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Controls and Sensors - WindESCo Swarm

Sandia Blade Workshop

2022-10

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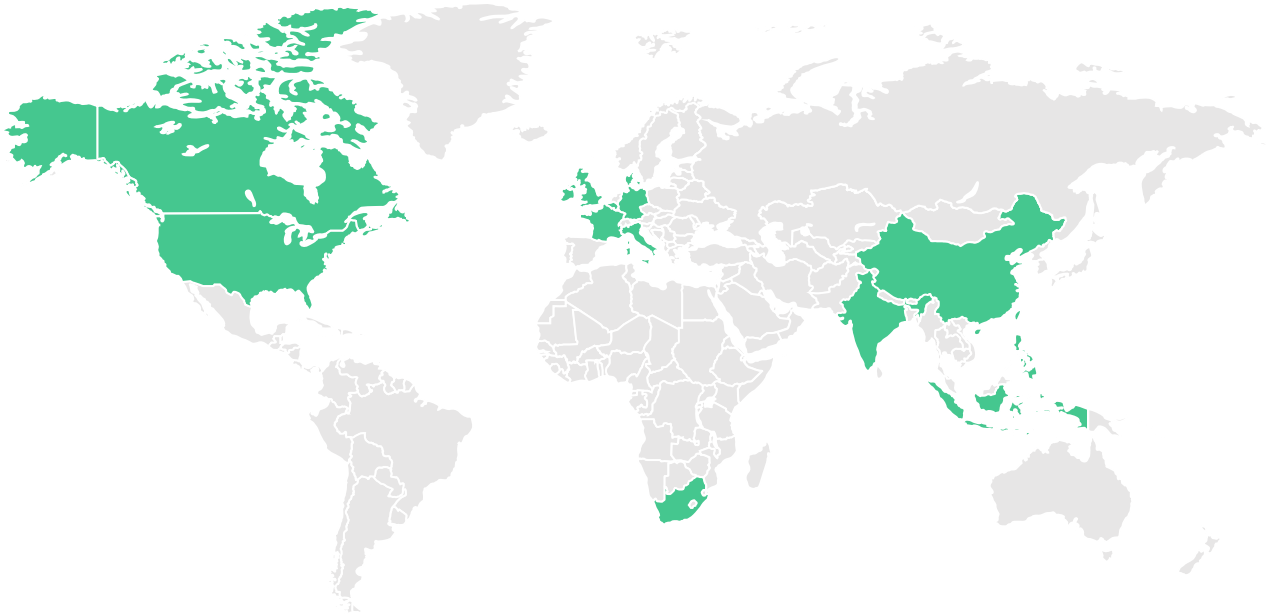
Trusted by the largest wind energy operators globally



14
Countries

42
Customers

58 turbine models
Analyzed

19 OEMs
Optimized

65%
Wind experts

Unlocking value for wind energy

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WindESCo Optimization Solutions

Find, Fix, Measure
Turbine-level optimization

- Domain expertise combined with AI turns data into increased revenue
- Scalable and cost-effective solution to deliver increase in revenue
- Leverages high-speed data (600x more data than industry standard)
- Software-only solution; no warranty impact

The most advanced wind energy performance analytics platform

Swarm
Wind plant-level optimization

- Autonomous, cooperative control system for wind plant-level optimization
- Delivering increase in plant output
- OEM agnostic retrofit solution for both onshore and offshore wind plants
- Combined software and IoT hardware solution without warranty impact

First commercially available retrofit solution for plant level optimization

Confidential & Proprietary

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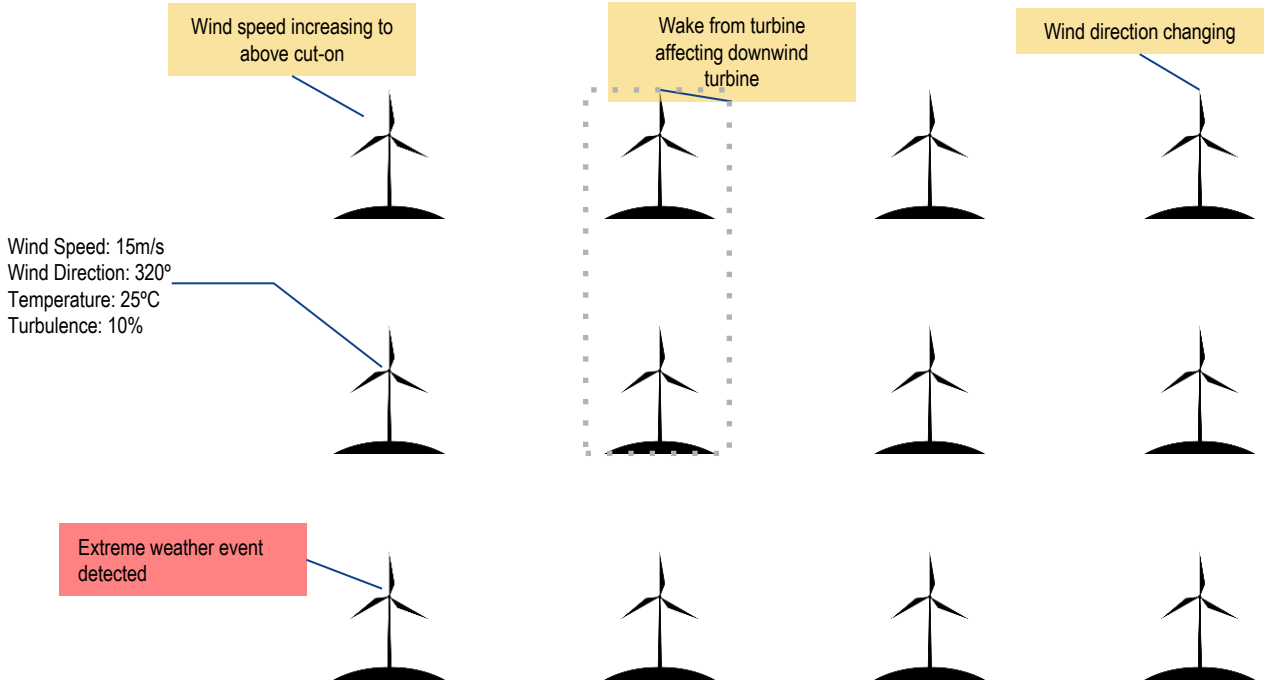
Shortcomings with Existing Plant Operations



Turbines in a wind plant operate in isolation to other turbines

Turbines attempt to maximize their own output, without any concern for the neighbors

Turbines are ignorant of the big picture events and flow conditions at the plant

Wind plant continue to lose 5 to 15% of their output and are increasingly prone to extreme weather events

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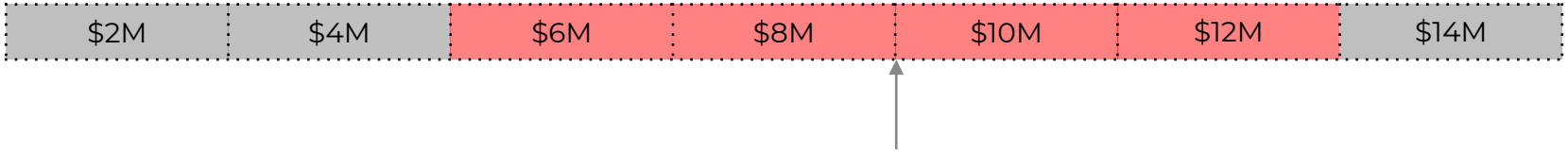
Price Wind Plants are Paying



Median 5-year present value lost by an average 100 MW wind plant*

* Assumptions

1. Present value of loss in revenue over 5 years per 100 MW of capacity
2. Discount rate = 9%

Globally this is costing the industry $16B in lost revenue annually

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Validated by Research Institutes

TransAlta / Stanford University	NextEra / NREL	ReNew / MIT
Tests at TransAlta wind plant in Alberta have shown overall power output could be ramped 47% in lower wind velocities and 7-13% in average winds, while also reducing power fluctuations to the grid.	Field trials conducted by NextEra and NREL were consistent with simulated predictions, suggesting that wake steering can increase annual profits by as much as $1 million depending on plant size.	Field trials at a wind plant increased energy output at a wind plant by 3% between wind speeds between 6 and 8 m/s and 1.2% over all wind speeds and directions.
Source: Recharge News	Source: NREL	Source: Nature

Extensive field trials by research institutes have proven the basic value proposition of collective control

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System Approach

Turbine level optimization

Plant level optimization

Requires integrating software and hardware

Swarm System

Combining IoT, Edge and Cloud analytics

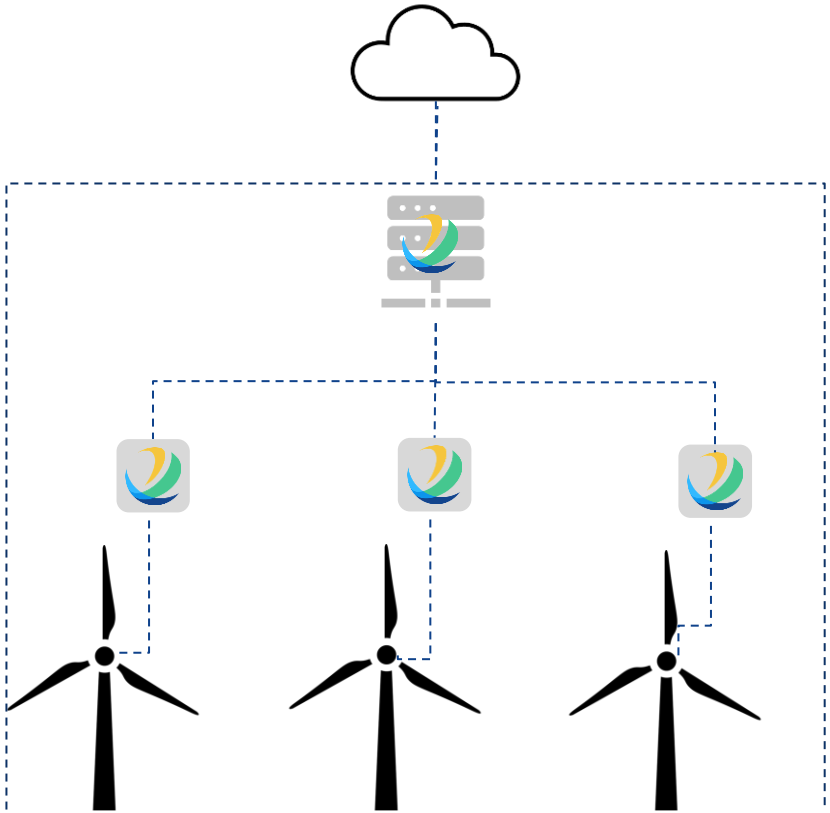
Swarm Edge

Swarm Server

Patent allows us to implement Swarm as a retrofit solution

PLC based edge device enables seamless integration with any wind turbine OEM

Swarm edge in the wind plant network can be a gateway for additional value propositions



Swarm Server allows us to implement on-premise optimization within the wind plant firewall

Cybersecurity compliant systems allows us to keep critical infrastructure safe

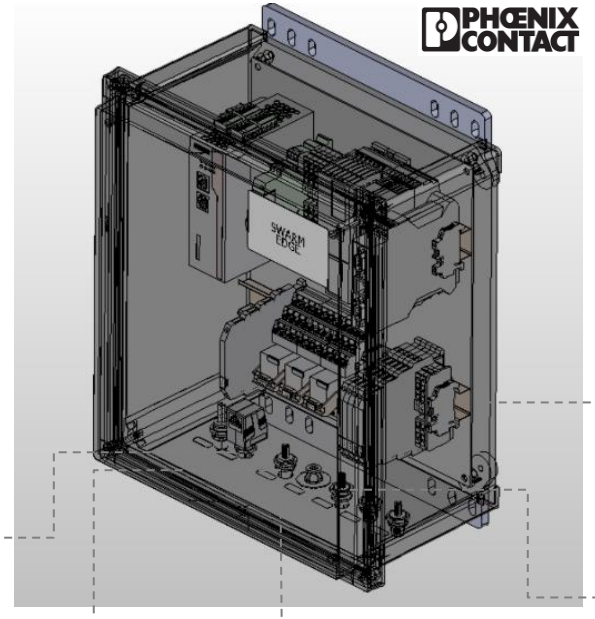
Modular design allows multiple applications to run in parallel

Our Swarm Solution increases plant revenue by $6-$10M/GW per year

Swarm Edge

Turbine agnostic IoT device installed in every turbine under Swarm

Implements nacelle position setpoint received from the central Swarm Server



Rated for
- IP65 water and dust resistant
- Shock resistant for 5G

Interface to turbine controller

Interface to turbine wind sensor

Cybersecure wind farm network integration

Interface to WindESCo sensors:
- Nacelle position sensor
- Accelerometer
- Gyroscope
- Temperature sensor

Swarm Edge is a powerful IoT Edge Control device

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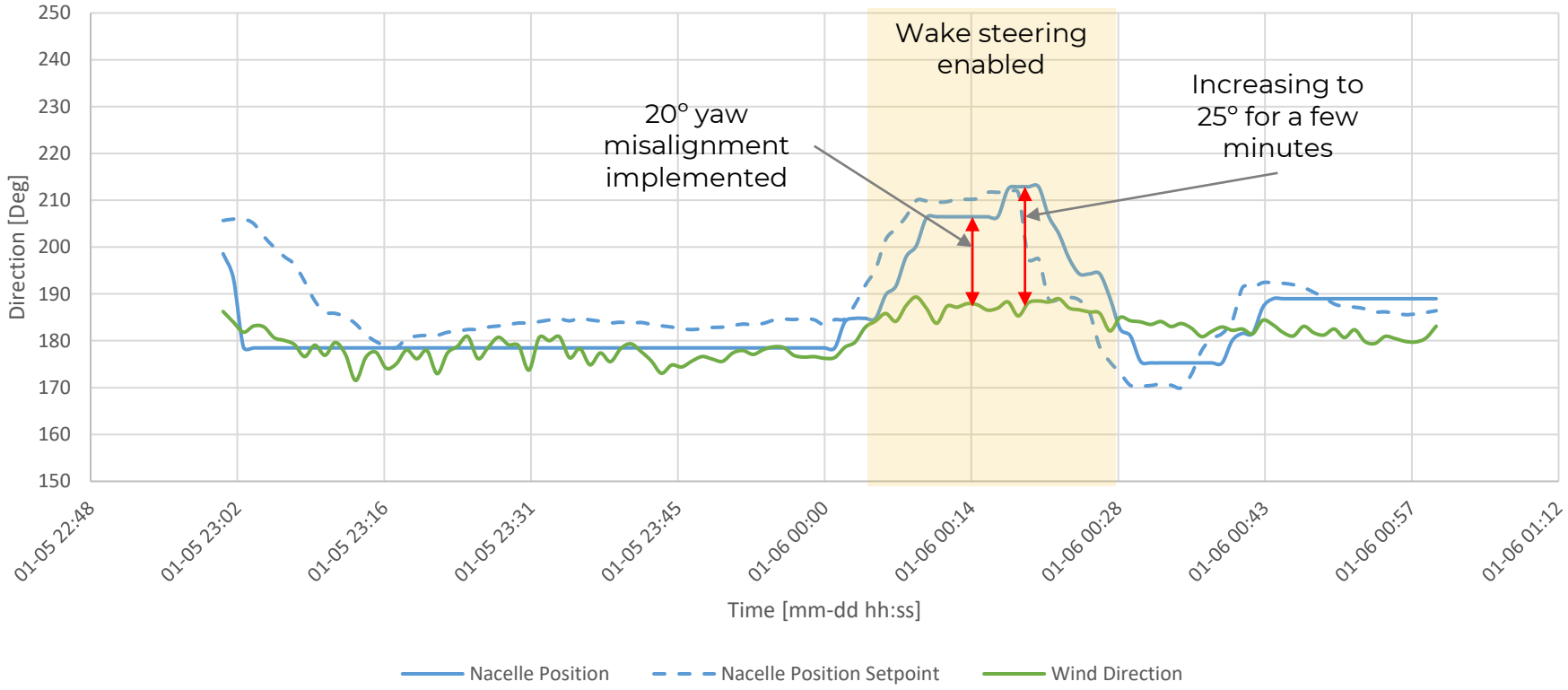
Tracking Nacelle Position Example



Able to get the turbine to within 3° of the setpoint

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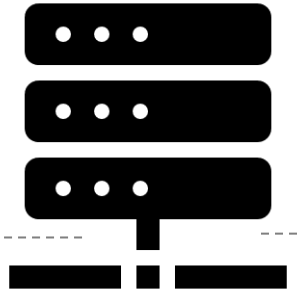
Swarm Server

Server installed within the wind plant firewall

Sends nacelle position setpoints to each of the Swarm Edges



Interfaces with OEM OPC Server for near real time SCADA data

Interfaces with Swarm Cloud for system analytics and long-term optimization

Estimates optimization setpoints based on SCADA data and Swarm Edge data from all turbines

Interfaces with Swarm Edge devices installed at the wind plant

Multiple applications run in parallel to enable Swarm

Swarm Server runs real time model and analytics in the loop leveraging data from all turbines

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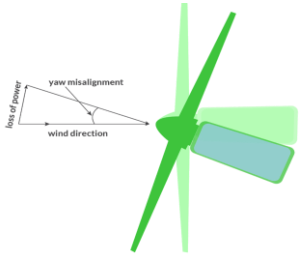
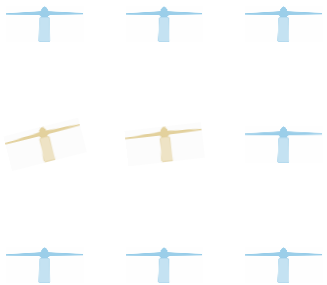
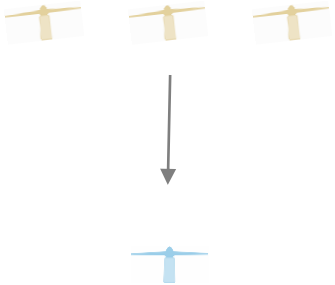
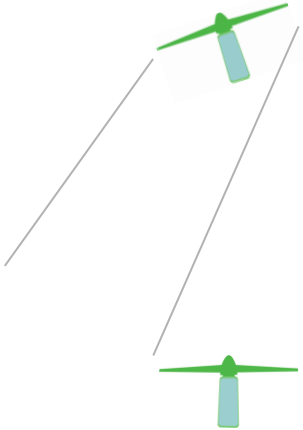
Swarm Applications









1 Online Static Yaw Misalignment Correction

Correct turbine nacelle positioning to optimize power production under normal operating conditions

Output ●

Lifetime ●

2 Collective Yaw

Evaluate wind direction using all available wind information across the wind plant

Output ●

Lifetime ●

3 Predictive Yaw

Predict wind direction change using data from all turbines across a wind plant

Output ●

Lifetime ●

4 Wake Steering

Off yaw upwind turbines to reduce wake impact on downwind turbines

Output ●

Lifetime

Multiple applications run in parallel

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Swarm Trials

3 turbine commercial wind project
(2018 - 2021)

Built and pilot tested Swarm Edge system

Dec 2020: Demonstrated wake steering action using our model-in-the-loop control system

Milford Site 10x Clipper Turbine Test (Aug 2021 - Aug 2022)
Serial production ongoing (165 turbines)

Continued testing on Swarm System since Nov 2021

Minimal load increase measured using load sensors installed on two turbines

Swarm System completed 15,000 turbines hours of autonomous operation

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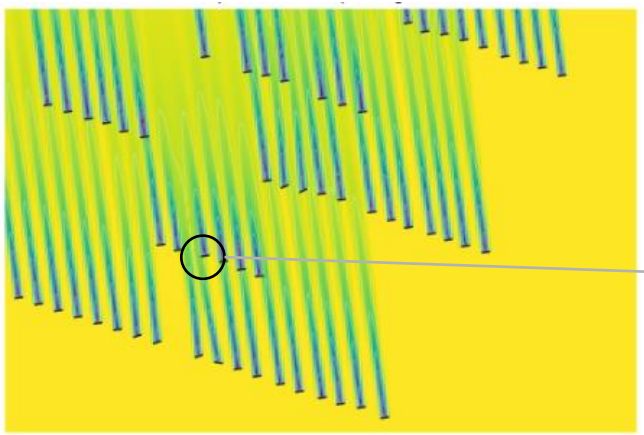
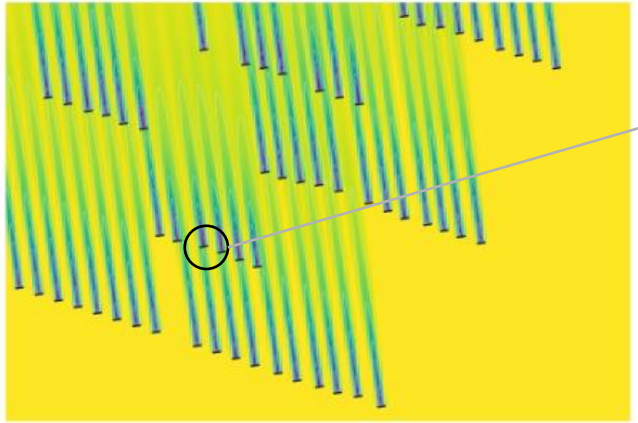
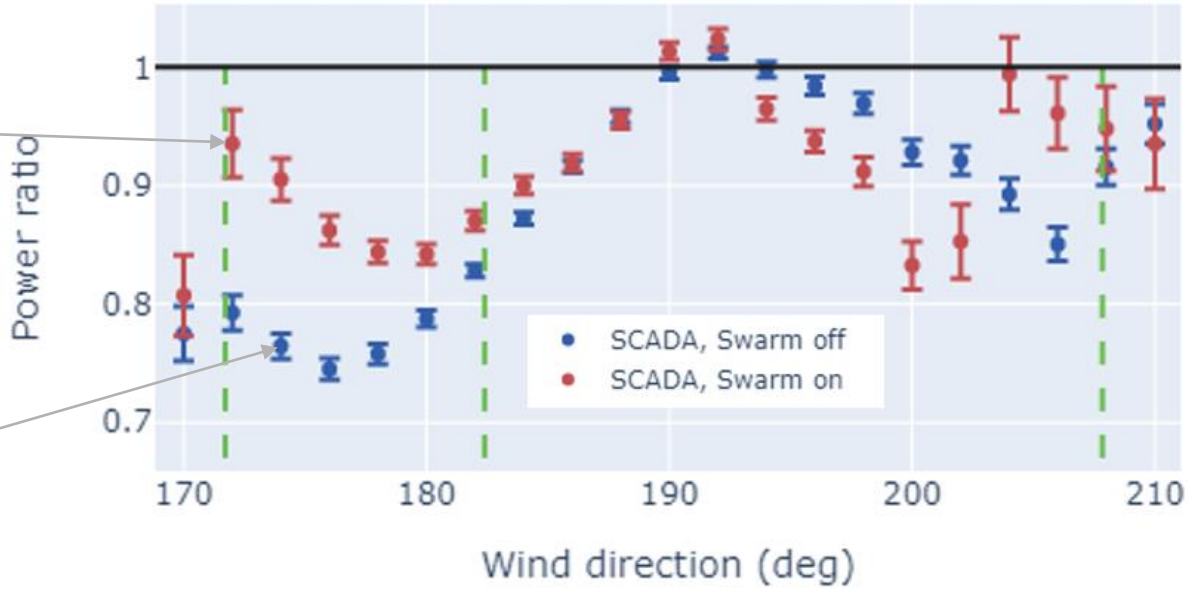
Swarm at Work - Example







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Turbine Loads

Embedded strain gages measure blade bending at 20 Hz

Strain data combined with SCADA data to measure loads on the turbine

System installed on 2 turbines under Swarm

WindESCo proprietary load measurement system is monitoring loads on 2 turbines under Swarm

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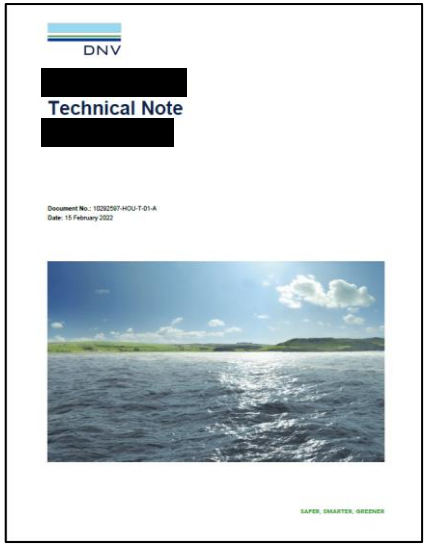
Loads

- In general, very low loads impact to overall turbine loads and component life
  - Swarm only operate in low wind below rated power
  - Upstream turbine steered within +/- 20-25 deg range - well below turbine yaw misalignment limit
  - System falls back to original turbine control with fault
- WindESCo developed site specific loads analysis method to use generic turbine aeroelastic model to assess relative loads change from original turbine certification
- Site specific load assessment on commercial project was approved by DNV for customer
- General certification for loads method and safety concept in progress with UL - targeting end of October
- Site specific loads assessment process with UL check will be available by the end of year


DNV

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Technical Note

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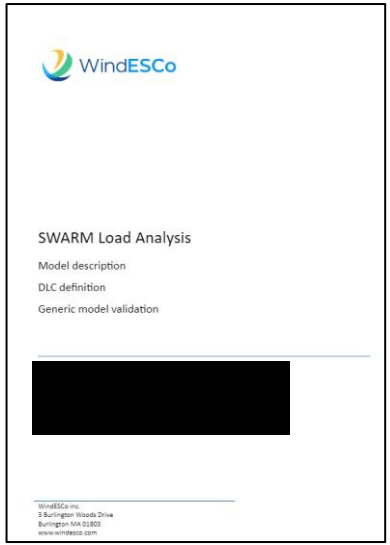
SAFER. SMARTER. GREENER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SWARM Load Analysis

Model description

DLC definition

Generic model validation

[redacted]

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Very low load impact estimated from Swarm

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Measurement Method

Direct Paired Analysis

Swarm On	Swarm Off	On	Off	On	Off
1 hr	1 hr				

- Toggling is used to produce relevant comparison periods
- For each turbine, the mean power is determined within each toggle period (i.e., Swarm on and off) and the difference in mean power between adjacent toggling periods is calculated
- These mean power differences are aggregated over each turbine and over the annual period to determine the IAEP

Industry accepted toggle on / toggle off is used to measure the increase in AEP

Summary

- Wake steering has limited commercial application
- Has to be combined with other co-operative control applications
- Cooperative solution requires a system approach combining hardware and software
- Edge devices installed in each turbines can serve as a gateway for sensor integration
- Sensor integration provides additional performance optimization

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Questions