polytech Beyond the idea

fos4X rotor blade sensing

Why every wind turbine rotor blade should have PolyTech sensors

The impact of blade bending moments and natural frequencies to your wind turbine

In this white paper you will learn:

- That all new wind turbines should have sensors in the blades to assess bending moments and natural frequencies.
- About several business cases on a more abstract level with their respective effect on levelized cost of energy.
- How easy it is to integrate our modular hardware platform and software solutions into your processes.

Summary – Motivation for rotor blade sensing

The structural responses of the rotor blades contain important information about the wind field and the loads acting on a wind turbine. Unwanted loads need to be minimized in order to reduce material costs in the structures. The rotor blades and tower systems account for almost half the material costs of a wind turbine [1]. In this respect, the measured loads (i.e. bending moments) and vibration modes are important input variables for the optimal control of the turbine.

With the implementation of active load reduction mechanisms (using the available actuators), our customers are able to design the mechanical structures more cost-effectively and to reduce the material costs of the entire turbine by up to 10% (i.e. between 15 and 35 k Euro per MW rated power). At the same time, it is possible to use the same turbine type for a wider range of wind conditions and to optimize the design for specific locations. Therefore, our customers can reduce the complexity of their product portfolio while expanding the range of economically viable locations for their products.

Commercial view

Our customers have different motivations why they use sensors for bending moment and natural frequency determination. The financial motivations and technical aspects are described in an abstract manner in Figure 1. In general our customers are on a path to make their products smarter and to enable a more autonomous operation.

The levelized cost of energy (LCOE) is repeatedly the most important indicator in all our customers' efforts to increase the degree of autonomy of wind turbines and wind parks.

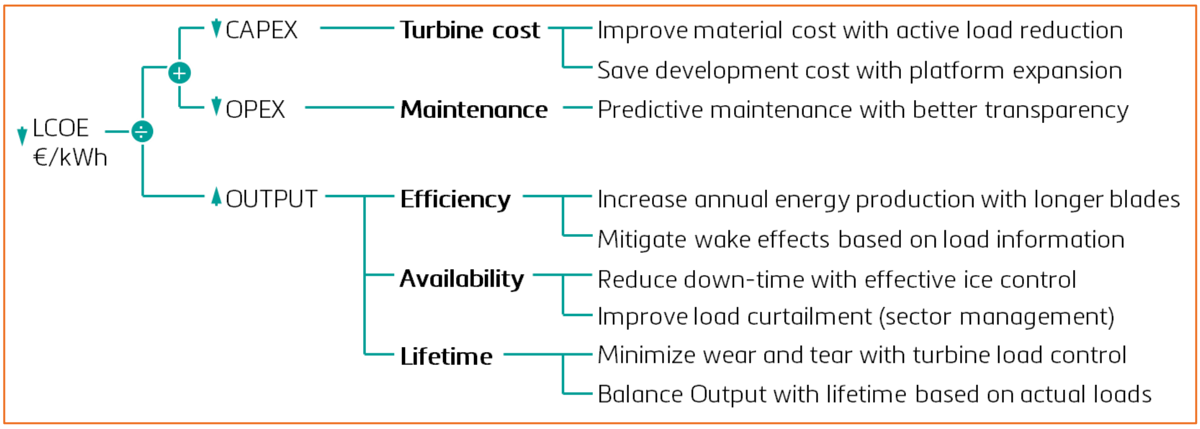

Figure 1 shows examples of the various levers that can be pulled to bring down cost of energy by utilizing rotor blade sensors. Driver tree to reduce levelized cost of energy (LCOE) with applications that make use of rotor blade sensing. CAPEX reductions immediately affect our customers' bills-of-material and R&D cost. Applications that reduce OPEX and those that increase output enable digital business models over the turbine lifetime.

Business case calculations

The following business cases can all be realized based on bending moment measurement and tracking of the natural frequencies of the rotor blades. The fos4Blade [2] platform provides bending moments and natural frequencies. Our suite of algorithms is available with the retroX system [3].

Below the technical effects and root causes are described for each business case. Each case closes with a table, that indicates the improvement with regard to the different levers that influence the levelized cost of energy (LCOE): Capital expenditure (CAPEX, i.e. turbine cost), operational expenditures (OPEX, i.e. maintenance and repair cost), annual energy production (AEP, i.e. power curve, curtailments, availability) and lifetime (LT, i.e. lifetime of components that usually do not fail throughout the service life such as blades, hub, tower).

Pitch angle offset optimization

With blade bending moment sensors in place it is possible to determine deviations in loads that are causes by pitch angle errors. Causes for pitch angles vary from unprecise marking of 0° angle during production to suboptimal setting offset-levels to even wrong bolting of the blades during construction or after blade exchanges. In any case the aerodynamic performance suffers and the ideal power curve cannot be met. A 4.5° pitch misalignment between blades can lead to 5.5% reduction in annual energy production [4]. In addition, higher load and vibration levels occur that cause higher wear and tear in components such as pitch bearings, main bearing, gearbox or generator bearing.

CAPEX	OPEX	AEP	LT
→	↘	↗	↗

Yaw error correction

A yaw error, which results from suboptimal maintenance or sub-system operation (wrong yaw offset, wrong compass north), can cause severe efficiency reductions and leads to asymmetric loading including higher rotor load levels. A few millimeters of wind vane misplacement can cause 15° of misalignment and up to 5-6% in annual energy production [5]. The lost yield is often already reason enough to worry, but damages to bearings can be costly as well as it might reduce overall turbine lifetime.

CAPEX	OPEX	AEP	LT
→	↘	↗	↗

Mass imbalance optimization

Unbalances of the rotor can occur after blade exchanges, major blade services or during operation through water, ice or dirt aggregations. An unbalanced rotor can have a severe impact on the overall turbine performance and lifetime. This is true for almost all components in the stationary part of the turbine down to the tower-soil-interaction. Although a mass imbalance can be measured with a nacelle accelerometer we find that corrective action is not taking place. Also the raw dynamic vibration data (or at least the result of the imbalance measurement) is not made available to the operator. Especially in retrofit it is therefore sensible to activate this feature.

CAPEX	OPEX	AEP	LT
→	↘	↗	↗

Extreme load reduction

To achieve a high capacity factor in locations with varying wind conditions it is desirable to use large rotor diameters and reduce extreme loads when wind speed or vertical shear is high. Gusts and extreme directional changes result in extreme loads and components such as the blade, the main bearing or the generator bearing will suffer severely. Especially for new turbine generations active load reduction allows higher capacity factors (i.e. higher AEP) and a more versatile turbine platform (i.e. greater variety of sites). Especially in the Chinese market where wind assessment has been done poorly and design buffers are low retrofitting turbines with bending moment measurement and implementation of an extreme load reduction (1P or cyclic pitch) is a successful approach.

CAPEX	OPEX	AEP	LT
↘	↘	↗	↗

Sector curtailment optimization

A major positive effect on cost of energy can be achieved if fatigue loads are being reduced. This can be done by means of individual pitch control. With continuous maneuvers, pitch bearings and actuators experience a completely different operation. Therefore, the turbine has to be redesigned to allow this kind of operation. For new turbine generations massive material cost reductions will be realized in this way in future.

But also for existing turbines efficient fatigue load reductions can be realized without major production losses. If loads (or the current turbulence intensity) are known, the output power can be reduced to limit fatigue loads. Often this is done with a fixed sector curtailment that results in major AEP losses.

CAPEX	OPEX	AEP	LT
↘	↘	↗	↗

Ice mass control

In some locations, ice curtailment has a major impact on annual energy production. Energy loss due to ice formation depends on the severity of icing conditions, and it can represent between 2 and 17% of annual energy production [6]. This situation is even worse as turbines are sometimes stopped based on imprecise ice measurement and manual restart is the standard process (i.e. OPEX cost and lost production time).

CAPEX	OPEX	AEP	LT
→	↘	↗	→

Continuous blade health monitoring

Blade inspections may be triggered by a blade condition monitoring system. Especially in remote locations drone inspections are becoming reality, which could be automatically dispositioned based on early damage warnings. For blades with series issues a continuous monitoring can significantly increase operational safety and thus improve energy production and operational expenditures. For new blade generations, continuous monitoring will be standard to allow for smaller safety margins and thus material cost reductions.

CAPEX	OPEX	AEP	LT
↘	↘	↗	↗

Technical view, system setup and modularity

fos4Blade [2] is a modular sensor system designed for use in wind turbines that enables cost- and performance-optimized configuration for any future smart wind turbine. Along with the IIoT sensors we provide libraries and container-based real-time algorithms with which relevant physical quantities can be calculated with high accuracy. Operating parameters such as pitch angle, rotational rate or outside temperature are compensated to achieve optimal results. We use self-optimizing methods to take into account blade-specific production deviations or structural changes caused by ageing.

System setup and modularity

An important requirement in the development of the fos4Blade sensor platform [2] is to offer a simultaneously versatile and cost-efficient sensor system that meets the demands of modern digital infrastructure as well as the special requirements of demanding environmental conditions. The result is a modular hardware and software offering in which each customer can configure the optimum setup for cost and performance for the specific requirement (extreme load minimization, predictive maintenance, ice mass measurement, wind field assessment, etc.). From a minimum equipment with only one strain sensor per blade to an equipment for the simultaneous determination of in-plane and out-of-plane bending moments as well as vibration characteristics of the blades, customer requirements can be met at optimum cost. For R&D applications, the platform can even be expanded to include fiber-optic temperature and pressure sensors as well as microphones. Furthermore, electrical sensors can be integrated into the data acquisition system.

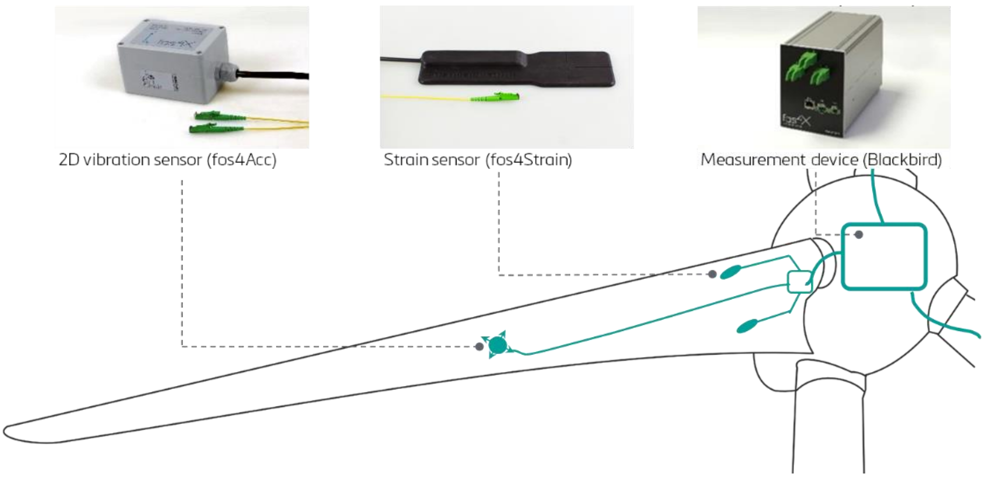

Figure 1: The modular fos4Blade IIoT sensor set consists of a central measurement device with 1-5 measurement channels per blade and an application specific combination of fiber-optic strain and vibration sensors in the blades.

Any further questions?

For any further questions, please contact us via fos4x.com or polytech.com

Sources

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