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How weather intelligence boosts wind farm performance and efficiency

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Wind farms face weather-related challenges that impact turbine performance and profitability, such as wind variability, rain, hail, lightning, and turbulence. Accurate weather data is key to optimising energy production, reducing maintenance costs, and improving safety. Integrating wind lidars, environmental sensors, and digital tools helps wind farm managers make real-time adjustments, enhancing energy efficiency and minimising downtime.

While wind farms aim to harness the power of wind to produce electricity used to power homes, businesses and industries, the planet's natural movement of air and other weather conditions crucially impact turbine performance and wind farm profit.

From heavy rain and gusty winds to blistering heat and freezing cold, to less-known factors like lightning, dust, temperature and visibility, changing wind and other weather conditions can influence energy production, safety, reliability and operational costs.

Wind energy offers a clean, sustainable source of electricity generation, but unlocking its full potential to meet our ambitious energy goals demands innovative weather intelligence solutions that help optimise assets, mitigate costly repairs and downtime and drive efficiency across the entire wind farm life cycle.

Weather challenges for wind farms and turbines

In the face of varying weather conditions, balancing energy production, costs, safety and reliability remains difficult for wind farm operators. Wind and weather dynamism present a myriad of challenges, from wind variability and turbulent wind conditions affecting output to severe storms causing structural damage, blade erosion and operational disruptions that require extensive repairs and maintenance.

Turbines are designed to operate optimally within specific wind speed ranges. Therefore, any variability in wind speed and direction outside these ranges can lead to suboptimal performance or even shutdowns to prevent damage. Ramp events and rapid wind

direction changes cause extra loads and production losses.

Turbulence can exert additional loads on turbine blades, tower structures and other components, causing fatigue and structural stress. These turbulent conditions can also

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WindCube vertical profiler for Wind Resource Assessment

provoke increased maintenance requirements and potential downtime. Turbines located downstream of others within a wind farm can experience reduced wind speeds and wake effects, leading to lower energy production.

Temperature fluctuations can impact the density of air, either reducing air density for lower energy output or increasing air density and imposing higher loads on turbine components. Dust, sand and other airborne particles can accumulate on turbine surfaces, diminishing aerodynamic performance and increasingly wearing on components. Turbines are also susceptible to lightning strikes, which can damage electronic components, control systems and other critical infrastructure.

Rain, thunderstorms, hurricanes, cold weather and high winds also pose severe risks to wind turbines and farms. Falling rain and hail can damage turbine blades or contribute to erosion and degradation of turbine components. High humidity can cause corrosion that affects the structural integrity of turbines, thereby escalating maintenance costs and leading to additional downtime.

In cold climates, icing on turbine blades can reduce aerodynamic efficiency and increase loads. Ice accumulation can also imbalance the turbine rotor, leading to vibration, blade damage and reduced energy production.

Finally, wind power output oscillation due to varying weather conditions creates grid integration and stability challenges. Improving energy forecasting accuracy, especially ramp events for smoother grid integration, is essential for our energy transition.

Weather-centric wind farm challenges are formidable, but integrating accurate wind and weather data into operations enables operators to proactively mitigate risks, optimise performance and maximise the return on their asset investment throughout the project's life cycle.

The value of precise weather information

Harnessing weather intelligence equips wind farm owners and operators to overcome weather-related problems, empowering proactive optimisation of turbine performance, massive cost reduction and enhanced energy production.

Wind farm managers can benefit from incorporating accurate, near real-time weather data into their operations. By doing so, they can protect turbines against fatigue and extreme loads, which helps extend their lifespan and reduce maintenance costs. They can also optimise turbine set-point adjustments and curtailment strategies based on shifting weather conditions, ensuring efficient energy production while reducing safety risks.

Analysing current wind and weather conditions allows managers to identify opportunities for performance optimisation. For example, they can adjust blade pitch angles or yaw alignments, facilitating early interventions and improvements. This proactive approach also aids in conducting quick and accurate Power Performance Testing under various weather conditions, ensuring compliance with industry standards and contractual obligations.

By accounting for atmospheric conditions, wind farm managers can reduce wake losses and strategically position turbines to minimise wake effects, ultimately maximising energy capture, farm efficiency, and revenue. Improved weather forecasting, particularly for predicting ramp events, leads to smoother grid integration and more reliable power delivery.

Accurate weather data also aids in detecting and forecasting wind gusts and rapid changes in wind direction, allowing managers to take proactive measures to maintain stable operation and mitigate risks. Lightning forecasting capabilities help protect personnel and assets, minimising downtime and associated costs. Monitoring air density, visibility, icing, precipitation, hail, and dust particles enables optimised curtailment strategies, ensuring maximum production during favorable conditions.

Weather-augmented wind farms incorporate wind lidars, weather and environmental sensors, and data analytics into the wind turbine and farm management ecosystem, leveraging weather data to enhance profitability through proactive optimisation.

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FD70 sensor for precipitation detection

Wind and weather monitoring and measurement technologies

Leveraging weather intelligence demands modern wind farms integrate a suite of wind and weather monitoring solutions to optimise the performance, cost and reliability of wind turbines and boost safety and energy production.

Wind lidars

Lidars assist across the wind farm development life cycle, from wind resource assessment to ongoing performance testing.

Nacelle-mounted lidars provide valuable data for turbine control, performance optimisation and power performance testing, including shear, veer, turbulence intensity and rotor induction effects, on and offshore. Devices like WindCube Nacelle measure wind conditions at hub height at an unprecedented range of 700 meters, providing a comprehensive picture of the wind profile.

Scanning lidars, like the WindCube Scan, offer complete 3D wind mapping, gust detection and minute-to-hour-ahead forecasting, enhancing energy generation planning and grid integration. Configurable for multiple uses, monitoring, atmospheric cross-sectioning and wind profiling, scanning lidar can also measure multiple turbine locations at once, creating massive operational assessment efficiencies to better understand the turbine wake behaviour.

Vertical profiling lidars continuously monitor wind conditions, providing independent verification of on-site measurements.

As the average hub heights and rotor diameters of wind turbines rapidly increase to meet greater turbine generation capacities, the inadequacy of meteorological masts (met masts), an older, more traditional method of measurement, is amplified. Lidar offers a generational leap forward, improving the quality and quantity of wind data without relying on data extrapolation techniques that can introduce error and uncertainty.

Various other weather and environmental sensors can also be used on wind farms. For example, precipitation sensors provide detailed droplet measurements. By detecting 100% of precipitation from the lightest drop to the end of the storm, decision-makers can anticipate and prevent turbine blade degradation or damage and other blade or turbine erosion.

Digital solutions

Software platforms, offer lidar-augmented nowcasting and event forecasting, data analysis, reporting and performance optimisation capabilities, streamlining planning and response processes and enhancing data visibility. Energy forecast providers produce site-specific sub-hourly energy forecasts with calibrated prediction intervals that help wind farm operators plan, invest, and trade with confidence.

By providing actionable data at a glance, modern, cloud-based solutions deliver weather data via customisable dashboards, empowering decision-makers with access to business-critical insights on any device.

In addition, integrating modern lightning data services into wind farm operations enables lightning detection, forecasting and trustworthy alerts, protecting assets and personnel from potential strikes. The deployment of these cutting-edge technologies and the integration of weather data into wind farm operations unlock numerous benefits at both the turbine and farm levels.

The weather-augmented wind farm of tomorrow

With the global transition toward renewable energy gathering more momentum by the moment, the wind industry faces an imperative to maximise safety, turbine performance and efficiency while reducing costs and enhancing reliability.

Between reduced loads on turbine components, increased reliability through proactive maintenance, enhanced employee safety, lower overall costs resulting from reduced downtime and enhanced power curve performance through precise adjustments, mitigating risks associated with adverse weather events delivers consequential turbine-level benefits.

At the wind farm level, weather intelligence enables reduced losses and increased production, better performance monitoring and diagnosis of underperformances and failures, reduced curtailments, minimised uncertainties and expenses across the life cycle and, ultimately, maximum energy output and revenue.

The ability to proactively anticipate, and mitigate, the impact of adverse weather empowers wind farm managers to implement strategies that unlock the full potential of their assets. By integrating lidars, weather sensors, lightning detection networks and advanced digital solutions, wind farms can fully capitalise on the power of wind while minimising weather-related risks and maximising returns on investment.

Our ever-evolving renewable energy landscape necessitates the adoption of weather intelligence to realise the true potential of wind energy and a sustainable, carbon-neutral future.

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About the author

Matthieu Boquet is Head of Wind Operations for Vaisala.

In this role, he drives strategy and execution for the WindCube lidar suite, to meet the industry's high-level expectations while helping customers continually generate value from their lidars.