Optimizing wind plant production with cooperative control

WindESCo discusses why taking a collective approach to energy production improvement, by thinking of a field of wind turbines as a system rather than viewing single turbines in isolation, could have a positive impact on performance levels.

Underperformance is a key challenge in the wind industry, garnering the attention of investors, independent power producers, utilities and corporate buyers alike. Despite a growing market of dashboarding solutions that attempt to identify underperformance, little progress has been made at recovering the AEP that is so often lost at wind farms compared to projections.

Original equipment manufacturers have also grappled with the underperformance of their turbines, but commercial solutions designed to improve energy production fall short.

For years, WindESCo has consistently driven 1 to 2% AEP improvement at wind plants, using high resolution data to uncover and fix wind turbine under-performance. With the launch of its next-gen solution, WindESCo Swarm, a way to realize 3 to 5% improvement across a site.

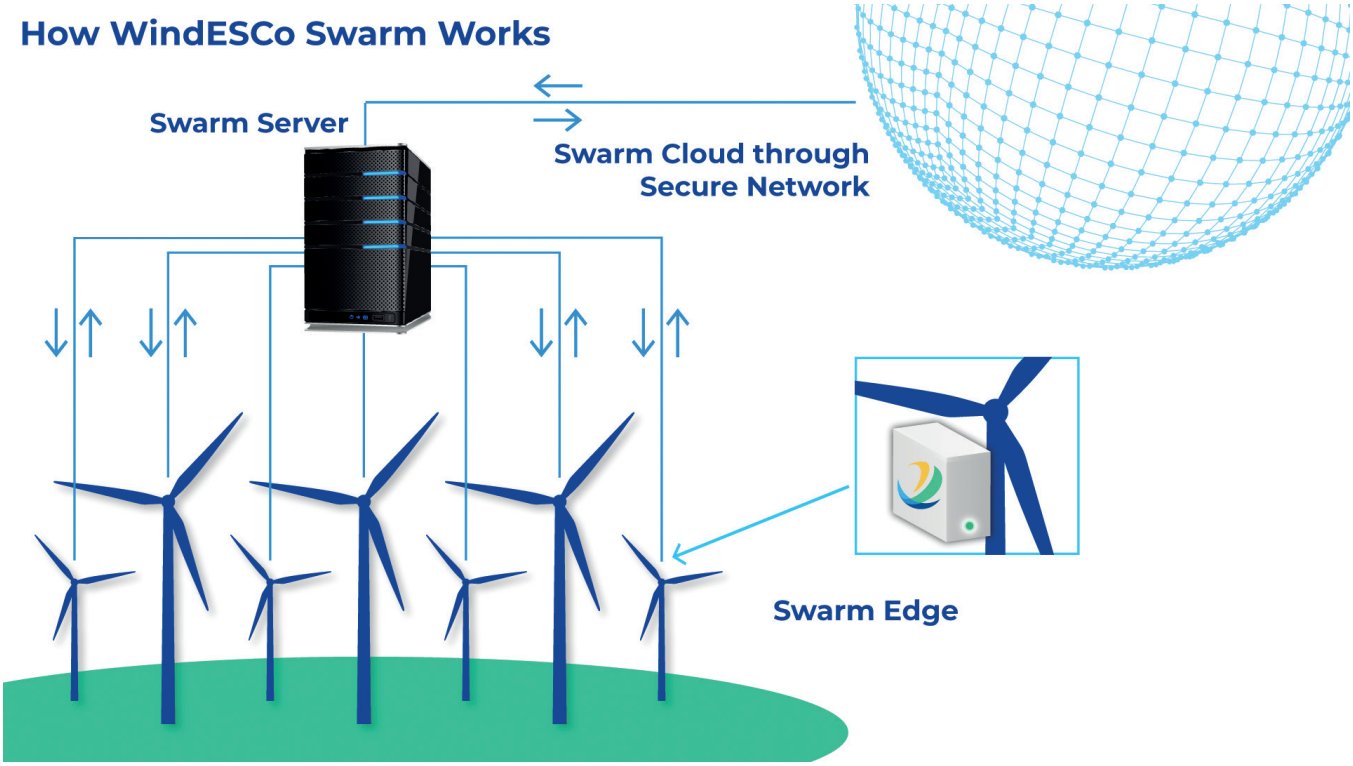
Taking a system approach

The world we live in is digitally and socially interconnected. Businesses, individuals and nations increasingly understand the value of cooperation. Despite this, wind turbines, even those in large plants, almost exclusively operate independently.

Turbine operators employ control strategies designed to maximize individual asset production, rather than working together as a collective, cooperative unit to achieve wind plant optimization.

This isolated operational approach amplifies reactive and local turbine control behaviour, that is the behaviour that results in turbines constantly chasing the local wind effects. It also generates turbine-to-turbine wake effects that hinder wind plant optimization.

Individual assets are optimized, while the overall performance of the plant suffers. As a result of these turbine-centric control strategies, wind plants regularly lose



between 5 to 20% of their potential power[1].

A lot of research has been done or is ongoing to manage the wake effect by steering or derating the upstream turbines. However, few have generated sufficient AEP improvements that could justify the additional hardware and software costs required for wake mitigation.

Introducing swarming

In nature, many species have realized the evolutionary benefits of operating as a coordinated unit. Beehives, starling flocks and herring schools, for different reasons, group together in large numbers and move in sync.

In the same way, WindESCo developed a new technique to swarm wind turbines, allowing them to become social, reacting to their neighbours, and sharing information to continuously optimize AEP for the entire plant.

Taking cues from nature, and the intuitive decision-making of birds in flight, WindESCo Swarm™ enables turbines to cooperatively adjust positioning to boost production for the entire farm, not just single machines, by 3-5% annually. By swarming a wind site, WindESCo has introduced an autonomous, cooperative control technique for continuously optimizing AEP.

1 Lee J. C. Y. and Fields J. M. "An overview of wind-energy-production prediction bias, losses, and uncertainties." Wind Energ. Sci., 6, 311-365, 2021 https://doi.org/10.5194/wes-6-311-2021

The Swarm technology stack

By combining hardware and software as an integrated system, owners can unlock value by allowing turbines to communicate with and learn from each other. To develop the system, WindESCo used a multidisciplinary approach, combining the fields of turbine loads, controls, meteorology, sensing and machine learning.

The system has been developed with three years of concentrated effort and has been tested on 13 turbines on two wind plants. The first commercial implementation on three wind plants with over 300 MW of capacity is underway in North America. It is currently being offered as a retrofit solution that is compatible with most turbine OEMs and models. The system can also be made part of new wind plants or as a retrofit solution offered by OEMs and controller manufacturers.

The retrofit Swarm application can be divided into four layers:

Swarm Edge: the IIoT edge device and software connected to the turbine controller get real-time turbine level data and implement cooperative control.

Swarm Server: the wind plant level server within the firewall that communicates with each Swarm Edge and the wind plant SCADA server.

Swarm Software: the core software layer running on the Swarm Server that communicates with all the Swarm Edge devices and makes real time optimization decisions.

Swarm Cloud: the offline data analytics and model optimization layer that provides longer term analytics and visualization of Swarm effectiveness at a wind plant.

Offering multiple value propositions, when combined together, can increase Annual Energy Production between 3 to 5% at a wind plant level. Below are some examples of the different applications that have been implemented as part of the Swarm system.

	Site A	Site B
Capacity	80 MW	248 MW
Estimated Annual Benefits	0.5 % $107,000	1.1 % $300,000
Reduction in Yaw Actions	88%	74%
Reduction in Yaw Distance Traveled	83%	88%

Yaw by consensus

When each turbine operates independently, it must solely rely on its sensors to determine the wind direction and appropriately modify its control settings. These sensors are typically mounted on the nacelle and measure the flow direction at a signal point near the center of the rotor, which doesn't

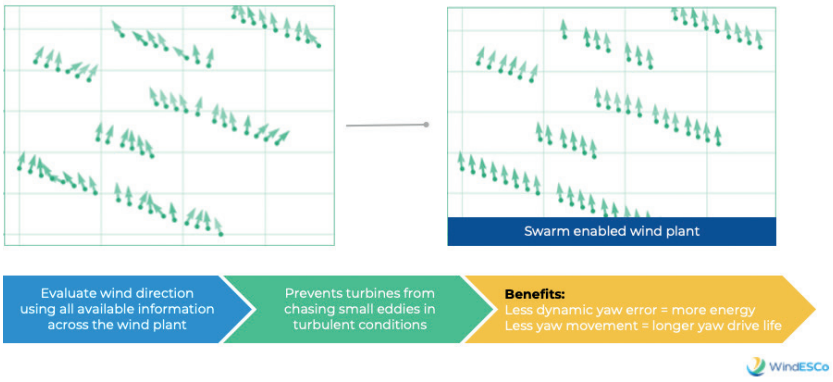
adequately characterize the average flow through the wind turbine rotor sweep.

By combining measurements from varying subsets of turbines in the wind plant, a comprehensive characterization of the wind plant complex flow field can be determined and the yaw positioning of individual turbines can be optimized to maximize energy capture.

In this way, by sharing knowledge of the wind all turbines can improve their performance. This is known as yaw by consensus.

This increases energy capture while minimizing total yaw activity. The following benefits were estimated for two recently analyzed plants.

Swarm Application: Yaw by Consensus



Wake steering

Wind plants lose between 5 and 20% of their output to wakes. One of the most effective strategies for mitigating wakes to increase the overall plant production is wake steering. Here, the yaw position of the upwind turbine is modified so that it no longer faces directly into the wind.

As a result, the downstream propagation of the wind turbine wake can be deflected, or steered, away from the downstream turbines. The downstream turbines are then exposed to undisturbed higher velocity flow and can generate more energy.

Although the upwind turbine will produce slightly less power than if it were pointing directly into the wind, the wind plant as a whole will generate additional power as a result of the wake losses being mitigated.

Other Swarm applications

Two additional applications are introduced by WindESCo Swarm that provide further automated benefits to a wind plant through yaw control improvements. OEMs have optimized their yaw controllers for a specific set of general site conditions, however, decisions about when to yaw are not always optimum for the site due to differences from the modeled site conditions.

One of the yaw control improvements could dynamically adjust the nacelle position of the turbine to maximize energy capture and minimize the wear and tear on the yaw drive components. Another one could use predicted wind direction from nearby turbines to help capture more energy or reduce extreme loading on the turbines.

Monitoring and updates over secured network

Swarm is not a static upgrade for your wind plant. Instead, it will get even better over time, through remote monitoring and offline data analytics. WindESCo is continuously improving the system, applying the latest state of the art analytics and algorithms to achieve even better performance on wind plants.

Significant returns on investment

Two financial models were considered for swarming. The first financial option is through WindESCo's System-as-a-service (SysaaS) model, similar to common software-as-a-service implementations. This model delivers hardware, software and implementation to a customer for a recurring service fee.

The second takes advantage of significant tax benefits available in the US market through the Production Tax Credit (PTC) program for repowering equipment. Similar tax incentive programs may exist in other markets.

The Return of Investment and the Net Present Value for customers, showing that continuous optimization through WindESCo Swarm over consecutive years unlocks cumulative AEP improvements and increased profit generation for project owners.

The table below shows an example financial model with a five-year Net Present Value and Return of Investment for the System-as-a-service model mentioned above.

Turbine Rating (MW)	2.5 MW	1.5 MW
5 year NPV	$15.8 - 30.1 Million	$14.0 - 28.4 Million
5 year ROI	Up to 5.3 times	Up to 3.8 times
Payback Period	Less than 1 year	
Assumptions: Portfolio capacity = 1 GW Power Price = $60/MWh Net Capacity Factor = 35% Discount Rate = 9%		

Asset longevity case study

As part of Swarm's development, WindESCo has deployed software and hardware on test site wind farms in the US. This prototype testing demonstrated the ability to perform energy performance optimization with no adverse effects on asset lifespan.

In addition to measuring changes in power performance, these turbines are instrumented for blade root bending load measurements and the damage equivalent loads are measured with and without wake steering.

Analysis showed an anticipated change of less than 1% in fatigue loading on these turbines and experimental results for the period analyzed support this result by showing no statistically significant difference in the fatigue loading on the turbines when wake steering.

Conclusion

Optimizing turbines in a one-off manner has not generated significant enough AEP gains to move the needle on the value and profitability of wind assets. Meanwhile wind plants consistently miss production expectations by 8 to 20%.

To solve this problem, the industry must move away from its single-turbine approach to AEP improvement and instead think of a field of wind turbines as a system, which must work cooperatively to perform at its peak. This can now be achieved through swarming.

WindESCo Swarm is commercially available and licensable technology that allows wind plant operators to capture 3 to 5% additional AEP without reducing asset longevity.

For more information email contact@windesco.com.

www.windesco.com