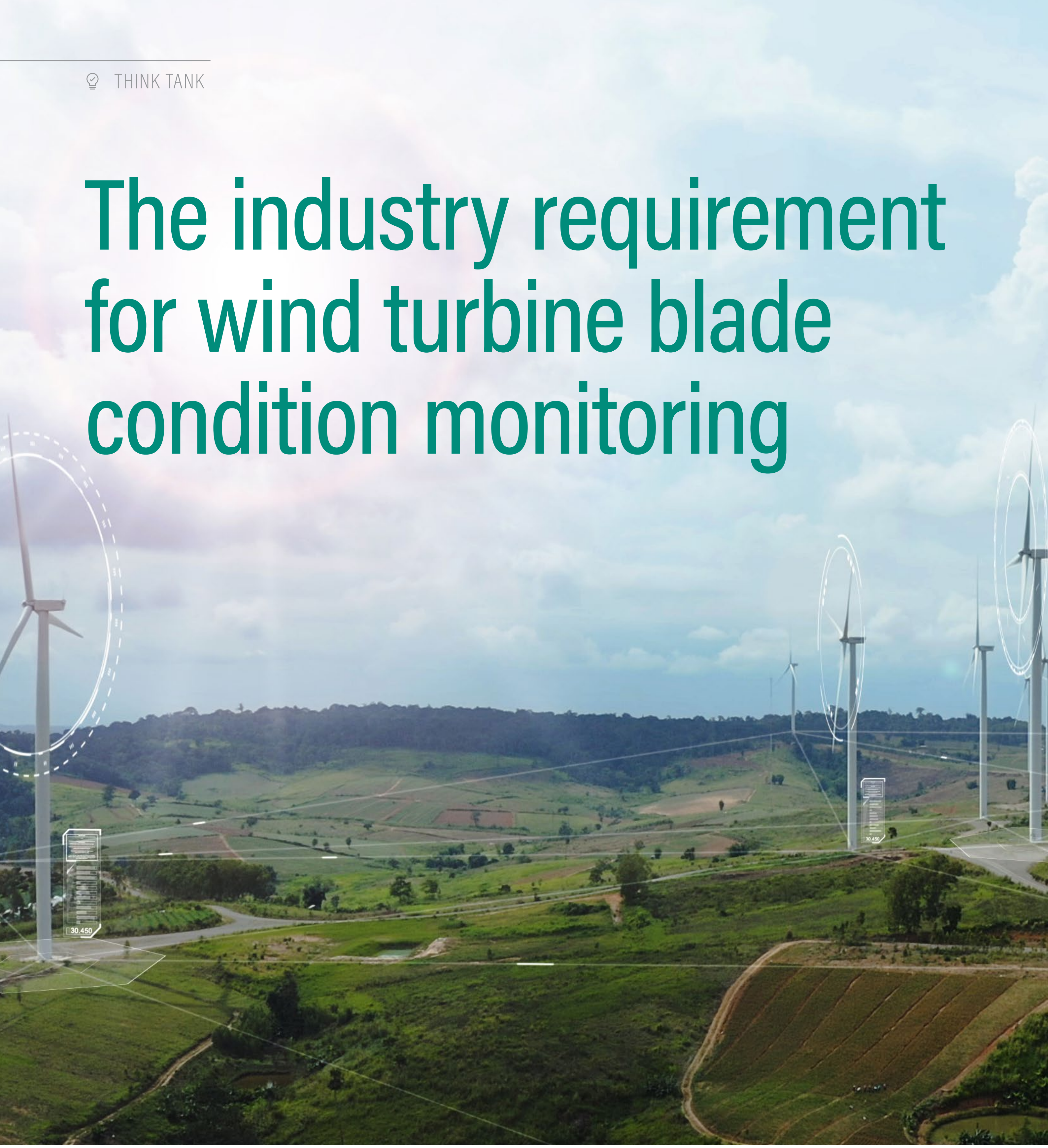
The industry requirement for wind turbine blade condition monitoring

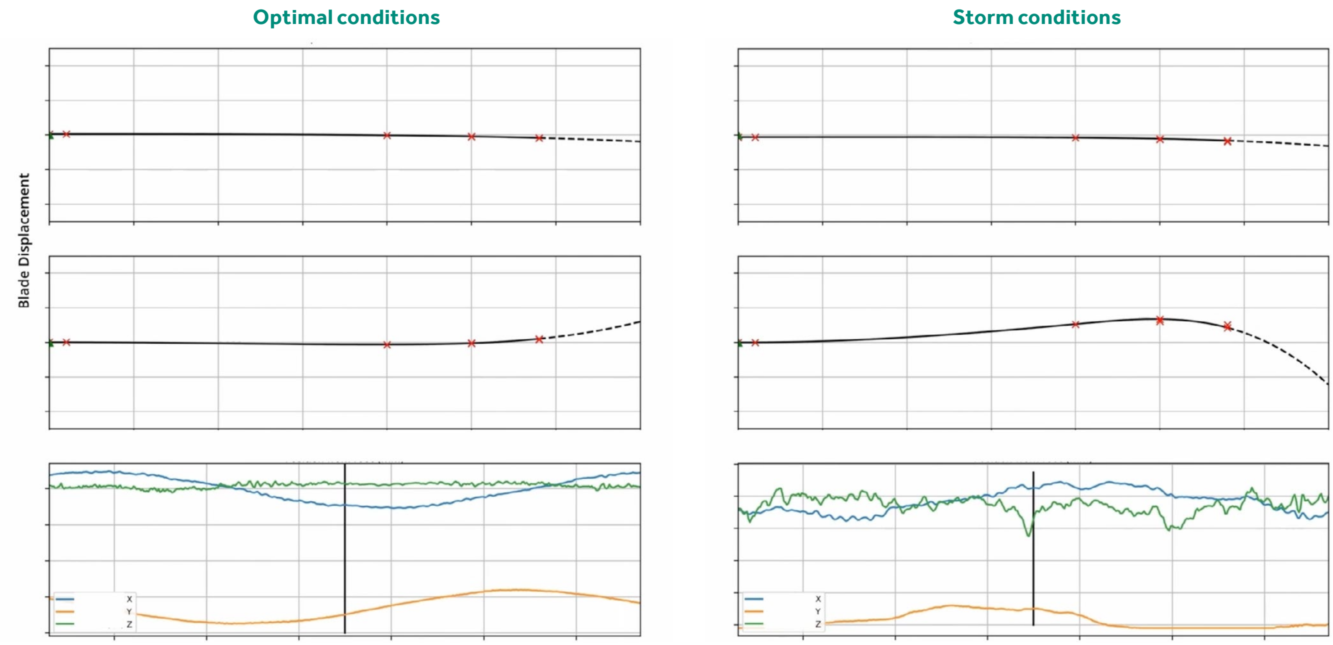


In the early years of wind energy, the industry faced numerous challenges, with issues related to gearboxes and the mechanical drivetrain leading to significant losses in revenue and high operation and maintenance (O&M) costs. To address these concerns, condition monitoring systems (CMS) emerged as a 'standard' component of predictive and preventative maintenance strategies, vastly increasing turbine reliability. As the wind industry continues to evolve, the focus for improving reliability has now shifted towards wind turbine blades.

With the growing recognition of the risks and costs associated with turbine blades, the question arises: will blade CMS also become standard? With blades getting ever longer, new materials, new manufacturing methods, and ambitiously short design-to-serial production cycles, plus the pressure from developers and owners for ever longer turbine life-spans, Eleven-I, a 2019 founded startup operating out of the north west of England, believes so, as CEO Bill Slatter explains in this article.

The function of any CMS system is to sense a physical characteristic; analyse the measurements taken to infer the condition of the component; and use this to make meaningful and useful predictions, leading to cost effective decision making by the O&M and asset management teams.

A CMS delivers 24/7 monitoring, additional to the regular turbine SCADA data, on plants which are otherwise infrequently inspected, and often in remote locations. For wind turbine mechanical drivetrains, sensing vibration, and temperatures have been the basis of CMS, which combined with oil / filter sampling, and endoscope inspections, has proved highly effective. Degradation in drivetrain condition is generally identified early, leading to suitable monitoring routines, early ‘up tower’ interventions and more efficiently planned major repair or replacement programs, performed in lower wind seasons, with short turbine downtime and minimised mobilisation costs.



For blades, performance and reliability issues include loss of power curve, the relationship between power produced for a given wind speed, through reduced aerodynamic performance. This stems from such sources as damage to the blade surface, particularly leading edge erosion, loss of blade surface mounted parts, eg., vortex generators, which improve aerodynamics, or lightning damage.

They are also subject to increased noise, especially from damage to the faster moving parts of the blade near the tip.
This is important when turbines are subject to stringent planning constraints near local communities.

Furthermore, bonding of the blade surface halves at the leading or trailing edge, most blades are formed in two moulds, with the halves bonded together.

Reliability can also be compromised due to structural defects resulting from one or combinations of design or manufacturing issues and fatigue. Continued use beyond the design life of the blade, with significant abnormal loading events, is a potential accelerator of this.

Sensing

There are a number of options available. Strain sensors, for example, are the long-standing, preferred solution of blade designers and prototyping teams. They are highly accurate at measuring loads at critical points on the blade. However, they are expensive to install, especially on already erected turbines, unreliable long-term and not practical for serial production roll-out.

Another option is acoustic sensors, using the noise created by blades to recognise changes and patterns. The sensors are relatively low cost, reliable and can be installed comparatively easily in the hub, blade root, or on the turbine tower. Many hundreds have been installed on operational turbines, although there are known limitations to the size of blade for which they are effective. Many significant blade faults, especially structural faults, do not have a significant noise signature.

Accelerometer based sensors also present opportunities. MEMs based sensors are inexpensive, reliable and highly accurate, benefitting from their use in smartphones, smart vehicles and numerous other applications, and well established in wind turbine drive train CMS systems. Eleven-I uses lab-grade 3-axis accelerometers mounted inside the blade, connected to an Eleven-I Aggregator in the turbine hub, which then interfaces with the turbine control system, or out to the Cloud via a mobile network.

‘Two or three sensors per blade is sufficient to give a really accurate understanding of how the blade is behaving,’ says Slatter. ‘The system takes non-specialist technicians around half a day per turbine to install and commission on an operational turbine, or can easily be installed at the factory or before turbine erection. Our first installations were in summer 2021 and have operated reliably since. We’ve built a robust and low cost platform using edge computing, mobile communications and the cloud to get the data to where we need it.’

Analytics

From knowing acceleration, determining speed and position of each sensor is achieved. After that it’s time for some physics. ‘Whilst there are fantastic tools coming from the data science world which can give insights from huge quantities of data, Eleven-I believes that understanding what is happening in the structure of the blade is critical to early diagnosis of structural faults,’ explains Dr Phil Shackleton, a mechanical engineer and Eleven-I’s Chief Analytics Officer.

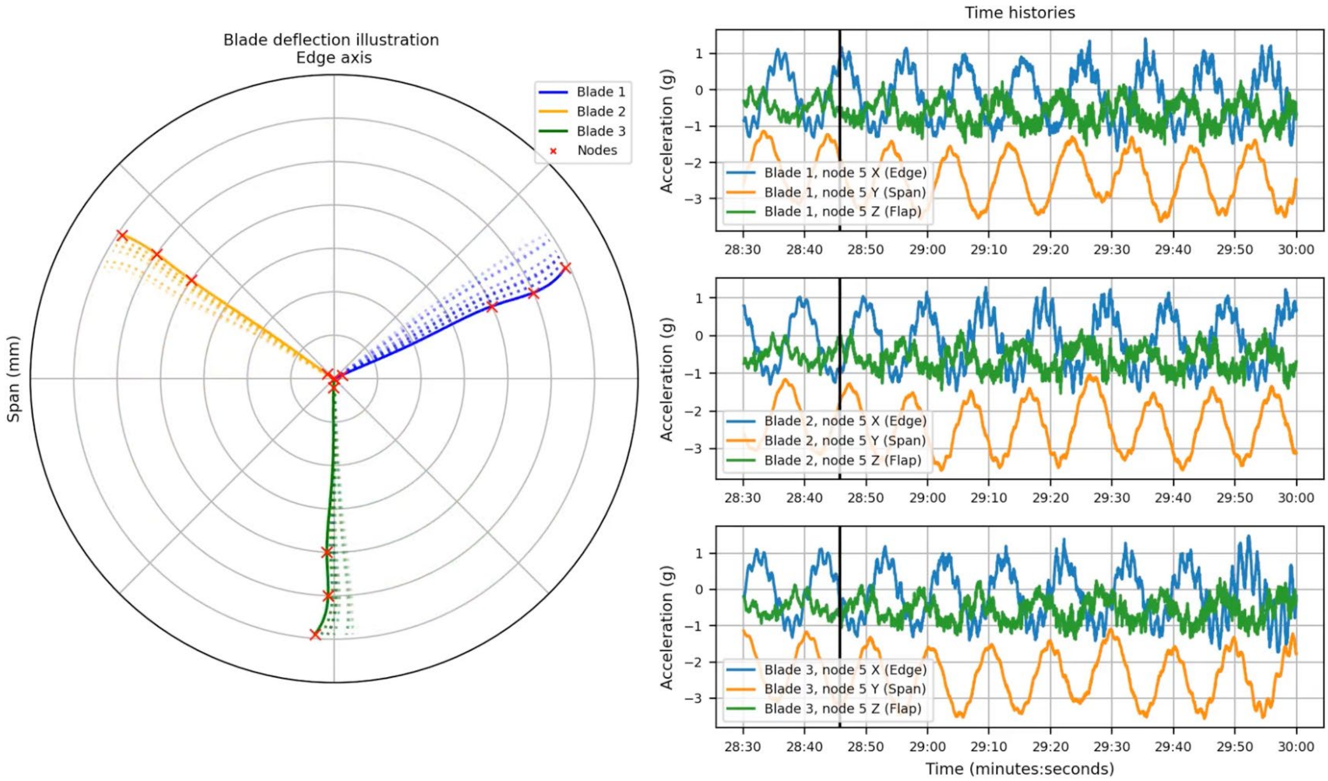
‘We’ve developed physics based tools which allow us to estimate the position and deflected shape of the blade in space, calculate Eigen frequencies, or resonant frequencies, and mode shapes, determine the energy in the blade, blade twist and so on. All of this can be done while the turbine is in any operating state, at rated power, idle, or during a trip event.

‘As we continue to roll out more and more systems, our statistical tools let us compare blade performance against historic benchmarks, and with other blades on the same turbine, or other turbines elsewhere in the wind farm or wider fleet. Anomaly detection is a powerful approach and helps us target development of new analytics and with growing data sets we can bring in other data science techniques like machine learning. The Cloud platform we’ve built allows us and our customers to configure automated analytics and visualise and interrogate the data and the analyses outputs.

‘We’ve found our engagement with an OEM prototyping team incredibly valuable in developing and validating our models,’ says Bill Slatter. ‘Not only their blade and load engineers, but their control system experts who took a great interest in the results coming back from our system and analytics.’

The suppliers of acoustic based systems have also made significant investments into their analytics. ‘Analytics is the core of the IP,’ says Slatter. ‘We’ve developed our sensor nodes so that they can accommodate acoustic and other sensors.

Even if blade CMS is not a standard, there are already a lot of turbines out there with blade issues, and that number is only increasing.



We are under no illusion that just having the sensor is the same as doing something useful with it, but it gives us flexibility.'

Prediction

It is early days, but Eleven-I's deployment of systems is accelerating and every day brings more data back from the field. 'We have to be lucky, and have systems on turbines which are unlucky,' says Slatter. 'We've detected blade root problems which are virtually impossible to detect with visual inspection, because the problem only manifests itself in operation. We have seen blade root structural damage well before it was detected by visual inspection, and seen extreme loads caused by storms or relatively rare conditions which excite resonances on the blades, which can substantially reduce design life. Once we've analysed what is happening, it is relatively quick to make a robust tool and put it online, meaning that the system alerts on conditions automatically.

Will blade CMS become standard?

'We believe it will increasingly become so, perhaps sooner rather than later,' says Slatter.

'The business case for prototype turbines, and turbines with serial defects is particularly strong, and represents most of our current workload. We also believe there is a very strong case for large offshore turbines. The business case is strengthened if the system is factory installed, like for most drivetrain CMS systems, meaning much lower Capex. We also believe that there is a strong business case for turbines nearing the end of their design lives, as the 2 to 3 MW class of turbines that started to be installed in the late 2000's ages. Asset managers will find the 24/7 security of a CMS good value, and may make conversations with their insurers easier.

'Overall, we recognise that leading edge erosion is probably best handled via inspection - it happens slowly and so regular inspection with drones will be the standard. We think that acoustic sensors will have their place, especially for blade tip damage with smaller turbines, but we believe structural issues will need our physics based approach, which then supports a more focussed inspection and early repair regime.

'The market is growing rapidly. Wind is economical as a source of new power in much of the world, install rates are growing, offshore wind is taking off dramatically. Even if blade CMS is not a standard, there are already a lot of turbines out there with blade issues, and that number is only increasing.'

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