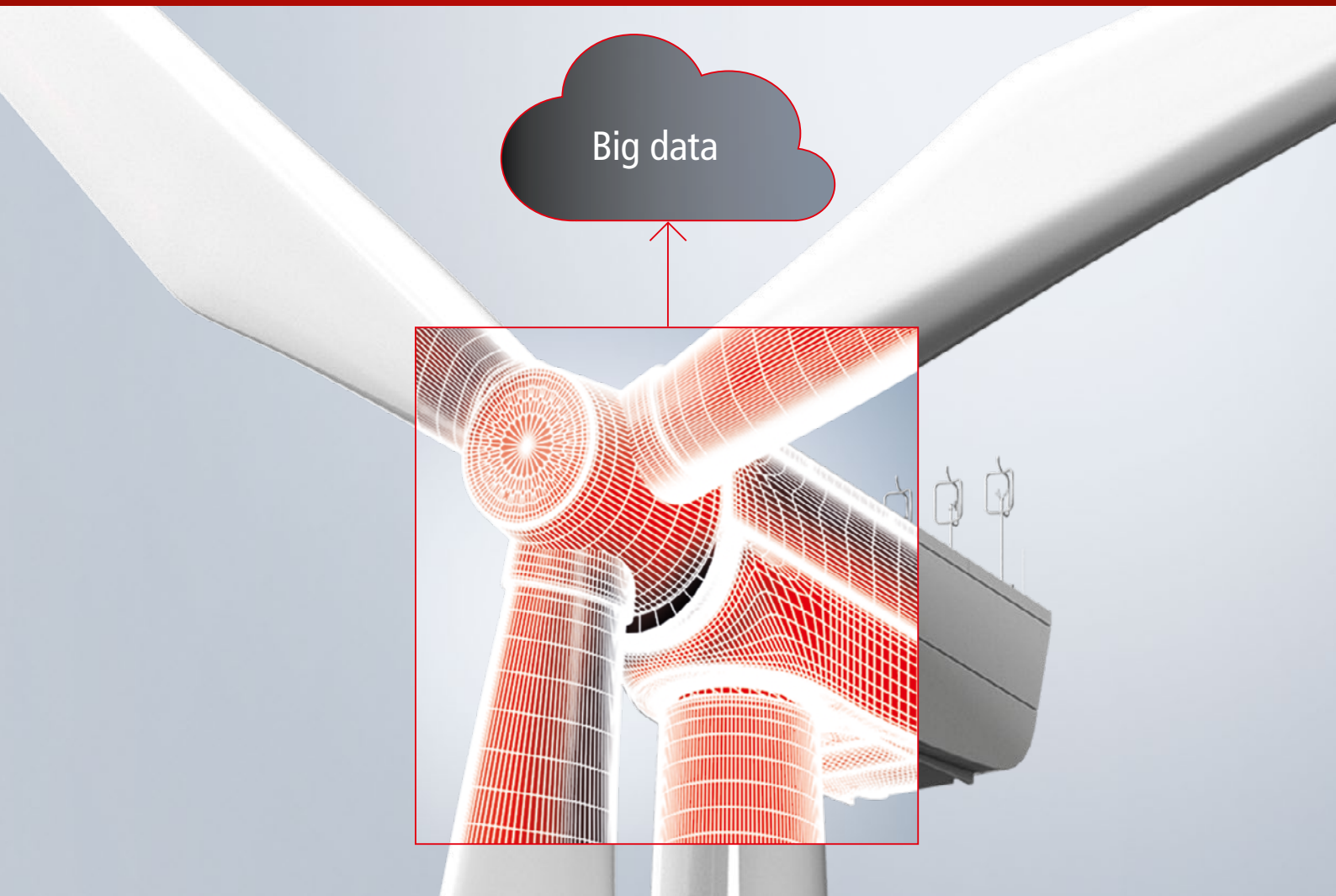
BECKHOFF New Automation Technology

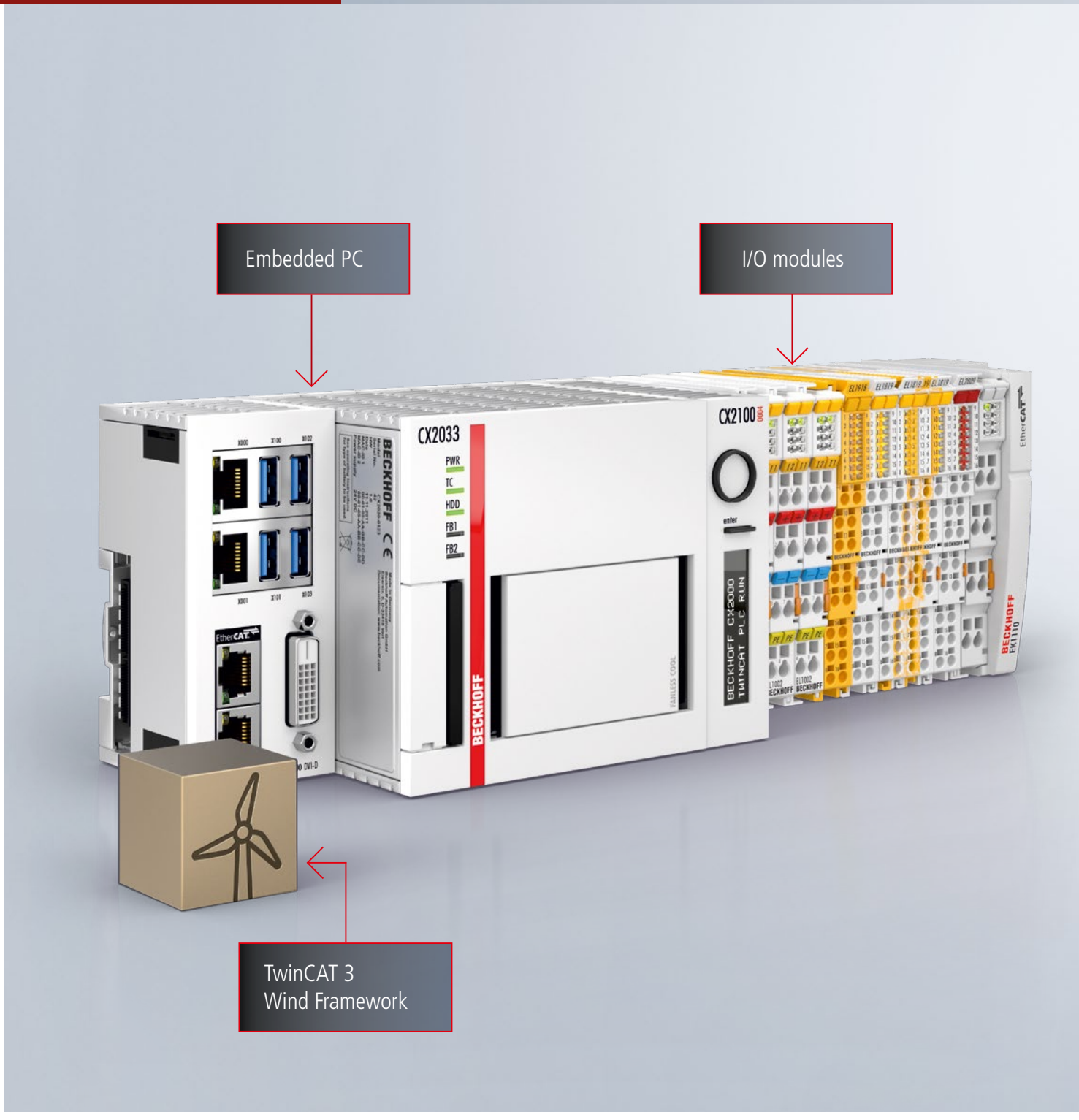
PC-based control for Wind 4.0



PC-based control: Universal control platform for wind turbines

With PC- and EtherCAT-based control technology, Beckhoff implements system solutions that have been tried and tested worldwide: More than 100,000 wind turbines all over the world have been automated using Beckhoff technology, each providing up to 16 MW capacity. An embedded PC with line-connected I/O modules, EtherCAT as universal communication system and TwinCAT automation software functions serve as the central control system. Robust hardware components and compliance with industrial communication standards provide optimum protection for your investment. With a wealth of industry experience, our wind energy experts will provide support from control cabinet design to system commissioning.

All functions are run on a central CPU, from operational management, pitch control, visualization and safety technology through to condition monitoring, remote access functions and wind farm networking. With outstanding flexibility in control system design, high scalability in terms of performance and a superior level of integration, PC-based control makes wind turbines more efficient and profitable. The modularity of the hardware and software portfolio enables you to configure a controller that exactly matches the performance requirements of your system and



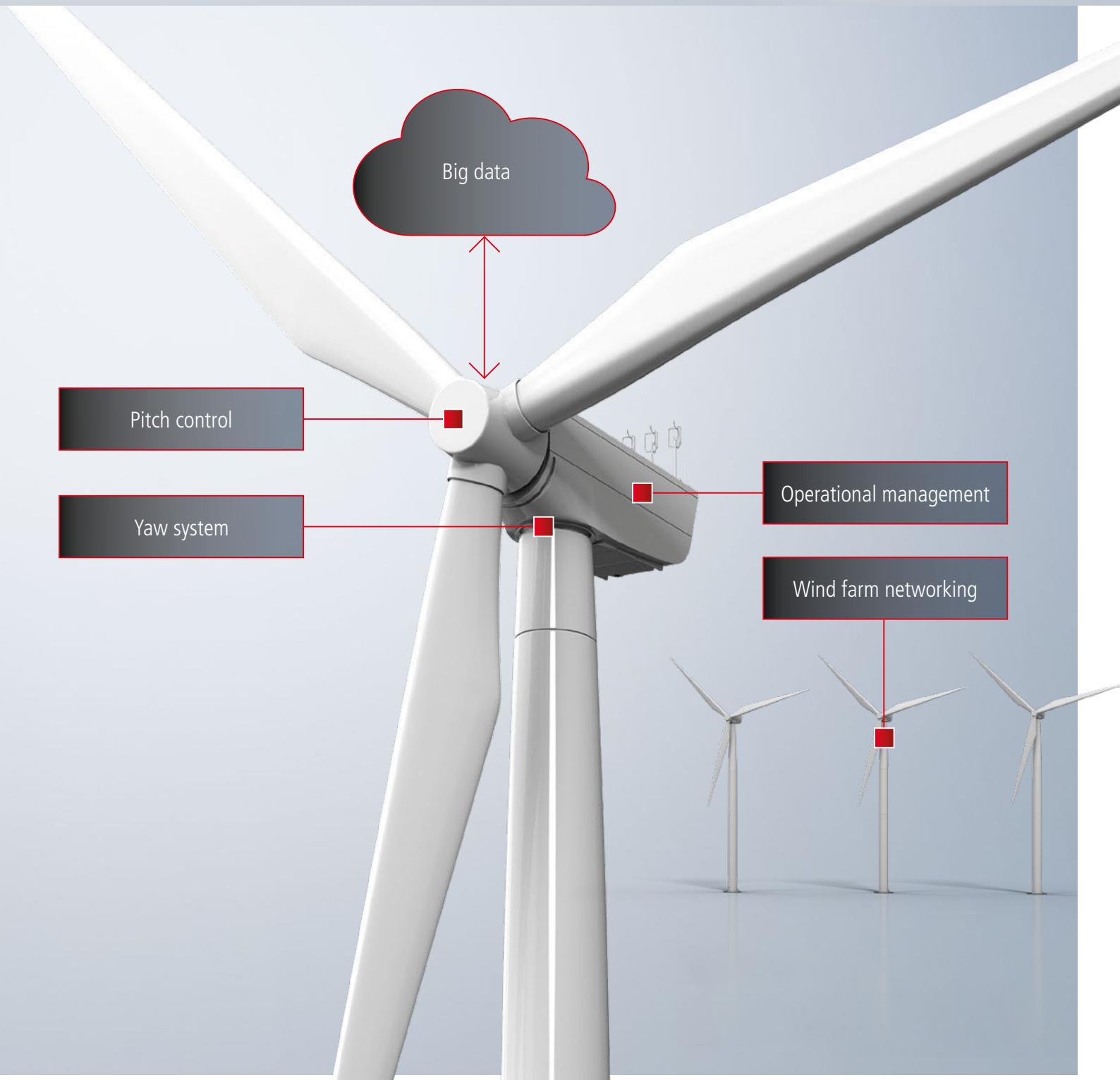
allows subsequent extensions and modifications, for example a retrofit of condition monitoring functions, without great expense. In the TwinCAT 3 Wind Framework, we created a software tool that transfers the concept of Industrie 4.0 to the wind energy industry and provides system manufacturers with optimum assistance in system programming.

Our range of services is supplemented by control cabinet design, ranging from the creation of circuit diagrams to the manufacture of prototypes or series production.

▶ **www.beckhoff.com/wind**

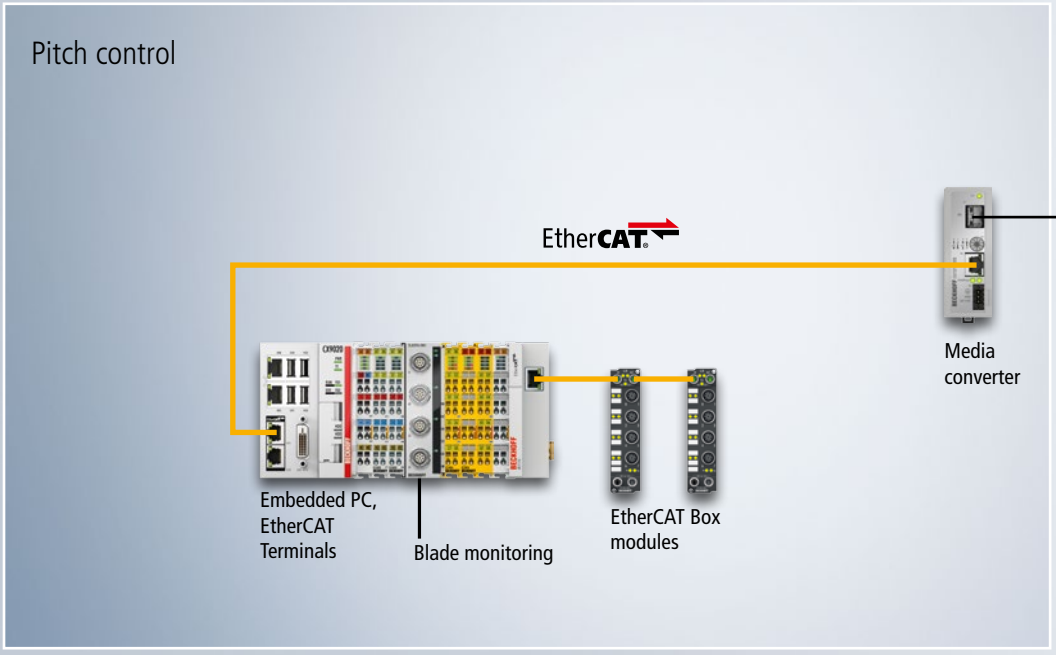
PC-based control for wind turbines

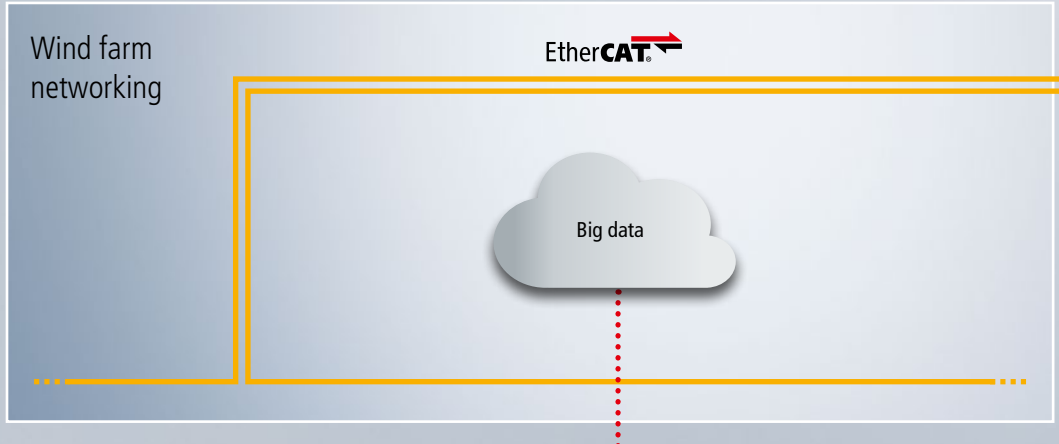
- integrated control platform for operational management, pitch control, wind farm networking and yaw system
- flexibility in control system design
- scalable performance
- modular expandability
- reduced hardware and engineering costs
- increased efficiency and profitability



One system solution for all control functions

An embedded PC installed in the tower base acquires and processes all data, monitors the grid feed-in and communicates with the central control room. Safety and measurement technology as well as condition monitoring are seamlessly integrated into the controller via appropriate I/O modules. The converter in the base of the tower, the I/O system for operational management in the nacelle and the pitch controller in the hub are connected to the master controller via EtherCAT. Lower-level fieldbuses such as CANopen, PROFIBUS, and Ethernet TCP/IP can be relocated to the field via fieldbus master or slave terminals for the control of subsystems. The universal use of EtherCAT accelerates communication, and at the same time simplifies the project planning, programming and cabling of the wind turbine. Open hardware and software interfaces enable integrated communication from sensors to cloud systems.

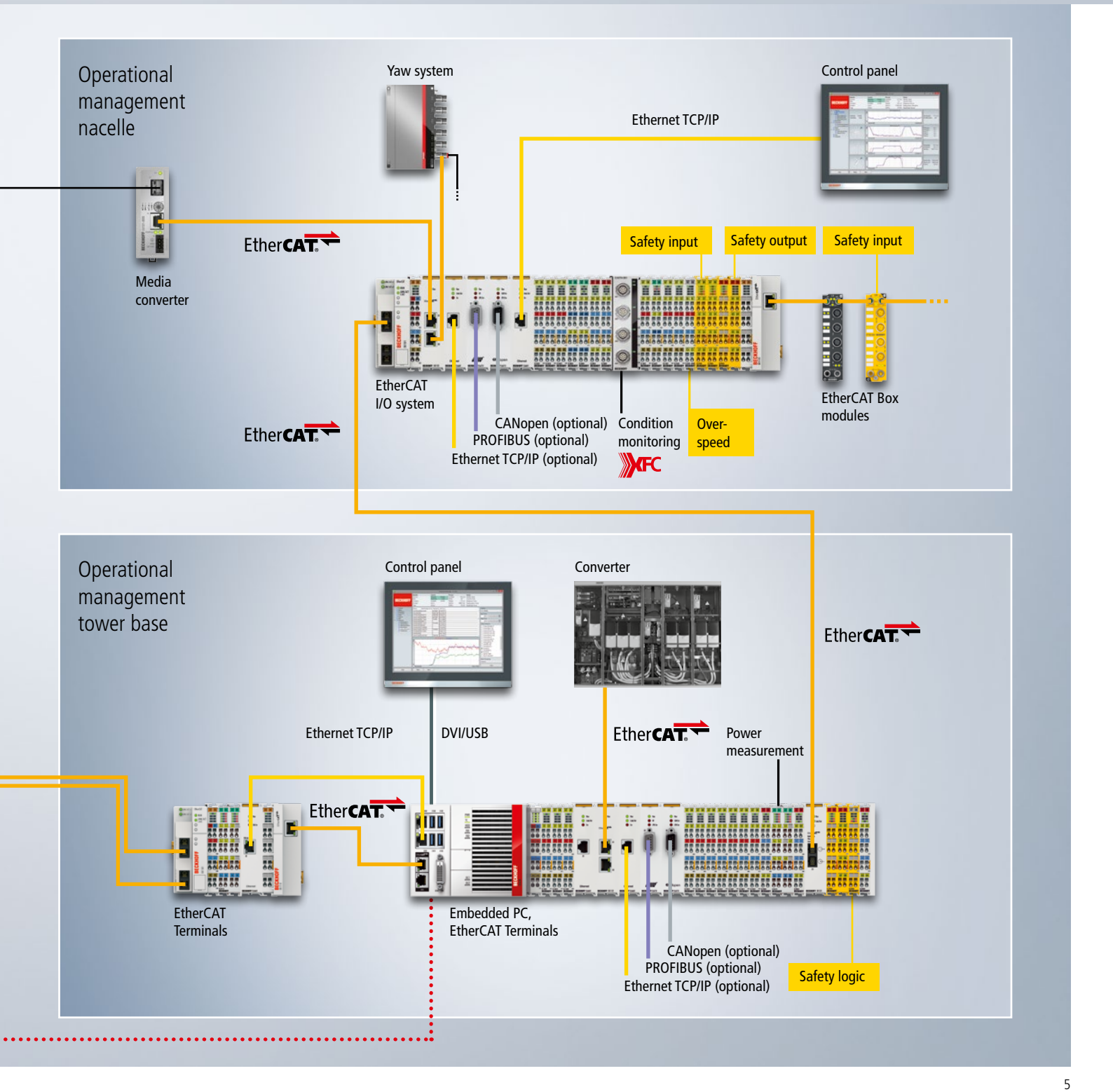




Pitch control
We offer a complete control solution for pitch systems: The DIN-rail-mountable Beckhoff Embedded PCs with line-connected EtherCAT I/O Terminals or IP67-rated box modules, are ideally suited to the collective or individual adjustment of the rotor blades. Encoder terminals for all types of blade pitch sensors are available as standard. Intelligent control routines reduce the loads acting on the system components resulting in a prolonged lifetime.

Operational management
For operational management in the tower base and nacelle, a complete hardware and software solution is available. Interfacing with higher-level control systems is based on internationally standardized telecontrol protocols. Servers that allow remote access to the control system are integrated into the embedded PC. TwinSAFE enables the integration of the conventionally hard-wired, higher-level safety chain into the automation system. Communication between tower base and nacelle is implemented inexpensively and flexibly over fiber-optic cables using EtherCAT.

Power measurement
The EL3453 3-phase EtherCAT Terminal for measurement voltages up to 690 V AC focuses on demanding process control tasks. For this purpose, the terminal updates its process values with each half-wave, which corresponds to an interval of 10 ms at 50 Hz. With regard to the equipment, up to four galvanically isolated current measuring channels for 100 mA, 1 A or 5 A and a surge overload capacity of 60 A can be used, which are freely adjustable in the measuring range. Additionally, a broad portfolio of current transformers is available for the implementation of reliable power sensors directly in the field.

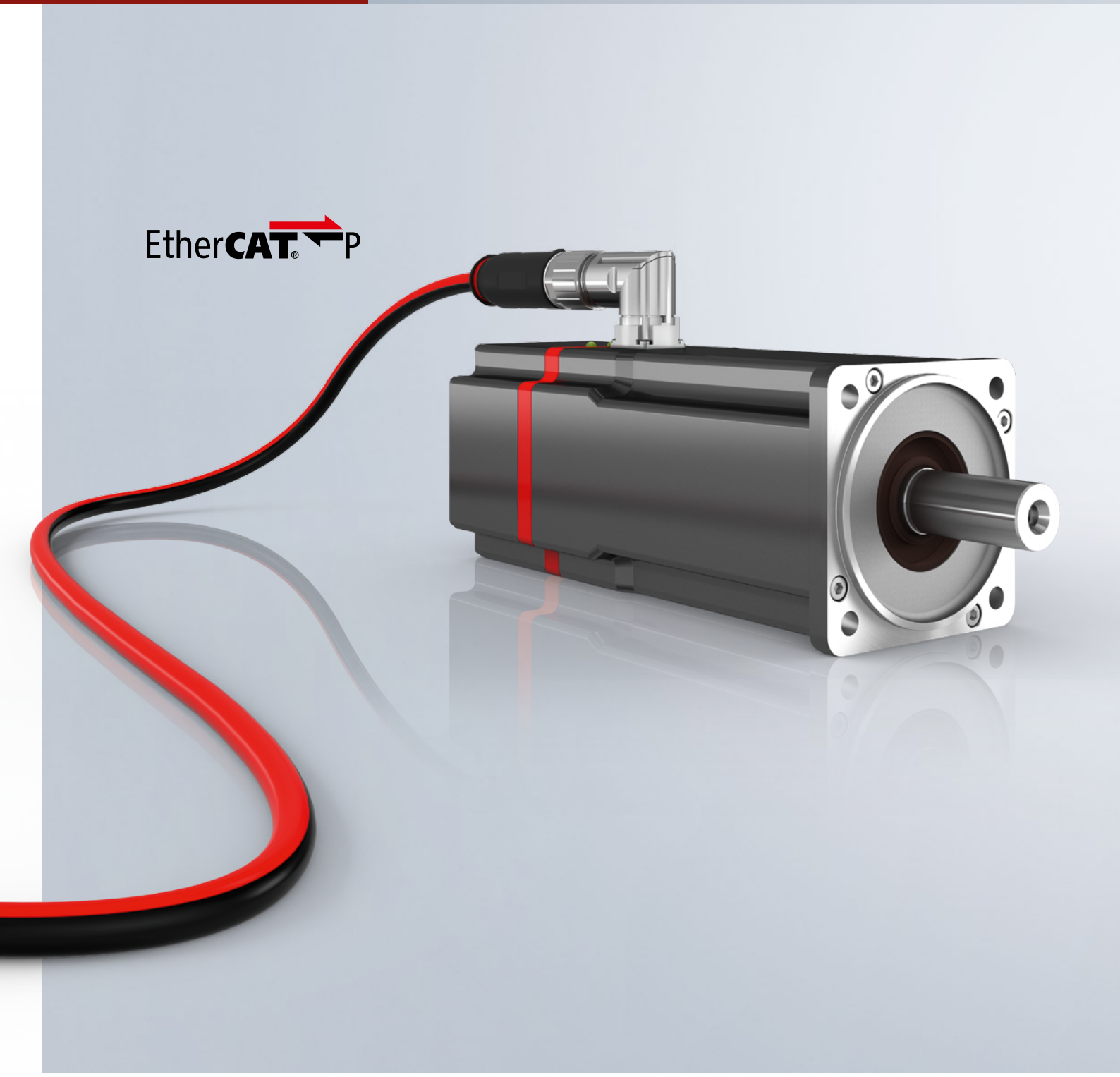


AMP8000 drive system optimizes the wind yield

If the wind direction changes, the yaw system rotates the wind turbine rotor optimally into the wind. Apart from the electric drives, hydraulic brake systems are typically also used for this horizontal alignment and locking of the nacelle.

However, the permanent use of the brake unit in the active wind tracking results in constant wear in the yaw system, leading to high maintenance expenditure. The use of the existing electric drive systems to develop the required counter-torque and to clamp the mechanism results in less wear and is more efficient.

Traditional drive systems are often based on mains-operated asynchronous motors without soft start, as these are relatively inexpensive. To achieve a safe starting torque in soft supply networks despite that, the motor and the upstream power supply elements are often greatly oversized. However, modern wind turbines offer less and less space for control cabinets. Additional weight and volume must be avoided in particular in the nacelle. These requirements are fulfilled by the AMP8000 drive system with decentralized servo functionality integrated in the motor. Depending on the turbine size and load requirement, the quantity and output of the motors can be adapted for the reliable dimensioning of the drive and braking torques. In comparison with

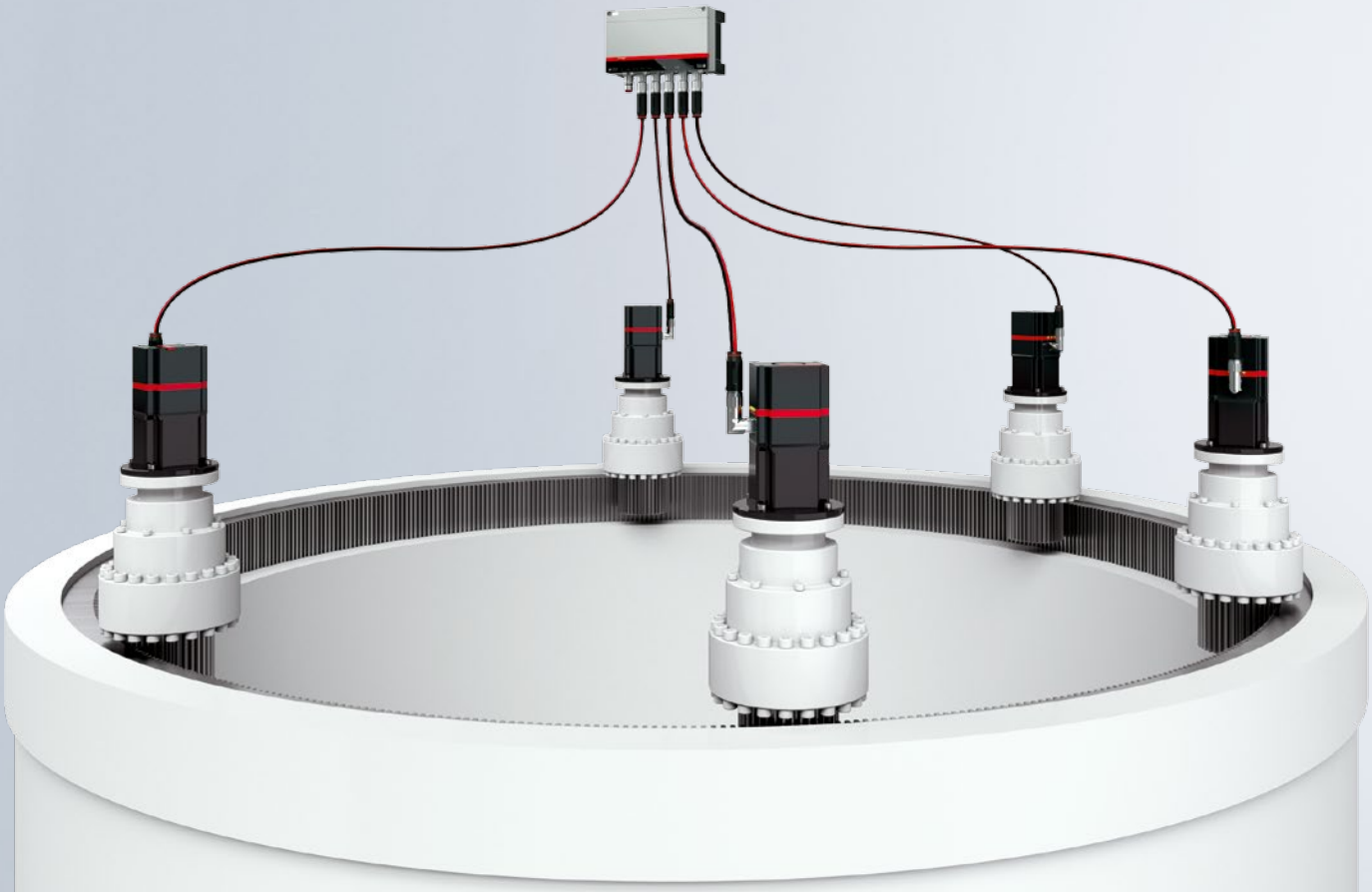


traditional solutions, the servo drive system based on the AMP modules from Beckhoff offers greater efficiency and the safety of adequate breakaway torques even in the case of grid fluctuations.

On account of the wear-prone braking systems, the wind tracking is operated only very sparsely in many turbines. With the new approach, in which the dynamic braking power is achieved without the assistance of the hydraulic brake system, a higher energy yield can be achieved at many wind farm locations through more dynamic wind tracking.

Distributed servo drive technology in the nacelle adjustment

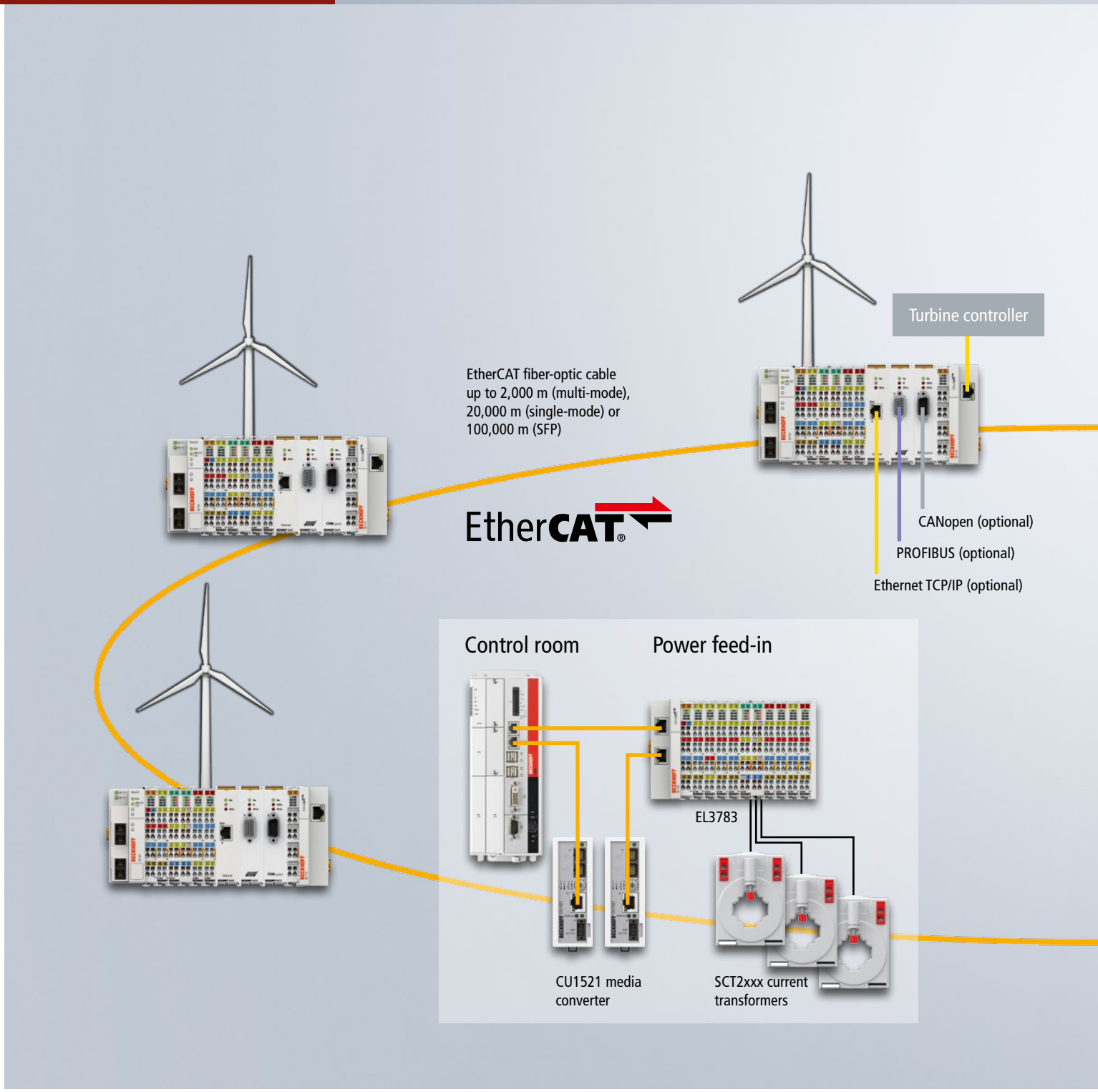
- increased energy yield through more dynamic wind tracking
- cost reduction through lower maintenance requirement
- AMP modules reduce installation space and weight in the nacelle.
- minimization of the cabling and assembly costs
- optional safety functions
- integrated condition monitoring and remote diagnostics



Ultra-fast wind farm networking: With EtherCAT

Producers of renewable energies are faced with the challenge to support grids in the event of voltage drops (LVRT). Wind farm networking with EtherCAT sets new benchmarks due to its high speed: In case of an LVRT, the setpoint values can be specified for all wind turbines in the entire farm network in less than 1 ms and the control of current, voltage, and frequency can be adapted efficiently. The existing fiber-optic-based Ethernet infrastructure can be used for this purpose up to distances of 100 km without a loss of speed. Even the synchronization of the IGBTs of converters within a wind farm can be realized with this technology.

Wind farm networking with EtherCAT is not only faster compared to conventional Ethernet solutions, but also offers substantial cost benefits by eliminating the need for costly switches or hubs. With the EL3783 EtherCAT power measurement terminal integrated into the automation system, momentary current and voltage values can be measured at high frequencies with up to 20,000 samples/s. With EtherCAT distributed clock functionality, the measured values of all wind turbines and the measurement at the feed-in point of a farm can be synchronized to a timeframe smaller than 1 µs. TwinCAT supports the standardized IEC 61400-25 communication protocol



for wind turbines, which simplifies the monitoring and control of heterogeneous wind farm system environments, including the connection to electric utilities.

EtherCAT: The high-speed fieldbus for wind farms

- ultra-fast wind farm networking
- response times under 1 ms
- current and voltage measurement with 20,000 samples/s
- optimum protection against voltage drops
- monitoring of heterogeneous wind farm environments through standardized communication protocols

System-integrated condition monitoring

The operation and maintenance of modern wind turbines incurs considerable costs. To maintain competitiveness, failure risks must be minimized, maintenance costs lowered and the availability and energy efficiency of the system increased. This is where condition monitoring enters the game: Monitoring of gear units and generators is generally recommended, not just for offshore wind turbines or systems in remote regions.

Beckhoff uses the powerful processors of modern PC technology and EtherCAT as fast communication system, integrating condition monitoring functionality seamlessly into the controller. The vibrations of bearings or electrical machines are picked up by standard measurement terminals from Beckhoff and transmitted to the controller via EtherCAT. Configuration, programming and diagnostics are carried out within one system using TwinCAT.

With improved error detection and holistic system analysis capabilities, the control system-integrated condition monitoring from Beckhoff is superior to conventional hardware-based condition monitoring solutions. Through integration of further signals from operational management, including temperatures, pressures and current, among others, false alarms can be prevented and error detection is improved. Integration of

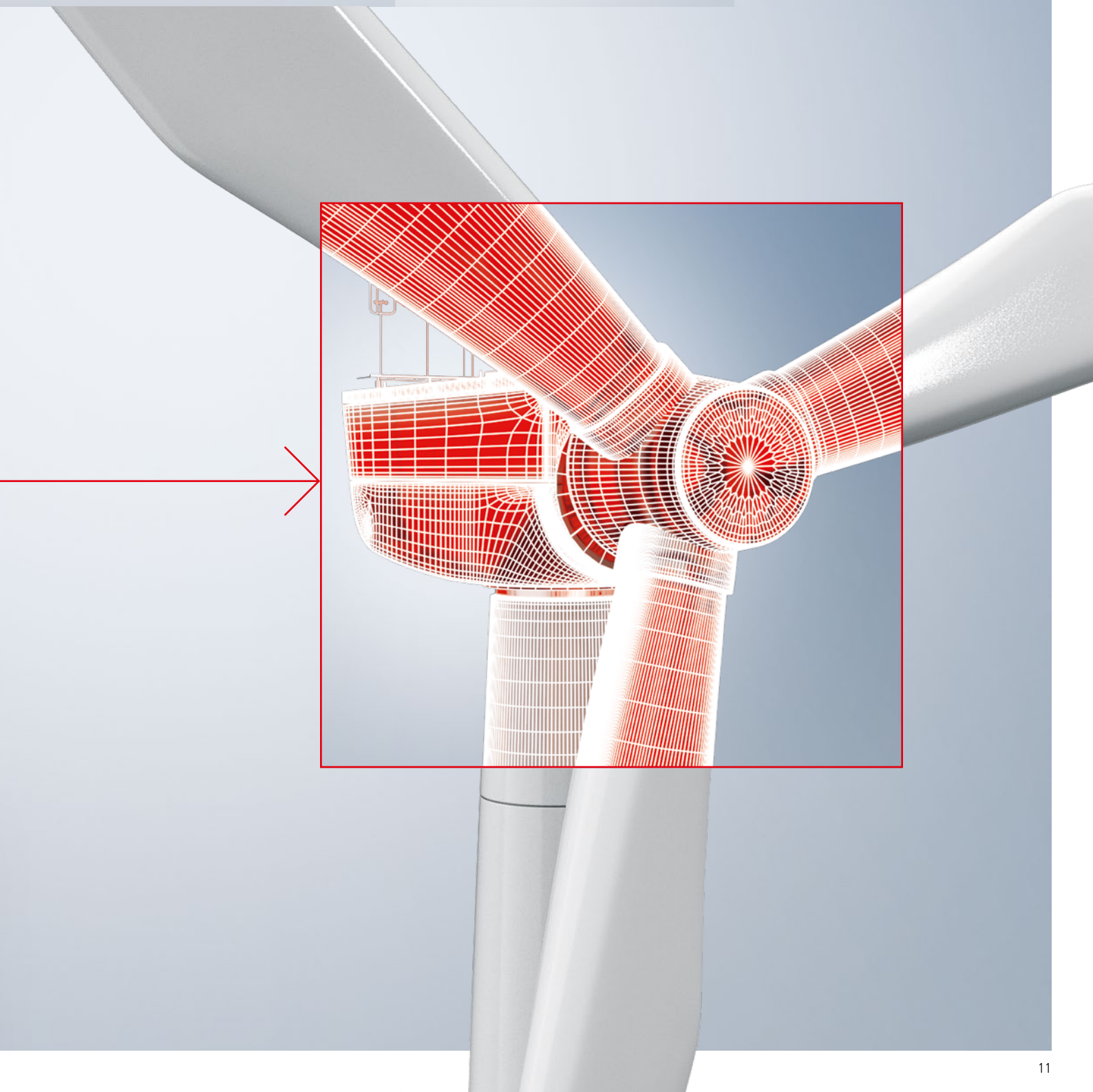
EtherCAT®

condition monitoring into the central PC-based controller is advantageous, in particular where large amounts of data from different devices need to be analyzed or if damage frequencies need to be evaluated in relation to the rotary speed. The controller acquires and processes the signals in the microsecond range.

However, cost reductions with regard to system, installation and maintenance also highlight the merits of system-integrated condition monitoring. Existing systems can be retrofitted simply and inexpensively.

Condition monitoring increases efficiency and availability of wind turbines

- time-synchronous data logging in < 1 µs
- reliable data analysis
- enhanced diagnostics
- increased system availability
- longer service life of wind turbines
- reduced maintenance costs
- reduced system costs
- enhanced competitiveness



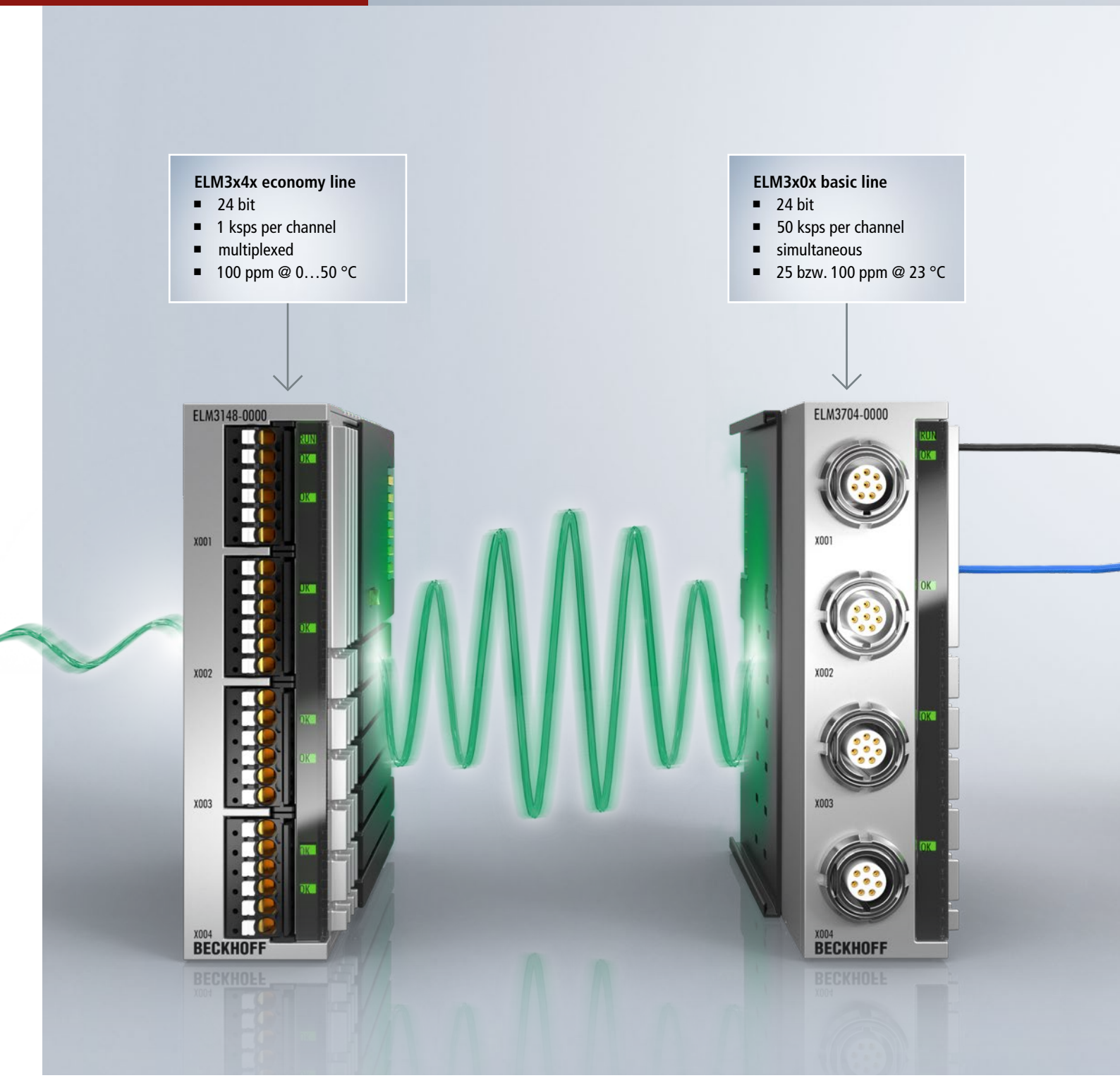
Beckhoff measurement technology: The right device class for every application

With our continually expanding measurement technology portfolio, we serve the entire bandwidth of requirements in industrial measurement technology: from 1 Hz to the kHz range, from the measurement of current and voltage and from vibration to force measurement. IP20 components read in the sensors from inside the control cabinet. Seamlessly integrated into the EtherCAT I/O system, the high-end measurement modules from the ELM device series also record those process-critical measuring channels for which the standard analog technology in the EL/KL terminal system is not suitable. The basic line measurement modules are conceived for the recording of highly dynamic events with high measuring accuracy – simultaneously on all channels and modules. The economy line is intended for the recording of less dynamic processes. An integrated 24 V sensor supply and 24 V power contacts reduce the wiring work in the control cabinet. With their enormous temperature stability of 100 ppm in the temperature range normally found in control cabinets, these modules even tower above the basic line.

Typical signal forms required for the measurement of prototypes or for condition monitoring, such as strain gauges, temperature sensors and accelerometers, are naturally also available.

ELM3x4x economy line
- 24 bit
- 1 ksps per channel
- multiplexed
- 100 ppm @ 0…50 °C

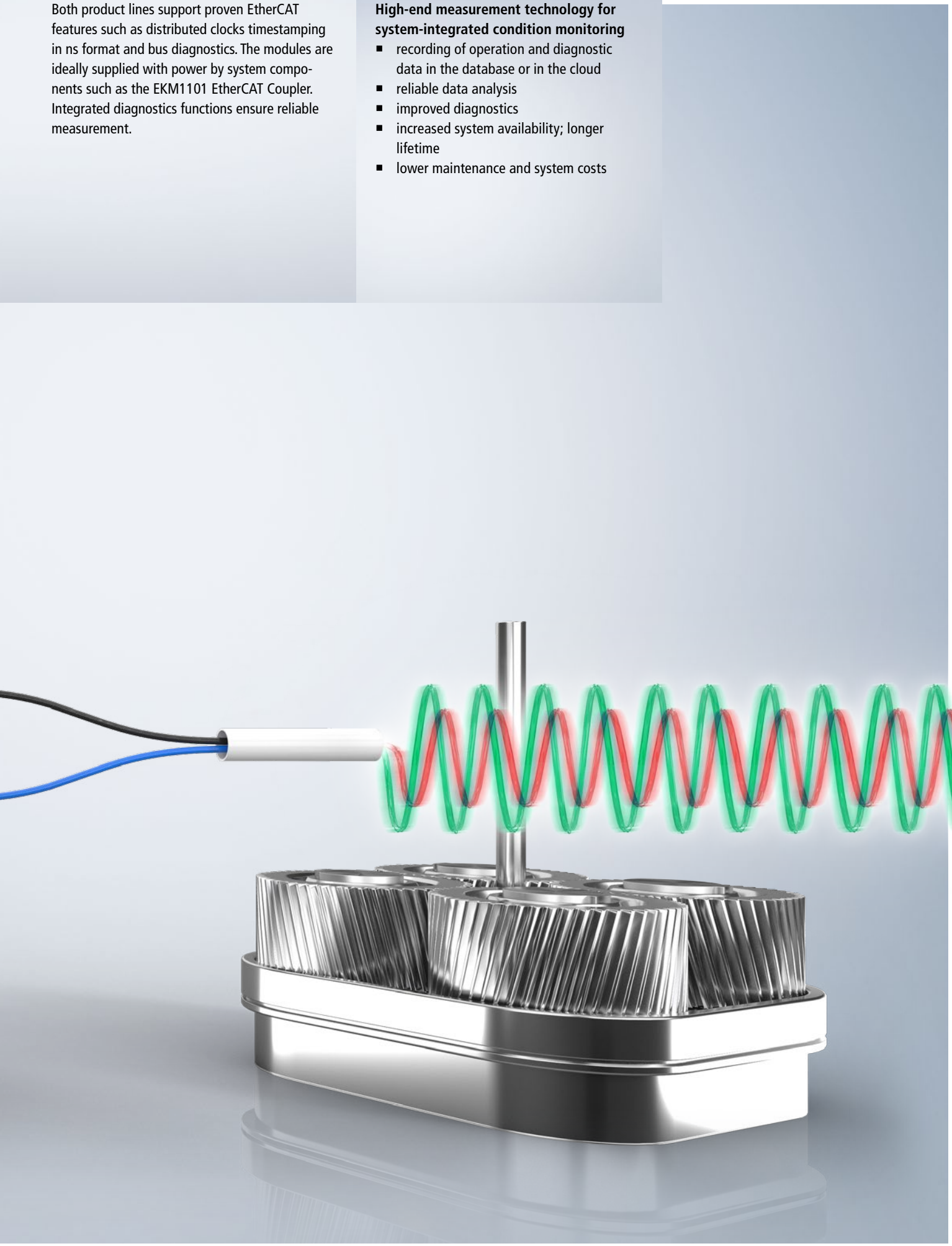
ELM3x0x basic line
- 24 bit
- 50 ksps per channel
- simultaneous
- 25 bzw. 100 ppm @ 23 °C



Both product lines support proven EtherCAT features such as distributed clocks timestamping in ns format and bus diagnostics. The modules are ideally supplied with power by system components such as the EKM1101 EtherCAT Coupler. Integrated diagnostics functions ensure reliable measurement.

High-end measurement technology for system-integrated condition monitoring

- recording of operation and diagnostic data in the database or in the cloud
- reliable data analysis
- improved diagnostics
- increased system availability; longer lifetime
- lower maintenance and system costs



Three steps to integrated condition monitoring

High-frequency data acquisition via EtherCAT Terminals

The Beckhoff EL3873 power measuring terminal with oversampling function for the state monitoring of a 3-phase AC voltage system and the EL1252 digital input terminal with timestamping function for the chronologically precise detection of binary control signals are available for the monitoring of the mains voltage.

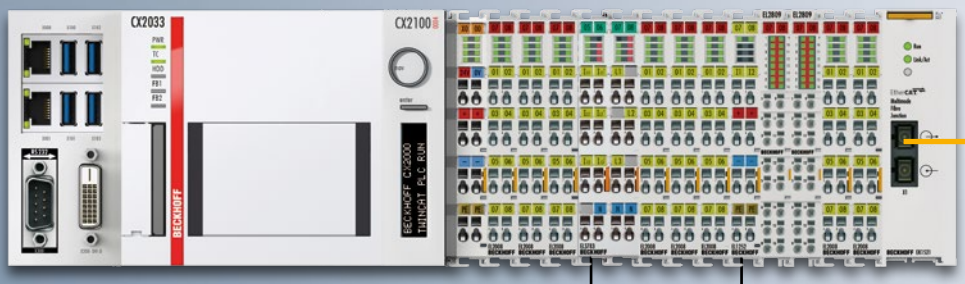
When retrofitting a wind turbine with condition monitoring, it is only necessary to expand the turbine controller by a terminal block with the appropriate EtherCAT measuring terminals. Strain gauges (SG) can be evaluated via the ELM modules. The EL3751 EtherCAT Terminal offers a multi-functional input for analog measurement technology. The EL3632 enables the direct connection of various acceleration sensors via an Integrated Electronics Piezo-Electric interface (IEPE) and performs the high-precision vibration measurement. The raw data are recorded synchronously (< 1 µs) with other system data, such as power and speed, which increases the reliability of the data and reduces false alarms.

A modular construction kit of mathematical algorithms for the analysis of measured values is available in the TwinCAT Conditioning Monitoring library. The library's functions are primarily

Step 1

Existing turbine control system

Step 2



EtherCAT

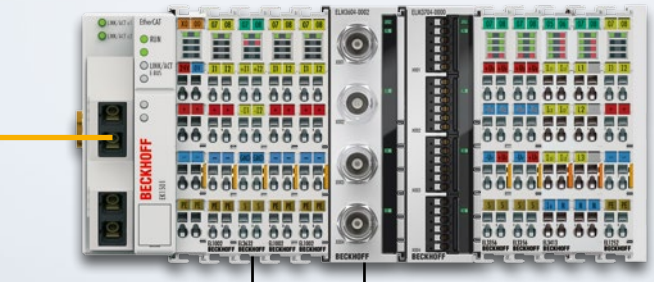
EL3783:
Power measurement terminal

EL1252:
2-channel digital input terminal with timestamping

relevant to analysis, statistics and classification. In addition to spectral analysis via FFT or using, for instance, an envelope spectrum, it is possible to calculate key statistical values such as the kurtosis or the crest factor. Combining these algorithms with limit value monitoring is, for instance, ideally suited to monitoring roller bearings. However, it is recommended to analyze the status data in the condition monitoring software of a third party, which is directly integrated into the Beckhoff control platform as a licensed TcCom module under TwinCAT 3. Noted companies in the wind power industry have already implemented their solutions in TwinCAT.

If component-related threshold values are exceeded, the CM system triggers alarms that inform the system operator about wear, imbalances or impermissible operating states. These alarms can be reported for further processing directly to the system controller or other operator systems. Of course, the continual machine monitoring can take place online. Trends in the characteristic values are analyzed here and translated into recommendations for action, for example for the planning of maintenance intervals.

Condition monitoring hardware



ELM3604-0002:
4-channel analog input terminal (IEPE)

EL3632:
2-channel analog input terminal for condition monitoring (IEPE)

Step 3

Condition monitoring software

TwinCAT 3 Wind Framework: Know-how from over 100,000 wind turbines

The TwinCAT 3 Wind Framework bundles our industry expertise gained in the automation of more than 100,000 wind turbines and makes Industrie 4.0 concepts available for wind energy. The modular software package includes all necessary functions and tools for the modern and efficient engineering of wind turbines. All basic functions are encapsulated as TwinCAT modules in simple to use function blocks in TwinCAT 3 and provide a modular range of components for the programmer to choose from, simplifying the development of the application software.

Apart from basic functions for operational management and state machine, there are software function blocks for event management, parameter configuration, user management, data connection, power and condition monitoring and simulation. The integrated database link enables the comprehensive acquisition, evaluation and provision of data from operational management, condition monitoring and power management in real-time. All data are continuously recorded, summarized in the central controller and analyzed in detail. This way, for example, signs of wear in individual components of the wind turbine that could lead to operational failure are detected at an early stage, thus increasing the availability of the system.

System operator

Big data

Communication

Secure vertical and horizontal communication

- support for all common bus systems (EtherCAT, Ethernet, PROFIBUS, etc.)
- comprehensive messaging/connectivity (ADS, OPC UA, live diagnostics, etc.)

The software modules and application templates are tried and tested and offer high quality and future security. In the same way as modifications to the hardware, individual software modules can be added or removed. This makes engineering as simple as possible. The development process is also optimized by distribution across the team: Development and tests on customer-specific modules can be carried out in parallel, thus further reducing the time-to-market.

TwinCAT 3 Wind Framework

- future-proof standard application software
- maximized ease of engineering
- secure and efficient software development
- increased software quality and optimized reusability
- significantly reduced time-to-market
- in-depth monitoring and interaction
- continuous acquisition and evaluation of signals
- application of Industrie 4.0 properties in wind energy

Manufacturer

Engineering

Universal and integrated engineering throughout the wind turbine life cycle

- IEC 61131-3, C/C++, MATLAB®/Simulink®
- object orientation, modularization
- data exchange between engineering tools
- automated engineering

Big data

Optimized processing, availability and evaluation of all relevant data in real-time for wind turbine operators and manufacturers

- data acquisition and data warehousing
- data analysis and data mining
- power and condition monitoring

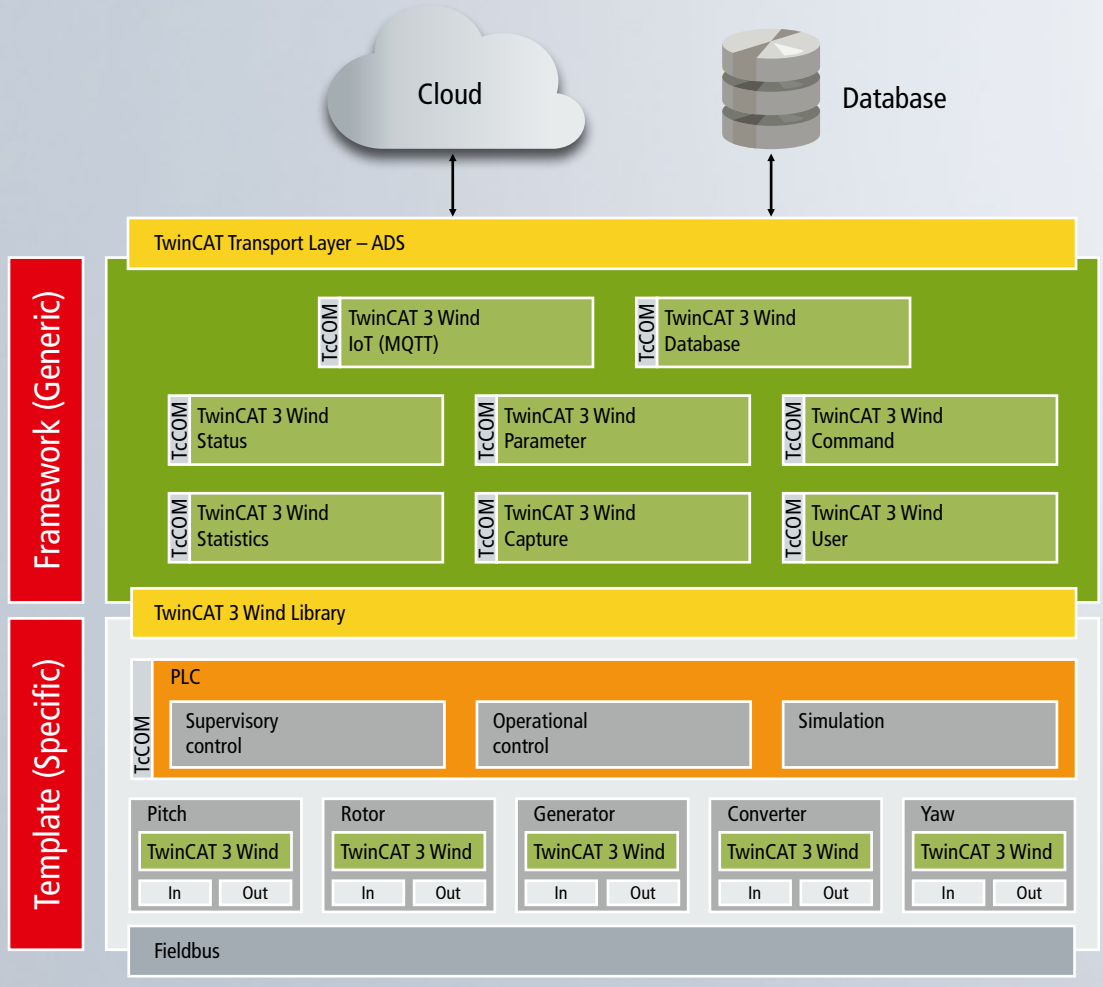
TwinCAT 3 Wind Framework: Modular engineering

The TwinCAT 3 Wind Framework enables universal and integrative engineering over the complete life cycle of the system. C/C++ and MATLAB®/Simulink® are available as programming languages in addition to IEC 61131-3 for object-oriented, modular programming.

The programming of operational management software using the TwinCAT 3 Wind Framework is facilitated by a library and an application template. The library provides all functions of the Wind Framework as PLC function blocks. The application template provides a modular architecture for the operational management software for wind turbines in the form of a PLC project.

Each subsystem of the wind turbine is represented by a self-contained object. In this way, the subsystems can be developed, used and tested independently. As a result, the subsystem software modules are interchangeable, as is already common practice in the mechanical modularization of systems. This increases the quality, flexibility and reusability of the software, while at the same time reducing development time and costs.

General control functions of the wind turbine, such as pitch and torque control, are prepared in the software as operational control. For control purposes, the integration of further modules is



The TwinCAT 3 Wind Framework offers a modular control architecture for wind turbines.

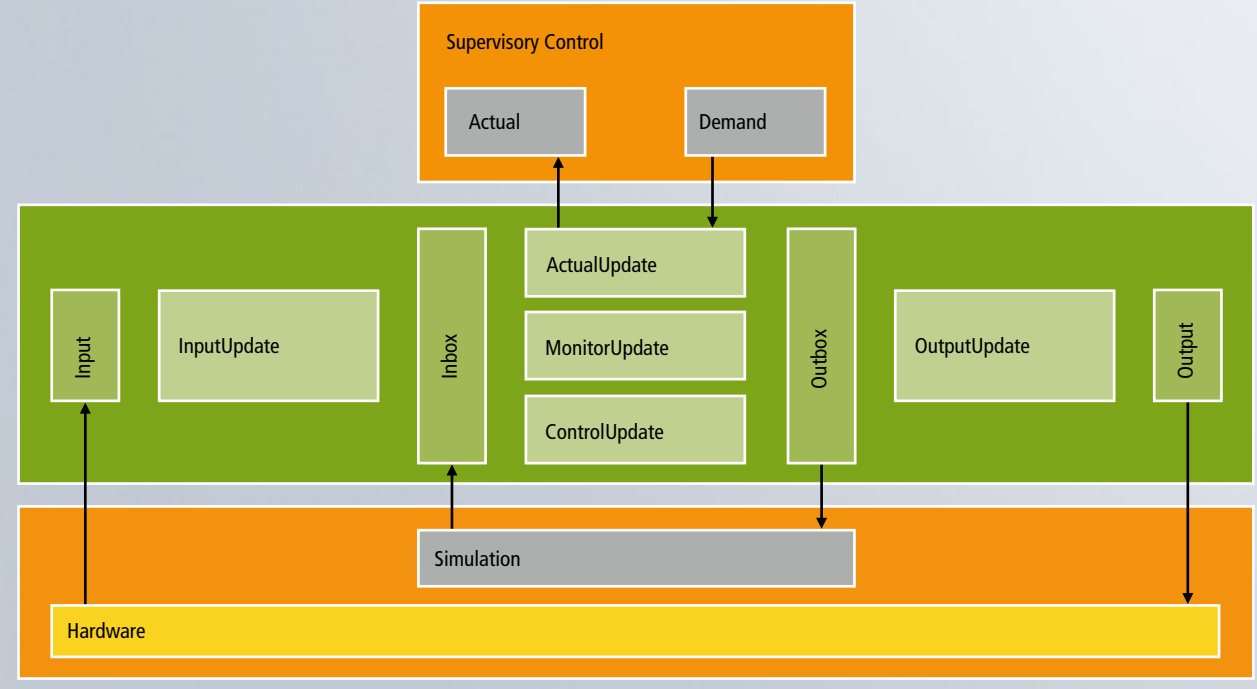
possible, for example to integrate algorithms for load calculation.

On top of that, an adaptive simulation of the wind turbine is integrated into the application. This enables testing of the entire operational management within the development environment. The simulations integrated in the application can be used to map, analyze and verify the processes of the whole system, the operating modes and also individual subsystems. Each subsystem can be operated separately and independently, by switching between the simulation and the actual hardware. In this way, it is possible to activate nacelle components, for example, on the factory floor for testing.

The generic TwinCAT modules provide higher-level services. Each module is ready for use and only needs to be integrated in TwinCAT 3 as a TcCOM module. The modules can be used separately and independently of each other or in combination, in order to facilitate interaction and data exchange.

The status module supports the monitoring of all components and enables error detection, event management, error handling and reporting. Status objects are created that represent an event and are used to display messages, warnings or errors. The parameter and command modules provide services for configuration and interaction with the application. Signal logging and a statistical analysis is provided by the capture and mean modules. Initial evaluations for subsequent diagnostics are carried out in real-time. In this way, it is possible, for example, to monitor a unit and its behavior and to read out the switching frequency and operating time.

The integrated user management tests and logs all interactions by the user. In this way, it is possible to specify during the programming phase which rights are required to use each function.



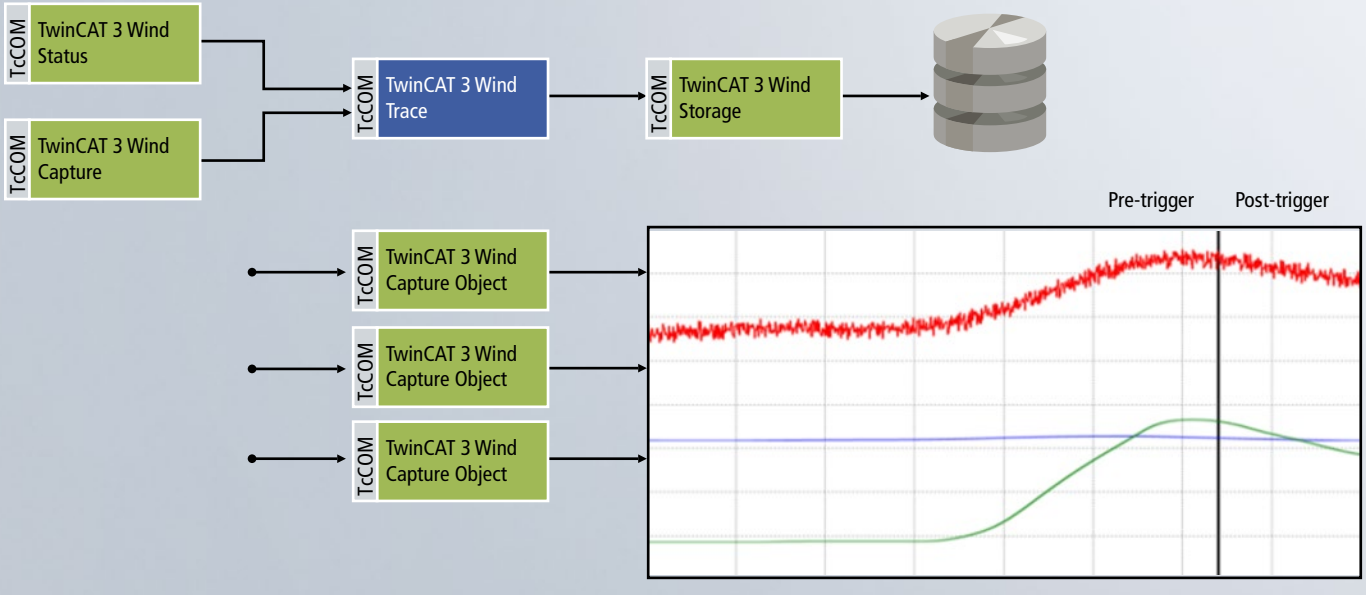
Seamless switching between simulation and hardware ensures that no changes to the source code are required for partial commissioning.

TwinCAT 3 Wind Framework: Big data optimizes wind turbines

All information from the various TwinCAT modules is continuously transmitted in real-time to the database module. It is then saved in the database, or retrieved from it, via SQL procedures. The TwinCAT 3 Database Server manages the data in the database.

Interfacing with the SQL database through the database module and the TwinCAT 3 Database Server enables efficient and compact data management based on a uniform, familiar format. Logging of all events and signals, and storing and loading the entire configuration of all objects enables detailed analysis. Any pre-processing required is carried out by the TwinCAT modules in real-time. Logging and pre-processing of all data in real-time, followed by a reliable transfer to the database, enables evaluation on demand and outside of the operational management. Based on this historic data, it is possible to detect state changes and the causes of faults, create detailed statistics and ultimately optimize the system.

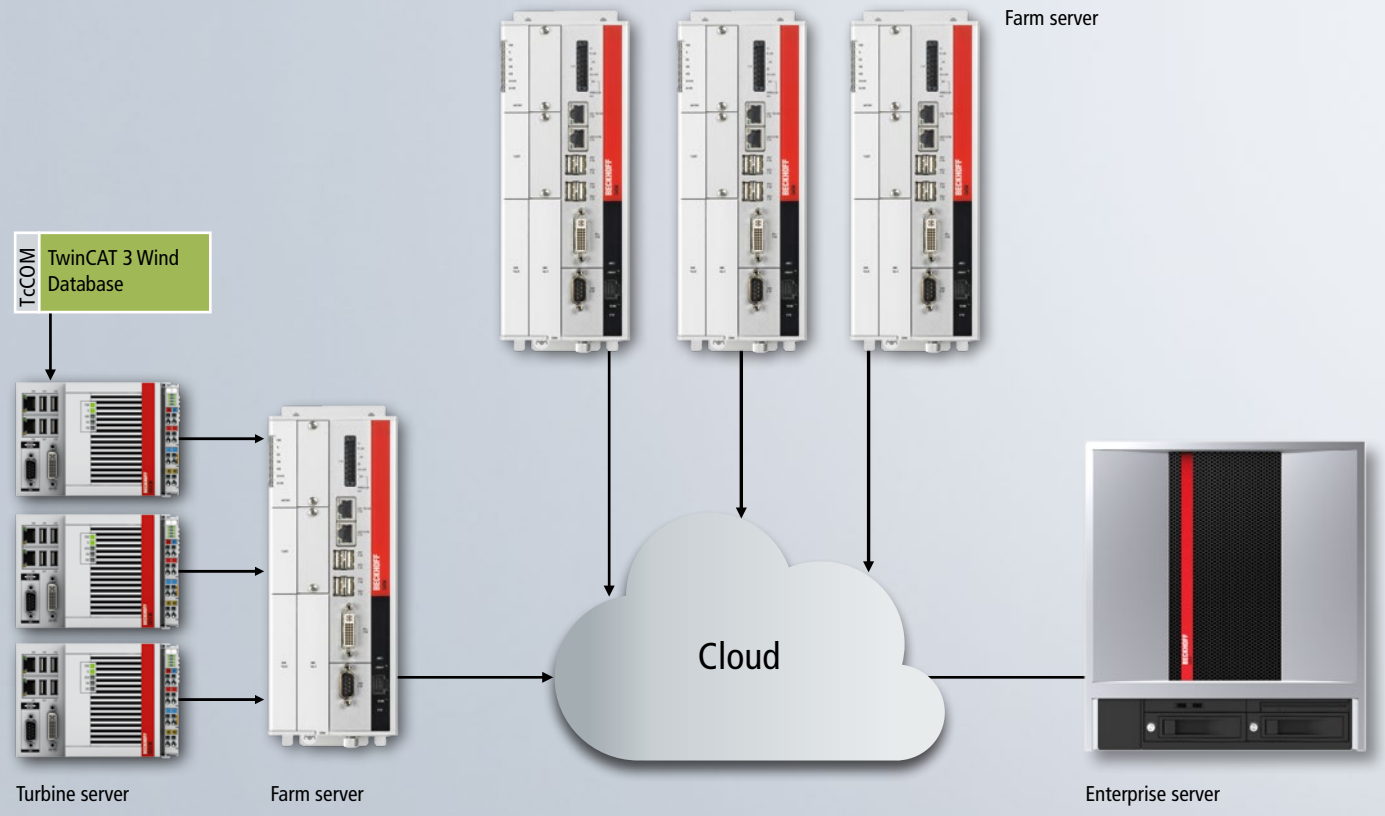
The database is organized in such a way that the data from individual or multiple systems can be collected and managed within a single database. In this way, the data can simply be merged using predefined processes in order to prepare for higher-level analyses and comparisons. If the data from all systems are consolidated on



During important events, critical signals are recorded in a high-resolution trace.

a central company server or in the cloud to form a data warehouse, it is possible to store the data permanently over the complete lifetime of the systems. Such huge data volumes from any number of systems, which are generated in real-time and are accumulated on central servers, can generally be referred to as big data. Big data applications are a further building block towards Industrie 4.0, supported by the option to integrate additional data from wind farm management or from monitoring and measuring systems.

Uniformly accessible, these data facilitate extensive and automated evaluation. They can be used to detect faults or irregularities, create statistics and optimize the operational management, and also for condition-based monitoring and predictive system maintenance.



All system data can be consolidated on central servers for higher-level analysis.

Our references

IEH at KIT, Germany

Renewable energies: Controlling power generation plants with embedded PCs and TwinCAT software

▶ **www.ieh.kit.edu**

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Goldwind, China

TwinCAT Wind and over-sampling technology enable highly efficient condition monitoring.

▶ **www.goldwindglobal.com**

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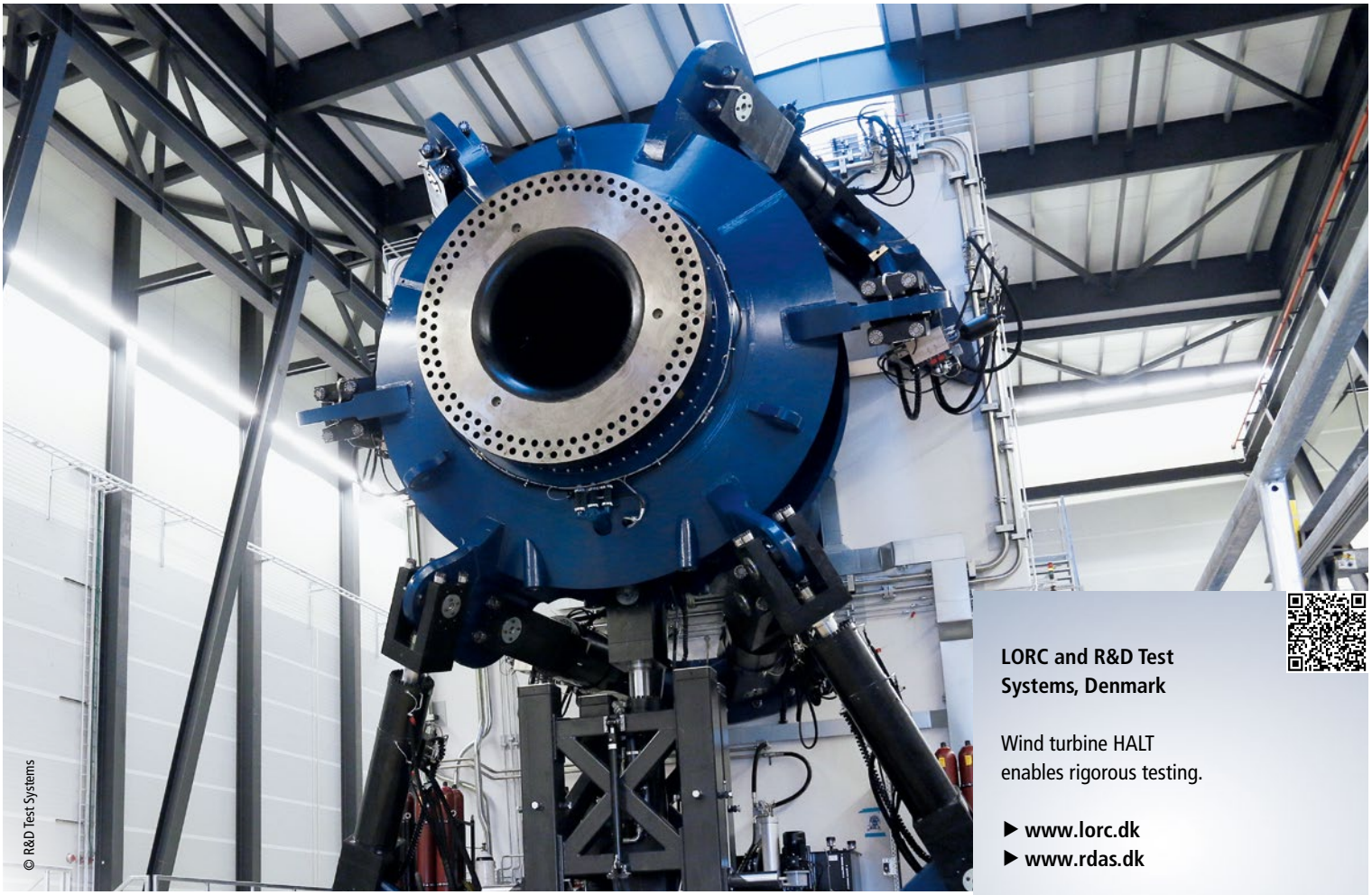
Leine & Linde, Germany

PC-based control combined with strain sensors for monitoring rotor blades in wind turbines

▶ **www.leinelinde.com**



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