Hardware & Reality Hacking - Wind Energy

Saving carbon dioxide by creating an affordable digital twin of a wind turbine for data driven optimization

Robert Erdmann, Chief Digital Officer

Munich, 07.06.2019

Agenda

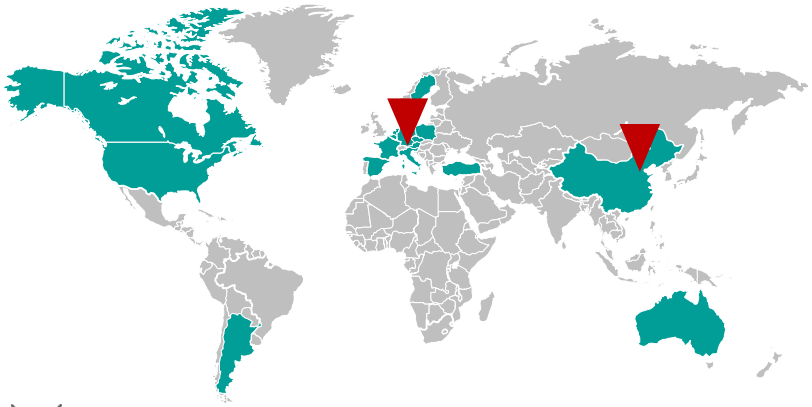
1. Company
2. Market
3. Hardware
4. Applications
5. Tooling
6. Other cool stuff

But first, a short movie...

Agenda

fos4X has a 8-year history with strong growth, series integrations with several wind turbine manufacturers, a strong patent base, and a passionate team of industry experts

- Founded in 2010
- Spin-off of Technical University Munich
- 80 full-time employees
- 2 offices (Munich & Beijing)
- 10,000+ sensors live in 19 countries
- All top 10 OEMs are customers already
- 31 patents granted, 101 pending
- Deloitte Technology Fast 50 Award 2018
- Series B of 7 MEUR in mid-2018



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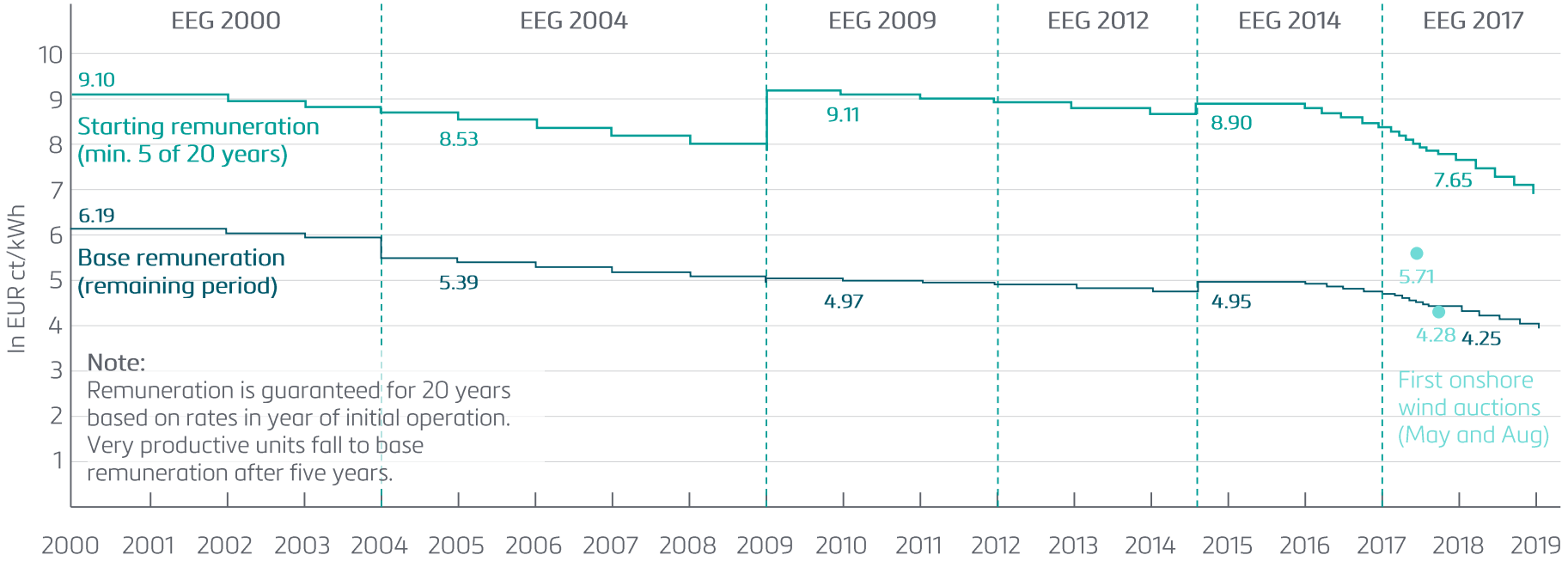
With subsidies running out, OEMs are under significant pressure to drive down CoE.

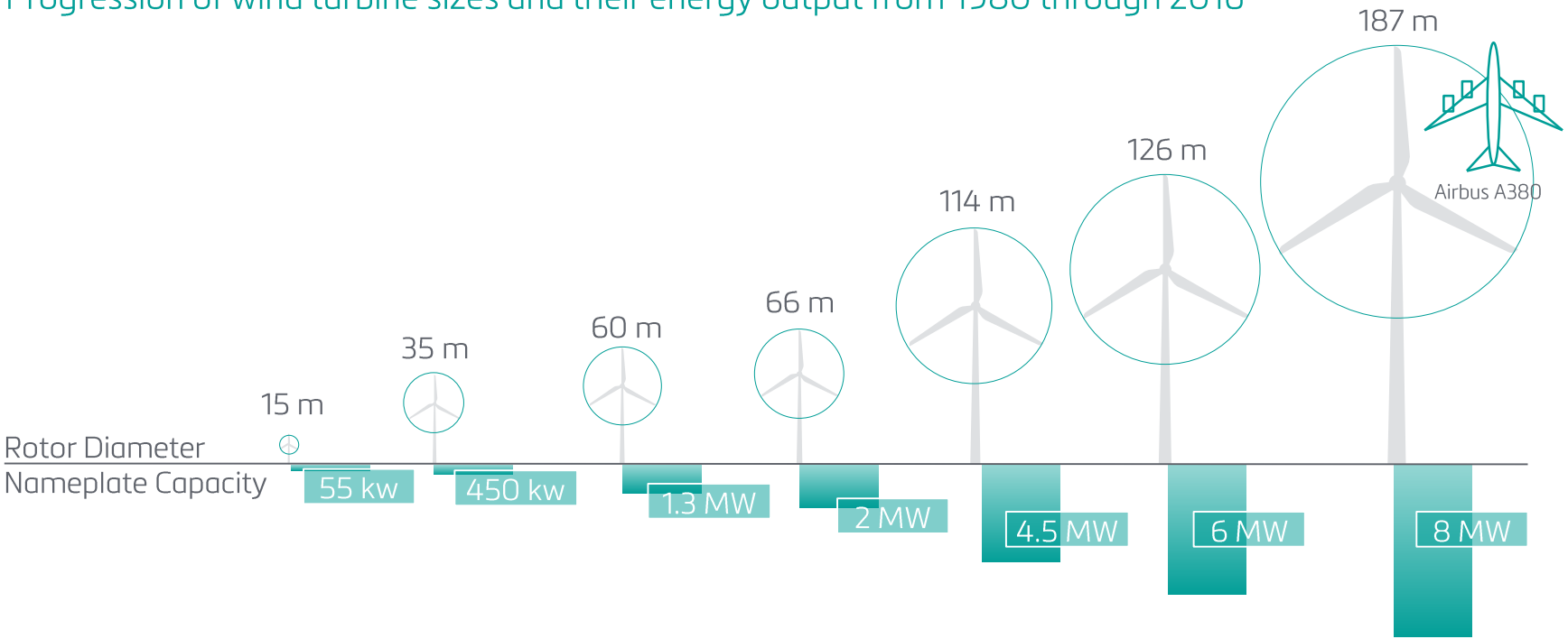
Guaranteed 20-year remuneration rates of German onshore wind power 2000–2018



(1) Data: BNetzA 2017, Windmonitor Fraunhofer IWES

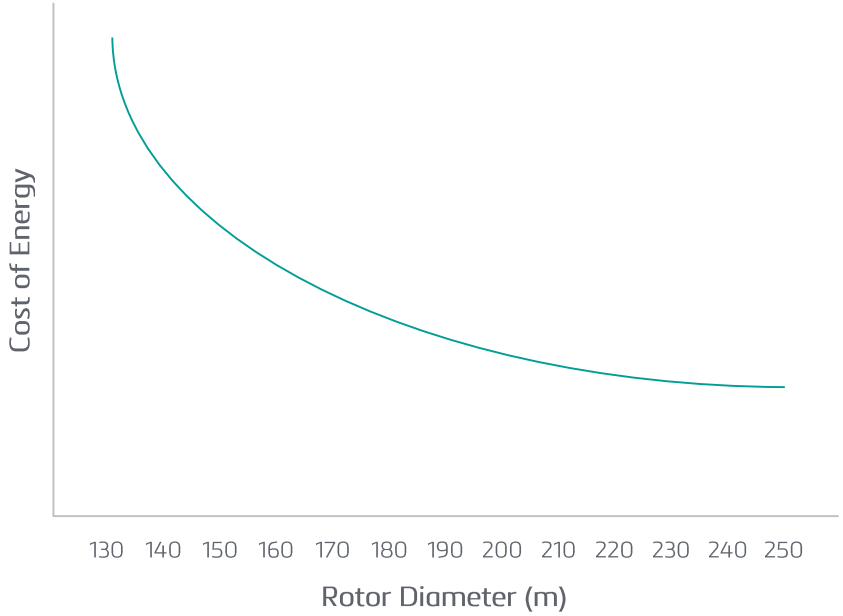
OEMs still believe in bigger is better...

Progression of wind turbine sizes and their energy output from 1980 through 2016

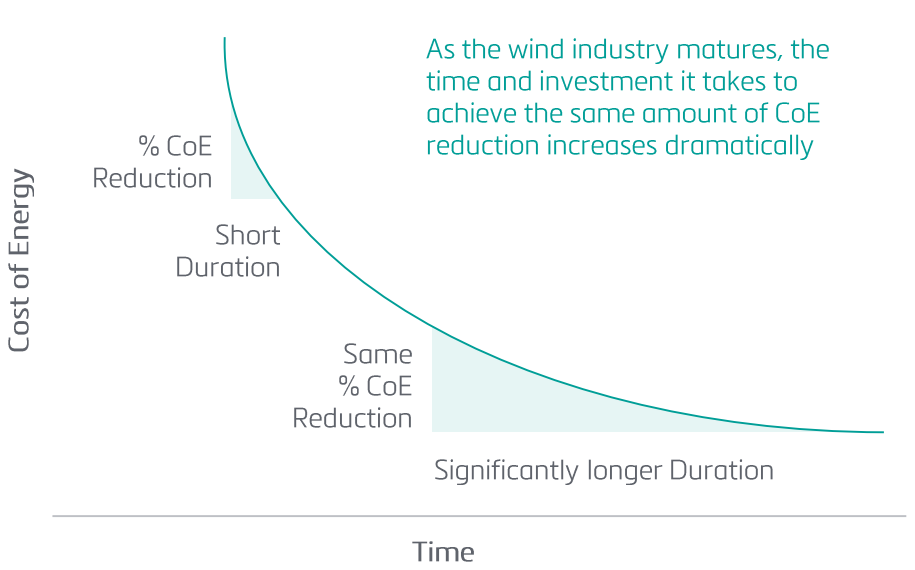


… but the reduction of CoE by increased size is already tapering off

CoE vs. Rotor Diameter



Wind Industry Technology Maturity



There's no replacement for displacement! Or is there??
Edge computing has been around in the automotive industry for decades.

In the 80s and early 90s, the era of muscle cars, increases in horsepower had to come from a larger engine, i.e. more and bigger cylinders.

- Twelve cylinders seem to be a practical limit
- Other issues start coming into play, like metallurgy and vibration

Since then, gains in horsepower (or efficiency) have come from

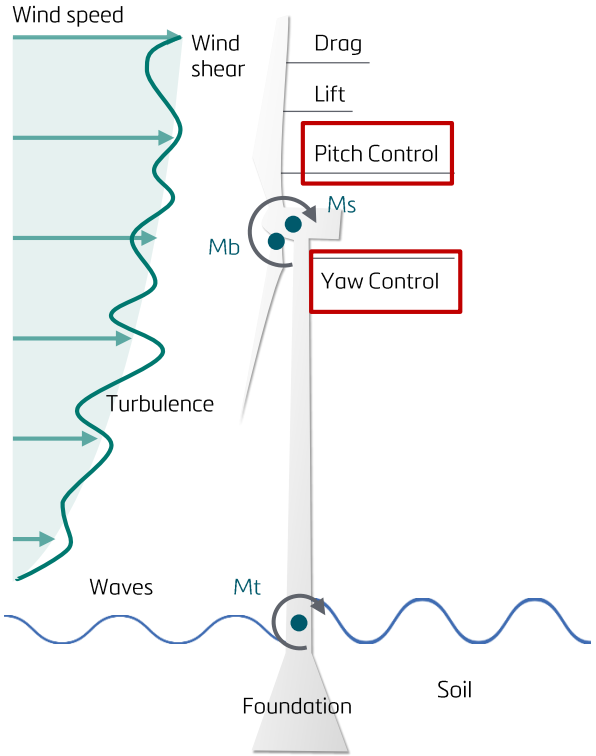
- Increasing the compression ratio (of the air-fuel-mix)
- Stuffing more (air) into each cylinder – hence turbochargers entered the market
- Cooling the incoming air – hence intercoolers
- Letting air come in more easily – hence two intake valves per cylinder
- Letting exhaust exit more easily – hence two exhaust valves per cylinder
- Making everything lighter
- Injecting the fuel

To design and operate these motors, manufacturers need data, which they get from countless sensors (lambda sensor, boost pressure...).

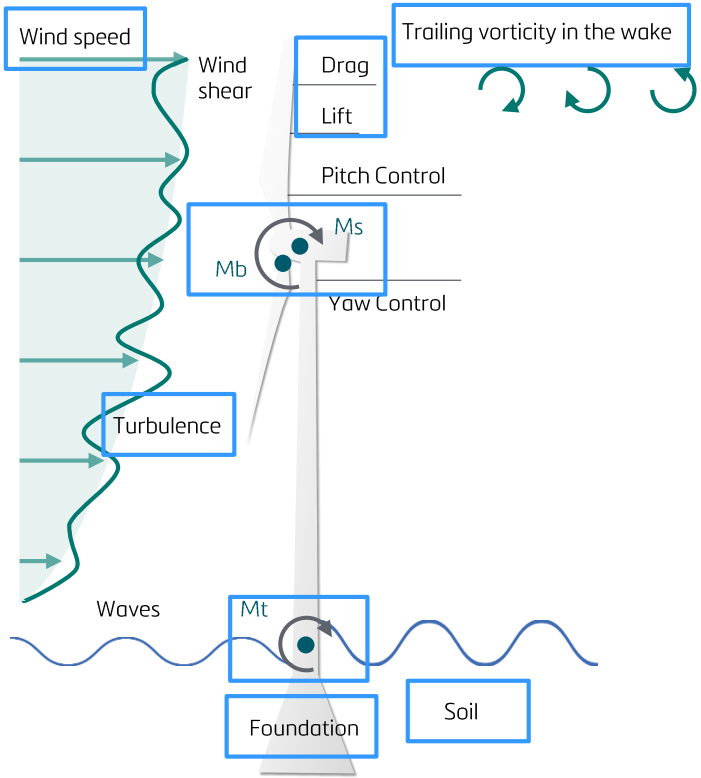
The data is collected in the control unit, where edge computing takes place, controlling the engine in real-time.

The aggregated data is put on a bus, which can be accessed for diagnostics at the repair shop.

Further reductions in CoE will come from data-driven optimization, in the design of the turbines as well as their control and operational regime.

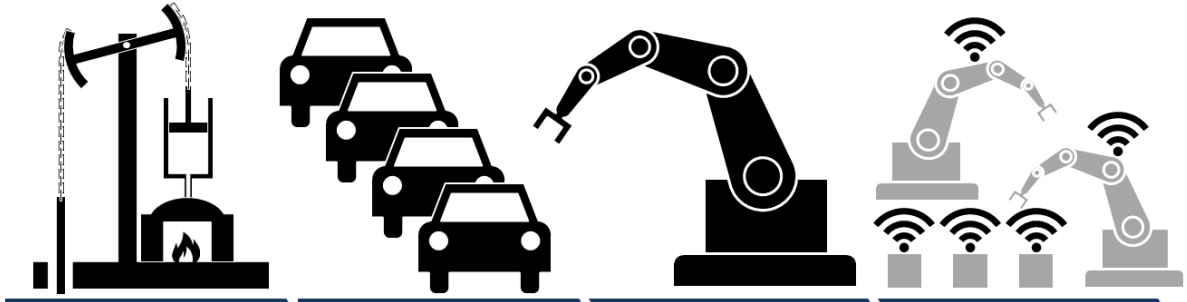


Today: Controller settings based on simulations & limited number of variables.



Tomorrow: Large set of relevant variables, actually measured in real-time.

The next industrial revolution is about cognifying existing systems



1st	2nd	3rd	4th
Mechanization, water power, steam power	Mass production, assembly line, electricity	Computer and automation	Cyber Physical Systems

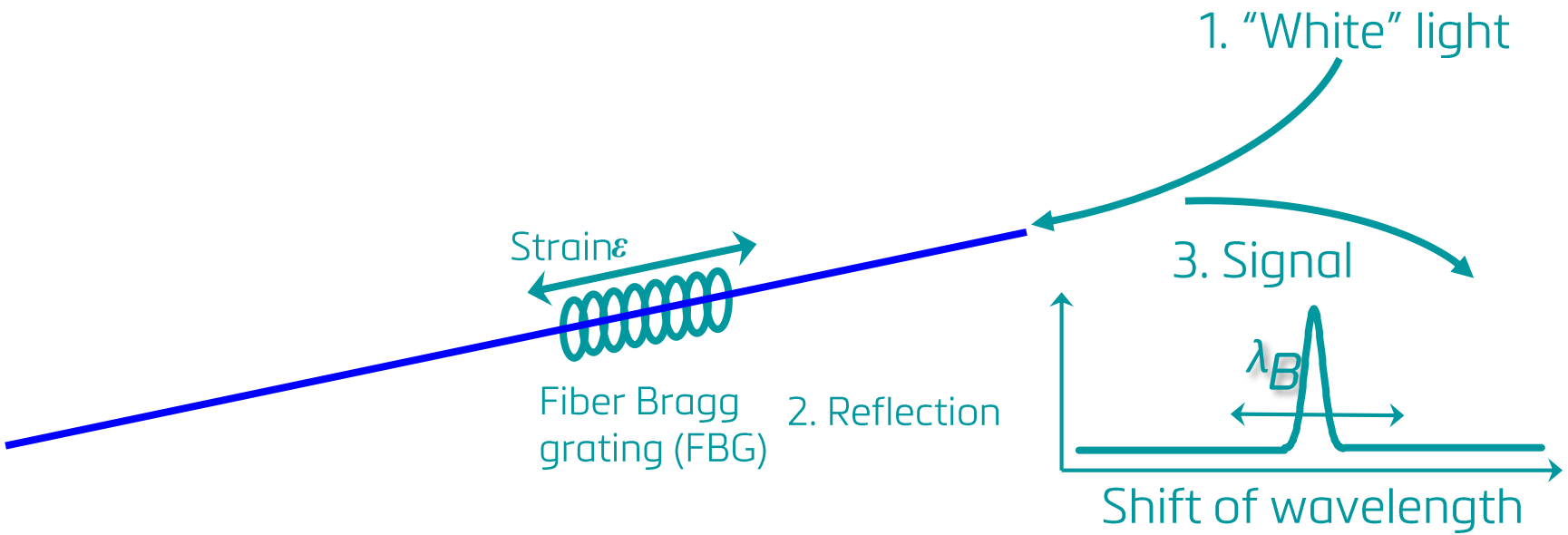
Electrifying → Cognifying

(1) Upper chart: Credit: Christoph Roser at AllAboutLean.com. – Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47640595

(2) Concept of cognification: Kevin Kelly, e.g. at TED: How AI can bring on a second Industrial Revolution

Agenda

Fiber Bragg gratings convert a mechanical strain variation into an optical wavelength shift



FBG sensor

- Differences in reflected light are used to determine differences in strain (or temperature)
- Only fiber optical cables are used, no electrical cabling

We use this technology to measure strain and vibration

fos4Strain – Blade strain sensor

Strain amplification
Temperature compensation

fos4Acc – Blade vibration sensor

Intrinsic lightning protection
Measurement deep inside rotor blade

Fiber-optic sensors have advantages over conventional sensors

No electrical power at sensor position

Passive working principle

No EMI(1) and no lightning issues

Optical information transmission

Lower cabling and application cost

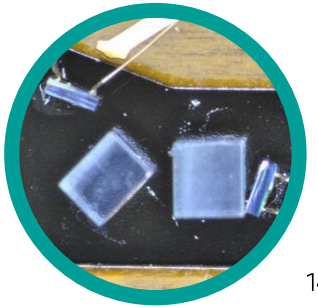
Mass product telecom fibers

Fit and forget: Long life, no maintenance

Robust sensors for FRP(1) structures

Proprietary demodulation

We revolutionized fiber optic measurement thanks to an innovative signal demodulation technology, making this previously premium technology fit for disruption.

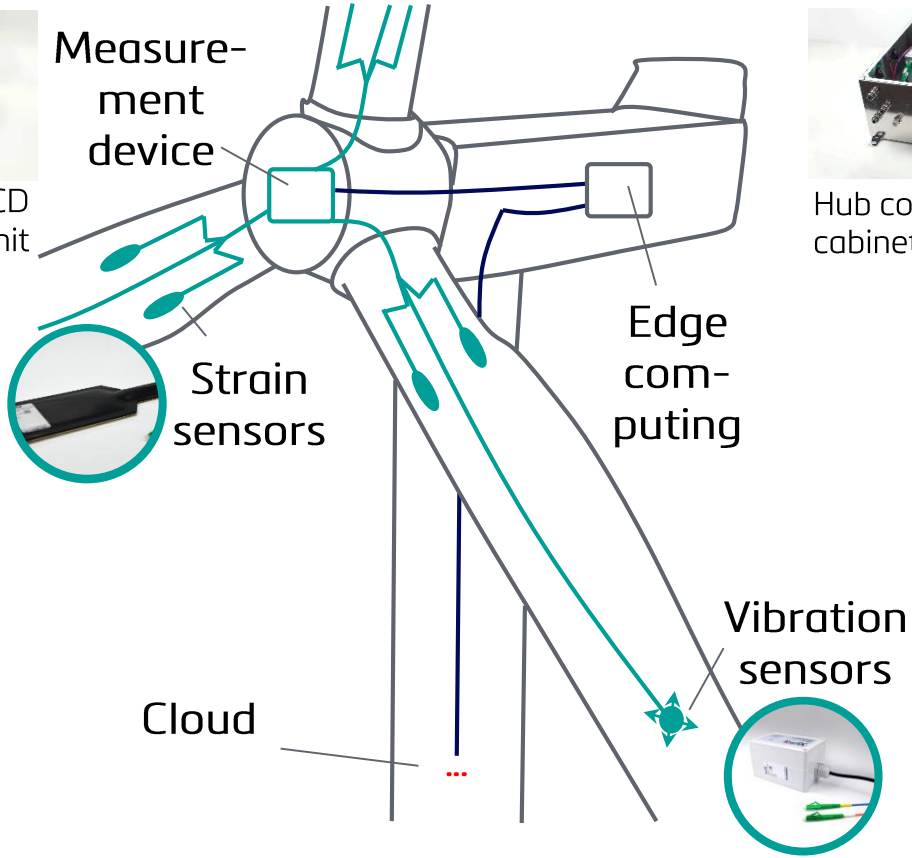


(1) EMI: electromagnetic interference
(2) FRP: fiber-reinforced plastic

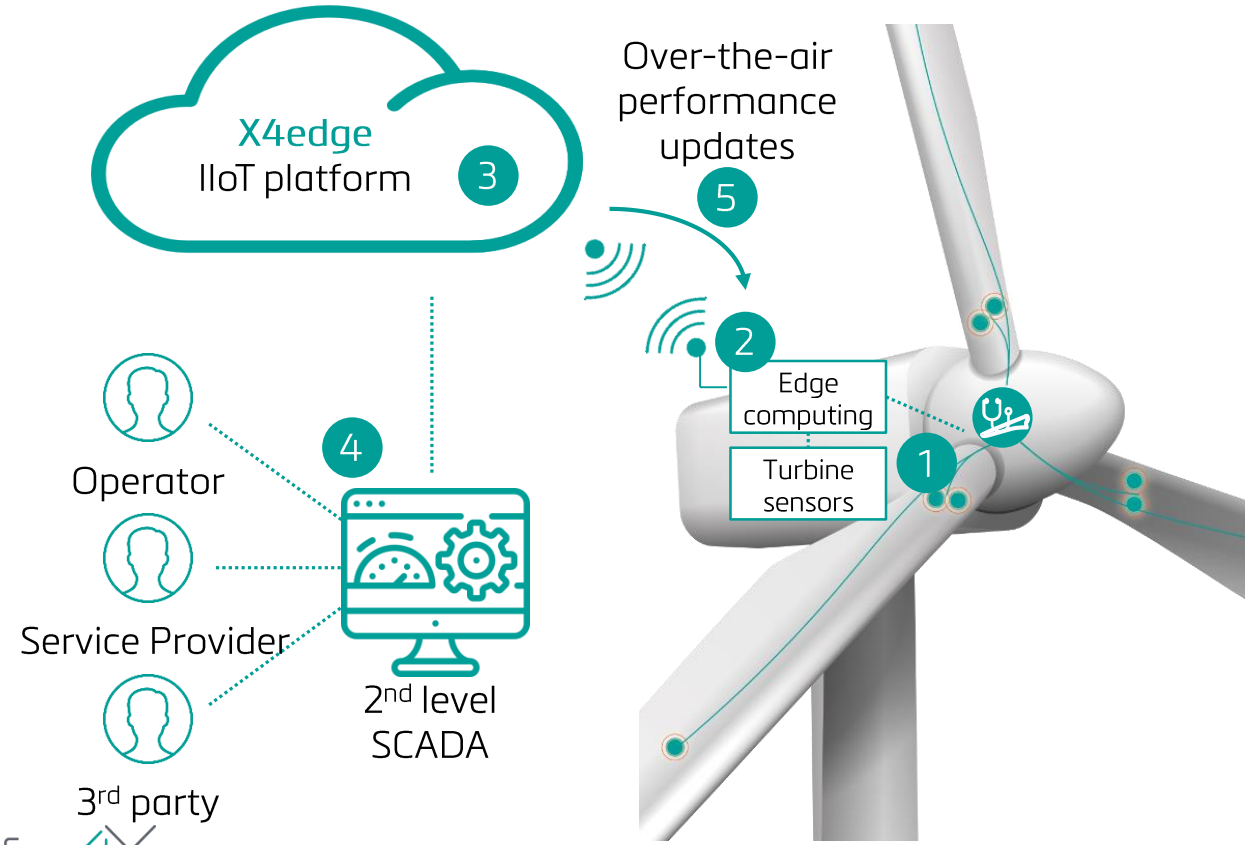
The standard retrofit solution – fos4Blade(15)

fos4Blackbird OECD measurement unit

Hub control cabinet



Proposition to wind farm operators: Update your turbines with smart sensors and edge analytics that connect to your established operating and monitoring systems - retroX



Description

1. Acquire more and smarter data with retrofit solution
2. Analyze data in real-time and transfer to cloud
3. Automate analyses and connect to other systems
4. Access smarter turbine data through established channels
5. Improve performance with over-the-air updates

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Which operator pain points can be addressed by connecting turbines to a digital backbone

Reduce OpEx

- Get better trans-parency of assets with more and smarter data
- Automate recurring analyses and make informed decisions
- Improve maintenance planning and empower predictive approaches

Identify Risk

- Detect premature structural damage early on
- Be informed about the structural pain points of your assets
- Improve risk reporting for management and owners

Extend Lifetime

- Improve commercial decision making for continued operation
- Use real measured load data to allow for less conservative lifetime assessment
- Be able to trade life time for output or make better PPAs

Increase AEP

- Create turbine specific portfolio of initiatives for AEP optimization
- Tackle static performance issues (e.g. rotor imbalance)
- Reduce curtailments with additional apps (e.g. blade ice detection)

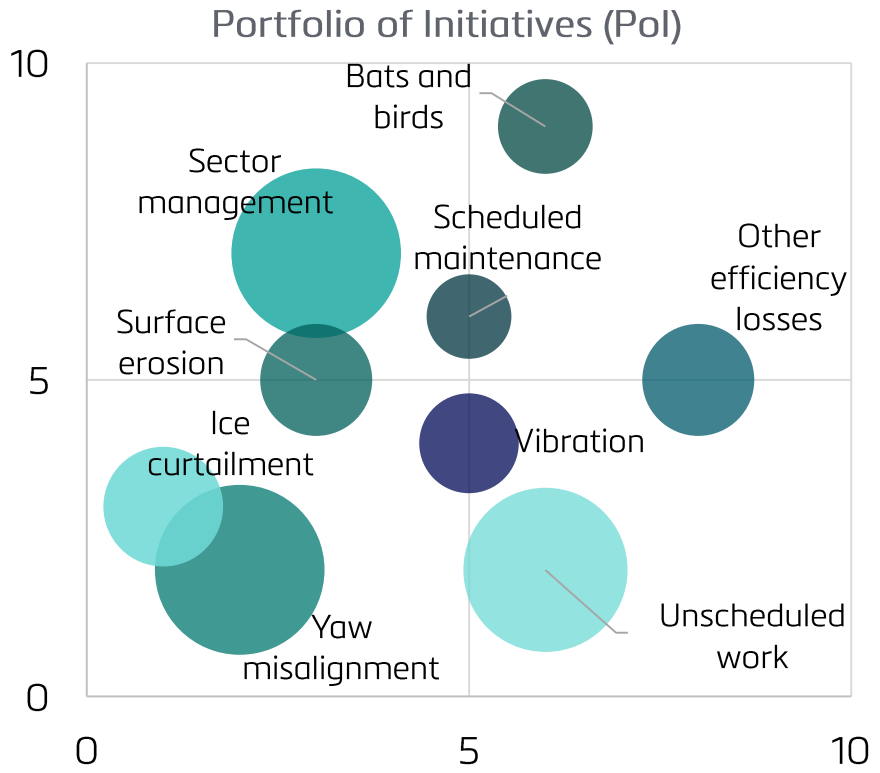
Receive continuous transparency into turbine losses and a monthly portfolio of initiatives

Our **structured performance assessment** helps you to prioritize your asset optimization initiatives

We combine load and vibration data with turbine operational data in an **automated process**

The resulting Portfolio of Initiatives (PoI) shows which optimization initiatives have

- the highest potential (bubble size)
- at lowest expense (Y-axis) and
- shortest implementation time (X-Axis)



Portfolio of applications based on retroX digital backbone

ROTOR ICE CONTROL

Stops a wind turbine with ice-buildup and restarts auto-matically after melting

TURBINE LOAD CONTROL

Avoids detrimental loads, helps optimize blade design, and enables turbine lifetime extension

TURBINE INTEGRITY CONTROL

Identifies different types of degradation and damage based on analytical and empirical tools

TURBINE EFFICIENCY CONTROL

Improves sector curtailment and power curve over the entire range of wind speeds and terrains

BLADE NOISE CONTROL

Manages noise curtailment to increase overall energy output or even enable a specific site at all

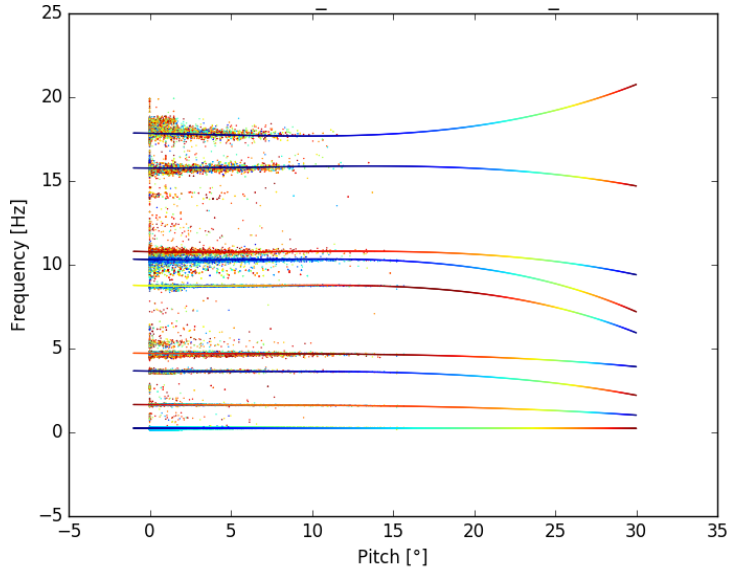
WIND FARM CONTROL

Supports the optimization of the entire wind park, for example by balancing wake effects

Rotor Ice Control increases AEP by 4% to 20%, depending on climate, compared to nacelle-based ice detection system.

Turn-key solution

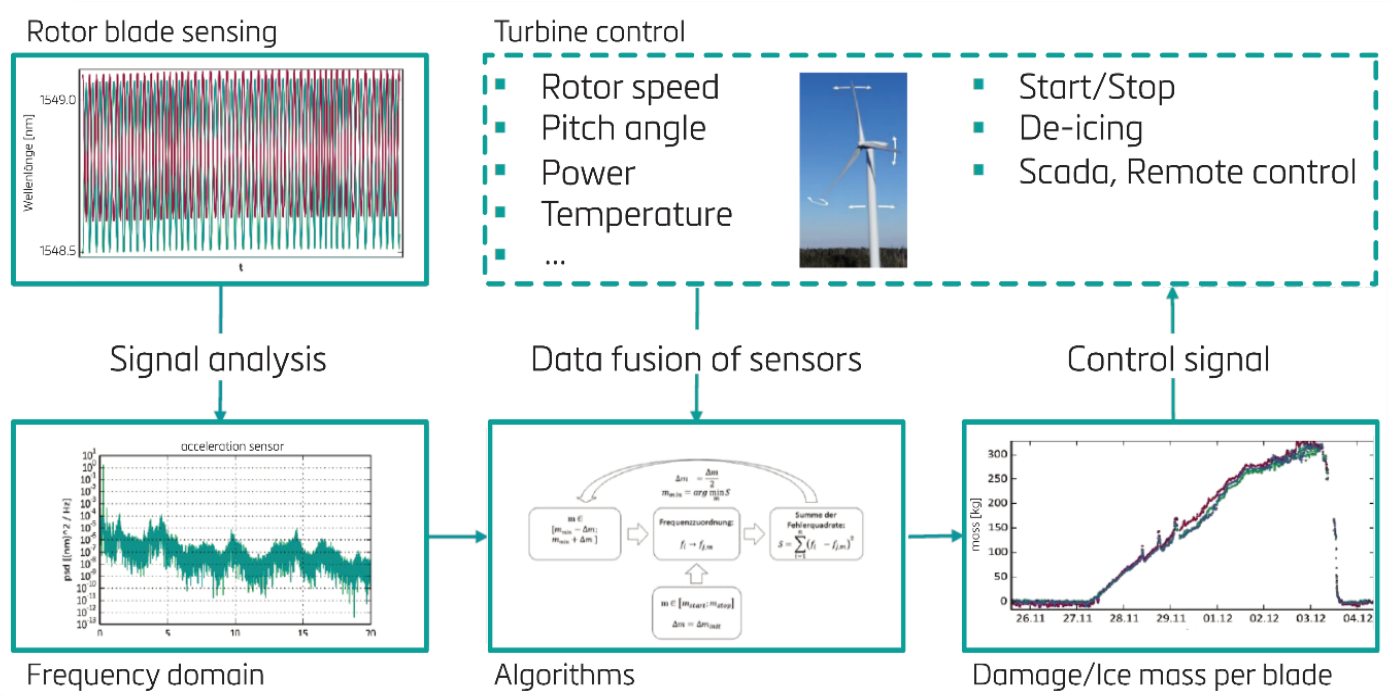
- Automatic stop and restart
- Retrofit or ex-factory
- Robust series hardware
- Precise vibration data from fiber optic sensors at 40 Hz or more
- Sophisticated data fusion & parameter identification algorithms
- Autonomously learning system with direct controller input
- First in recent Nergica benchmark



DNV·GL

This certified configuration allows
- Blade ice detection
- Blade condition monitoring

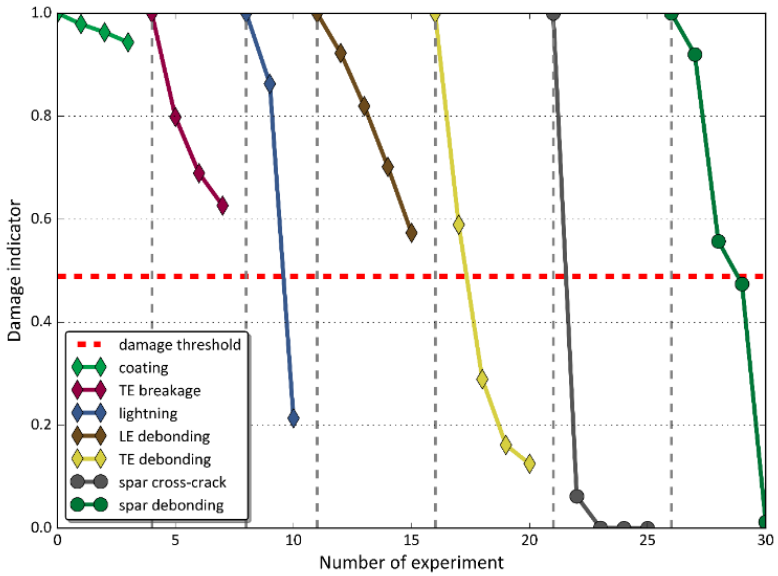
How is ice mass estimated? Wavelengths are converted into frequency, which relates to blade properties under excitation



Turbine Integrity Control helps avoid fatal accidents, trigger fail-safe operation, and schedule maintenance.

Turn-key solution

- Identifies different types of (slow) degradation and (sudden) damage
- Retrofit or ex-factory
- Robust series hardware
- Precise vibration data from fiber optic sensors at 40 Hz or more
- Sophisticated data fusion & parameter identification algorithms
- Cloud-based for benchmarking across multiple turbines



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Damage simulation in-house

Hütter Wind Turbine Blade:
courtesy SWE Stuttgart

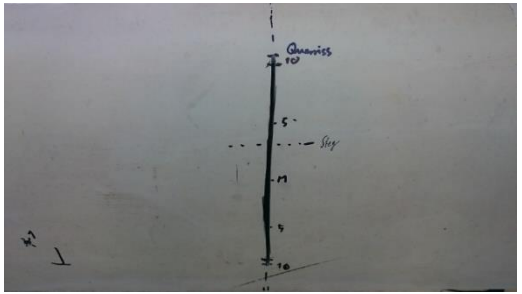
Standard blade testing procedure:
- Cantilever beam
- Root fixed test stand

Sensors:
- 2 x Temperature
- 6 x Accelerometers

5m Rotor blade

Simulated lightning damage

TE Adhesive Failure



Spar cap damage

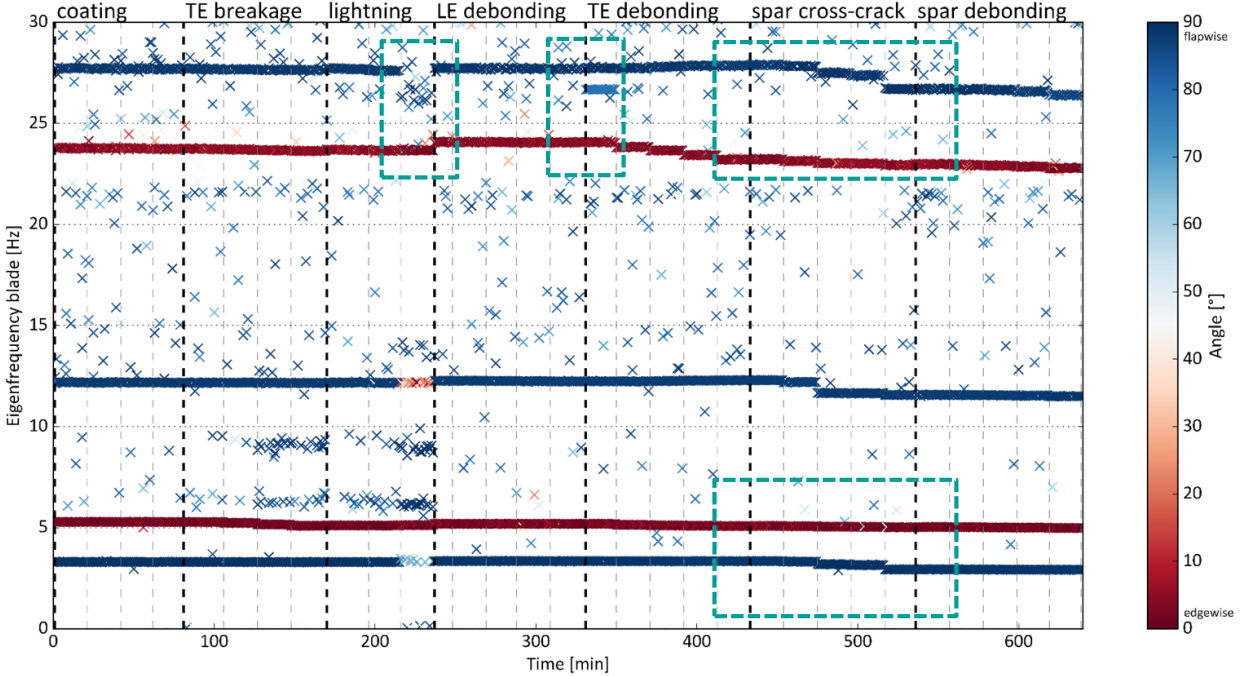
Frequency analysis

Tracking of natural frequencies:

- Main vibration modes monitored
- High time and angular resolution

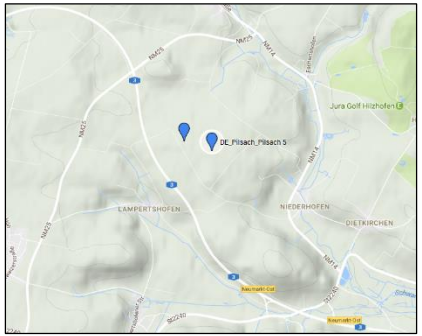
Angular resolution

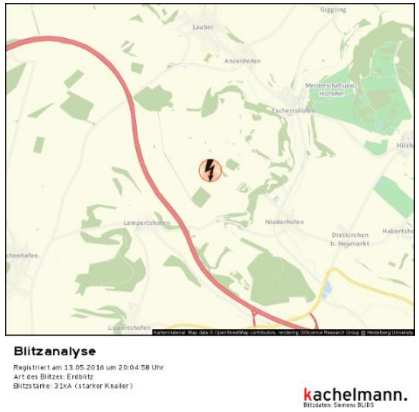
- Separated edge and flap data

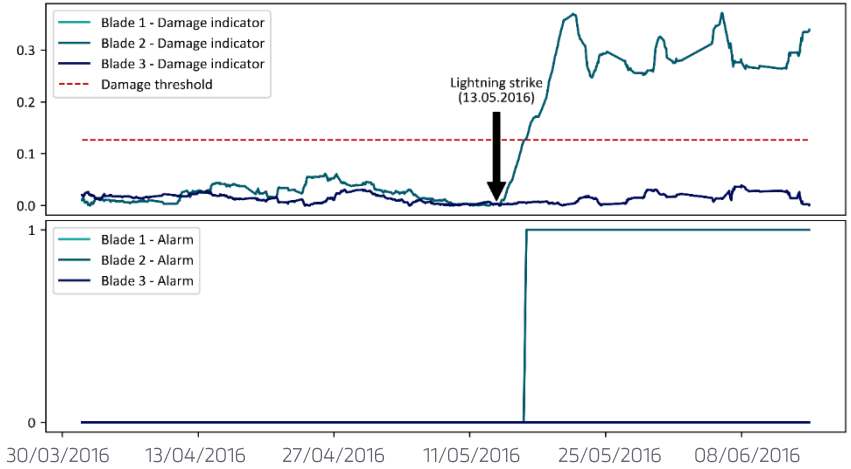


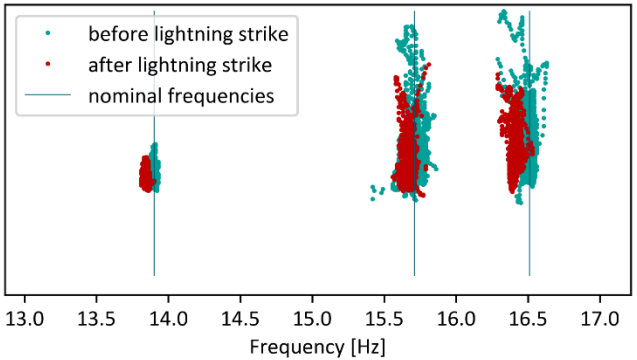
(1) Frequency Analysis

Turbine Integrity Control captures lightning strike via shift of nominal frequencies





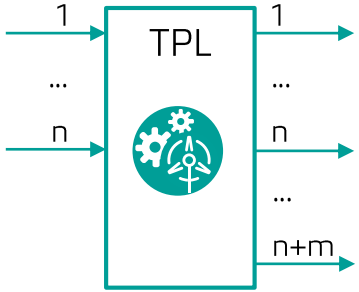




The basis for asset optimization and an extract of our analytical competence is the Turbine Physics Library, a real-time digital twin right at the edge.

Data from physical sensors

- Field bus data
- Blade vibration
- Blade strain
- Other 3rd party sensors
- ...



Data from virtual sensors

- Natural frequencies
- Blade bending moments
- Turbulence intensity
- Aerodynamic imbalance
- Yaw error
- ...

Delivers real-time signals of virtual sensors based on (model-based) fusion of existing sensor data

Aggregates data from the various components of a wind turbine, not just blades

Provides an image of states within the turbine that cannot be measured directly

Enables direct control by sitting right at the edge

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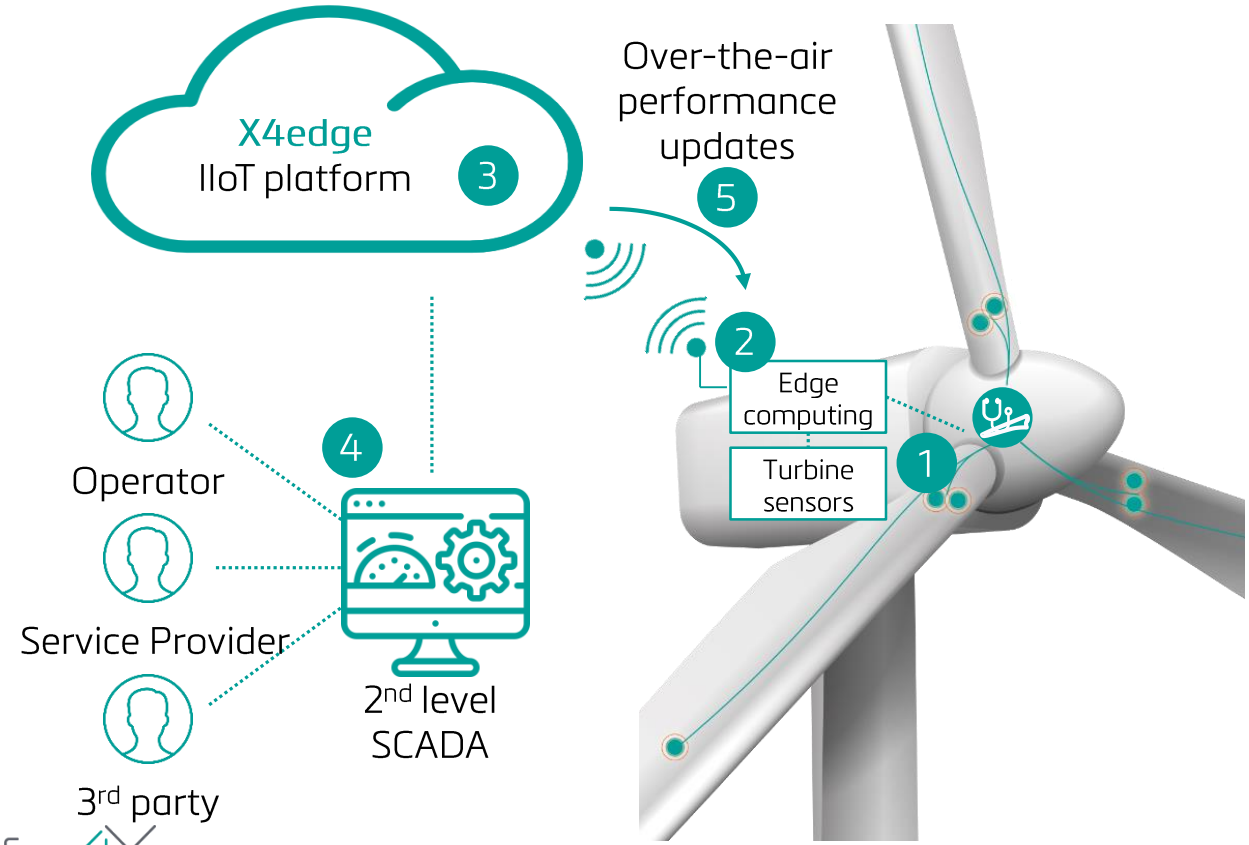

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Initial requirements

- 15 channels x 40 Hz + lots of other data sources = lots of data per turbine
- The same Python code should run on a (thin) edge computer, in the cloud, and on developer laptop (probably using containers)
- Need the uncompressed data for product development
- Compressed 1 sec data goes to customer dashboard
- System needs to be rather autonomous, visits are very costly
- New applications can be pushed to the turbine upon customer request
- Backward compatibility to installed base of systems
- Billing?
- Third parties?

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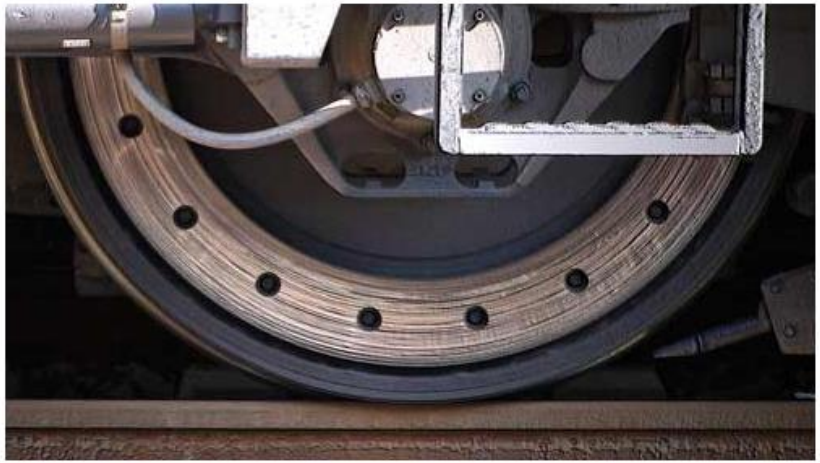
Process Measurement with distributed temperature sensors

Our customers use distributed, fiber-optic temperature measurement in the control of various industrial processes, among other things in tools for the production of fiber composite structures or in steel continuous casting plants. The multitude of necessary measuring points is particularly impressive in these applications, so that we have, for example, extended our measuring instrument for the distributed strain and temperature measurement on behalf of *SMS group GmbH* to 64 measurement channels with 18 sensors each.

With up to 1,152 temperature measuring points, the process in steelworks worldwide can be better controlled and rejects and downtimes can be reduced. An important criterion for the use of fiber-optic sensors in process measurement technology is the low physical space of fiber-optic sensors and the associated cabling.

Railway Engineering – another environment with harsh conditions



In railway engineering, fiber-optic sensor technology plays an increasingly important role, for example in axis counting. Force measurement on current collectors, points diagagnosis or status monitoring of bogies are also typical applications. In the case of axle counting, we are working with our partner *Thales* to introduce fiber optic axle meters.

This safety-critical application is particularly predestined for the use of fiber-optic sensors, since the use of electronic components in the field can thereby be avoided. Besides the advantage of lower costs, electromagnetic interference, lightning damage and copper theft are a thing of the past. The Fit-and-Forget approach is also designed to significantly reduce maintenance costs over the system runtime.

Aerodynamics with pressure sensors

Our fiber-optic pressure sensors are used in pitot tubes and flush with surfaces for aerodynamic tests. The measurement of aerodynamic parameters such as quasi-static pressure distribution and aeroacoustics have long been used by our sensors.

We are now supporting our distributor and specialist for customer-specific pressure transducers *Vectoflow* in the development of a fiber-optic pitot tube. It is to stand out against current products by its particular robustness against environmental influences and by a more dynamic response.

Electromobility with temperature sensors in the middle of high voltage

Fiber-optic temperature sensors are used in test areas of the automotive industry in the field of the electrified powertrain. Due to the high power density, electric motors require high operating voltages and operating currents. For the development and the test fields, sensors are required which, unlike conventional electrical sensors, are immune to inductive alternating fields and at the same time do not require any special requirements for insulation and handling. At the same time, usability is particularly important here: in the application, the sensors must not differ from conventional systems.

In cooperation with *imc Test & Measurement*, we have developed special temperature sensors which can be integrated into the motor components, converters and batteries, which require little installation space and do not have any disturbing effects in this demanding environment.

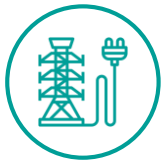
We will launch f retroX with a handful of clients this year and work with them to deliver the analytical software roadmap described

- Retrofit fiber-optic sensors and connect to the IIoT
- Utilize high-frequency data for model-based analytics
- Leverage data-driven optimization to grow profit

Special Wind Farms

Independent Service Providers (ISP)

Wind Farms Operators



Utilities


fos4X
rotor blade sensing