take into account information from nearby turbines. In an autonomous wind farm, enabling cooperation to achieve farm-level objectives, turbines will need to use information from nearby turbines to optimize performance, ensure resiliency when other sensors fail, and adapt to changing local conditions. A key element of achieving an autonomous wind farm is to develop algorithms that provide necessary information to ensure reliable, robust, and efficient operation of wind turbines in a wind plant using local sensor information that is already being collected, such as supervisory control and data acquisition (SCADA) data, local meteorological stations, and nearby radars/sodars/lidars. In this work consensus control is applied in a hybrid analysis to data from an existing wind farm to demonstrate the benefit of consensus control.

Summary of Research Results:

Task 1: Evaluate potential effectiveness of axial control and characteristics of optimal pilot project -

NREL

An analysis was performed of a 3-turbine site to determine the effectiveness of axial controls to reduce loads. A FLORIS model (https://github.com/NREL/floris) was built of the site layout:



And assuming the default National Renewable Energy Laboratory (NREL) 5MW turbine characteristics. FLORIS was optimized to minimize thrust of an upstream turbine and TI of a downstream waked turbine, and found that for example considering T1:

- Reductions in thrust:
  - @170º: 40.5% (Waking T3 @ 3.15D)
  - @76º: 33% (Waking T2 @ 5 D)
- Reductions in TI
  - @350º: 31% (Waked by T3 @ 3.15D)
  - @256º: 23% (Waked by T2 @ 5 D)

With similar results on other turbines

After this task was completed, it was determined by WindESCo that the selected test site would not be able to implement de-rating control, with DOE, the AOP governing the project was modified and a new scope of work, and a new test site, was agreed to. The following tasks were therefore replaced"

Task 2: Evaluate effect of power-limit control vs pitch control on the wake – NREL and WindESCo

Task 3: Select and instrument pilot demonstration wind farm – Conducted by WindESCo

Task 4: Define control strategy for selected pilot project wind farm - NREL

Task 5. Simulate expected performance of pilot demonstration with and without wake mitigation control -NREL

Task 6. Implement control at pilot demonstration and collect experimental data – Conducted by

WindESCo

Task 7. Evaluate results and compare model predictions with experimental data – Conducted by NREL

With the following scope of work:

Task 1: For the new test site, develop a FLORIS model and calibrate to the SCADA data

This task was to designed, tune and analyze FLORIS model of the Millford site. An initial FLORIS model was developed for the previous wake-steering work, however, using the provided data from the site can be used to thoroughly tune FLORIS and analyze its performance. The data will be collected by WindESCo using their on-blade sensors and wind farm SCADA systems.

The FLORIS model was completed for the new site, using the provided layout and SCADA information. The FLORIS models of the site completed in this task are shown in the following figures.

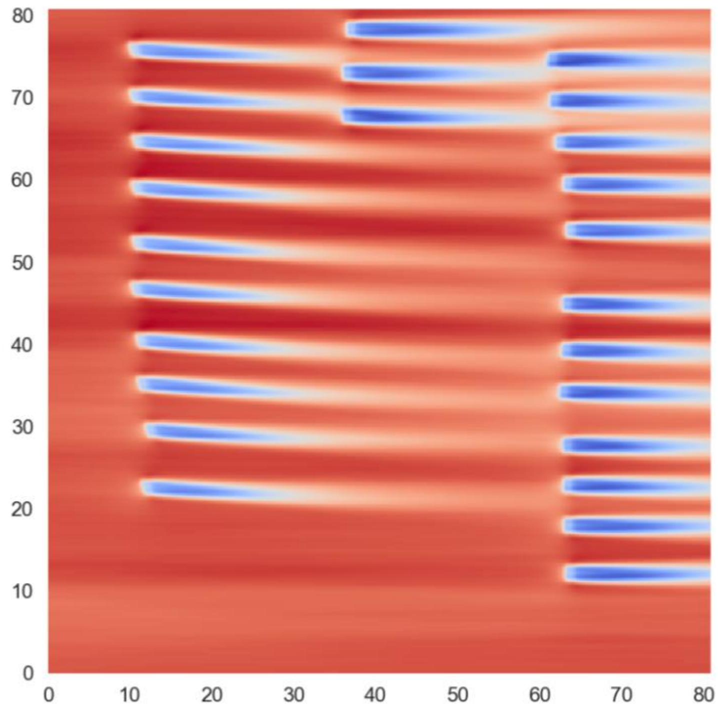


Figure 1: Visualization of FLORIS representation of new test site

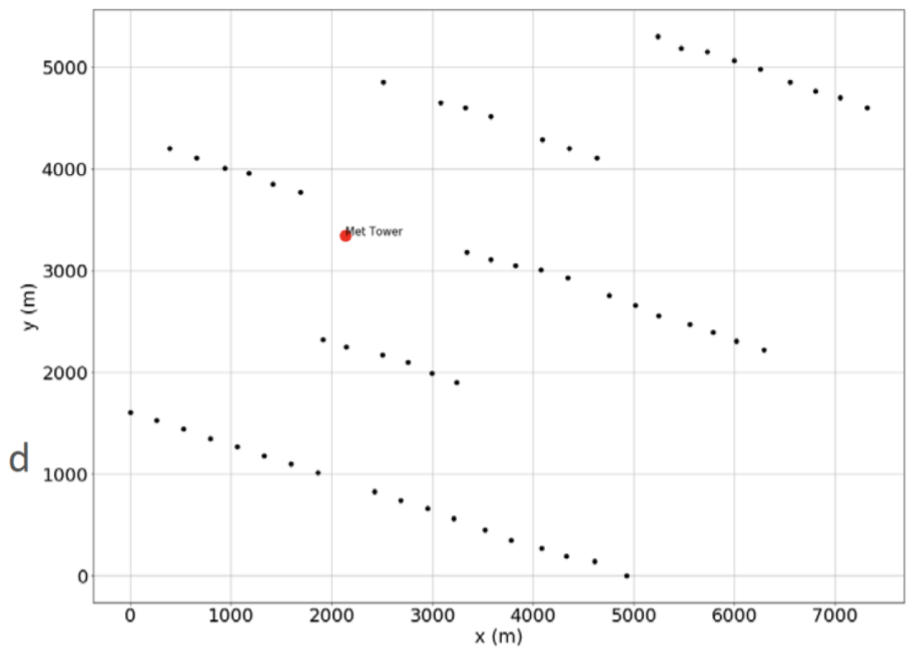


Figure 2: Map of turbine locations at new test site from FLORIS input

This model could then be used in the main work of task 2.

Task 2: Design a consensus yaw controller and perform a hybrid analysis, using provided historical SCADA data to demonstrate effectiveness.

Consensus control is a technology invented by NREL within the AES LDRD and was in this work applied, through hybrid analysis to historical SCADA data, to the test site identified by WindESCo. In consensus control, a distributed optimization is performed over the individual wind direction measurements by individual turbines, into a map of wind direction, through a consensus optimization. The consensus optimizations are visualized in Fig 3.

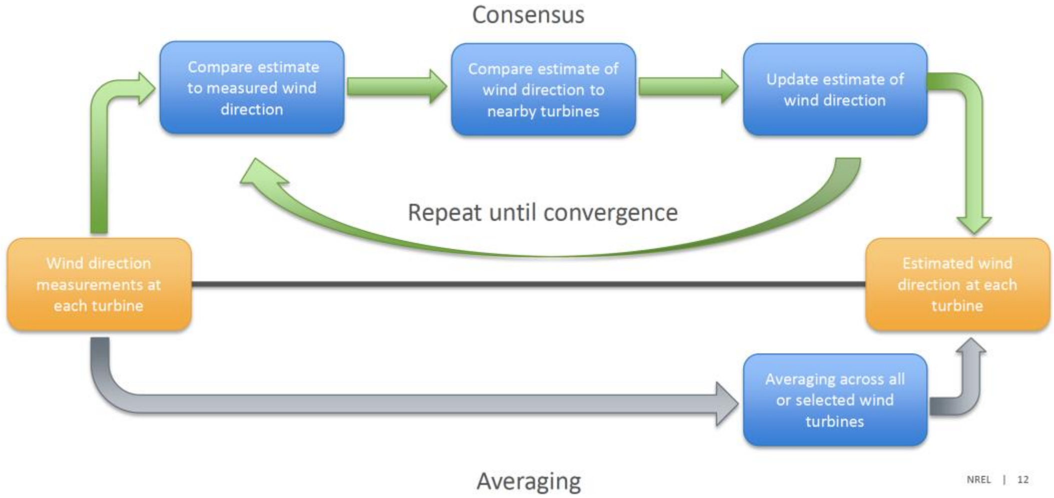
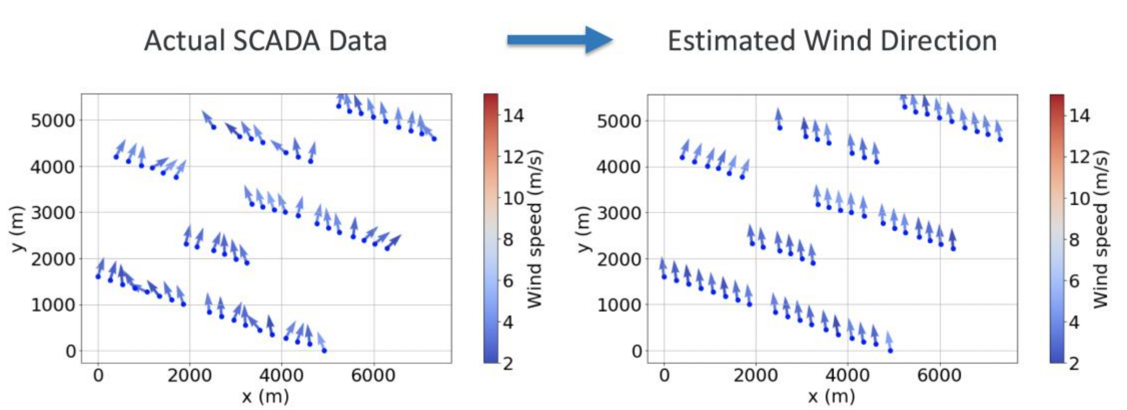


Figure 3: Consensus control versus simple averaging

Consensus collective can be used, if implemented through hardware which enables inter-turbine communication which WindESCo can supply, to provide a better estimate of wind direction by sharing information between turbines. This can be used to improve turbine alignment and reduce unnecessary yawing motions.

This task successfully developed a consensus-based wind farm controller for the new site. In this step, the control implementation of the wind farm controller is developed using the finalized FLORIS model completed in task 1. The following figure shows the consensus controller estimating the true wind direction for the new site from the noisy individual measurements.

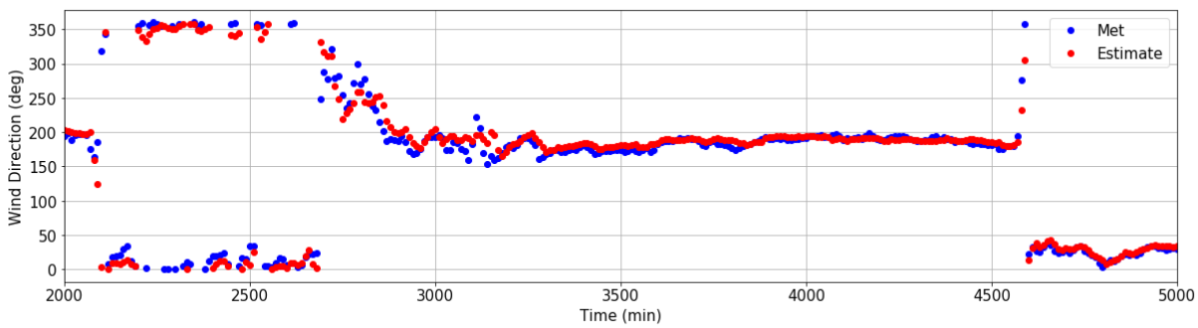


Task 3: Hybrid analysis of controller performance.

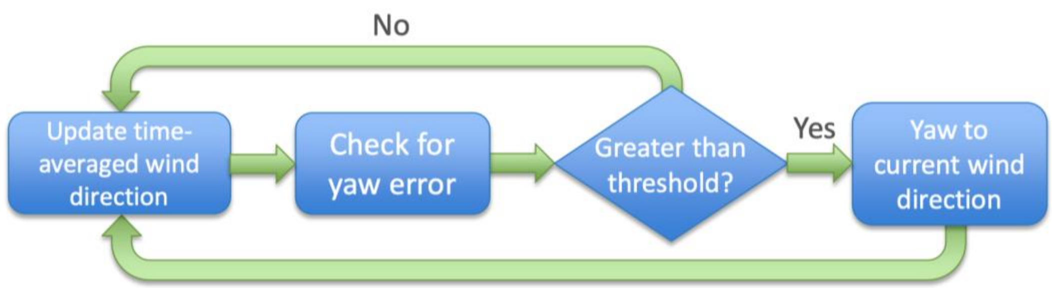
Finally, in task 3, a hybrid analysis is completed, wherein SCADA data collected by WindESCo is used and applied to the consensus control algorithm designed in task 2

In this project, a hybrid resimulation was performed to estimate the benefit of consensus control for this site over the period of provided SCADA data.

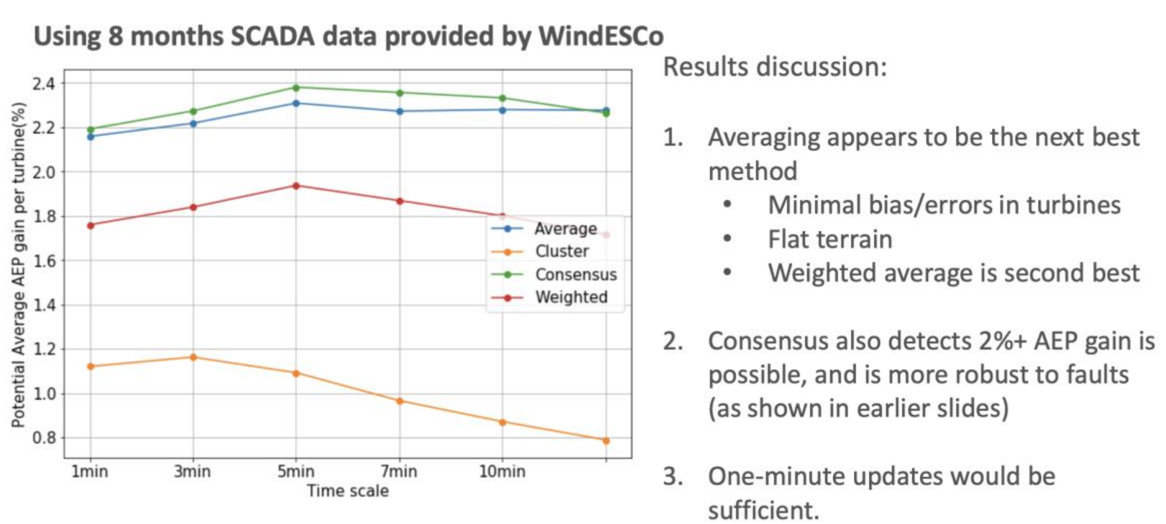
A first test compared the prediction of consensus control of wind direction at a location where a met tower was sited, this enabled a first check of accuracy:



The full hybrid analysis used a typical yaw control system to model the turbine behavior if using the normal vane signal, versus the new consensus signal



This allows a prediction of counterfactual power which would have been produced if consensus had been applied. For completeness, consensus was compared to other possible methods:



A further analysis showed that, depending on the assumptions of the turbine yaw controller, a meaningful reduction in yawing motions can be expected:

Yaw Reduction [%] From Baseline Wind Signal

Controller	Time Step						
	10 min	7 min	5 min	3 min	1 min	30 sec	10 sec
Deadband	21.24%	27.48%	30.22%	38.06%	51.18%	53.67%	57.13%
Cumulative Error	19.92%	25.68%	28.75%	36.14%	45.40%	44.23%	38.24%
Deadband w/ avg.	21.24%	20.23%	22.96%	26.86%	30.63%	31.31%	32.85%
Cumulative Error w/ avg.	19.92%	19.61%	22.73%	27.35%	32.19%	33.45%	35.72%

Table 1: Results of the yaw controller analysis.

The final results were provided to WindESCo in the form of a slide deck, and to DoE in a report. The results were also presented at the 2019 DOE peer review. This final result slide deck is available online here: https://www.nrel.gov/docs/fy19osti/73352.pdf

Subject Inventions Listing:

None

ROI #:

None