Enhancing wind farm performance: the crucial role of monitoring blade deflection

In the ever-evolving landscape of wind energy, turbine blades play a pivotal role in harnessing the power of the wind to generate clean energy. However, ensuring the optimal performance and longevity of the blades involves overcoming various challenges.

Blade deflection is emerging as a critical factor when blades are reaching unprecedented lengths. This article explores how monitoring deflections on a wind turbine blade can significantly improve wind farm performance, reduce operational and maintenance costs, extend its overall lifespan, and ultimately increase the valuation of wind assets.

The importance of monitoring

Blade deflection, the bending and twisting of blades due to aerodynamic and gravitational forces, is a natural phenomenon that occurs during turbine operation. A certain degree of deflection is required and factored into the design. However, excessive or irregular deflection can lead to reduced energy output, increased wear and tear, and impact the longevity of the turbine blade. This challenge grows with the introduction of longer blades.

A recent study[1] based on the inspection of more than 10,000 blades shows that the risk of crack propagation in longer (>55m) blades is about five times higher compared to small blades and becomes an almost certainty after just three years of operation.

This data is supported by announcements from major OEMs that unplanned maintenance and repairs on the newer, longer type of blades is seriously impacting their profitability. Numerical modelling has shown that medium-sized cracks in the primary structure of the blade have a measurable effect on the deflection of the blade. Blade deflection can, therefore, be an effective measurement unit for condition monitoring and serve as input for predictive maintenance strategies.

Additionally, the commercialization of floating wind is emerging. Developers are reducing the Levelized Cost of Energy as much as possible by planning turbines up to 20 MW and increasing lifespan up to 35 years. Turbines mounted on floaters are exposed to additional mechanical stresses due to the motions induced by the waves. Small motions at the floater base result in high translations at the blade tip.

Blades will show deflection behaviours which up to now have been impossible to predict in numerical models. Understanding this behaviour in real-time allows the operator to optimize the performance and lifetime of the blades.

Fibersail works with the industry to find solutions that address these challenges. It has been deploying its Condition Monitoring System (see Figure 1) in various operational pilots to demonstrate that monitoring blade deflection, also called 'shape sensing', can deliver the value the industry needs (see Figure 2).

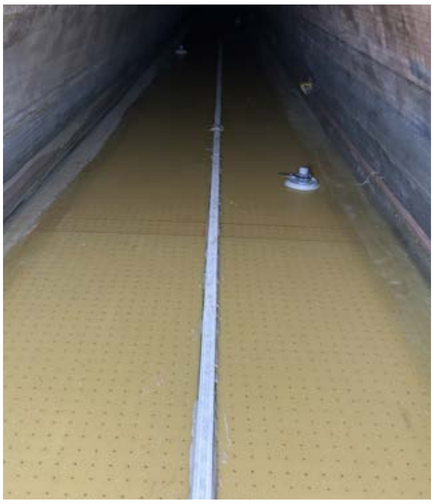

Figure 1: Shape sensor installed in a blade

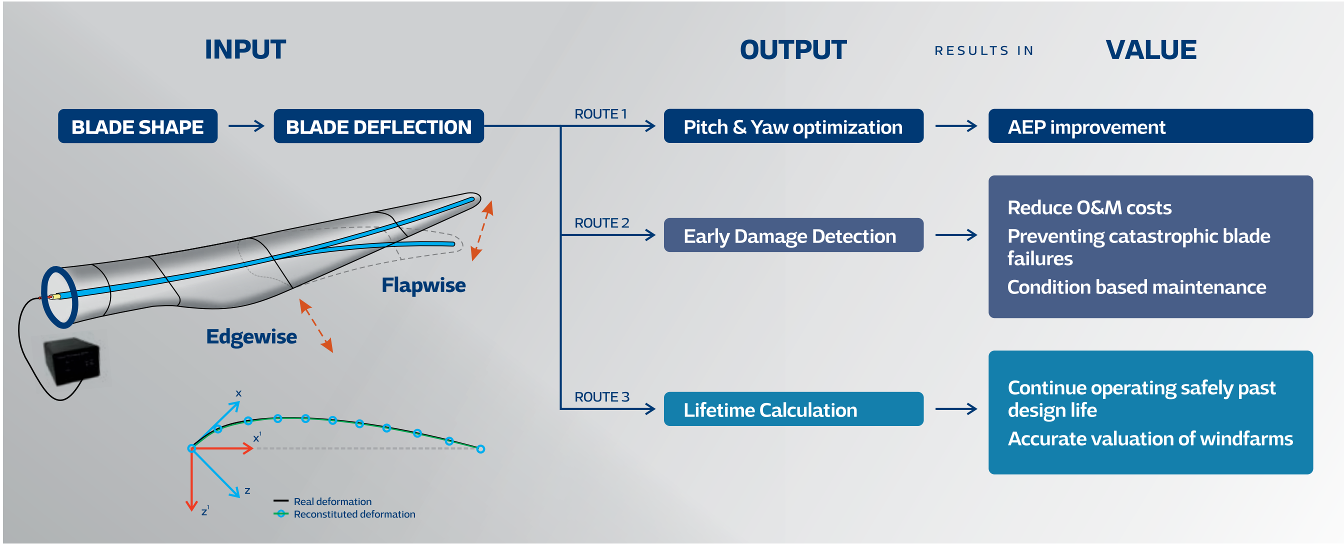

Figure 2: Fibersail value propositions demonstration roadmap

Pitch and yaw optimization for AEP improvement

Quite often, the pitch and yaw conditions defined in the control system for the best operation of a wind turbine are not met in the field. Whether caused by a limitation on maintenance activity, occasional system malfunctioning or site-specific conditions outside the theoretical expectations, the potential for AEP improvement due to pitch and yaw optimization is enormous. To tackle it, Fibersail set several demonstrator projects to showcase how shape-sensing can deliver immediate value to the customer.

Taking as an example a wind turbine instrumented with Fibersail Condition Monitoring System (CMS), we can see, in Figure 3, the variation of flapwise blade deflection as a function of wind speed and power output during turbine operation.

Focusing on the pitch optimization, Figure 4 represents the flapwise blade deflection as a function of active power production. Note that this analysis is focused on power production conditions, for wind speed between turbine cut-in and rate speed. We can clearly identify two distinct blade deflection behaviors. In this case, the erroneous pitch condition with a pitch offset of 0.5° was identified based on the variation of flapwise deflection close to 0.1 [a.u.].

Similarly, Figure 5 represents the flapwise blade deflection as function of rotor azimuth before, with erroneous yaw and after, with normal yaw, the nacelle aligns with the main wind direction. In this case, a yaw offset of 4° induces a maximum variation in flapwise deflection of 0.2 [a.u.], clearly identifying the offset.

The results obtained prove that Fibersail's shape sensing solution allows the detection and quantification of aerodynamic imbalances, in this case, blade pitch and yaw misalignment.

Optimizing pitch and yaw angles in this situation will result in an immediate AEP improvement of 1%, or around 10.000 EURO/turbine/year for a typical 6 MW wind turbine. Additional value is gained by the reduced blade deflections, increasing the lifetime of the blades.

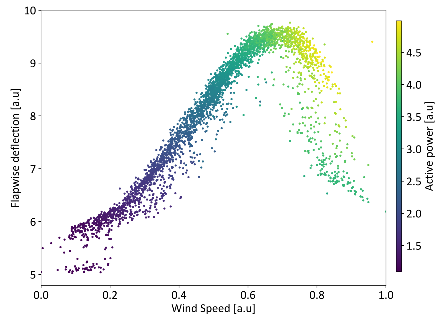

Figure 3: Flapwise blade deflection and power output variation with wind speed evolution during turbine power production

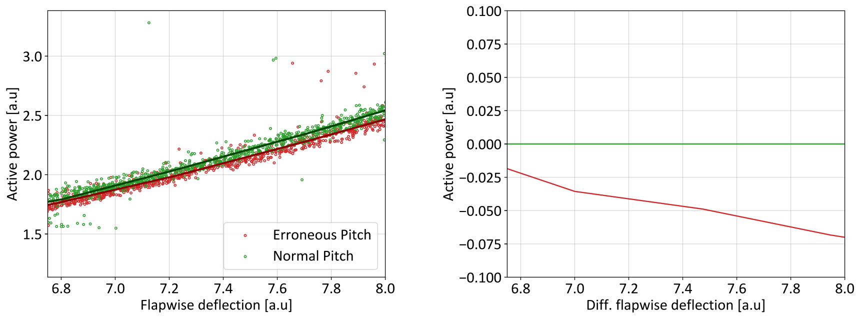

Figure 4: Flapwise blade deflection variation and respective differences as a function of power output, considering normal and erroneous blade pitch angle conditions, power production for wind speed between turbine cut-in and rate speed

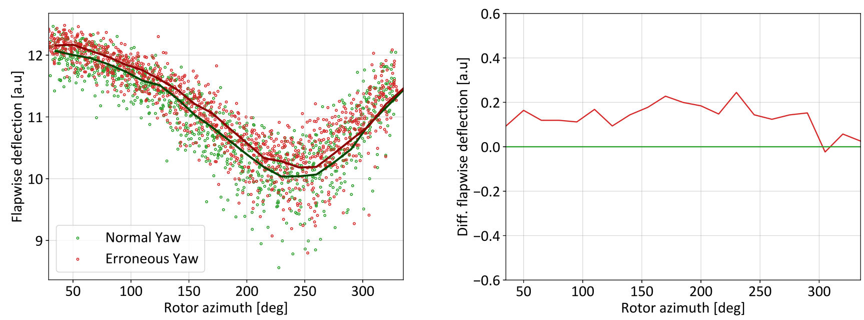

Figure 5: Flapwise blade deflection variation and respective differences as a function of rotor azimuth, considering yaw misalignment, power production for wind speed above turbine rate speed

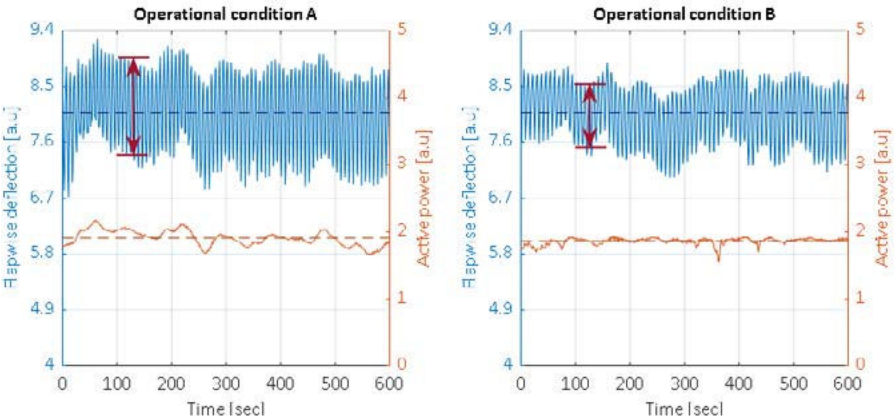

Figure 6: Flapwise blade deflection amplitude and active power output variation with time, considering two time periods with similar environmental conditions

Increased lifetime and asset valuation through minimizing blade deflection

Shape sensing offers a pathway to optimize energy output at reduced load levels. Currently, load sensors are widely used in new turbines. However, each blade deflects differently with similar loads, due to the manufacturing tolerances of these large composite structures. A different blade shape means there is room for various load levels and power outputs.

As shown in Figure 6, we can observe that, for the same wind turbine, equivalent yield output is achieved through a significantly different blade deflection amplitude, flapwise deflection amplitude of 2% in operational condition A and just 1% in operational condition B.

Although not yet fully quantified, reduced blade deflection for the same power output is more benign to the turbine structural health. The transparency provided by Fibersail CMS allows the optimization of the turbines to site-specific conditions and in line with the asset valuation strategies.

The asset owner can decide the best operational conditions, based on the tariff per MWh versus asset depreciation by fatigue usage. This will maximize the project profit in the long run, as shown in Figure 7, by comparing 'operational condition A with more deflection, vs B with less deflection for same AEP'.

Early damage detection

The cost of unplanned maintenance on wind farms has been growing and currently sits around 65% of total O&M budget. Longer blades tend to fail more often due to the much higher loads and manufacturing tolerances. Preventing these blade failures by monitoring the structural health means a huge cost saving to the owner/operator. Lost production and the cost of a new blade alone could hit 1,000.000 EURO for a 6 MW turbine if the new blade needs to be manufactured first.

Fibersail is enhancing its SHM system to detect blade damage based on vibration, strain, and shape-based methods. By continuously monitoring the dynamic and structural behavior of the blades, it is possible to signal damage situations in advance by detecting changes in the shape and dynamics of the blade.

What type and severity of damage is detectable with the shape sensor? Numerical model simulations show deflections of up to 22 cm in a 100 m blade when imposing small to medium sized cracks to the primary structure. This falls well within the current resolution of the shape sensor.

We are working with industry and academy partners to learn how different types of damage modes impact blade behavior, by developing high-fidelity numerical models and, on the other hand, to prove the new methodologies in full-scale blades. The recently started Reliablade2 project is one of these works.

By identifying issues early on, operators can schedule maintenance during periods of low wind, optimizing the availability and reliability of the turbines while avoiding costly unscheduled repairs.

Conclusion

The cumulative effect of monitoring and minimizing blade deflection is a notable extension of the wind farm's operational life. By addressing structural issues promptly and fine-tuning performance parameters, operators can mitigate wear and tear, thereby prolonging the lifespan of the turbines and the overall wind farm infrastructure.

Monitoring wind turbine blade deflection emerges as a crucial practice for optimizing wind farm performance, reducing operational costs, and extending the lifespan of the blades. Predictive maintenance, made possible through real-time deflection monitoring, revolutionizes the approach to turbine blade care, shifting from reactive to proactive strategies.

Moreover, the ability to minimize blade deflection while maintaining energy output is a game-changer, offering operators a unique opportunity to balance efficiency and longevity in the dynamic realm of renewable energy. As we navigate towards a sustainable future, the integration of advanced blade monitoring technologies becomes paramount for unlocking the full potential of wind energy.

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1. Skyspecs, December 2023, presentation at Wind Turbine Blades 2023, Dusseldorf, Germany.

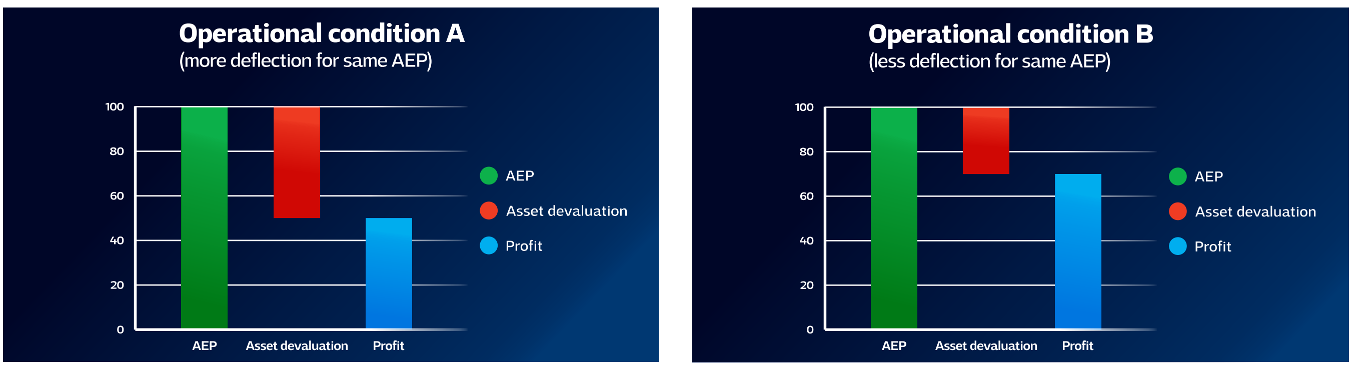

Figure 7: comparing operational modes with high vs low deflection for same power output