Load & Optimization

The latest products and technical advances that are helping the wind industry to improve cost of energy by managing turbine loads during operation.

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Great at Control

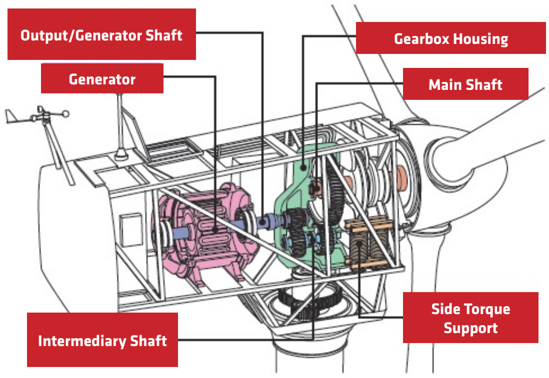
Load & Optimization

Exploring advances in products and services aimed at helping owners/operators to control turbine loads.

Wind turbines are affected by a variety of loads and need to be able to withstand normal conditions and extreme circumstances during heavy storms and hurricanes – both when operating and non-operating.

Dynamic turbine loads occur when the installation is in operation, and these can be impact- or fatigue-related, continuously variable or cyclic in nature, or otherwise. The loading on the blades varies during each revolution as the rotor turns, but is also affected by yaw motions, wind loading and continuously changing load combinations. With horizontal-axis turbines, the gravity load on a blade changes twice per revolution; first the blade is lifted to the highest point with the blade tip in upwards position, and then it 'falls' to the lowest point.

When a wind gust hits the rotor, the gearbox of a non-integrated drivetrain is pushed in a counter-reaction into one of the side torque supports. This sudden movement typically causes temporary misalignment of the output shaft in relation to the generator shaft. Dynamic loads are also known to cause continuously varying structural deformations, such as in the main shaft, main carrier and generator frame.



Misalignment Risk from Wind Gust

If potential dynamic loads can be reduced, the rotor and nacelle mass – and to a lesser extend the tower and foundation mass – could be reduced, cutting the cost of the wind turbine.

Static turbine loads occur on the rotor for example, as the rotor mass introduces a downward gravity force, which is passed on to all the interlinked structural elements. Static deformation of structural elements can change during a turbine's lifetime, for instance as part of a welded component settles during the first months of operation.

> "The cumulative effect of dynamic bending loads at the tower base is reinforced by greater tower heights relative to the rotor diameter"

As turbine size increases, so does the difference in wind speeds on a blade at the highest and lowest positions. The same is true for dynamic bending loads at the tower base, the cumulative effect of which is reinforced by greater tower heights relative to the rotor diameter.

Finally, there are impact loads and fatigue loads to consider. Extreme impact loads – such as under hurricane conditions – can cause immediate damage and even component or system failure, whereas fatigue loads (when a component is subjected to repeated loading and unloading, such as flexing and relaxing of blades during turbulent wind conditions) can lead to premature component/system damage and even catastrophic failure.

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Market Demand

Since the start of the modern wind industry in the late 1970s, numerous turbine makes and models have been introduced – initially in only a few pioneering countries but, increasingly, in markets across the globe.

In the early years, the vast majority of the kilowatt-class models were rather rudimentary, operating at fixed speeds in combination with either stall output limitation (where at higher wind speeds, the blades are pitched to produce a stall and slow the turbine) or pitch control. Lagerwey of the Netherlands, Enercon of Germany, and US-based Kenetech all produced variable-speed turbines up to about 500kW during the 1980s and the early 1990s. Since the early 2000s, pitch-controlled variable speed has been the semi-standard turbine technology; it is now used in power ratings as high as 8MW and is likely to be used in even bigger turbines.

Owners/operators of optimized variable-speed wind systems all strive for the lowest possible lifecycle-based cost of energy (CoE). This can best be achieved through a combination of low capital expenses, low operations and maintenance (O&M) cost, high-yield performance and maximum availability.

An ongoing trend is to fit very large turbine rotors in relation to the megawatt power rating – an effective means of lowering CoE. Fitting long, slender blades can maximize energy production, but the dynamic loads must be limited by using the latest control technologies. This trend for large rotors is beneficial for low and medium wind speeds onshore, as well as for the most demanding offshore IEC Class I sites.

With rotor-swept areas increasing faster than power rating, more work is needed in terms of advanced control and rotor blades, and in designing cost-effective mechanical structures, says Jørgen Lakkenborg, leading project manager for loads and control at Danish control-system specialist Mita-Teknik.

Product/Service Development

Six to eight years ago, individual or cyclic pitch control was promoted as a means to mitigate dynamic wind loads on the rotor and turbine structure. A key element of this technology is that the pitch angle of each rotor blade is adjusted continuously during each rotor revolution to compensate for the difference in wind speeds hitting the blade at its highest and lowest positions. Manufacturer GE was among the first to bring in cyclic pitch technology, introduced in its 2.5MW turbine platform. The company claimed the load-reduction benefits achieved enabled a substantial increase in rotor diameter by retaining the same structural turbine design loads.

However, experts dispute whether the specific nature of this cyclic blade-pitching technology would actually achieve the claimed load reduction and other benefits. Some argue that turbine-pitch systems are too slow to react to variations in wind speed; others say the substantial increase in pitch-action frequency will increase wear and reduce turbine reliability.

These "classic" cyclic pitch systems operate according to a predetermined 120-degree shifted sinusoid signal (a signal based on a mathematical curve that describes a smooth repetitive oscillation), which is different from a real dynamic, load-based control strategy, says Jørgen Lakkenborg, leading project manager for loads and control at Danish control system specialist Mita-Teknik.

Normally, turbines operate between cut-in wind speed (2.5 – 3.5 metres per second) and cut-out wind speed, commonly 25m/s and sometimes up to 30m/s for high-wind offshore turbines. If the wind speed at hub height peaks above 25m/s during gusty weather conditions, the turbine shuts down and must pass a reset protocol before restarting. Frequent shutdowns can result in considerable loss of energy production.

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Enercon's storm-control feature is seen as a successful turbine control strategy. When it is activated, the turbine operates from rated speed at rated output level up to 25m/s; when wind speeds become higher it switches to reduced rotor speed with reduced rated output up to 34m/s, when it switches off. This reduces excessive loads on the turbine, while avoiding frequent shutdowns in gusty weather conditions, raising annual energy production substantially.

"These forward-looking systems can sense the approaching wind up to 300 metres in front of the rotor. At 15m/s this allows an extra 20 seconds lead time for control actions"

GE's "Brilliant" wind platform, first introduced in early 2013, uses industrial internet capabilities to analyse tens of thousands of data points in a wind farm each second, driving higher output, increasing productivity and creating new revenue streams for customers. Industrial internet and advanced controls help respond to the intermittency of the wind and offer predictability and enhanced reliability and availability. If, for instance, a turbine suffers anemometer failure, it can continue operation by connecting to a nearby turbine's anemometer.

Finally, turbine loads can further be curbed by choosing flexible rotor-blade mounting, and/or using lighter blades of similar length. However, flexible rotor-blade mounting usually increases the overall complexity, which could negatively affect reliability and long-term O&M requirements.

Forward-looking Wind Sensors

Nacelle-mounted or nacelle-integrated, forward-looking systems designed to provide advanced sensing of approaching wind speed, wind direction and rapid wind variations, are another promising development for load control. Such systems are based on fibre-optic pulsed lidar (light detection and ranging) systems, and optical remote-sensing technology. These forward-looking systems can sense the approaching wind up to 300 metres in front of the rotor. At 15 metres per second winds, this allows an additional 20 seconds of lead time to instigate the control actions such as adjusting the yaw system and/or the pitch system angle before the wind hits the rotor.

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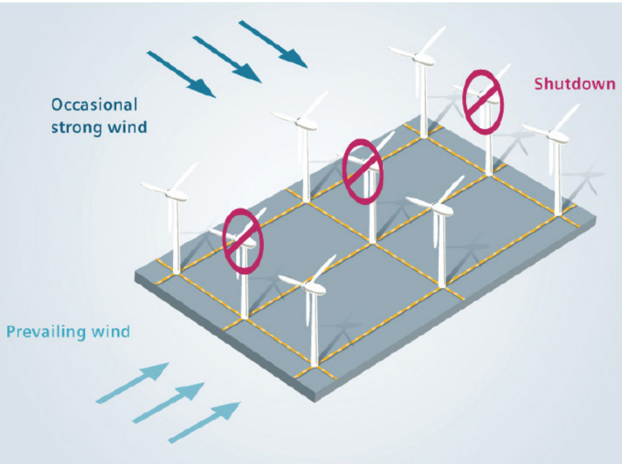
Balancing Performance Across a Wind Farm



Source: Siemens

Software-based technologies are being improved too, including programmes that manage the entire wind farm. When capturing wind, turbines create a wake that affects the volume and condition of the wind reaching the turbines sited behind.

By monitoring and managing the wake, individual turbine performance and loads can be balanced across the entire project. The turbines can operate as part of an interconnected, cohesive team, as opposed to competing with one another for the best wind.

GE recently announced its own wind and wake management software, which it says will enable an increase in a wind farm's overall power output, and that customers can expect a 5-10% reduction in wake losses and improved mechanical loads due to lower wake turbulence.(CoE). This can best be achieved through a combination of low capital expenses, low operations and maintenance (O&M) cost, high-yield performance and maximum availability.

Recent Innovations

One alternative innovative strategy for a load-based cyclic pitch system involves a technology that continuously measures the strain in each blade, says Lakkenborg of Mita-Teknik. This allows the actual pitch angle of each blade to be individually calculated and readjusted. Such technology is already applied in other industries, but needs further development for wind turbine use, he says.

Challenges Faced

A common hurdle for innovative turbine technology is the attitude of risk-averse project developers, banks and other financial parties, although this is not universally the case.

Of the hardware-based load-reducing/optimizing solutions, slender blades generally seem to score well. But for lightweight long blades containing carbon fibres, the picture appears at best mixed. Flexible blade-mounting solutions have been introduced several times in the past, but with limited success. Here, the trade-off seems to be between increased complexity and cost versus potential gains in terms of reduced loads and mass, and the prospect of enhanced installation lifetime.

Whether software-based advances are likely to be accepted by the market is hard to predict. Measures aimed at increasing the robustness of turbines, such as web-based control and data-exchange systems, have been standard fittings in state-of-the art turbines for years. Enhanced industrial internet-based systems, such as GE's, seem unlikely to face many barriers to their introduction.

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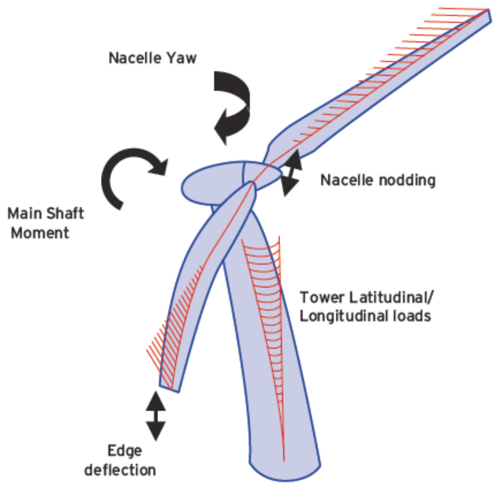
The real overall challenge for the wind industry is to continue advancing with innovative hardware and software solutions while sustaining CoE improvements and avoiding simultaneous loss of systems reliability and robustness; in this respect, load control and management is a key factor.



Model Emulator
Sensors on the wind turbine deliver information to GE's control logic estimator, which uses a physics based model, right, to continuously optimize control set points for near-operating conditions.

Source: GE

Technology Forecast

As turbines have become larger and more complex, the cost of control systems has fallen in relation to total capital expenditure, says Lakkenborg. He adds that, in many cases, it makes economic sense to use simulations to reduce loads. For this, the wind industry increasingly uses advanced software-based turbine design tools, such as DN V GL Bladed, which is considered an industry-standard integrated software tool for design and certification of both onshore and offshore turbines.

For new larger turbines, an optimum configuration can be achieved through a comprehensive CoE optimization analysis, with simulation of the main process driver. If the power rating is fixed initially for a new turbine design, and other dimensions are changeable, these variables can then be determined via iteration steps in an optimizing loop. These variable inputs typically include the blade manufacturer's preliminary data, the latest controller technology and wind-class-specific average wind-speed data. The final simulation process outcomes include rotor diameter, tip speed, turbine cost, annual energy production and O&M costs.

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A Selection of Load Optimization Products

Company	Lead Control Product	Key Features
Bachmann electronic	Operational and motion control systems, SCADA	Scalable from the turbine to the wind farm, retrofit CMS available
Dante Dynamics	Laser optical measurement systems and sensors	Solutions for blades, towers and entire wind farms
GE	Wind farm wake management software	Plant-level management application enables customers to recapture lost power output from waking effects
Mecal	Load simulation, component optimization, controller	Load and power output
Mita-Teknik	Control systems, including pitch control	Complete control systems to single modules for turbines of all sizes
Moog	Pitch control solutions	Offers solutions for wind turbines in onshore and offshore locations as well as remote-pitching software
Siemens	Siemens Turbine Load Control	Dynamically controls wind turbine based on real-time wind conditions, allowing it to operate with only marginal reduction in power output in high load conditions
SSB Wind Systems	Control systems	Has supplied different turbine manufacturers with drive and control systems for more than 20 years
Vestas	Vestas PowerPlus	Performance-enhancing upgrades, including extended cut-out to capture the full potential of high wind speeds and aerodynamic upgrades for Vestas blades
Wind Measurement International	Wind monitoring and assessment	Solutions to capture wind data with the highest degree of accuracy