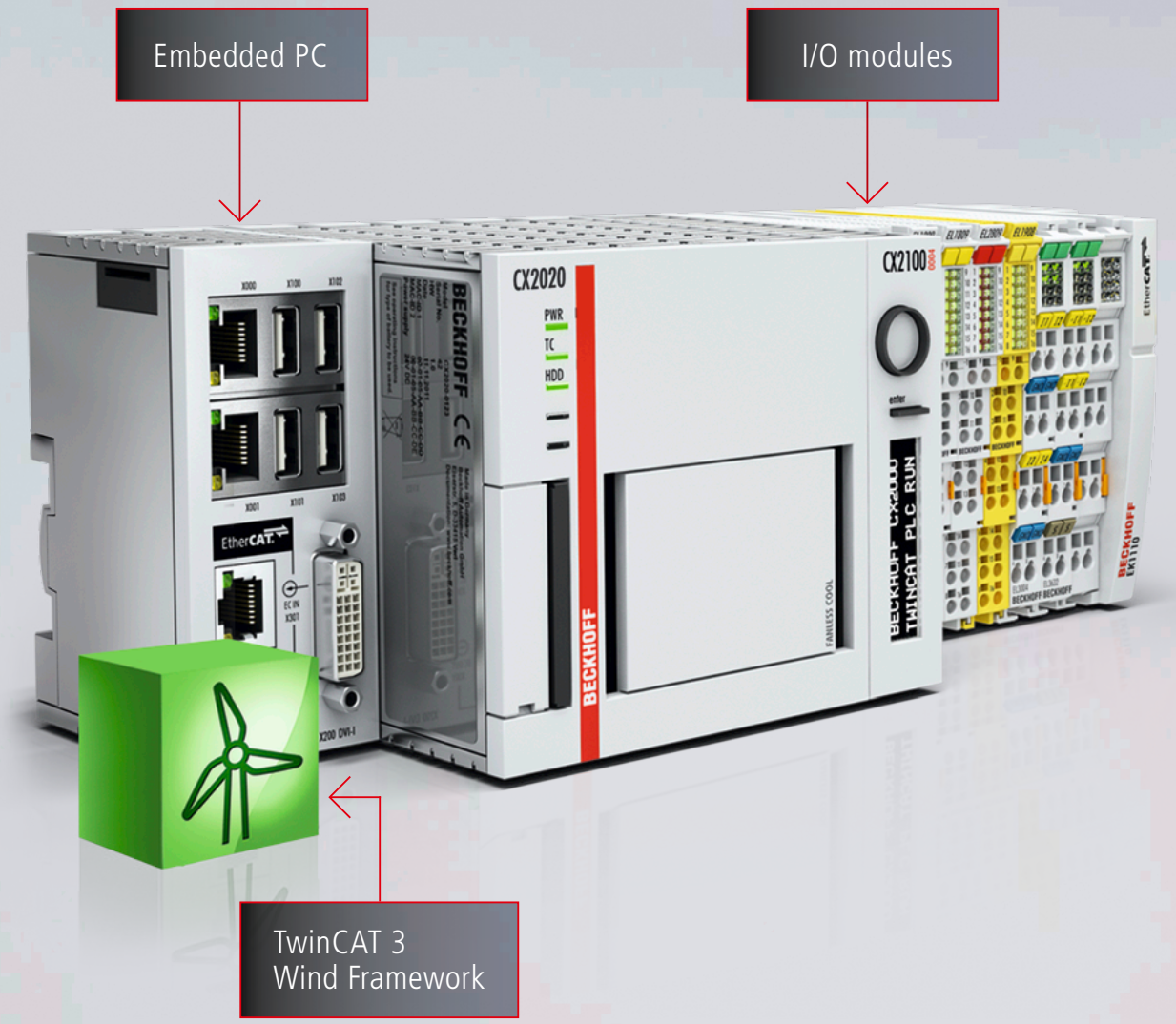
BECKHOFF New Automation Technology

# PC-based Control for Wind 4.0



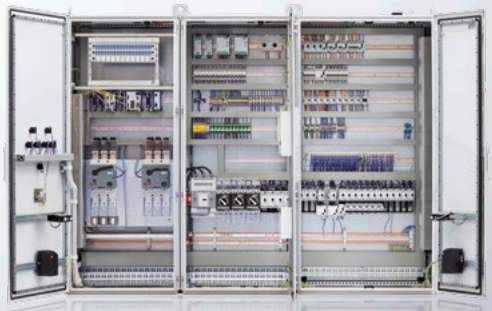

# PC-based control: universal control platform for wind turbines

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

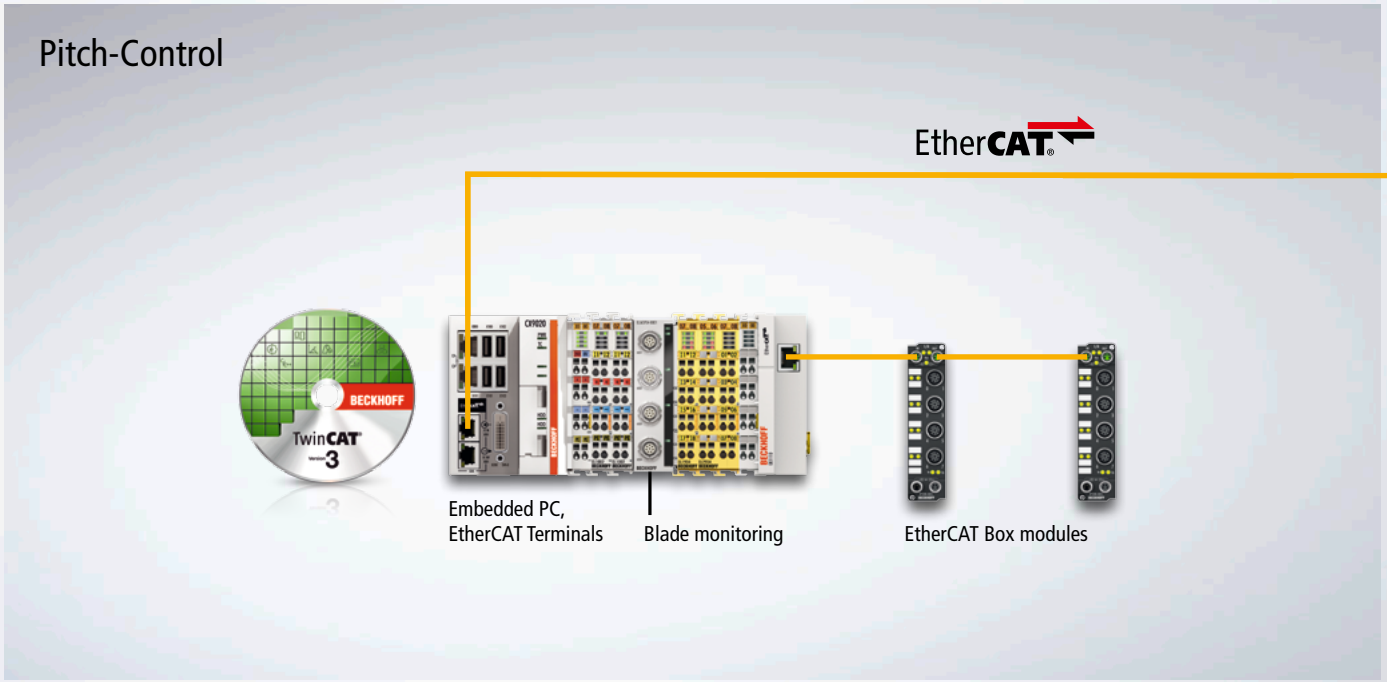
With PC- and EtherCAT-based control technology, Beckhoff implements system solutions that have been tried and tested worldwide: more than 60,000 wind turbines all over the world have been automated using Beckhoff technology, each providing up to 8 MW capacity. An Embedded PC with line-connected I/O modules, 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, the Beckhoff 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, visualisation 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 users to configure a controller that exactly matches the performance requirements of their system and allows subsequent extensions and modifications, for example a retrofit of Condition Monitoring functions, without great expense. In the new TwinCAT 3 Wind Framework, Beckhoff 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.



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




# One system solution for all control functions

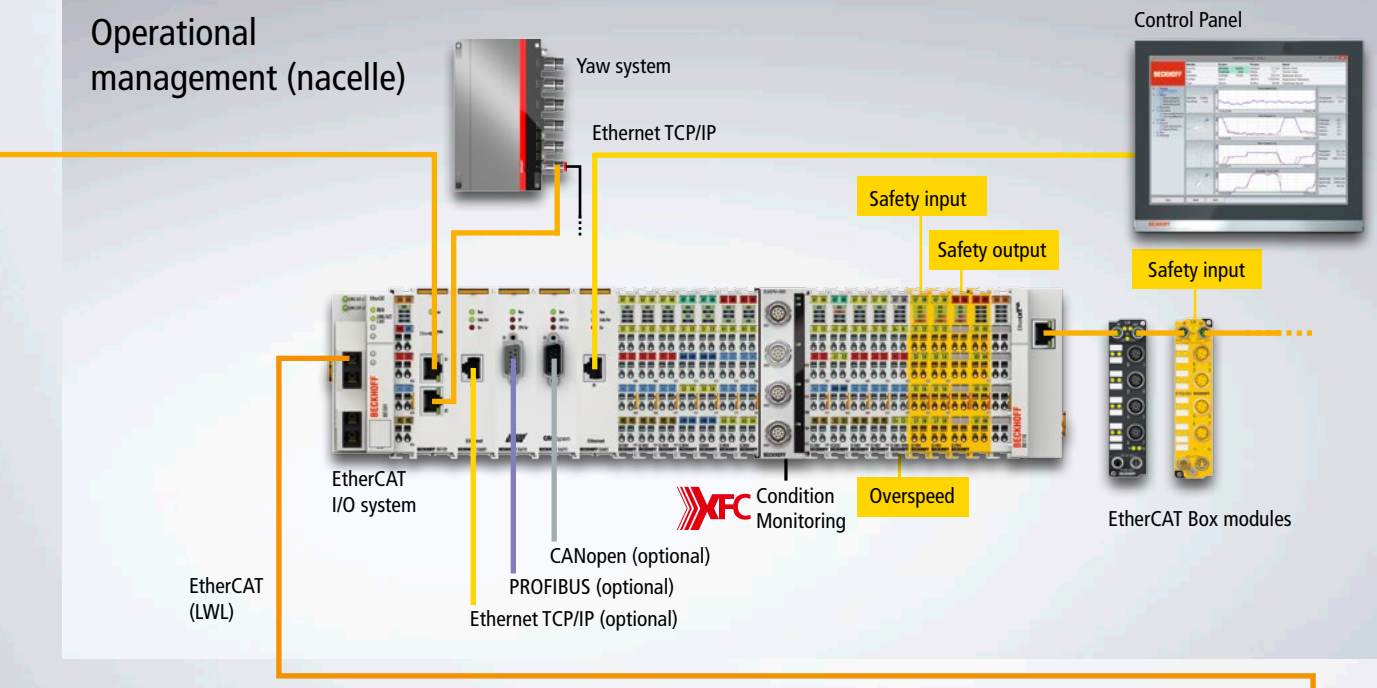
An Embedded PC installed in the tower base acquires and processes all data, monitors the grid feed-in and communicates with the central control room. Safety and measurement technology as well as Condition Monitoring are seamlessly integrated into the controller via appropriate I/O modules. The converter 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**
Beckhoff offers a complete control solution for pitch systems: The DIN-rail-mountable Beckhoff Embedded PCs with line-connected EtherCAT I/O Terminals or IP 67-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.

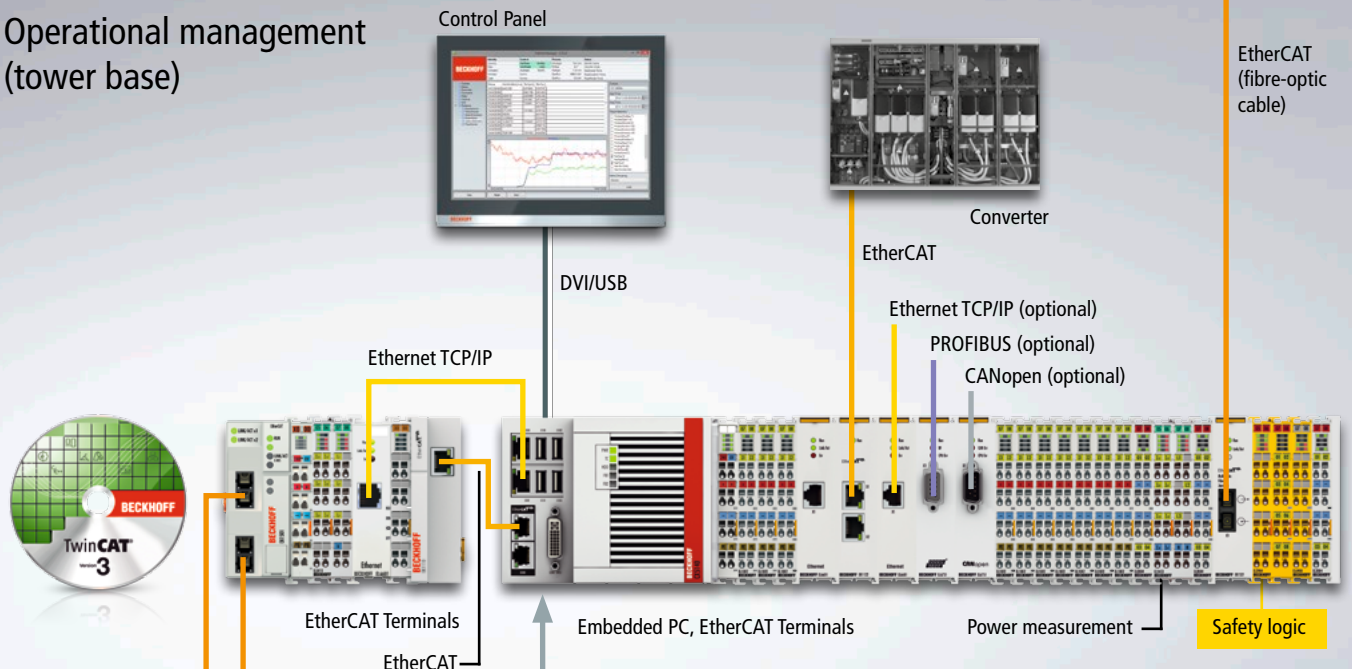
**Operational management**
For operational management in tower base and nacelle, a complete hardware and software solution programmed with TwinCAT 3 in IEC 61131, C/C++ and/or MATLAB®/Simulink® is available. Interfacing with higher-level control systems is based on internationally standardised telecontrol 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 fibre-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.

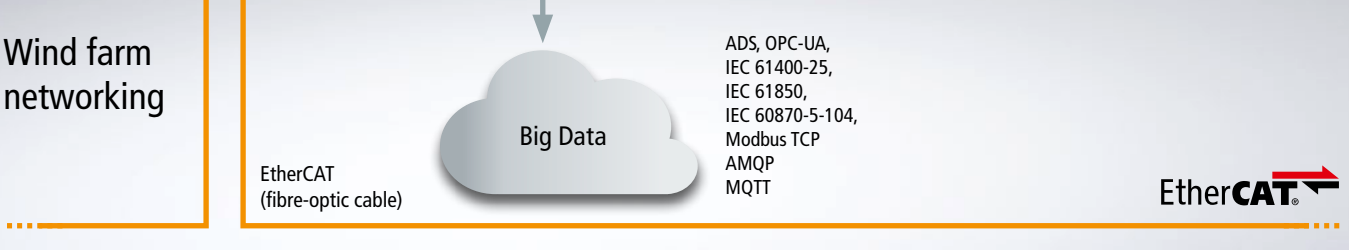
## Operational management (nacelle)



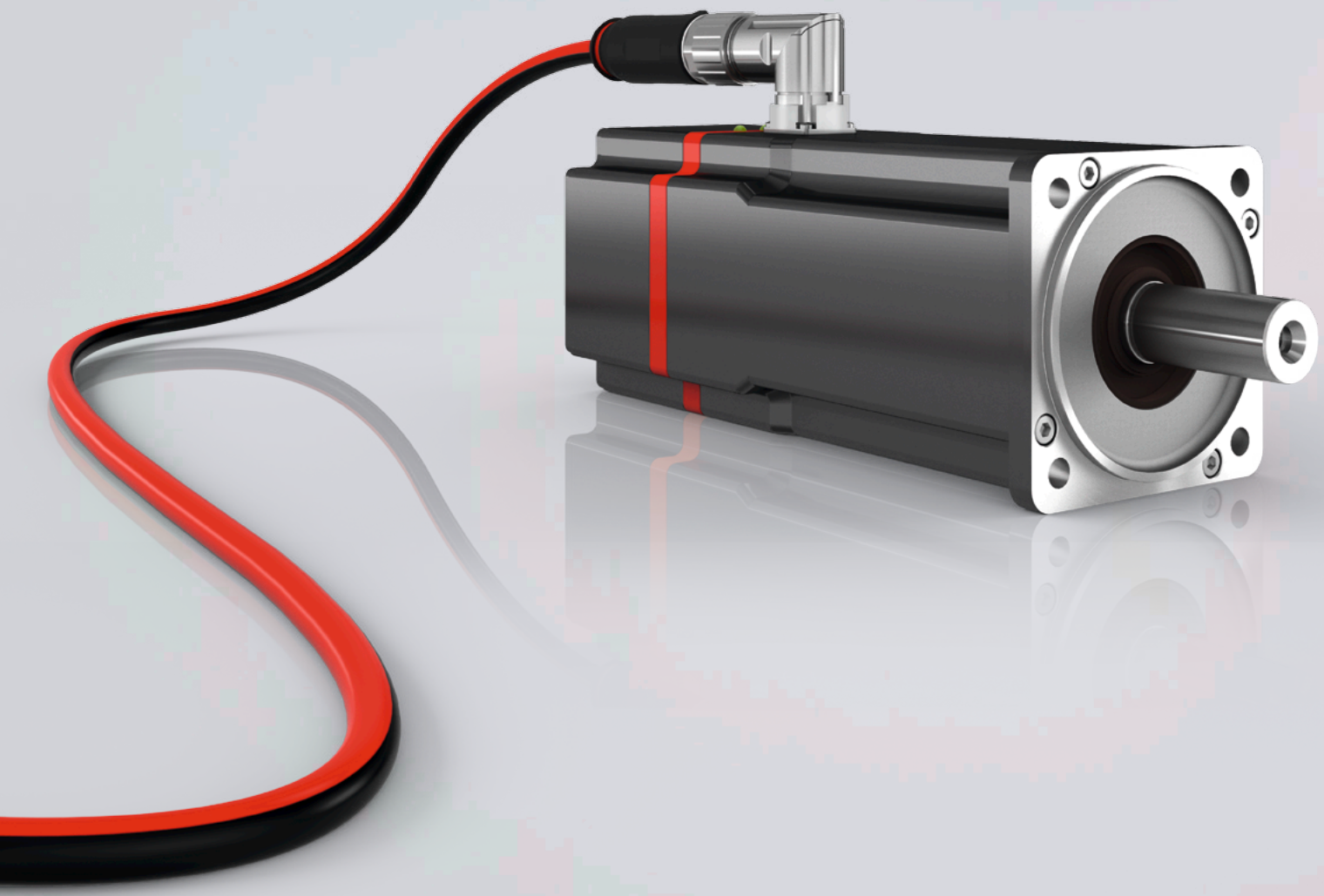

## Operational management (tower base)




## Wind farm networking




EtherCAT



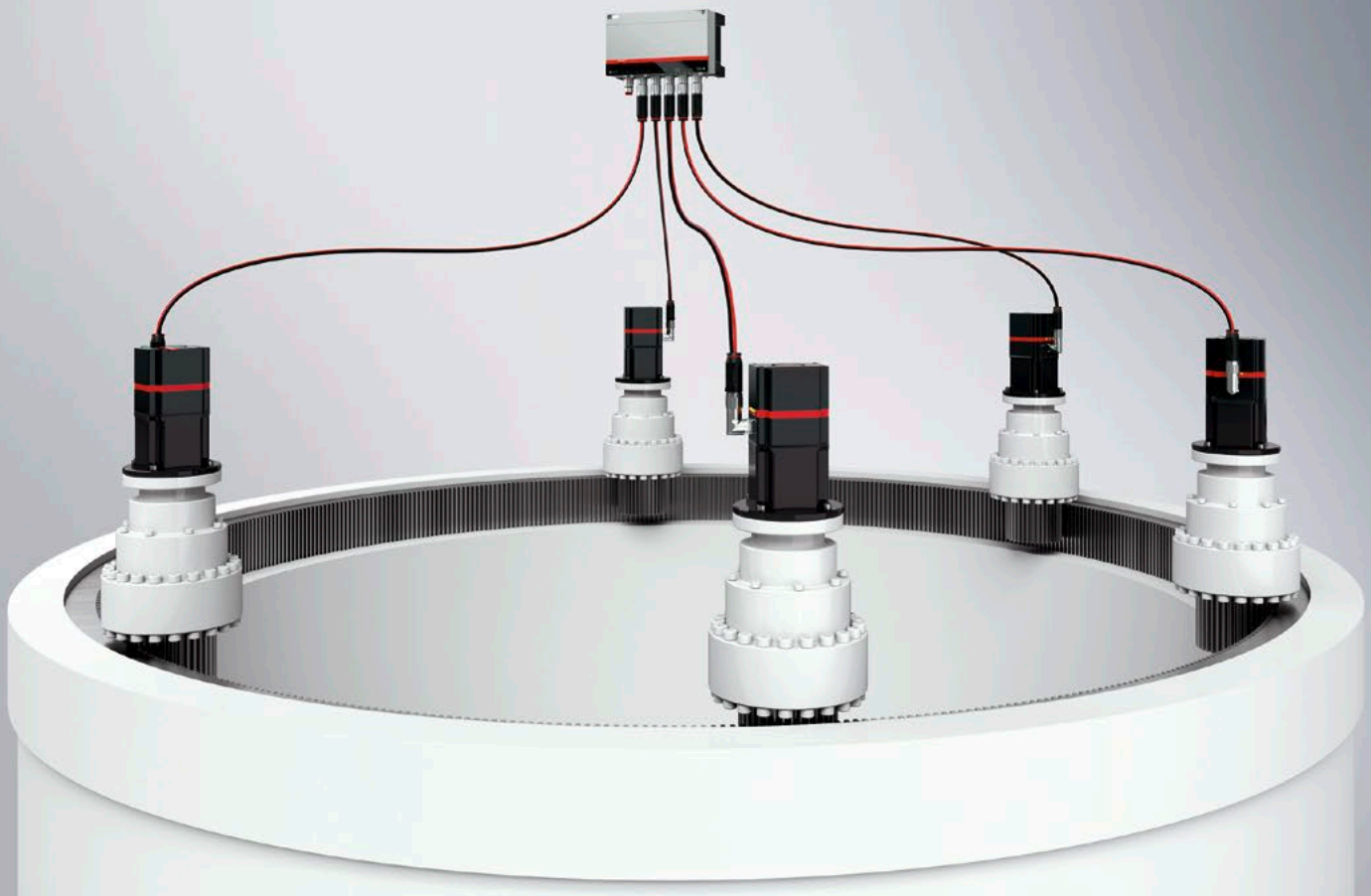
# AMP8000 drive system with servo functionality optimises the wind yield

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

**Distributed servo drive technology in the nacelle adjustment**

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.

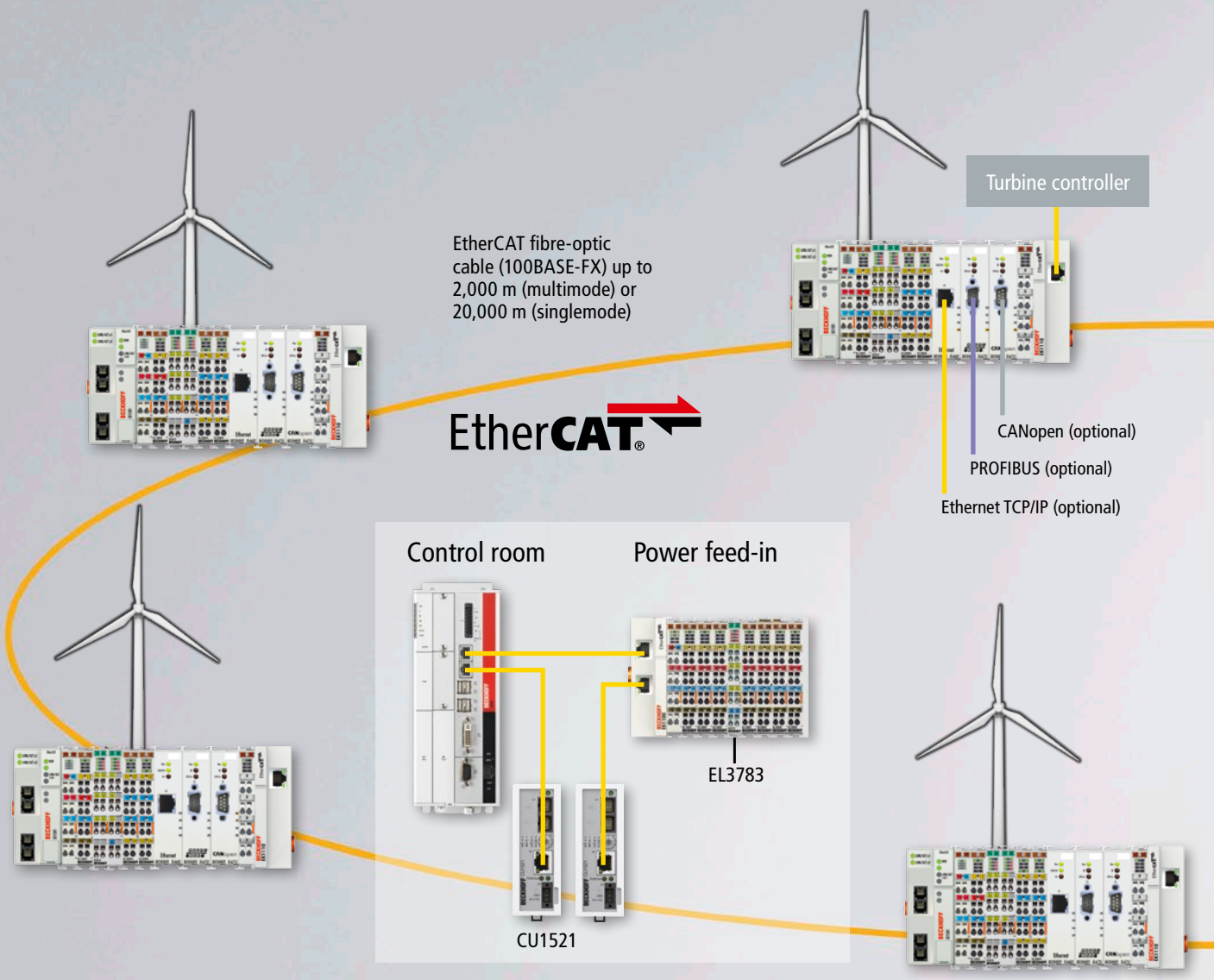
However, the permanent use of the brake unit in the active wind tracking results in constant wear in the yaw system, leading to high maintenance expenditure. The use of



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 new AMP8000 drive system with decentralised 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.




# Ultra-fast wind farm networking: with EtherCAT

- 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 standardised communication protocols

Producers of renewable energies are faced with the challenge to support grids in the event of voltage drops (Low Voltage Ride Through or 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 fibre-optic-based Ethernet infrastructure can be used for this


purpose up to distances of 20 km without a loss of speed. Even the synchronisation of the IGBTs of converters within a wind farm can be realised with this technology.

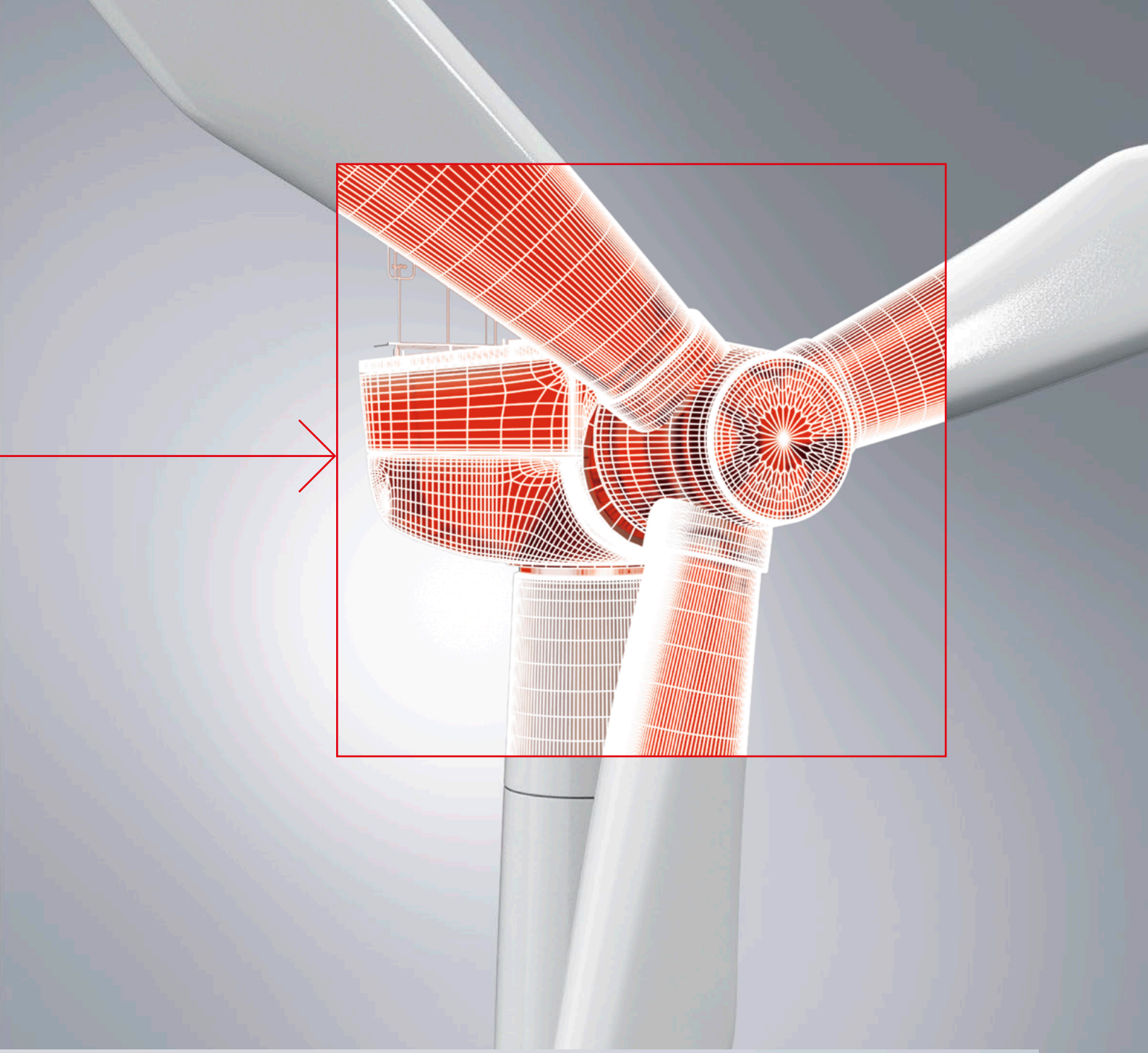
Wind farm networking with EtherCAT is not only faster compared to conventional Ethernet solutions, but also offers substantial cost benefits by eliminating the need for costly switches or hubs. With the EtherCAT power measurement terminal EL3783 integrated into the automation system, momentary current and voltage values can be measured at high frequencies with up to 10,000 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 synchronised to a timeframe smaller than 1 µs. TwinCAT supports the standardised 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®

# System-integrated Condition Monitoring

- 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

The operation and maintenance of modern wind turbines incurs considerable costs. To maintain competitiveness, failure risks must be minimised, 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.



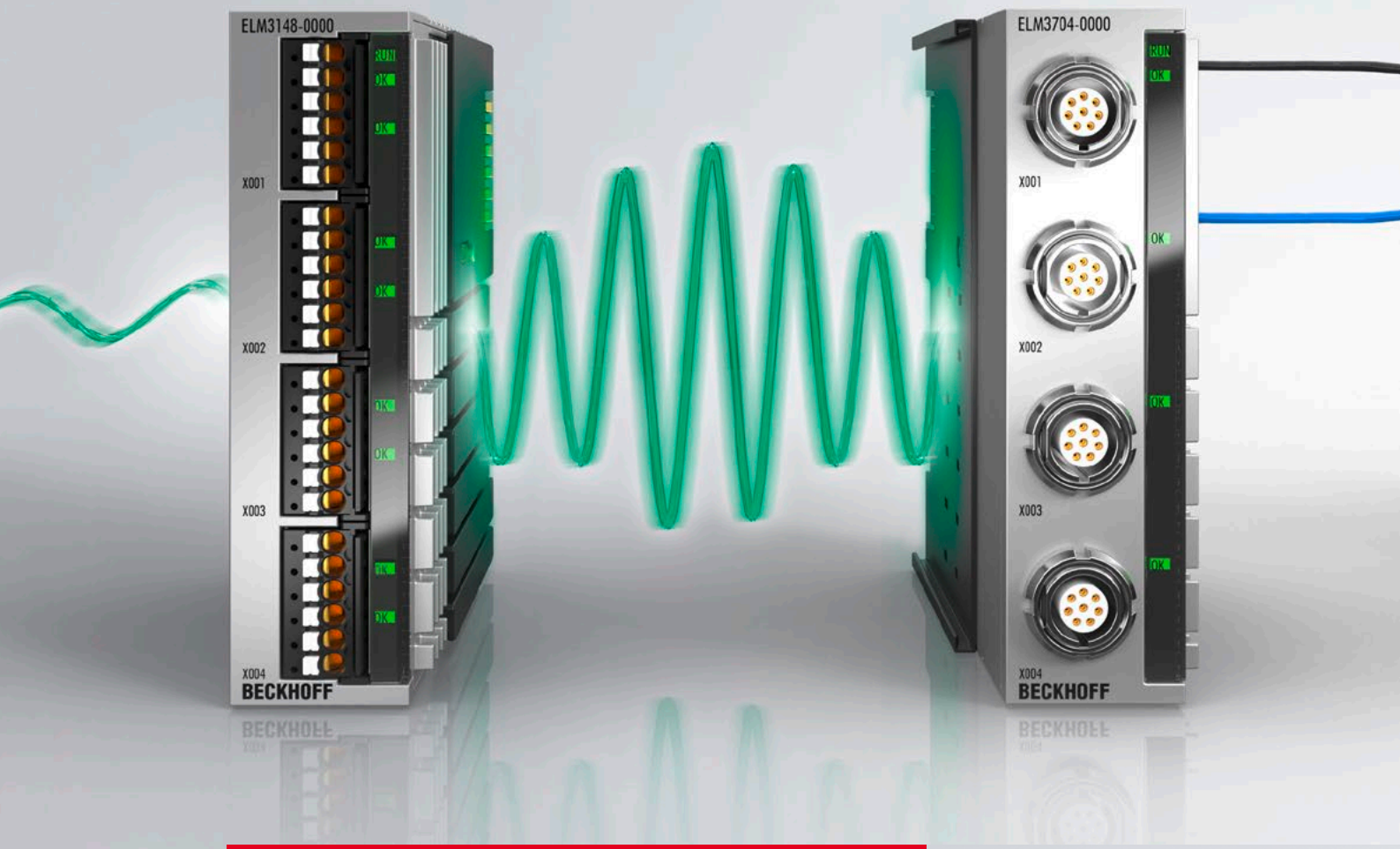
Beckhoff marries the powerful processors of modern PC technology together with EtherCAT as fast communication system, integrating Condition Monitoring functionality seamlessly into the controller. The vibrations of bearings or electrical machines are picked up by standard measurement terminals from Beckhoff 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 Condition Monitoring into the central PC-based controller is advantageous, in particular where large amounts of data from different devices need to be analysed 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.

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

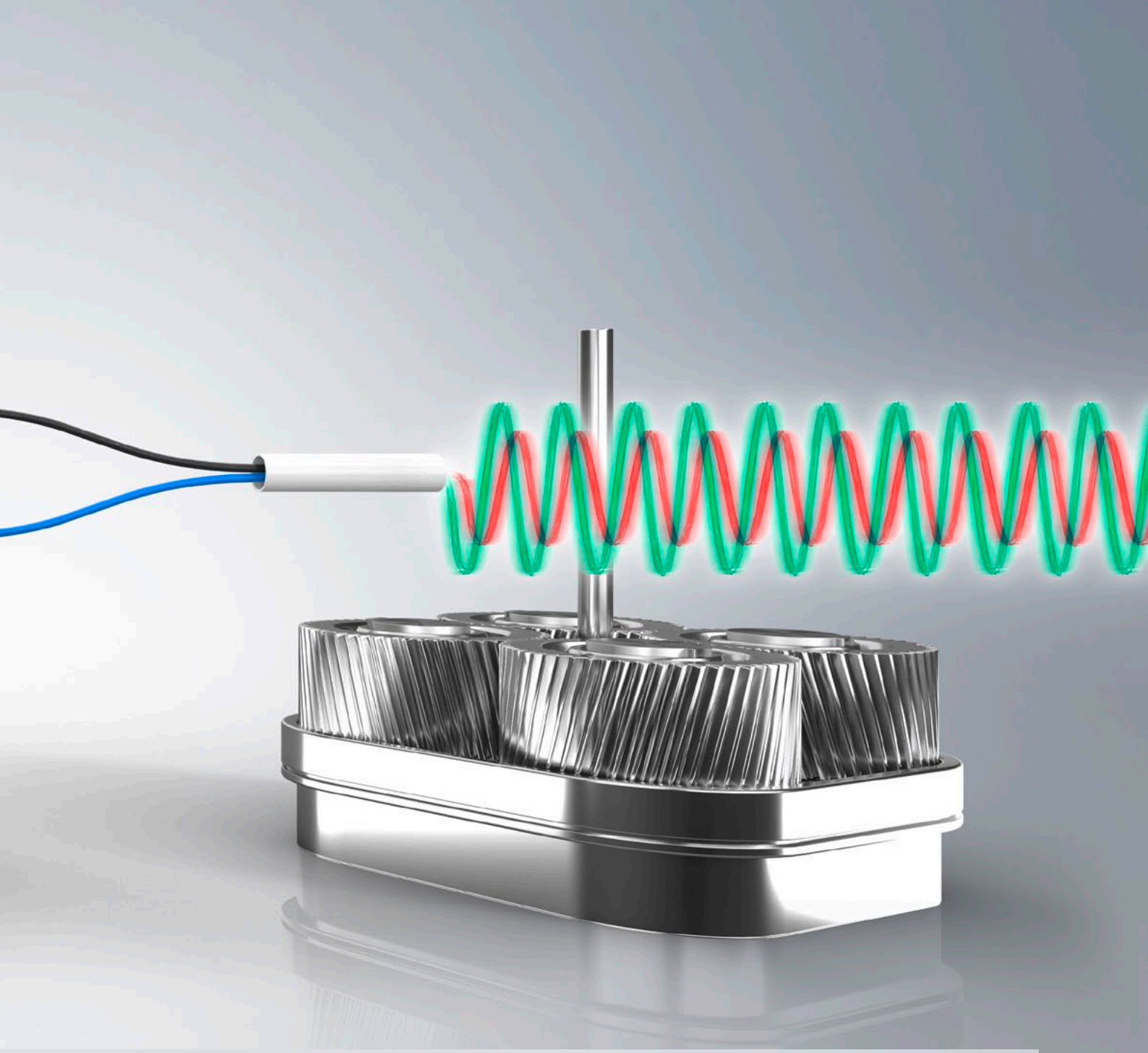
**ELM3x0x basic line**
24 bit
50 ksps per channel
simultaneous
25 or 100 ppm @ 23 °C




# Beckhoff measurement technology: the right device class for every application

- 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

With its continually expanding measurement technology portfolio, Beckhoff serves 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. IP 20 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.

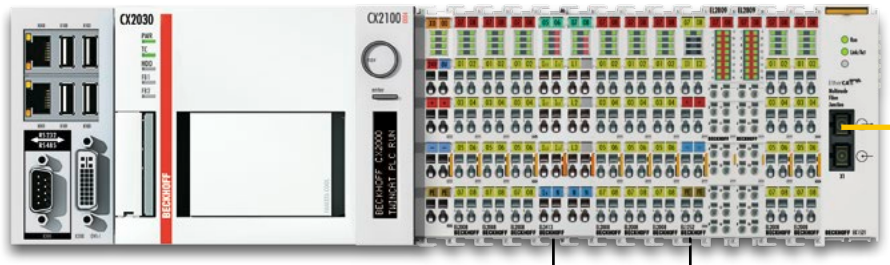
Typical signal forms required for the measurement of prototypes or for condition monitoring, such as strain gauges, temperature sensors and accelerometers, are naturally also available.

Both product lines support proven EtherCAT features such as Distributed Clocks time stamping 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.

# Three steps to integrated condition monitoring

## Step 1

Existing turbine control system




EtherCAT (fibre optic cable)

**EL3783:**
power measurement terminal

**EL1252:**
2-channel digital input terminal with timestamping

## Step 2

**High-frequency data acquisition via EtherCAT Terminals**

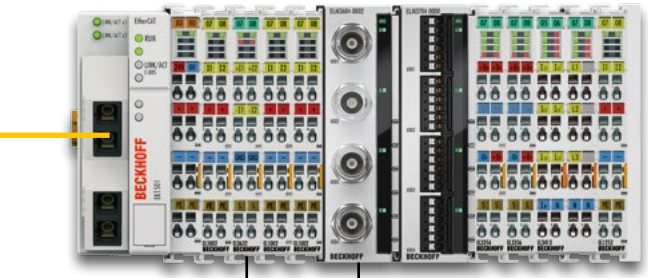
The Beckhoff EL3873 power measuring terminal with oversampling function for the state monitoring of a 3-phase AC voltage system and the EL1252 digital input terminal with time stamp function for the chronologically precise detection of binary control signals are available for the monitoring of the mains 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: High-precision, fast and sturdy measurement technology that can be

## Condition Monitoring hardware

## Step 3

## Condition Monitoring software




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

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


integrated directly into the control system is available in the EtherCAT measurement modules from the ELM device series. 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 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 analyse 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 analysed here and translated into recommendations for action, for example for the planning of maintenance intervals.


## 1 framework with 15 years of expertise from 60,000 systems

- future-proof standard application software
- maximised ease of engineering
- secure and efficient software development
- increased software quality and optimised 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

The TwinCAT 3 Wind Framework bundles the industry expertise that Beckhoff gained in the automation of more than 60,000 wind turbines and makes Industrie 4.0 concepts available to the wind energy industry. 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

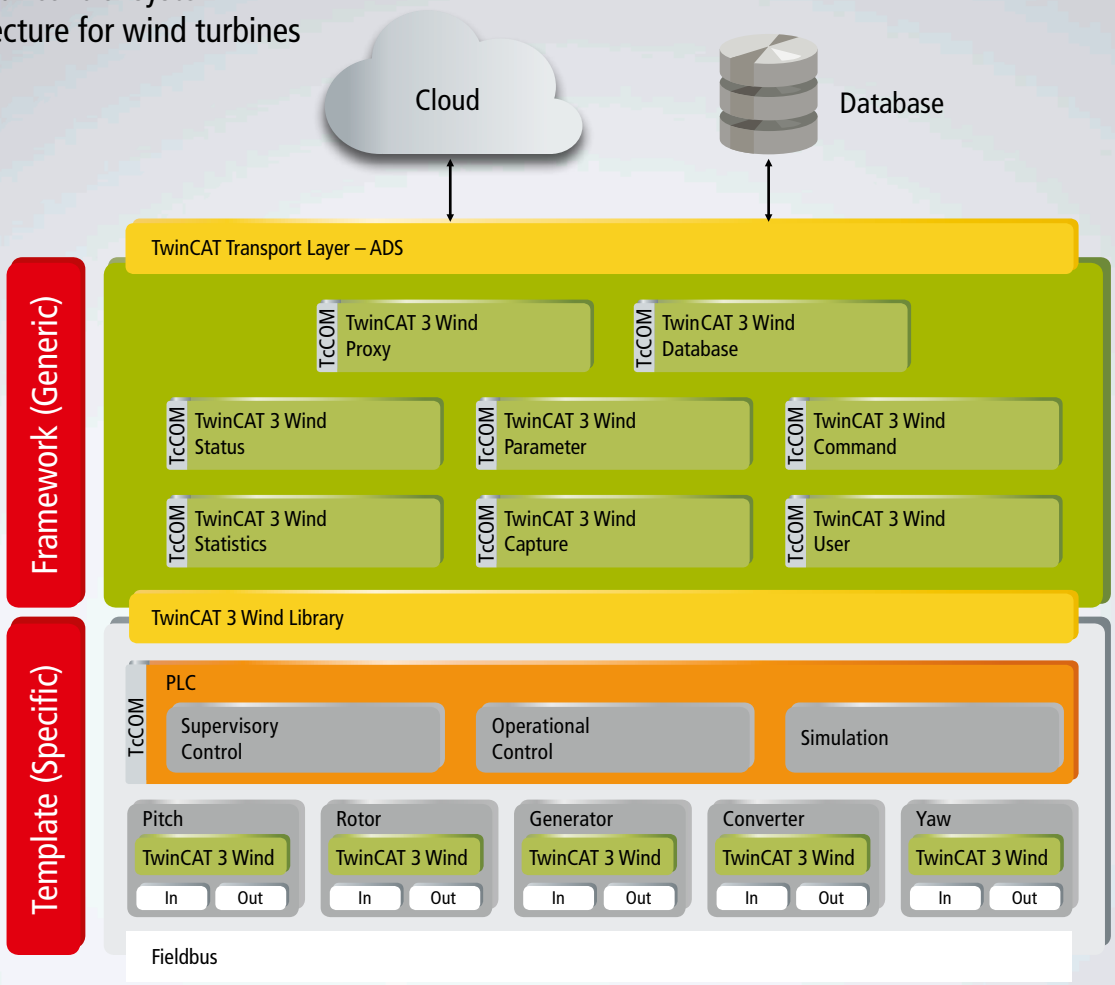
application software. Apart from basic functions for operational management and state machine, there are software function blocks for event management, parameter configuration, user management, data connection, power and condition monitoring and simulation. The integrated Big Data database link enables the comprehensive acquisition, evaluation and provision of data from operational management, condition monitoring and power management in real-time. All data are continuously recorded, summarised in the central controller and analysed 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.

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 and the developer can focus on the actual system functions. The development process is also optimised 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.

The consistent use of the TwinCAT modules and the uniform architecture of the subsystems create an application standard. This standardisation enables programmers to quickly familiarise themselves with the application and the source code, even if it was implemented by another programmer.

# Maximised flexibility: modular engineering for modular wind turbines


## Modular control system architecture for wind turbines

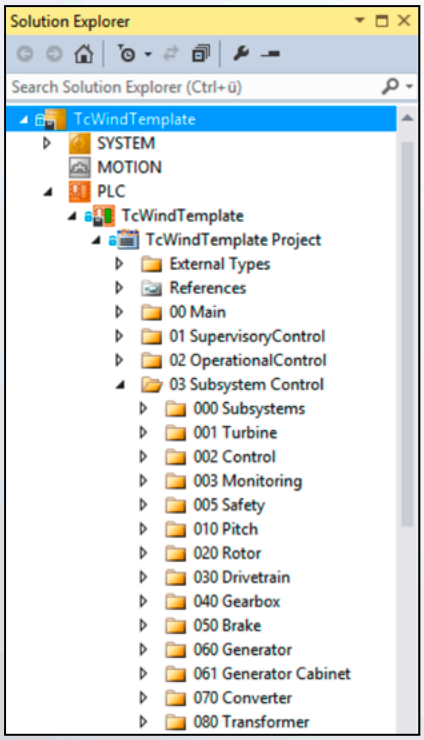



The TwinCAT 3 Wind Framework enables universal and integrative engineering over the complete life cycle of the system. C/C++ and MATLAB®/Simulink® are available as programming languages in addition to IEC 61131-3 for object-oriented, modular programming. Following the Industrie 4.0 concept, the engineering process is automated and engineering tools can exchange data with one another.

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, in which all required functionality of TwinCAT modules and functions is implemented.

Each subsystem of the wind turbine (such as pitch, gear unit, generator, converter, etc.) 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 modularisation of systems. This increases the quality, flexibility and re-usability of the software, while at the same time reducing development time and costs.

The different operating modes for starting, stopping and the higher-level state machine of the system are consolidated in the application template as Supervisory Control



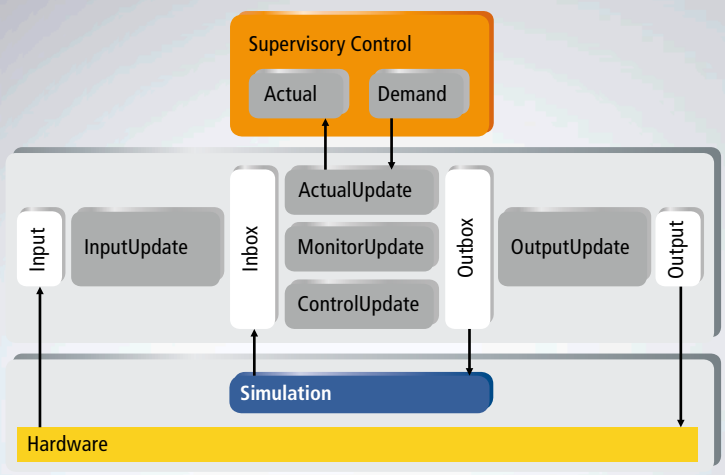

**The application template provides a complete operational management software.**

and implemented in simplified form as PLC function blocks. This results in higher-level set values for operating the system, which are used for control purposes.

General control functions of the wind turbine, such as pitch and torque control, are prepared in the software as Operational Control. For general control purposes, the integration of further modules is possible, for example to integrate algorithms for load calculation. These options include the automatic generation of a TwinCAT module from MATLAB®/Simulink® or the integration of control algorithms via C/C++. Thus, the same controller that was used for load calculation can also be used for general control purposes. The controller does not have to be translated beforehand into a second programming language, eliminating the need for error-prone implementation of the algorithms.

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 model can be adapted and configured to match the individual system. The system simulation is provided as a TwinCAT module, although just like the control application itself, it is ready to be replaced by a specific model from MATLAB®/Simulink® or C/C++, as required.

The simulations integrated in the application can be used to map, analyse 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. In addition, test benches can be configured for software-in-the-loop or hardware-in-the-loop simulations and even for training sessions using the original application software. Real-time simulations enable rapid control prototyping and virtual commissioning with a single version of the software, enabled by simple parameter modifications.




**The uniform architecture for the integration of subsystems creates a standard in the application and enables quick familiarisation by programmers.**

# Covering all functions: generic TwinCAT modules for higher-level services


System operator

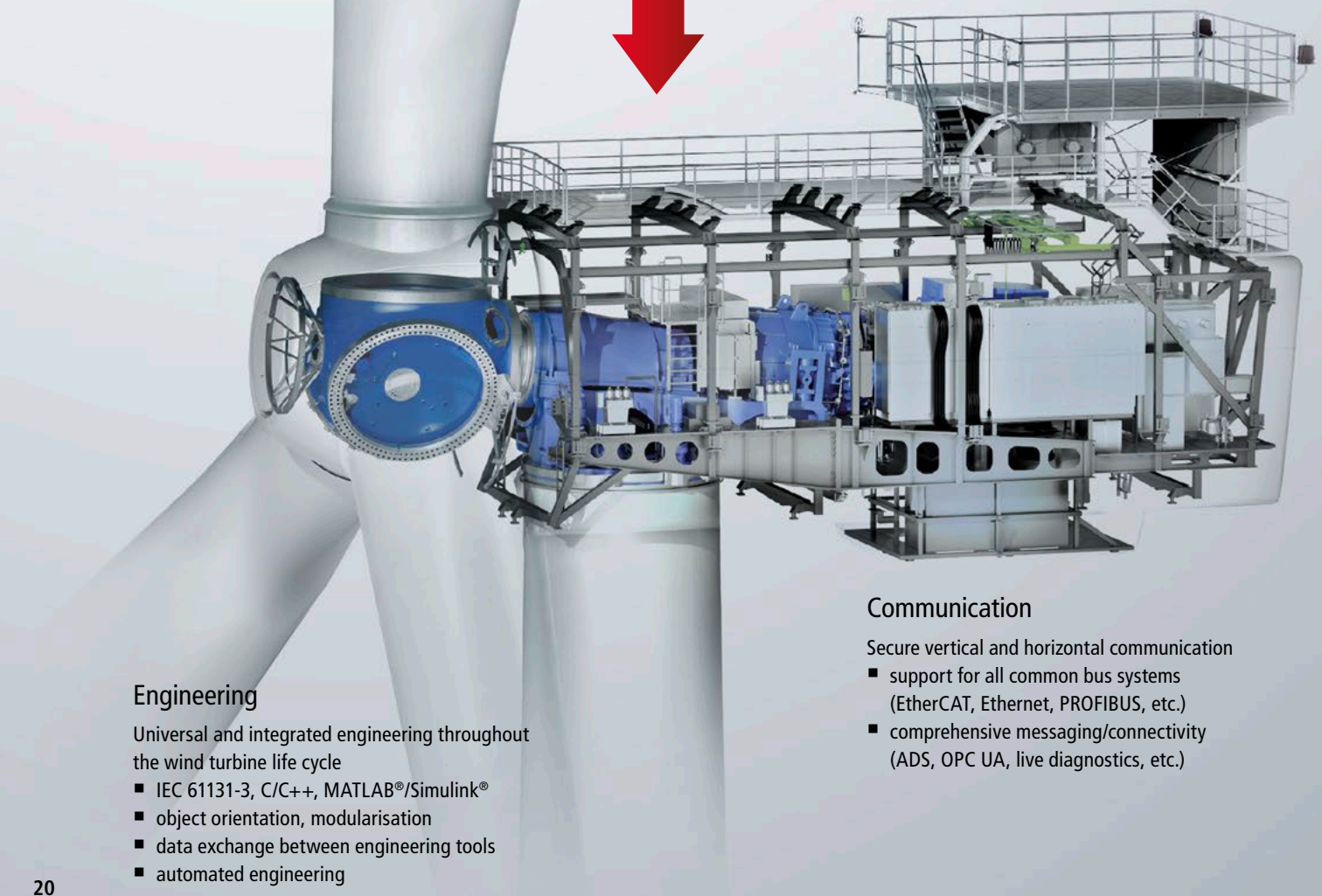
Big Data

Manufacturer

## Big Data

Optimised 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



## Communication

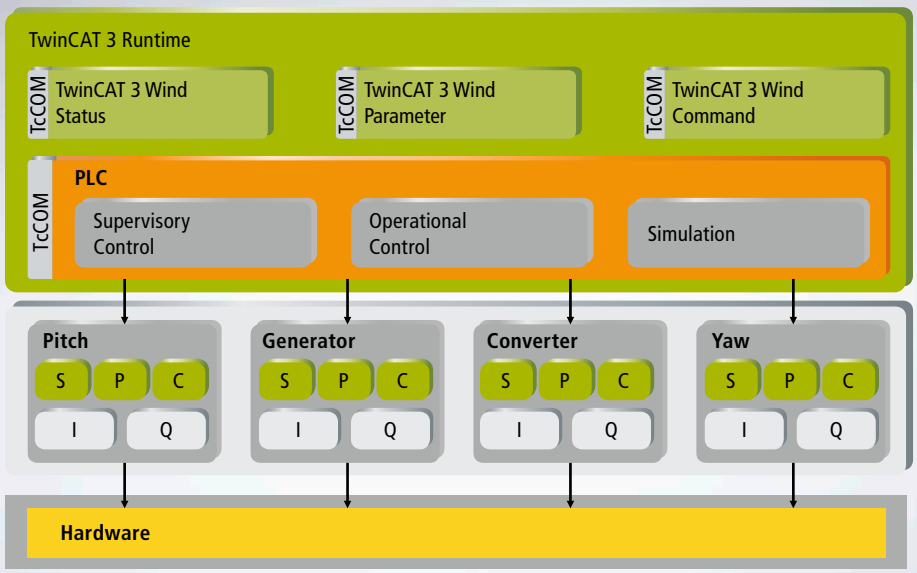
Secure vertical and horizontal communication

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

## Engineering

Universal and integrated engineering throughout the wind turbine life cycle

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




**Operational Control is implemented as a standalone TwinCAT module, and the subsystems are implemented as independent objects.**

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.

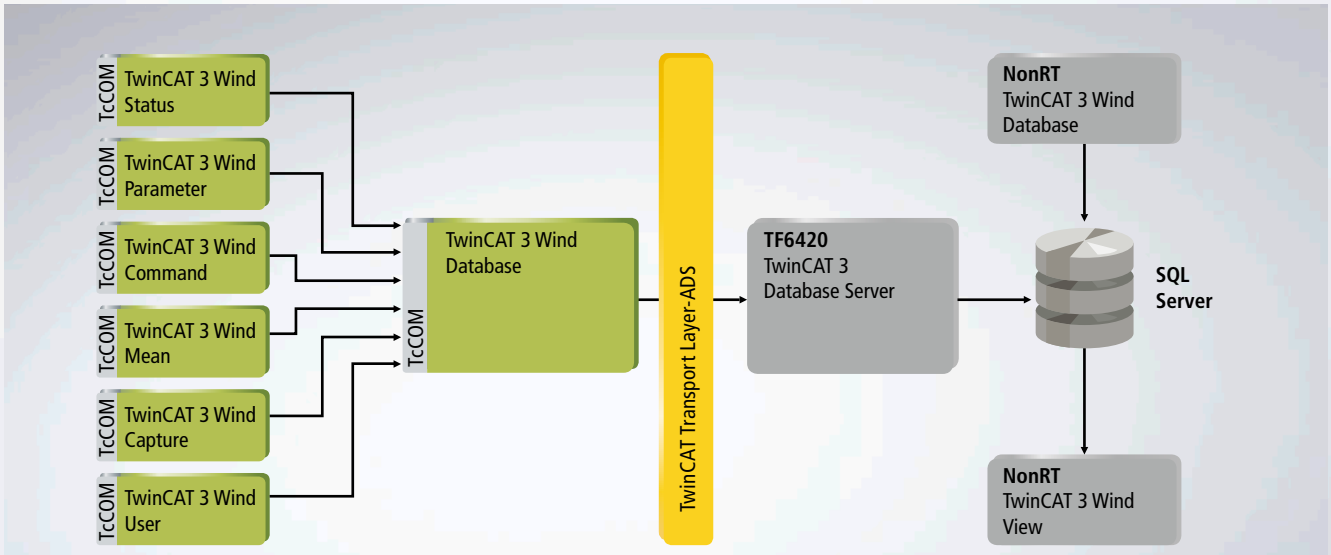
The Status module supports the monitoring of all components and enables error detection, event management, error handling and reporting. Status objects are created that represent an event and are used to display messages, warnings or errors. A system stop can optionally be configured as a response to specific events, and also event-triggered high-resolution logging of system data or sending of notifications. Events are evaluated by the Status module and the corresponding reactions are generated. In addition, each event is logged in the database and provided with a timestamp; this enables the frequency and duration of the occurrence of each event to be determined and conclusions to be drawn about the operation or level of availability of the system.

The Parameter and Command modules provide services for configuration and interaction with the application. A Parameter object can assume any value of any data type. For example, temperature monitoring limits can be implemented in the form of two Parameter objects, whose values indicate the minimum and maximum temperature or are used for switching the heating on or off. In this way, the entire wind turbine configuration can be mapped and modified, saved and reloaded via parameters. Command objects can be used to trigger or activate actions in the application. Each interaction, for example via a switch at the control cabinet door or a button from the visualisation, can be implemented via a Command object.

Signal logging and a statistical analysis is provided by the Capture and Mean modules. Raw data are flexibly recorded via Capture objects. 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 behaviour 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. These user rights are checked in the application. Thus, the operational management automatically ensures correct user access, independent of an external user management.

# Optimises reliability and prolongs the lifetime of wind turbines: Big Data

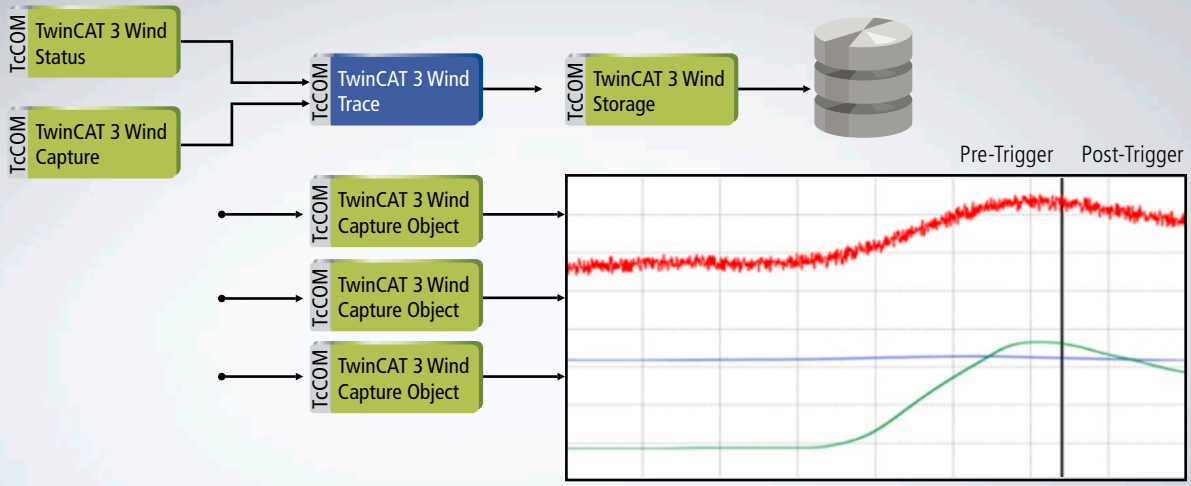



**Data from all TwinCAT modules are provided in a SQL database by the TwinCAT 3 Database Server.**

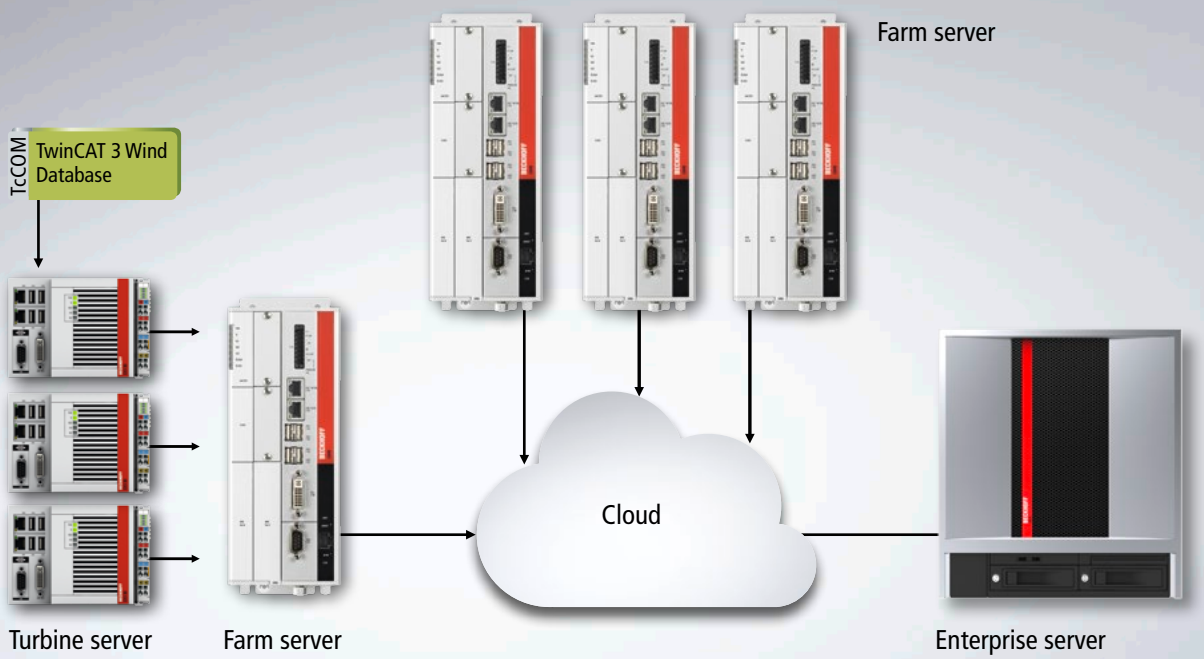
All information from the various TwinCAT modules is continuously transmitted in real-time to the database module. It is then saved in the database, or retrieved from it, via SQL procedures. The TwinCAT 3 Database Server manages the data in the database.

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. For instance, the Mean module calculates mean values consistently in each application cycle, and each value from each cycle is used for average calculations. The Capture module evaluates the scanning of values and integrations in each cycle, in order to make calculation as accurate as possible. 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 optimise the system.

The database is organised 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 procedures in order to prepare for higher-level analyses and comparisons. If the data from all systems are consolidated on 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 optimise the operational management, and also for condition-based monitoring and predictive system maintenance. Data Mining can be used to gain new insights into system operation. For example, it may be possible to determine relationships between component wear and their switching frequency and operating cycles, allowing components to be replaced before a costly failure occurs.




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




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

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www.chinawindey.com/en/about.aspx
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| | built-in Control Panel CP6832 |
| I/O system: | EtherCAT Bus Coupler |
| | Bus Terminals |
| Software: | TwinCAT PLC |

www.adwenoffshore.com

**Further references**

- Guodian United Power Technology Co., Ltd., Jiangsu Province, China
- Vensys Energy AG, Neunkirchen, Germany

Pitch
- Atech Antriebstechnik GmbH, Mehring, Germany
- Dongfang Electric Corporation (DEW), Chengdu, China

Brakes
- Svendborg Brakes A/S, Vejstrup, Denmark

Simulation/Test
- Lindo Offshore Renewables Center (LORC), Denmark
- IWES Fraunhofer, Germany

Condition Monitoring
- 8.2 Monitoring GmbH, Hamburg, Germany
- cms@wind GmbH, Hamburg, Germany
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