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The New Automation Technology Magazine

Wind Compendium 2022

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The Wind Compendium 2022, a special edition of our PC Control customer magazine, is a collection of selected application reports about wind power which have been realized with Beckhoff technology. The wide range of applications with varying degrees of complexity will give you an idea of how versatile the solutions are that can be implemented with the open and universal PC- and Ethernet-based control technology from Beckhoff and the benefits it provides.


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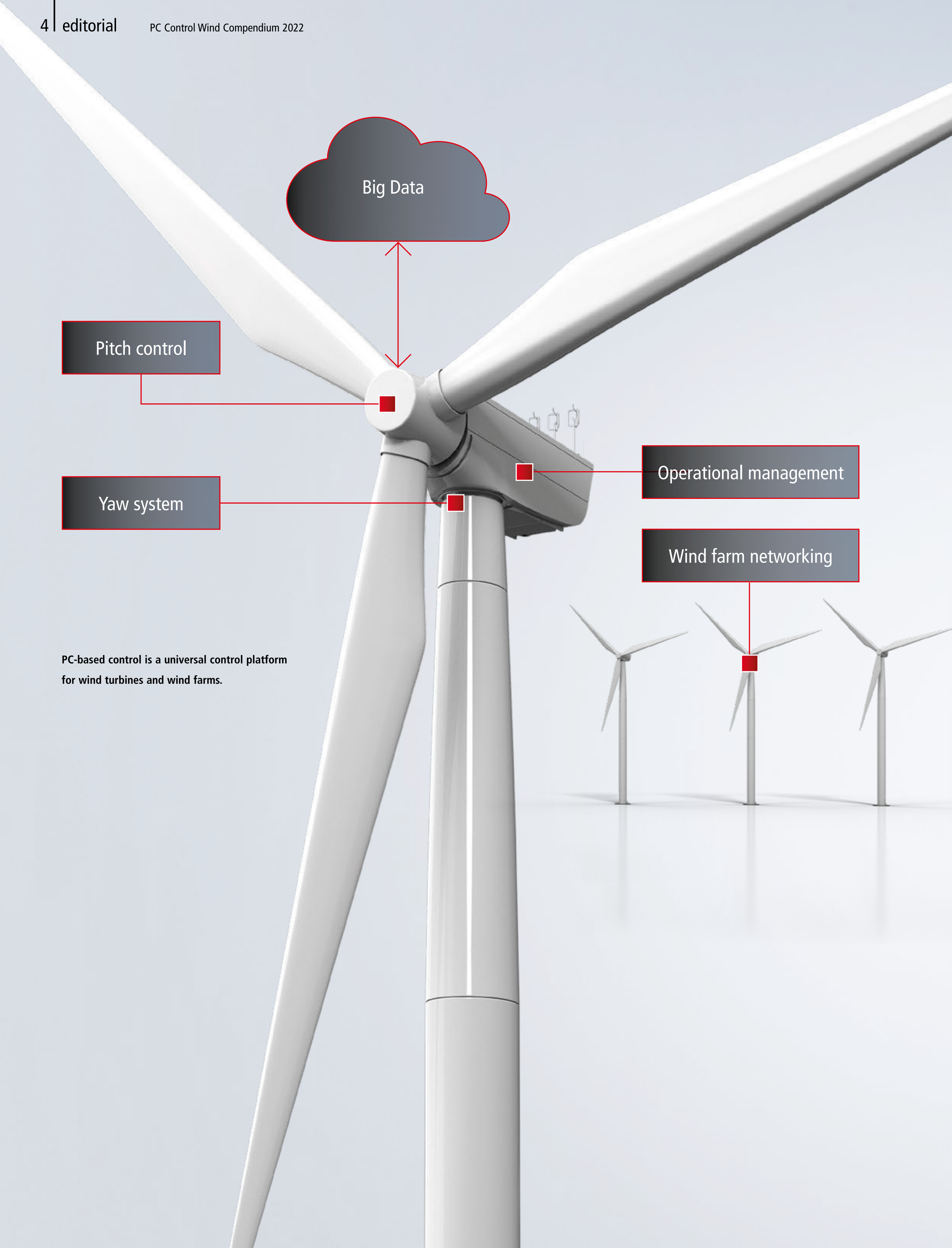

PC-based control is a universal control platform for wind turbines and wind farms.

Nils Johannsen, Technical Management Wind Energy, Beckhoff Automation

Wind energy – record installation and technology innovation

Impressive figures: according to the Global Offshore Wind Report 2022 of the Global Wind Energy Council (GWEC), offshore wind turbines with a total capacity of 21.1 GW were connected to the grid in 2021 – three times more than in in 2020. This puts the cumulative global offshore wind capacity at 56 GW at the end of 2021, or about 7% of the total installed wind capacity. According to GWEC, more than 315 GW of capacity will be added by 2031, and even this high growth is likely to be significantly exceeded in view of the Ukraine war and increasingly noticeable climate change. The importance of wind energy – both offshore and onshore – will therefore continue to rise, as too will the importance of the control technology that is essential for reliable and efficient power generation.

PC-based expertise from over 100,000 wind turbines

On the basis of PC-based control and EtherCAT technology, Beckhoff makes system solutions available for wind turbines that have been tried and tested worldwide: more than 100,000 wind turbines all over the world up to a size of 14 MW have been automated using PC-based control. This control architecture is perfectly suited to the requirement profiles of the wind power industry: openness and scalability, flexibility in the design of the controller, and a high degree of integration. All processes, from the operational management and control of pitch, converter, yaw, and brakes through to wind farm networking, are executed in software on an industrial PC. Safety technology and condition monitoring are integrated seamlessly into the terminal segment via corresponding I/O modules. In the TwinCAT 3 Wind Framework, the turbine manufacturer has a software tool at its disposal that not only gives it optimum assistance in the programming of its facilities, but also supports the Industrie 4.0 approach to wind energy. Software libraries and hardware components specially developed for the wind power industry round out Beckhoff's wide range of solutions.

PC-based control offers immense potential for technological innovation. One example is the system-integrated Condition Monitoring for the surveillance of blades, bearings, gearboxes and generators, as well as structural components such as the tower foundations. This is superior to conventional hardware-based Condition Monitoring solutions on account of its improved error detection and holistic system analysis capabilities. Wind farm networking with EtherCAT is not only faster compared to conventional Ethernet solutions, but it also offers substantial cost benefits by eliminating the need for costly switches or hubs. In addition, the EL3783 EtherCAT power measurement terminal integrated into the automation system can be used to measure momentary current and voltage values with up to 20,000 samples per second. And with the EtherCAT Distributed Clock functionality, the measured values of all wind turbines and the measurement at the point of common coupling of a wind farm can be synchronized to a timeframe smaller than 1 µs. Another innovation factor is the distributed servo drive technology in the nacelle adjustment: traditional yaw systems are often based on mains-operated asynchronous motors without soft starter, driving against an applied hydraulic brake. Nevertheless, to achieve a sufficient torque in soft supply networks, the motor and the upstream supply elements are often greatly oversized. This leads to volume and weight problems, as well as high fatigue loads on the mechanics. The AMP8000 drive system provides a remedy here with decentralized servo functionality integrated into the motor, as well as compact design and greater efficiency with the safety of adequate breakaway torques. This results in less mechanical stress, as the loads are balanced with no applied brake or mechanical backlash.

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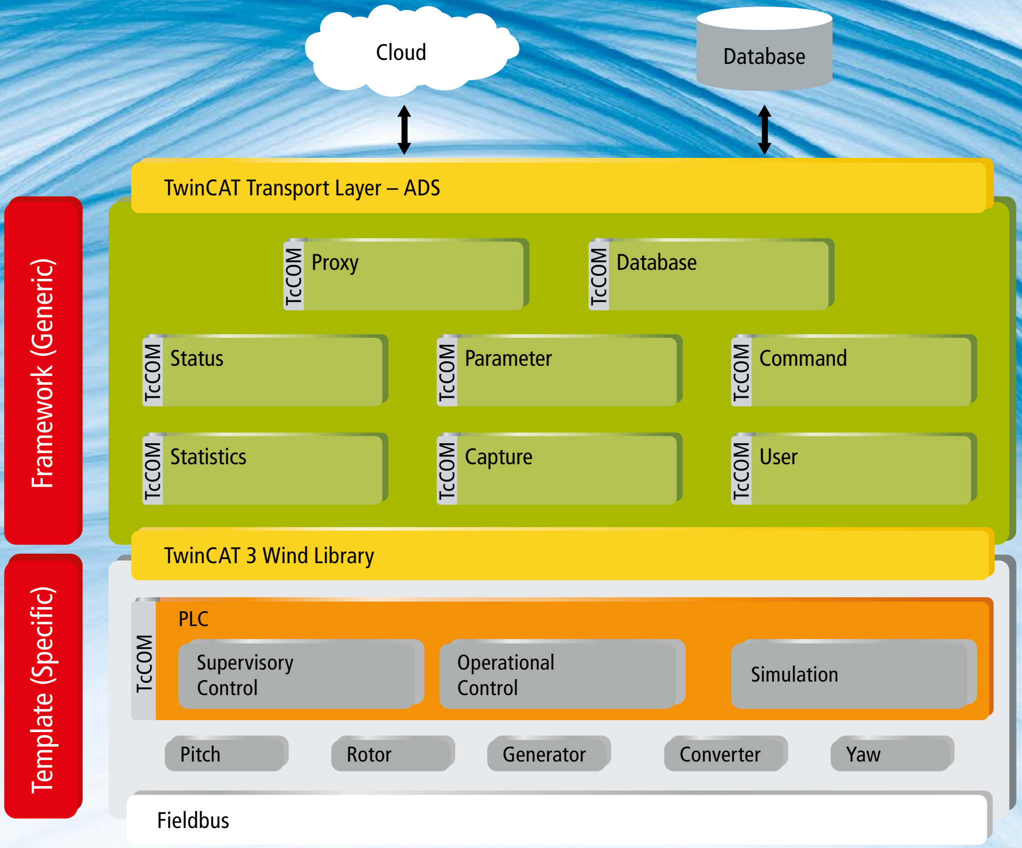
TwinCAT 3 Wind Framework for wind turbine automation

1 Framework and 20 years of expertise through 100,000 installations

The new TwinCAT 3 Wind Framework will enable manufacturers of wind turbines to program their systems quickly and easily on their own. All functions are integrated into one universal software package: from event management to database connectivity, and even basic functions such as state machine and hydraulics. A prefabricated application template considerably simplifies the programming process, enabling developers to concentrate on the essential system functions. The result: efficient engineering, shorter time-to-market, and the benefits of Industry 4.0 for the wind industry.



Application templates and encapsulated modules enable modular software architecture with high functionality

Beckhoff has offered advanced wind industry solutions for over 16 years. TwinCAT 2 Wind libraries have been tested and proven in a wide range of applications, offering users a robust basis for the development of software in the operational management of wind turbines.

The ever-accelerating development rate of increasingly larger wind turbines creates new challenges: more intelligent systems with additional sensors and actuators are used, further increasing the complexity of the systems. This makes fault analysis much more complex and stable operation increasingly difficult. To address these challenges, the existing concepts and technologies were combined, resulting in the development of the new TwinCAT 3 Wind Framework.

Comprehensive functionalities are implemented in encapsulated TwinCAT modules, which are then integrated into the TwinCAT 3 architecture. Efficient software development is ensured through a modular architecture in the application template, as well as through proven and directly applicable TwinCAT modules and functions. The flexible configuration makes adaptation to user-specific application requirements very straightforward. System diagnostic functionality is ensured by means of comprehensive data storage capacities in a database. The benefits include future-proof development, efficient commissioning, and optimum operation of wind turbine automation software.

TwinCAT 3 offers the option to implement IEC 61131-3, C++ and MATLAB®/Simulink® modules, load them into different CPU cores, run them in different real-times, and enable them to reliably interact with each other. The basis for this is the TwinCAT module language, which describes the characteristics of the TwinCAT modules, e.g. with regard to the process parameters or the methods.

Programming operational management software based on template and function library

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, through which all the options found in the TwinCAT modules and functions are implemented.

A simplified diagram of the application template is shown in Figure 1. Each subsystem of the wind turbine (such as pitch control or converter status) is represented by a discrete object. In this way, the subsystems (such as pitch, converter, etc.) can be developed, used and tested independently. The subsystems now also feature interchangeable software, as is already common practice in the mechanical modularization of systems. The modularization enables parallel development, and programmers can focus on the specific functions and system components they work on. This increases the quality, flexibility and reusability of the software, while at the same time reducing development time and engineering costs.

The different operating modes for starting and stopping, and the higher-level state machine of the system, are consolidated in the application template as supervisory control 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 these control purposes the integration of other modules is intended, for example to take over the algorithms from the load calculation.

These options include the automatic generation of a TwinCAT module from MATLAB®/Simulink®, or integration of control algorithms via C/C++. Thus, the same controller that is used for load calculation is also used for general control purposes. The controller does not have to be converted to a second programming language, and the error-prone second implementation of the algorithms is no longer required.

TE1400 – TwinCAT 3 Target for MATLAB®/Simulink®

The TwinCAT 3 Target for MATLAB®/Simulink® enables the generation of real-time capable TwinCAT modules from a MATLAB®/Simulink® model. These can then be executed in the TwinCAT 3 runtime, instantiated several times, parameterized and debugged, without the need to use MATLAB®/Simulink®. Transferring a whole block diagram from Simulink® into the TwinCAT module makes it possible to analyze and optimize the controller. This optimization can take place in the field and directly at the system, since only TwinCAT 3 Engineering is required to parameterize the controller.

The demanded values from the operational control are transferred to the subsystem control, where the individual subsystems are controlled. Each subsystem is implemented as a PLC function block in the form of a module with five methods

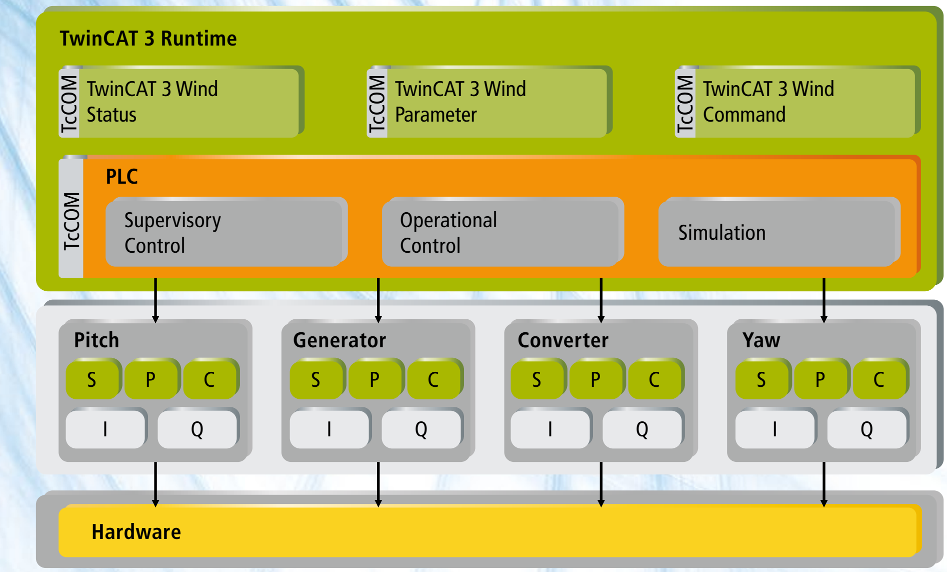


Fig. 1: Operational management is implemented as a standalone TwinCAT module, and the subsystems are implemented as independent objects.

and four data structures. The uniform architecture of the subsystems is shown in Figure 2. The Input/Output data structures are linked to the hardware inputs and outputs, and contain the numeric value of sensors, actuators, and fieldbus systems. The numerical data from the Input data structure are pre-processed in the InputUpdate method and transferred as physical values to the Inbox data structure. The methods ActualUpdate, MonitorUpdate and ControlUpdate are called for monitoring and controlling the system. They directly access the physical values from the Inbox. The new values for controlling the units are written into the Outbox data structure as physical values. The Outbox data structure is post-processed in the OutputUpdate method and provided as a numerical value. Interfacing with the higher-level supervisory control takes place via the Actual and Demand data structures. In addition, the Inbox and Outbox data structures enable simple simulation of the systems based on the physical values. In this way, each subsystem introduces its own simulation into the overall system.

Furthermore, an adaptive simulation of a 5 MW offshore wind turbine is integrated in the application template, which is preconfigured by the reference turbine of the National Renewable Energy Laboratory (NREAL). This enables testing of the entire operational management in the development environment, as the model is adaptable and configurable to match the respective system. The system simulation is provided as a TwinCAT module, although just like the control itself, it is ready to be replaced by a specific model from MATLAB®/Simulink® or C/C++, as required.

The integrated simulation in the application template can be used to reproduce and evaluate the processes of the whole system, as well as the individual operating modes and 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 directly with the original application software. Real-time simulations enable rapid control prototyping and virtual commissioning with a single version of the software, based solely on parameterization.

The operational management and subsystems are complemented by using the available TwinCAT modules from the TwinCAT 3 Wind Framework. Objects are created and configured via PLC function blocks from the PLC library. These objects integrate automatically into the higher-level TwinCAT modules from the Wind Framework, which provides the necessary services and functions. In this way, each subsystem defines an individual set of objects which contribute the information and settings for operational management.

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

Generic modules for higher-level services

The generic TwinCAT modules provide the higher-level services, providing the ability for each module to be used directly, integrated in TwinCAT 3 as a TcCOM module. The modules can also be used separately and independently of each other or in combination, in order to facilitate interaction and data exchange. Figure 3 highlights the available modules.

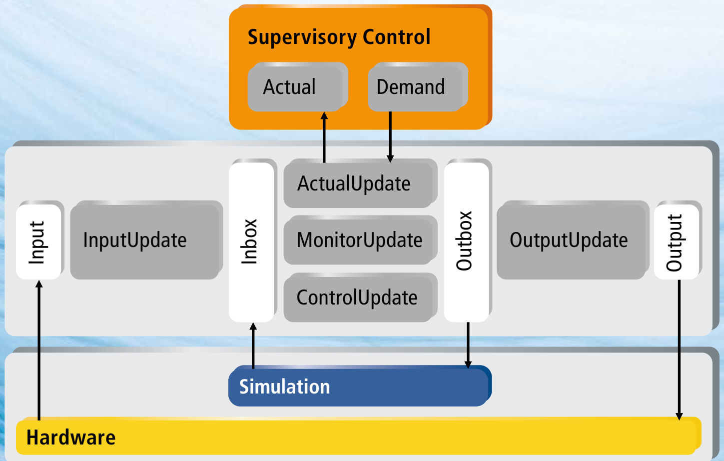


Fig. 2: The uniform architecture of the subsystems creates a standard in the application and enables quick familiarization by programmers.

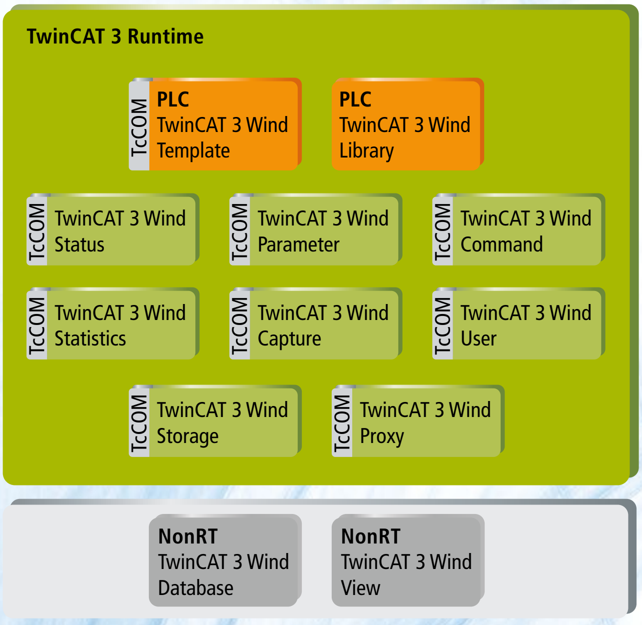


Fig. 3: The TwinCAT 3 Wind Framework provides functions via TwinCAT modules, as well as a PLC library, the database interface, and visualization.

All the information from the different TwinCAT modules is transferred permanently and in real-time to the Database module. This data is managed in a database via the TwinCAT 3 Database Server: it is prepared by the Database module as required and added to, or retrieved from, the database via SQL commands. The interface with a Microsoft SQL Server is fully implemented by the Database module. The Wind Framework provides the corresponding database scheme, including the tables and procedures for the Microsoft SQL Server. The extensive use is reflected in the modules described below.

TF6420 – TwinCAT 3 Database Server

The TwinCAT 3 Database Server enables data exchange from the TwinCAT real-time environment with different databases. SQL commands such as Insert or Select can be used, as well as Stored Procedures. Currently, 11 databases are supported, including Microsoft SQL, MySQL, PostgreSQL, and Oracle. In addition, a configurator for the visual setting of the parameters is included as a PLC library, which provides function blocks to run the SQL commands.

In automation applications, it is customary to cover the user administration in an external visualization or the SCADA system. User administration is integrated into the functions of the TwinCAT 3 Wind Framework, so that the user can check, manage, and record all interactions via the User module. In this way, it is possible to specify during programming which rights are required to use each function. These user rights are checked in the application so the operational management can automatically ensure correct user access, independent of an external management system.

Secure storage of accounts is ensured through cryptographic functions (hashes) in the database. Authentication is based on a name and password for activating the stored access level. The local access privilege can be determined through service switches at the control cabinets. It indicates whether user access is taking place remotely or locally, the latter resulting in higher rights.

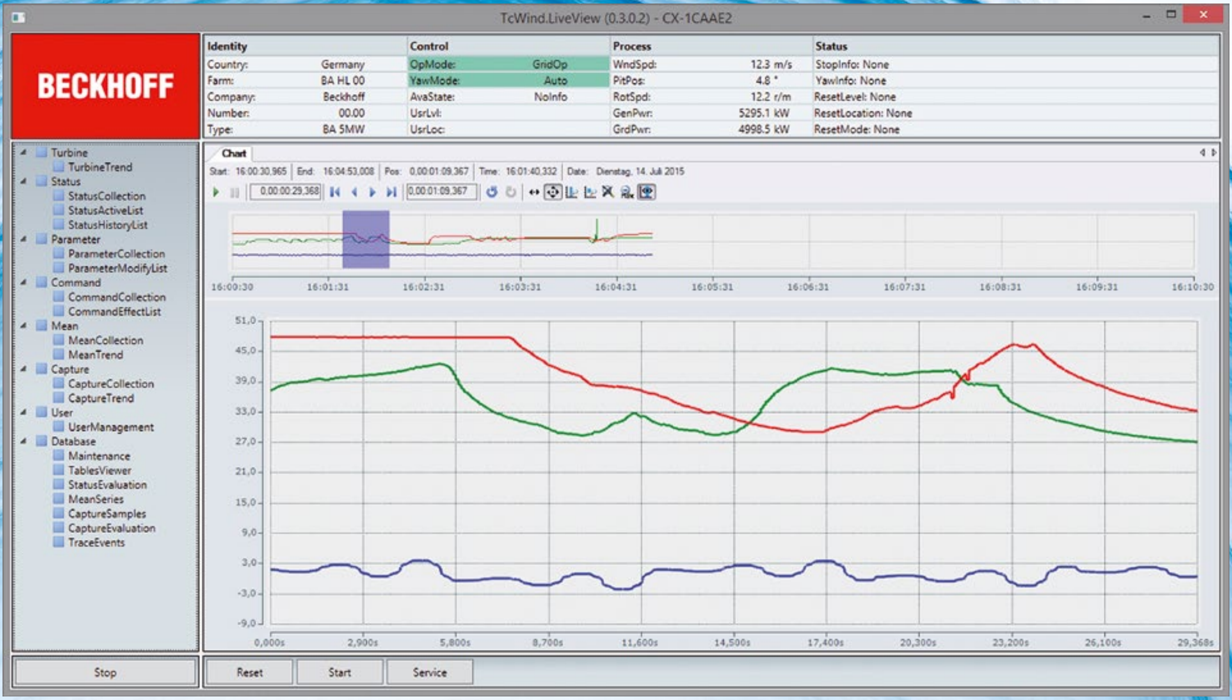
The Proxy module provides direct access to the real-time data of all modules and objects. This access can take place directly, via the TwinCAT ADS protocol, to retrieve any features of an object or the recorded data. Safe and vendor-independent communication via OPC UA or standard-compliant communication from IEC 61400-25 is enabled through further TwinCAT 3 functions.

TF6100 – TwinCAT 3 OPC UA Server

The TwinCAT 3 OPC UA Server enables communication based on the OPC Unified Architecture (IEC 62541). As a precursor for Industry 4.0 and the Internet of Things, OPC UA ensures secure, reliable and vendor-independent transfer of raw data from the sensor in the production level to the IT level and the ERP system. In this way, the control system enables object-orientated data communication for current and historic data, alarms and services (methods), and makes them available in a Service-oriented Architecture (SoA).

TF6510 – TwinCAT 3 IEC 61850/IEC 61400-25

The TwinCAT 3 IEC 61400-25 function enables data exchange based on IEC 61850 from the objects specified in IEC 61400-25 for wind turbines. The Manufacturing Message Specification (MMS) is the protocol implemented for communicating hierarchical data objects between the wind turbine and a control center. The TwinCAT Telecontrol Configurator, which is included, provides support during configuration of data models and generates the respective PLC code.



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Farm:	BA HL 00	YawMode:	Auto	PitPos:	4.8 °	YawInfo: None
Company:	Beckhoff	AvaState:	NoInfo	RotSpd:	12.2 r/m	ResetLevel: None
Number:	00.00	UsrLvl:		GenPwr:	5295.1 kW	ResetLocation: None
Type:	BA 5MW	UsrLoc:		GrdPwr:	4998.5 kW	ResetMode: None

Start: 16:00:30,965 | End: 16:04:53,008 | Pos: 0,00:01:09,367 | Time: 16:01:40,332 | Date: Dienstag, 14. Juli 2015

Fig. 4: The visualization is used to display current states, values, and settings.

With the TwinCAT 3 Wind Framework, a simple engineering visualization is available. It retrieves the data from the Proxy module and leverages the user administration integrated in the User module. The current states, values, and settings of all objects can be displayed. Simple reports and database analyses are possible, and the histories of the recorded data can be visualized. Figure 4 shows an example of such a diagram based on recorded data from the database.

A further service is provided by the Status module, which enables monitoring of all wind turbine components, provides error detection, event management, error handling and reporting. Status objects are created, each of which representing an event, and these are used for displaying individual messages, warnings, or errors. Examples include broken-wire sensor warnings or unit malfunction error messages.

A Status object has various configurable properties. For identification, each object is allocated in a group which corresponds to the respective system component, and a name in plain text. Delays for setting and resetting events, as well as various modes for automatic or manual resetting, are possible. For example, error resetting can be limited to an authorized group of persons by setting an access level and a local access authorization. A specific example would be limiting an error reset to a manual action by a service technician, and only if the technician is actually on site and in the nacelle.

Additional features include the option to set a system stop for each event as a system response, as well as triggering high-resolution logging of the system data or sending notifications. This flexible configuration of events is evaluated by the Status module, and the appropriate responses are generated from the current state of all events. An error in the pitch or the converter, for example, can be evaluated such that the system stops in response. Safe operation of the wind turbine is guaranteed through higher-level monitoring of all events. A list of all currently active events and a history of recent events is managed by the Status module, through which the events can be retrieved at any time. Each event is recorded in the database and furnished with a timestamp, which indicates when the event occurred and when it was reset. This allows the user to determine the frequency and duration of each event, and to draw conclusions about the operation and the availability of the turbines. In addition, statistical analysis of the events can be used to determine the most common causes for any downtime, providing a basis for optimization.

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, and all data types from the IEC 61131-3 standard are prepared in this way. Arrays can also be used as vectors or tables. 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. The value of a parameter can be limited through the properties of the Parameter object, and the options for changing the value can be limited via an access level. In addition, a default value is set for each parameter, which can be reset, if required.

In this way, the entire wind turbine configuration can be mapped and modified via parameters. Logging of all parameter changes, and persistent storage and loading of configurations, is enabled via the database connection through the Database module. The entire configuration of the wind turbine is thus stored in the database and can be matched to the configurations of other turbines.

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 visualization, can be implemented via a Command object. Here, different modes for implementation such as pressure switch, toggle switch, or dead man’s switch are offered. Their operation also requires authorization and is fully logged in the database. For better diagnosis and visualization, each Command object evaluates a confirmation and feedback. Using the protocol in the database, it is possible to ascertain at any time which operator triggered a system stop or an event reset and at what time, as well as changes of individual parameters.

Signal logging, as well as a statistical analysis, is provided by the Capture and Mean modules. Raw data are flexibly recorded via Capture objects, and the signal type (digital or analog) and the sampling rate for logging are set individually for each Capture object. Initial evaluations for subsequent diagnoses are carried out in real-time. The number of changes and the duration of the active state are evaluated for a digital signal. 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. When a unit is replaced, the service technician can reset the statistics manually. The optional integration of analog signals enables calculation of values such as flow rate, power generation, or consumption.

If such evaluations were carried out outside the real-time, there would be significant deviations from the actual values, due to non-deterministic recording and analysis of the information. The data determined in this way are permanently stored in the database, although they can be retrieved and used as instantaneous values.

The Mean module enables continuous determination of floating mean values; these Mean objects can calculate mean values from any analog signals over freely selectable time intervals. The properties offered include arithmetic mean, RMS value, standard deviation, and mean value calculation based on the wind direction, as well as minimum and maximum or turbulence intensity. The time interval over which the average value is logged in the database can be freely configured. Typical values for calculation and archiving are 30-second or 10-minute average values. In this way, it is possible to generate statistics such as the power curve, wind rose, or a capture matrix from the database over any period and on demand.

For significant events, which are described by a Status object, a Trace module can be used to trigger writing of a high-resolution protocol of the system data. The system data are provided based on the Capture objects and logged by the Trace module in cycle time. This protocol also includes data from configurable periods, before and after the time at which the event was triggered. Data from several seconds prior to the event is available and can be used for troubleshooting. It is also possible to check how the system responds to the event, since data from several seconds after the event is available.

Each determined value and each event are furnished with a timestamp. The timestamp is used by the local system and can also be obtained from a synchronized time source. The Time module is available for this purpose. It uses EtherCAT Distributed Clocks, in order to access a global synchronized time source via IEEE 1588 or PTPv2, for example. The cycles for logging signals via Capture or Mean objects are also synchronized based on this time. 10-minute average values are logged at fixed 10-minutes-interval at 11:00, 11:10, etc. (i.e. not at 11:03, 11:13, etc.). This ensures that data from different sources and systems are truly comparable, since all values were determined at the same time, and at identical intervals.

Database connectivity for detailed analyses

Interfacing with the SQL database via the Database module and the TwinCAT 3 Database Server offers efficient and compact data management, based on a uniform and familiar format. Logging of all events and signals, enhanced by the storing and loading of the entire configuration of all objects, enables detailed analyses. Any preprocessing required for this takes place in the TwinCAT modules in real-time. The Mean module calculates the mean values consistently in each application cycle, and each value from each cycle is used for averaging. The Capture module evaluates the scanning of values and integrations in each cycle, in order to make the calculation as accurate as possible.

Logging and preprocessing of all data in real-time, followed by reliable transfer to the database, forms the basis for evaluations on demand and outside the real-time environment. Based on this historic information it is possible to detect state changes and the causes of faults, calculate detailed statistics, and optimize the system. The database scheme is prepared in such a way that the data from individual or multiple systems can be collected and managed in a single database. The data can then be easily merged via prepared procedures, for higher-level analyses and comparisons. The merging of data is shown schematically in Figure 5.

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 keep the data permanently and over the complete lifetime of the systems. Such data quantities from any number of systems, which are generated in real-time and accumulated on central servers, can generally be referred to as Big Data. Big Data is a further building block towards Industry 4.0 and is supported by the option to integrate additional data from windfarm management or from monitoring and measuring systems.

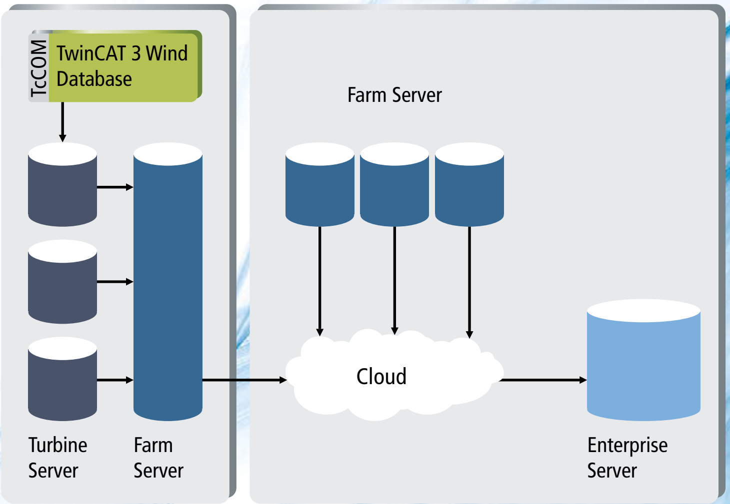


Fig. 5: The system data can be consolidated on central servers for higher-level analyses.

Uniformly accessible, these data allow extensive and automated evaluations. They can be used to detect faults or irregularities, calculate statistics and optimize the operational management, as well as enabling 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, so that future components can be replaced before they fail.

Conclusions

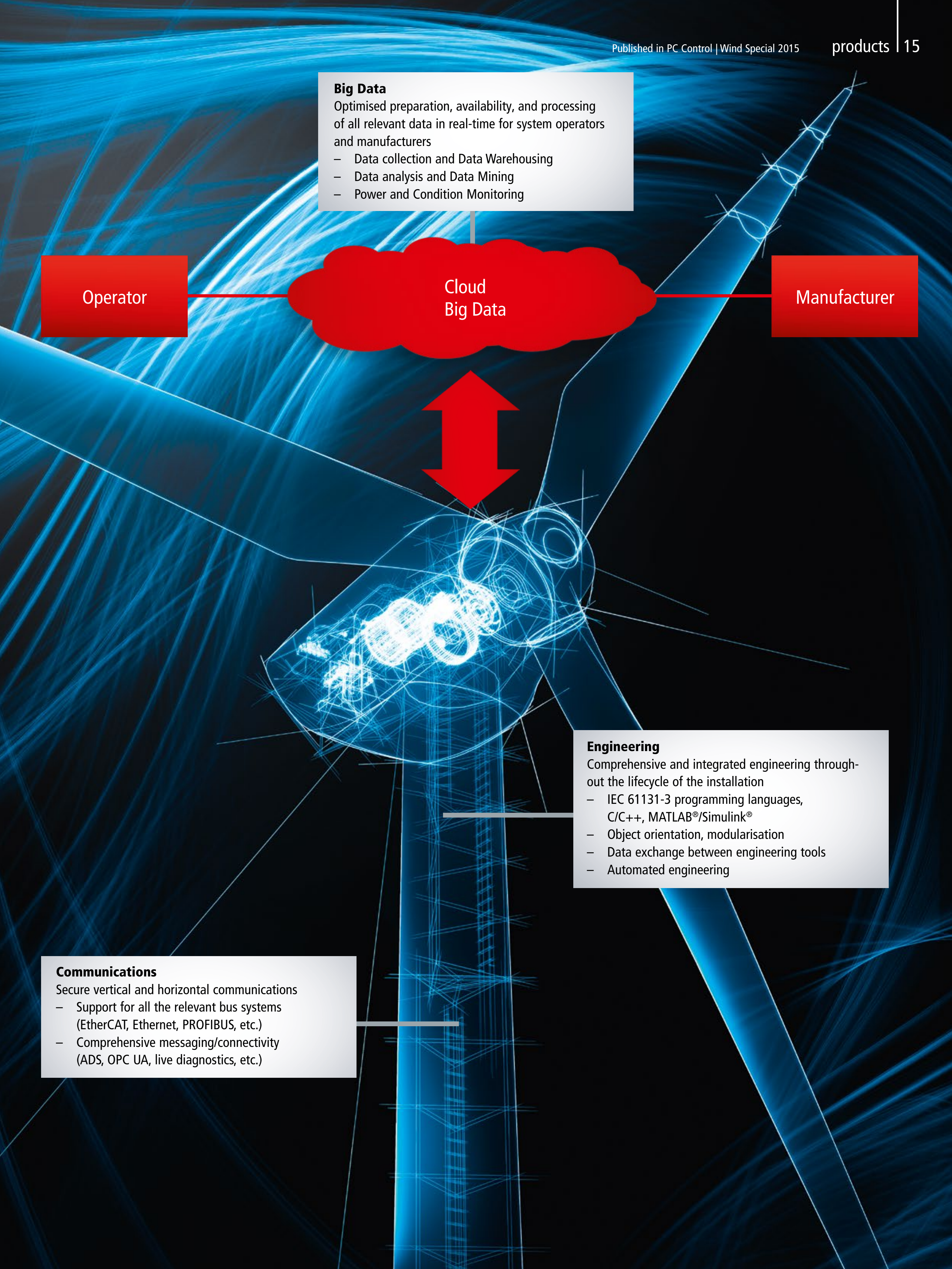
Advanced software engineering and Service-oriented Architecture (SoA) concepts were implemented in the TwinCAT 3 Wind Framework. The broad product portfolio offered by Beckhoff is thus extended with a TwinCAT 3 function library for wind turbines. With the modular architecture, the communication interfaces, the database connection, and the option to store all data centrally, the prerequisites for Industry 4.0 for wind turbines are achieved.

TwinCAT modules provide comprehensive services, in which essential operational management, user administration tasks, as well as comprehensive logging and data management, are already implemented. Programmers can use these functions via PLC function blocks and focus on their actual tasks.

The application template provides a ready-made, modular software architecture, prepared for extensions and adaptations to the specific system. Integration of controllers or simulations from MATLAB®/Simulink® or C/C++ can be easily realized, due to the flexible TwinCAT 3 architecture.

All system information is provided in databases, and provisions have been made to consolidate all data in a central database. Each individual database, as well as the central database, enables extensive monitoring and evaluation of the system states and operating modes of wind turbines.

More information:
www.beckhoff.com/twincat-wind



Big Data
Optimised preparation, availability, and processing of all relevant data in real-time for system operators and manufacturers

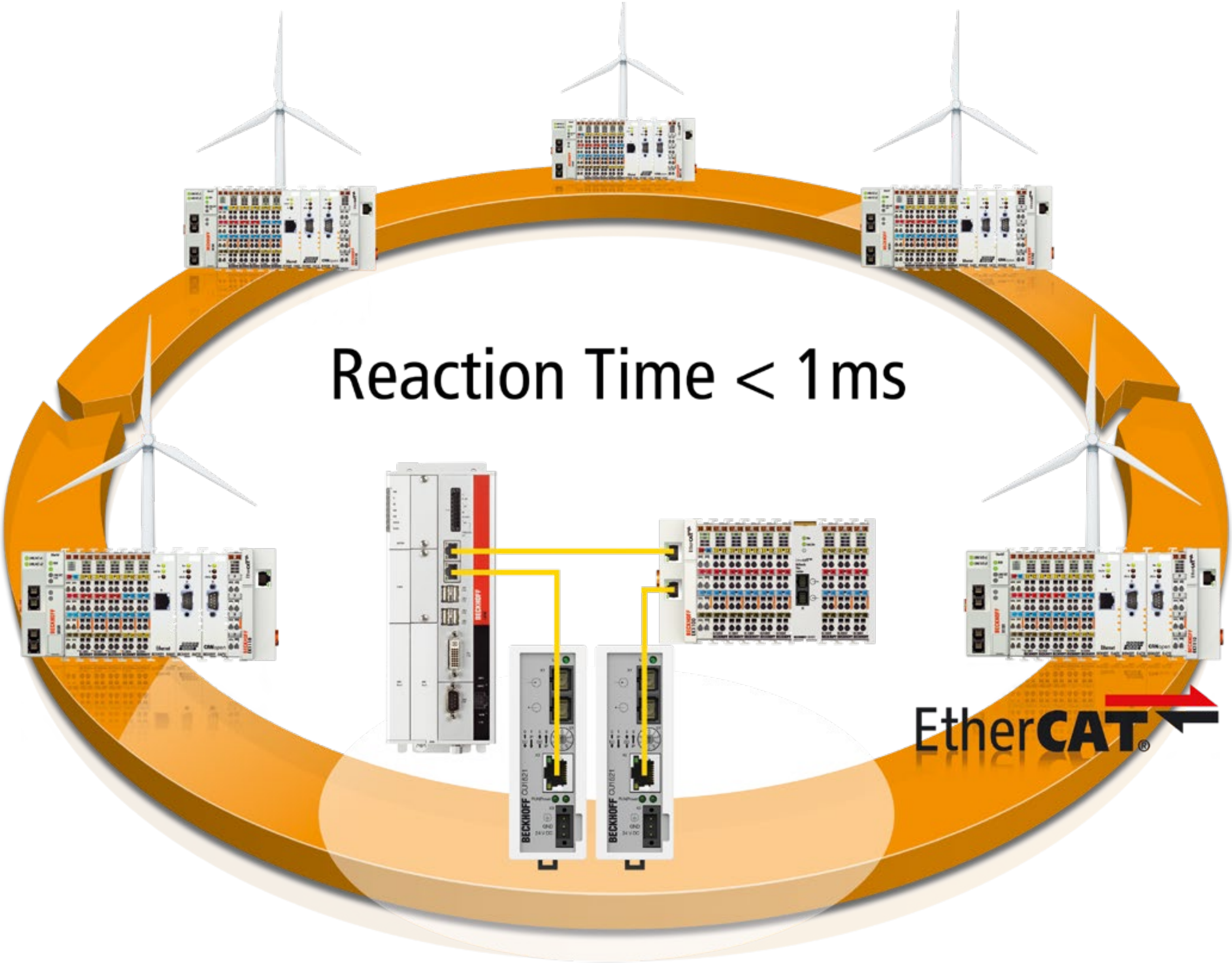
- Data collection and Data Warehousing
- Data analysis and Data Mining
- Power and Condition Monitoring

Engineering
Comprehensive and integrated engineering throughout the lifecycle of the installation

- IEC 61131-3 programming languages, C/C++, MATLAB®/Simulink®
- Object orientation, modularisation
- Data exchange between engineering tools
- Automated engineering

Communications
Secure vertical and horizontal communications

- Support for all the relevant bus systems (EtherCAT, Ethernet, PROFIBUS, etc.)
- Comprehensive messaging/connectivity (ADS, OPC UA, live diagnostics, etc.)



Ultra-fast wind farm networking optimizes grid compatibility

Real-time networks for wind farms feature a cycle time of less than 1 ms

The expansion of renewable energies is rapidly gathering pace worldwide. The need to reduce CO_2 emissions as well as the decreasing acceptance of nuclear power are major contributors to this development. Since the wind and sun light are not constantly available, however, feeding the renewable energies into the grids can lead to problems that are not insignificant. The fast EtherCAT-based automation solution from Beckhoff enables reaction times of less than 1 ms. The early diagnosis of voltage drops increases grid compatibility. In addition to wind turbines, this technology is also suitable for use with solar farms.

Initial steps have already been taken in this direction: Many international grid connection regulations – the so-called Grid Codes – now prescribe LVRT capability (Low Voltage Ride Through) for every wind turbine. This means that, in the case of sudden changes of voltage in the grid, due to short circuits for example, the plant must remain connected to the grid for a defined period of time and must feed in defined reactive currents for fault-finding and to support the voltage. Subsequently, it must return within a few seconds to full active power feed-in. The demanded reactive currents depend on the depth of the voltage drop and must be applied, depending on the requirement, at the wind turbine or at the grid connection point.

On this basis, every modern wind turbine is today able to react appropriately to a voltage drop in the grid. Wind farms are becoming increasingly large and installations of up to 500 MW are no longer a rarity. In view of the size of the internal power networks in the wind farm, LVRT conditioning executed purely at turbine level at the grid connection point often does not produce the effect desired by the grid operator. Due to the impedances lying between them, the voltages differ between the turbines and the grid connection point. This means that each wind turbine reacts differently to the changes in the grid. Also, the reactive currents fed in at turbine level are not identical to the resulting reactive current at the grid connection point.

The Beckhoff solution is designed to deal with this problem and enable a coordinated reaction of the entire wind farm to a voltage drop in the grid. In this way, the solution achieves a defined behavior of the entire farm at the grid connection point.

So far the following values have been regulated for the feed-in of wind turbines or wind farms:

- LVRT and local voltage limitation (temporal requirement of the control time: < 10 … 20 ms)
- Active power as well as reactive power or voltage (temporal requirement of the control time: 1 s - 60 s)

Due to the temporal requirements, the reaction in the LVRT case is presently realized at the turbine level in the converter. The delays in the control loop which occur due to centralized conditioning by a farm controller would hamper the attainment of the demanded dynamics.

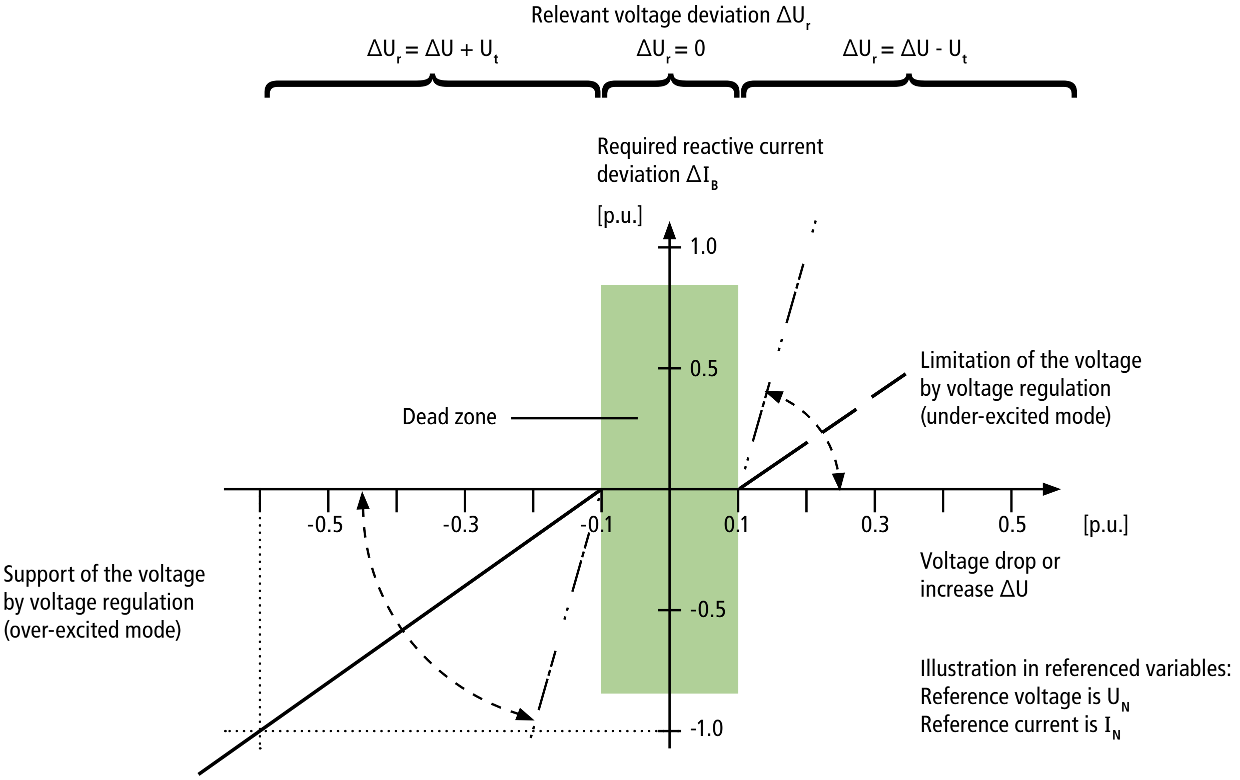
The voltage/reactive power level is realized at the wind farm level; only in this way can a set point value specified for the grid connection point also be achieved there. In conjunction with a weak grid connection and a Q(U)-characteristic, the high dynamics (control time 1 s) sometimes demanded represent a challenge here.

Wind farm networking with EtherCAT

The 2011 lecture by Melanie Hau and Martin Shan [1] on the subject of "Wind farm control for network integration" (see also article on page 30) showed that the speed of the wind farm networking and that of the turbine automation fieldbus both exert a significant influence on the attainable dynamics in the control of the voltage or reactive power in a wind farm.

This is precisely the point of attack of the Beckhoff solution, which is based on wind farm networking using EtherCAT. Wind farm networking has so far been realized using Ethernet. Ethernet fiber optic cables are used for the connection of the individual wind turbines to the master computer. Since EtherCAT is based on Ethernet and thus fully compatible with it, the same physics can be applied when using EtherCAT. The subject of cable redundancy is also fully solved with EtherCAT. The fiber optic cable ring in the wind farm is closed at the farm master. The necessary TCP/IP communication can take place via switch port terminals within the EtherCAT I/O system. The highlight here is that not only a significantly higher transmission rate is achieved by using EtherCAT, but also that significant cost benefits result in comparison with the redundancy-capable switches that have been used so far.

[1] Hau, Melanie and Shan, Martin. Windparkregelung zur Netzintegration. 16th Kassel Symposium Energy Systems Technology, 2011. http://www.iwes.fraunhofer.de/de/publikationen0/uebersicht/publikationen_veroeffentlichungengesamt/2011/windparkregelungzurnetzintegration.html



SDLWindV-Feed-in of reactive current in the case of a grid fault (Source: SDLWindV)

Power measurement at 10,000 samples/s

EtherCAT significantly increases system speed: A fully occupied EtherCAT telegram containing 1500 bytes can be sent by the master and received again in an impressive 77 µs. Assuming a process image of 50 input bytes and 50 output bytes for each wind turbine, the process image of a wind farm with more than 150 wind turbines can be refreshed in less than one millisecond. If the speed requirements or the number of wind turbines should significantly increase, several EtherCAT rings can also be realized on one master.

In addition there are further new technologies realized with EtherCAT: for instance, oversampling functionality permits the measurement or the output of signals in the field with a frequency of up to 100 kHz. This oversampling technology is used, for example, for the measurement of the current and the voltage at the grid connection point with the aid of the EL3773 EtherCAT Power Measurement Terminal. The sampling frequency here is 10 KHz.

The Distributed Clock function of an EtherCAT device, with a resolution of 1 ns and an accuracy of 10 ns, permits the temporal synchronization of measured and control values in a time window significantly smaller than 1 µs, since all Distributed Clocks in an EtherCAT topology are synchronized by propagation delay measurement. On the basis of this function the measured values in a wind farm can be synchronized extremely well. Even the synchronization of the IGBTs of converters within a wind farm can be achieved with this technology. To this end, both the turbine manufacturer and the converter supplier must be brought on board.

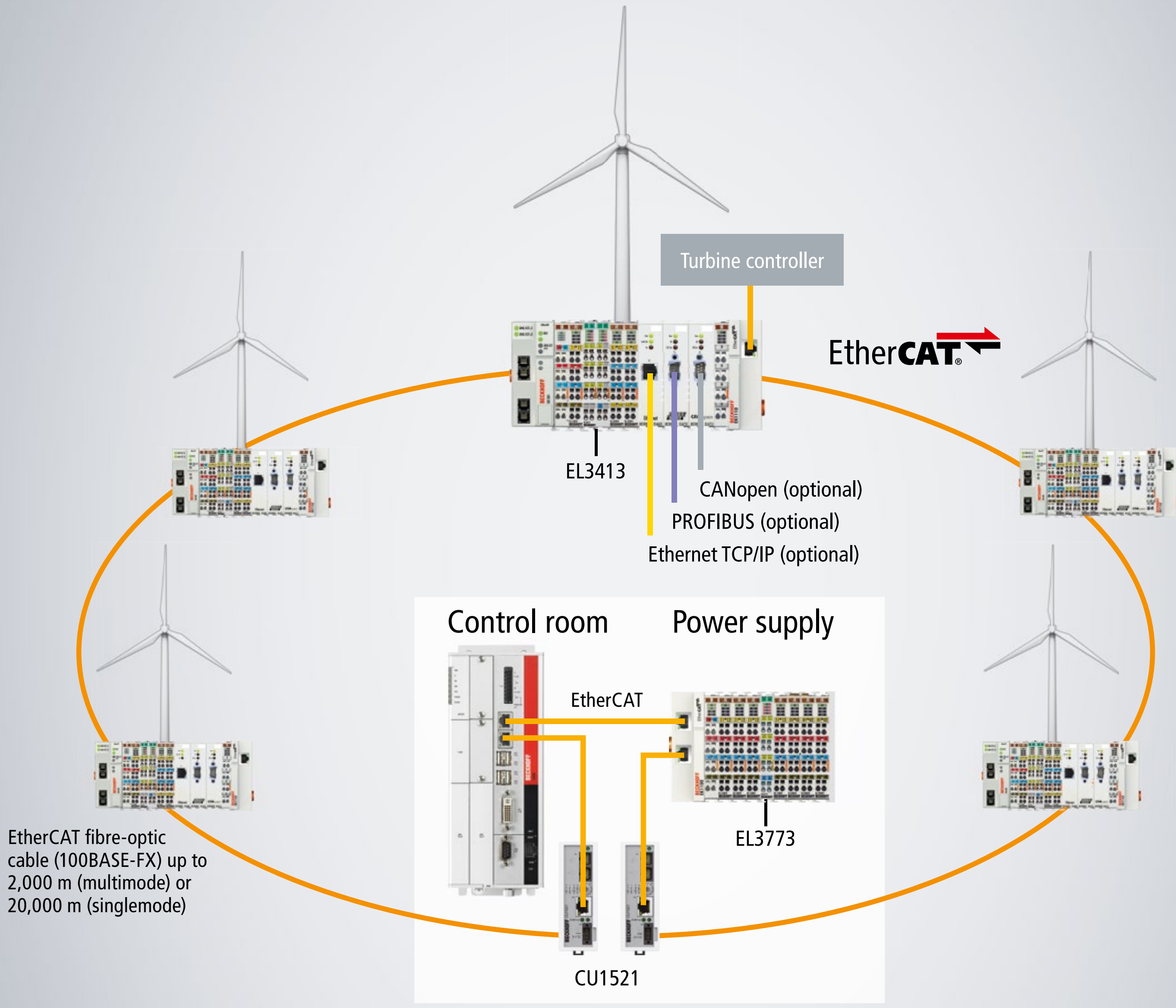
Wide range of applications due to open control technology

In summary, this means that, using available standard components, a wind farm controller can be realized that makes a defined reaction of the entire wind farm to a voltage drop in the grid possible at the grid connection point. Outside the fault case, too, highly dynamic voltage or reactive power controllers can be implemented in the wind farm for weak grid connections.

Due to the openness of the EtherCAT system, this solution is possible with controllers from third-party vendors as well: Master and Slave interfaces for all common fieldbus systems (such as PROFIBUS, PROFINET and CANopen) are available for the EtherCAT Terminal system. Serial protocols are available for most interfaces; communication can alternatively be accomplished with parallel wiring.

The EL3413 EtherCAT Power Measurement Terminal, which is equipped with a direct 690 Volt connection, can be used on any wind turbine for checking the controller. Extra signals such as weather data can be collected simply and inexpensively via this topology.

Author: Dirk Kordtomeikel, Business Manager Wind Energy, Beckhoff



In comparison with conventional IP solutions, wind farm networking with EtherCAT is faster and offers substantial cost benefits. The faster the farm networking is, the more effective the energy provider can react to voltage drops or changing grid requirements. The EtherCAT Power Measurement Terminal integrated in the automation system logs momentary current and voltage values at the feed-in point at up to 10,000 samples/s. Early diagnosis of voltage drops is thus guaranteed.

Unlike current alternative solutions, it is possible to generate a reaction of an entire wind farm to an LVRT case using EtherCAT. If a voltage drop is diagnosed at the feed-in point, this can be signaled to all turbines in the entire farm network within 1 ms. Via the EtherCAT Distributed Clocks, the measured values of all wind turbines and the measurement at the point of common coupling can be synchronized to a timeframe smaller than 1 µs. With these data, the current, voltage and frequency can be controlled accordingly and the grid can be supported. The existing fiber optic-based Ethernet infrastructure can be used.

More information:
www.beckhoff.com/ethercat
www.beckhoff.com/el3773
www.beckhoff.com/el3413

Published in PC Control 03 | 2022

EtherCAT measurement terminals in wind farm monitoring

Accurate and fast data are crucial for the essential synchronization in wind farms

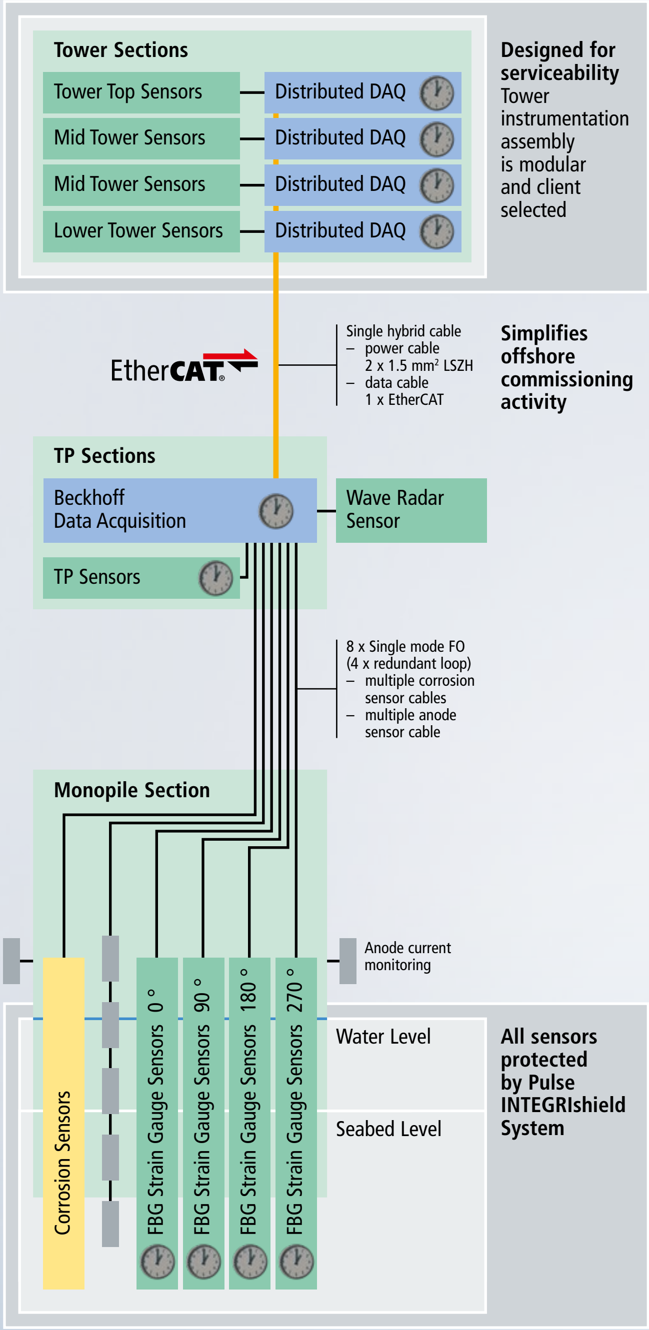
The UK aims to build enough wind farms to power every household by 2030. The potential of wind power was demonstrated by a recent record, when on a single day in January wind farms produced 19,835 megawatts, which is enough to cover more than half of England's electricity needs. The increased investment in renewable energy will be essential to hit the 2050 goal of Net Zero. Pulse Structural Monitoring Ltd, an Acteon company, have been tasked with monitoring selected turbine foundations in new wind farms, the solution is delivered by using Beckhoff technology and EtherCAT measurement terminals in particular throughout the design.

According to Pulse, the UK has become a world leader in offshore wind energy, with more capacity installed than any other country. However, offshore wind farms present difficulties due to the environment, making continuous monitoring of the whole turbine essential. By continuously monitoring the turbine, blades, and foundation performance, you can support decision making on planned maintenance and design validations for example, which in turn can help to avoid unplanned shut down periods or making costly repairs in the event of failure.

Measurement terminals in harsh environments

Environmental and operational loadings on the turbine affect all parts of the dynamically loaded structure. Part of the foundation's role is to support the wind turbine generator (WTG) load, provide stability and absorb additional loadings. The structural health of the foundation, which is considered as the top of the tower downwards, is critical to the performance and support of the WTG's performance. Structural Health Monitoring (SHM) systems for offshore wind turbine structures monitor a combination of corrosion and dynamic fatigue stress. Corrosion monitoring although an important parameter to be measured, due to the nature is less time critical. In contrast fatigue and modal properties monitoring are among the most important SHM techniques for wind turbine structures.

Pulse Structural Monitoring are delivering foundation SHM systems for clients in the renewables industry across the world using Beckhoff technology. Utilising Beckhoff's broad range of I/O terminals for sensor integration allows Pulse to ensure time stamped data acquisition throughout the structure. Pulse use the ELM370x module, which is an analogue input terminal from the EtherCAT measurement range. Due to the high sensitivity and measurement ability of these ELM modules, they are often used within labs but can also be integrated into industrial environments. This terminal can be set to over 30 different



Basic structure of the monitoring system implemented by Pulse

© Pulse

types of electrical signal, which makes it an exceptionally flexible measurement module for a range of sensors. To accurately determine the structural integrity throughout the full height of the structure, helping to ensure turbine operational efficiencies, the tower itself requires measurement points on four levels. This means that the I/O needs to be distributed, to have accelerometers and full bridge strain gauges terminated close to where they are positioned. Each level, on this top section, demands two ELM3704 modules for the varied signals, an EK1100 EtherCAT Coupler for communication and a power supply PS1011. These are fully enclosed and magnetically attached to the tower wall at defined heights giving accurate data capture across the tower.

For temperature, Pulse use the standard EL3202 terminal, a Beckhoff analogue input RTD EtherCAT terminal which provides data to allow for compensation algorithms to operate. The use of EtherCAT and it's Distributed Clocks on the wind turbine's foundation shows Pulse's dedication to highly accurate monitoring and with this the ability to synchronise data. This synchronisation is key to the critical analysis of the overall structure, taking data from high precision accelerometers, strain gauges and temperature sensors located along the length of the structure, from top of the tower to the foot of the monopile with the exact timing.

Synchronized data communication

Pulse have adopted the EtherCAT fieldbus and deploys this technology with the added benefit of power and communication through a single cable. EtherCAT P and EtherCAT/Ethernet with power (ENP) helps circumvent the common difficulty of getting power to the sensors and distributed I/O at the top of the tower. The EtherCAT P and ENP system can run power and communications through a single cable and daisy-chain the fieldbus throughout the structure. Pulse have even taken it a step further by becoming a member of the EtherCAT Technology Group to develop their own subsea data hub and motion monitoring EtherCAT products called INTEGRIpod-NX2.

"The most important thing in our industry is data," explained Stephen Harford, solutions architect at Pulse Structural Monitoring. "EtherCAT is already

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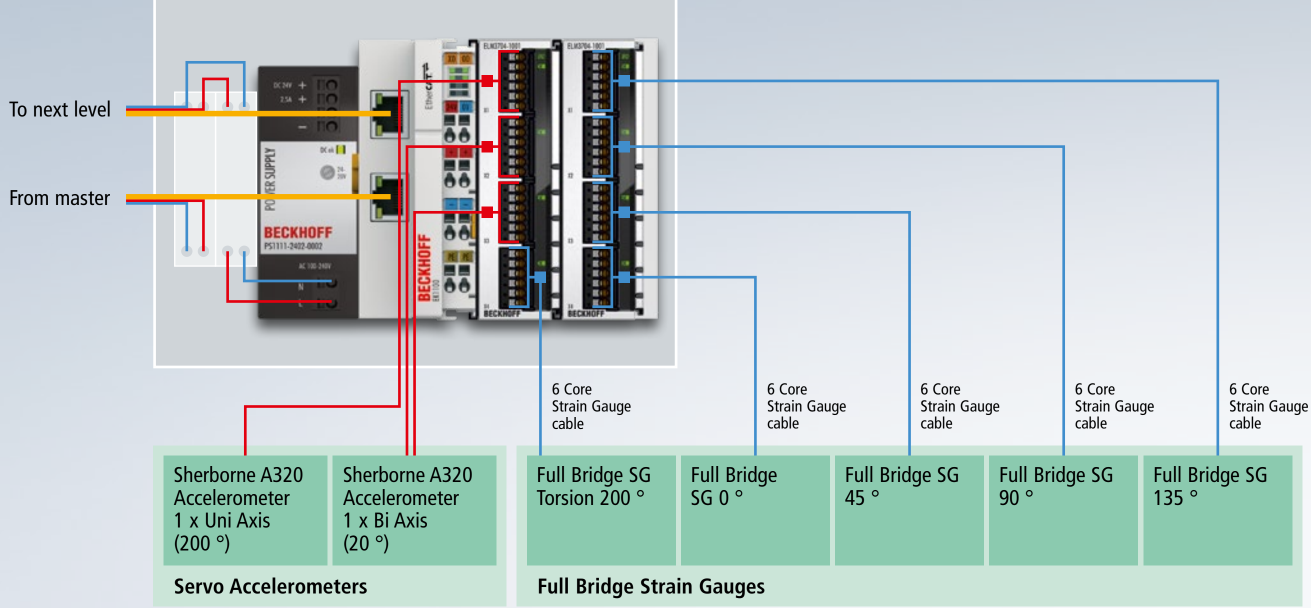


Decentralized data acquisition system for the four upper tower levels, consisting of two ELM3704 EtherCAT Terminals, an EK1100 EtherCAT Coupler and a power supply PS1011

© Pulse

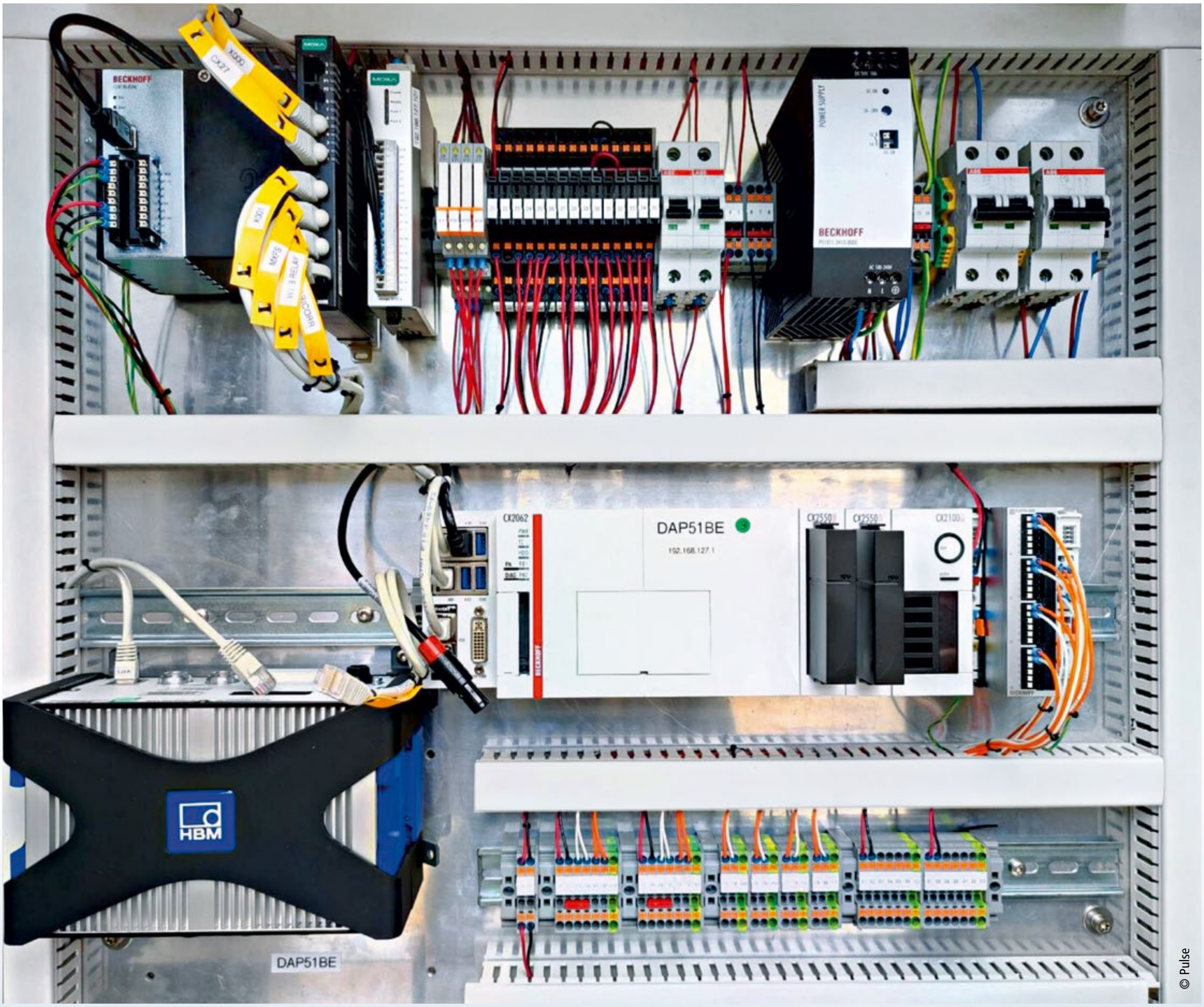
fast, which is essential for synchronization and getting the data we need. But EtherCAT with distributed clocks at every level allows us to take it one step further and keep full synchronization. With Beckhoff the quality of the technology is always guaranteed."

From Stephen Harford's point of view, partnership is also important: "Beckhoff have also made every effort to help us keep to the tight schedule that wind farms have. They have supported us at every stage, coming down to train us when we could not make it due to our tight schedule. This is why we're happy to successfully partner with Beckhoff on other projects we have."

Data management with TwinCAT

All the data from the sensors is centralised and collected in a Beckhoff embedded controller, the CX2062 Embedded PC with TwinCAT PLC (TC1200) and Windows 10 IoT in this case. The CX2062 was chosen for its flexibility in expanding memory, increasing interfaces and processing power to run the TwinCAT runtime software plus the data management and processing application developed by Pulse. Beckhoff provides a free and open DLL to access all real-time data within the TwinCAT system via ADS. This open platform allows Pulse to both analyse data and send it directly to the higher level Scada system, providing key insight to the turbine's health.

"What's been great about this project," explains Beth Ragdale, product manager with Beckhoff UK, "is how we can utilize our previous work in the renewables sector to provide Pulse with our expertise in this area. We've also managed to provide everything from standard I/O terminals to high accuracy measurement modules, and, with a hybrid of power and communication in a combined cable assisting Pulse to simplify their installations. That's why we're excited for the future projects we have together."



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Control cabinet with CX2000 Embedded PC and directly connected ELM series measurement terminals (center of picture) as well as a CU8130 UPS (top left) and a PS2000 power supply unit (top right)

More information:
www.acteon.com/structural-monitoring/pulse
www.beckhoff.com/wind


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EtherCAT measurement terminal enhances condition monitoring of large-diameter rolling bearings in wind turbines

Seamlessly integrated precision measurement and control technology provide mobile early fault detection

CMS Universal mobile condition monitoring solution

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Hamburg-based cms@wind GmbH specializes in monitoring slow-turning drive components in complex environments and develops mobile systems for condition monitoring (CM) based on structure-borne sound. The system detects abnormalities in slowly and irregularly rotating rolling bearings in drive trains measuring up to 4 meters in diameter. With regard to data acquisition, the high-precision ELM3602 EtherCAT Terminal made it possible to replace the previous measurement hardware with precision measurement technology integrated directly with standard control technology.

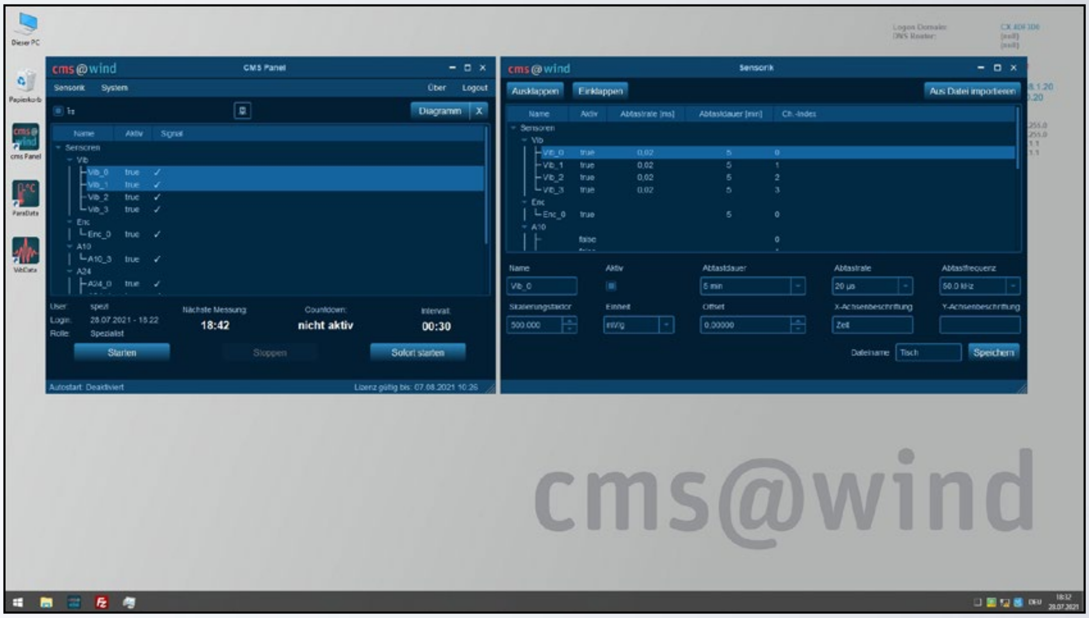
Until 2018, the solutions from cms@wind had relied exclusively on dedicated hardware for measurement technology. In 2017, however, the company recognized the advantages of the high-resolution ELM3602 EtherCAT measurement terminal for evaluating IEPE (Integrated Electronics Piezo-Electric) sensors, as owner Dr. Brit Hacke explains: "The ELM3602 met all key requirements of our application. The new measurement module is able to acquire vibration time signals at the IEPE input extremely reliably and without interference in true 24-bit mode."

In the case of slowly rotating large components, long-term data acquisition is required to facilitate a reliable diagnosis of incipient damage in the early stages by means of a reasonable number of recorded revolutions. According to Dr. Brit Hacke, measurement intervals of up to 5 minutes can be implemented without any problems, with data being reliably stored by the CX5130 Embedded PC used as computer hardware, and conveniently retrieved via remote access.

User-friendly condition monitoring for wind turbines

The systems from cms@wind were designed for large-scale components in wind turbines and are often used for measurement project implementation in locations that are difficult to access. Typical applications in the mobile area include temporary application from a few minutes to several months and often before the end of warranty in wind turbines from 3 MW upwards. In addition to monitoring conventional drive trains with three or more gear stages and high-speed generators, applications involving gearless systems have become more common.

According to Dr. Brit Hacke, customers increasingly wanted to have technicians install the CM solutions on site or else relocate them to other systems. The mobile systems make this possible; however, until now, they did not offer the user-friendly and responsive user interfaces typical of conventional measurement technology. This made familiarization more difficult for end users. Fortunately, the new CMS Panel developed by cms@wind and based on TwinCAT 3 now



Name	Aktiv	Signal
Sensoren		
Vib		
Vib_0	true	✓
Vib_1	true	✓
Vib_2	true	✓
Vib_3	true	✓
Enc		
Enc_0	true	✓
A10		
A10_3	true	✓
A24		
A24_0	true	✓

User: spezi
Login: 28.07.2021 - 15:22
Rolle: Spezialist
Nächste Messung: 18:42
Countdown: nicht aktiv
Intervall: 00:30
Autostart: Deaktiviert
Lizenz gültig bis: 07.08.2021 10:26

Name	Aktiv	Abtastrate [ms]	Abtastdauer [min]	Ch.-Index
Sensoren				
Vib				
Vib_0	true	0,02	5	0
Vib_1	true	0,02	5	1
Vib_2	true	0,02	5	2
Vib_3	true	0,02	5	3
Enc				
Enc_0	true		5	0
A10				
	false			0

Name: Vib_0
Abtastdauer: 5 min
Abtastrate: 20 µs
Abtastfrequenz: 50.0 kHz
Skalierungsfaktor: 500.000
Einheit: mV/g
Offset: 0,00000
X-Achsenbeschriftung: Zeit
Y-Achsenbeschriftung:
Dateiname: Tisch

Simple sensor adjustment via the CMS user interface

© cms@wind

Name	Aktiv	Signal
Sensoren		
Vib		
Vib_0	true	?
Vib_1	true	?
Vib_2	true	?
Vib_3	true	?
Enc		
Enc_0	true	?
A10		
A10_3	true	?
A24		
A24_0	true	?

User: spezi
Login: 28.07.2021 - 15:22
Rolle: Spezialist
Nächste Messung: 18:42
Countdown: 00:22:07
Intervall: 00:30
Autostart: Deaktiviert
Lizenz gültig bis: 07.08.2021 10:26

Representation of a shock pulse sequence

© cms@wind

allows on-site technicians to program the mobile systems professionally without advanced automation expertise and even verify the full functionality of all sensors after transferring them to another system. The operating menu corresponds to the working environment that is familiar to measurement technicians, and the signal curve can be viewed at any time while recording.

The new user interface has also made it possible to integrate additional sensors. In addition to the classic IEPE sensors in drive train and rolling bearing analysis, cms@wind also uses sensor technology for time-synchronous speed monitoring, detects low-frequency imbalances using MEMS technology, and on request even integrates decoupled signals from the controller into the projects to be able to assign specific events. Dr. Brit Hacke goes on to add: "Leveraging the comprehensive range of EtherCAT Terminals from Beckhoff, we can easily integrate additional signals. In the new CMS Universal condition monitoring solution, which has been available since 2021, for example, analog measurement signals based on ±10 V or 4 to 20 mA are provided in addition to Pt100 signals. The decision regarding which EtherCAT Terminal is used – for example, a classic EL3104 analog input terminal in 16-bit mode or a high-precision ELM measurement terminal with 24-bit resolution – is determined by the respective measurement task. Up to now, any technical limitations have only been apparent from the installation space in the case."

With CMS Universal, remote access and data transfer via mobile communication are possible in addition to conventional network integration. Direct on-site access is provided via a LAN or WLAN connection. The mobile devices have so far been used in offshore and onshore locations where systems permanently installed by the wind turbine manufacturers left end customers with a real information deficit.

More information:
www.cms-wind.de
www.beckhoff.com/condition-monitoring
www.beckhoff.com/elm3602

Published in PC Control 03 | 2021

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Inselnetzbetrieb | Netzparallelbetrieb

Start
Drehzahlregler: PI Umrichter
Spannungsregler: PID Simulink
Stop
Inselnetzbetrieb OK

Drehzahlregler: PI Umrichter
Drehzahl: 1500 min⁻¹ SET
Kp: 5.37 SET
Tn: 12.75 ms SET
Reset to Default

Spannungsregler: PID Simulink
Spannung: 400 V SET
Kp: 1 SET
Ki: 5 SET
Kd: 0 SET
Kff: 1 SET
Rate Limit: 0 SET
Reset to Default

	Source	Text	Raised	Confirmed	Cleared
1	MAIN.fbLimitTest	Spannungsgrenzwert überschritten! (>450.0 V, Inselnetz L1)	6.7.2021, 16:36:10,912	6.7.2021, 16:36:13,728	6.7.2021, 16:36:13,728
2	MAIN.fbLimitTest	Stromgrenzwert überschritten! (>10.0 A, SG L2)	6.7.2021, 16:35:00,184	6.7.2021, 16:35:06,039	6.7.2021, 16:35:06,039
3	MAIN.fbGlobalStateST.fbInverte	MDX818 ERROR: (ERROR: Feldbus Timeout (28))	18.5.2021, 15:01:55,989		18.5.2021, 15:01:56,010
4	MAIN.fbGlobalStateST.fbInverte	MDX818 ERROR: (ERROR: Feldbus Timeout (28))	18.5.2021, 15:01:55,988		18.5.2021, 15:01:55,989
5	MAIN.fbGlobalStateST.fbInverte	MDX818 ERROR: (ERROR: Feldbus Timeout (28))	18.5.2021, 14:50:53,455		18.5.2021, 14:50:53,475
6	MAIN.fbGlobalStateST.fbInverte	MDX818 ERROR: (ERROR: Feldbus Timeout (28))	18.5.2021, 14:50:53,454		18.5.2021, 14:50:53,455

Operation and monitoring of the grid emulation via TwinCAT HMI

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

Grid-friendly control methods for the power grid of the future

The Institute of Electrical Energy Systems and High Voltage Technology (IEH) at the Karlsruhe Institute of Technology (KIT) in Germany is researching ways to ensure system stability in the transmission grids that are changing as a result of the transition to renewable energy. In addition to simulative investigations, the behavior of power plants and inverter-based generation systems is being emulated in an island grid used as a dedicated test environment. Here, researchers are implementing innovative new control methods on Beckhoff Embedded PCs running TwinCAT to validate their application in realistic scenarios.

In many transmission grids, the proportion of electricity from renewable energy sources is increasing. Unlike conventional synchronous generator-based power plants, wind energy and photovoltaic plants feed their energy into the grid via an inverter; however, stability problems occur above a certain proportion of inverter-based operating resources when using conventional grid-following inverter controls. This is why innovative control methods are needed so that the integration of renewable generation systems does not have to be restricted as a result. The aim of these grid-forming control methods, as they are known, is to provide grid-supporting behavior – of the type that has been associated with synchronous generator-based power plants for more than 100 years – with inverters. The results of this include the ability for wind turbines to also provide instantaneous energy reserves.

Grid emulation

The investigation of the inverter behavior at a strongly changing grid frequency is not possible in the European interconnected grid. For this reason, a grid emulation was built at IEH for the realistic behavior of large power plants and therefore also for that of large transmission grids. This grid emulation consists of a synchronous generator with an excitation machine, which is driven by a variable-speed drive system comprising a drive inverter and an asynchronous machine rather than a turbine. To achieve a moment of inertia comparable to that of a turbine in a power plant, there is also a flywheel on the shaft. Frequency dips can be generated by connecting loads, as these occur during disturbances in large transmission grids. By physically providing the instantaneous reserve, the grid emulation (in contrast to power electronic grid emulations) allows an instantaneous reaction of the resources connected in the island grid to the grid frequency.

A CX5140 Embedded PC from Beckhoff serves as the central automation and control hardware, while various EtherCAT Terminals are used to measure mechanical and electrical variables. Encoders are installed in both machines to measure the rotary speed, and these are evaluated by EL5021 SinCos encoder interfaces. Torques can be established by means of two torque measuring shafts and an ELM300x analog voltage measuring terminal. EL3783 power monitoring oversampling terminals in combination with current transformers capture the 3-phase voltage, current and power values. The CX5140 Embedded PC communicates with the drive inverter via EtherCAT. Excitation of the synchronous generator's excitation machine is ensured by an EL2535-0005 pulse width current terminal. Power contactors are controlled by EL2634 relay terminals as further actuators.

The closed-loop control was designed in MATLAB®/Simulink® using model-based design and, after compilation, executed in real time on the Embedded PC using TwinCAT 3 Target for Simulink®. A convenient user interface for operating the test bed was implemented with TwinCAT HMI. Control parameters, setpoint values and limit values can be changed here during operation. In addition, measurements and the plant status can be displayed graphically. Measured values are visualized and recorded using TwinCAT Scope View.

Inverter emulation

The investigation of newly devised control methods for inverter-based generation plants calls for a flexible test facility that offers sufficient freedom with regard to how control methods are implemented. Since the first step focuses on the control of the grid side of the inverter, the behavior of the modulation and the power semiconductors of a 3-phase inverter can be emulated by three linear voltage amplifiers. The voltage amplifiers act here as controlled ideal voltage sources. The control cabinet for the inverter emulation is located between the voltage amplifier and the island grid of the grid emulation. In addition to the control hardware, other items installed in this cabinet include the adjustable mains filter, voltage and current measurements, as well as contactors and circuit breakers.

An Embedded PC with numerous EtherCAT Terminals is also used as the central platform in this test bed. A CX2030 facilitates the execution of even complex programs with fast cycle times. Six EL3702 two-channel analog input terminals capture the 3-phase voltage and currrent values by means of Hall-effect current sensors at several measurement points. The voltage setpoints are output by EL4732 analog output terminals and transmitted to the voltage amplifier as voltage levels.

Comparable to grid emulation, control methods developed and validated in MATLAB®/Simulink® are executed in real time on the CX2030. The main difference is the short control cycle time of just 50 µs. In combination with the EtherCAT Terminals and the voltage amplifier, a dead time of just 150 µs is achieved for the entire control loop. The test bed is also operated and monitored by a user interface created with TwinCAT HMI. Essential here is the rapid monitoring of limit values, which leads to a safe shutdown if exceeded.

© IEH/KIT

For inverter emulation, the CX2030 Embedded PC enables short control cycle times of 50 µs.

Test environment

With the inverter emulation being used in combination with the grid emulation, an island-like test environment is now available where the behavior of new grid-forming control methods can be easily investigated. Investigations with the 'Synchronverter' control method, which emulates the behavior of a synchronous generator with an inverter, have already been carried out and published. Experiments have shown that inverter-based generation systems with an appropriate control system can provide instantaneous reserve and thus support the grid. In contrast to real-time emulators, it was also possible to prove here that grid-forming control can be implemented on a control platform that is already established for use in industrial environments.

Going forward, the development of grid-forming control methods will be continued with the aim of using them in inverter-based operating equipment, such as wind turbines. Since the investigation based on inverter emulation was successful, a test bed that represents the drive train of a wind turbine, consisting of a generator and full inverter in downscaled performance, is in the process of being set up. Here, the focus will be on the use of components used in wind turbines, such as control hardware and power semiconductors. Investigations will continue into how the implementation of a grid-forming control system in a wind turbine is possible.

Publications:
1) Schulze, W. et al.: Emulation of grid-forming inverters using real-time PC and 4-quadrant voltage amplifier. Forschung im Ingenieurwesen [Engineering Research] 85, 425–430 (2021).
2) Schulze, W. et al.: Frequency influenceable grid emulation for the analysis of grid-forming inverters using a generator set. In 55th International Universities Power Engineering Conference (UPEC), Torino, Italy (2020).

More information:
www.ieh.kit.edu
www.beckhoff.com/wind

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

Digital strain measurement: condition monitoring directly integrated into control technology

A fully digital measurement chain from strain sensor to the control and management levels is a prerequisite for high-performance and integrated condition monitoring in wind turbines. Find out in this interview with Matthias Finke, Deputy Marketing Manager at Leine & Linde, based at the company's Hamburg location, how this has been achieved in the case of ESR strain sensors in conjunction with PC-based control.

Matthias Finke,
Deputy Marketing Manager
at Leine & Linde

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What characterizes ESR strain sensors?

Matthias Finke: The ESR series strain sensors are designed for permanent and temporary measurement of stress on practically all large structural components. What is referred to here specifically is their use in wind turbine rotors for supporting regulation of the individual blades. Other fields of use include load monitoring of cranes, material inspections and stress tests. The centerpiece of the sensor is an electro-optical position encoder, which has already proven its worth in many industries over decades. Particularly worthy of mention in this regard is the mechanical robustness coupled with a very high sensor resolution of 0.025 µm/m. In addition, an extremely broad measuring range of ±5,000 µm/m is offered as well as a maximum transmission rate of up to 30 kHz, which means that both static and highly dynamic applications can be supported. A highly integrated application-specific integrated circuit (ASIC) digitizes signals directly in the sensor, resulting in a low signal-to-noise ratio. The standardized EnDat 2.2 interface allows transmission of the incorporated electronic type plate and ensures comprehensive diagnostic capabilities. The ESR sensor series therefore represents the next evolutionary advance in digital strain measurement and the ideal basis for integrated condition monitoring.

What specific advantages are offered by the EnDat 2.2 interface?

Matthias Finke: EnDat 2.2 allows a fully digital measurement chain to be realized from individual strain sensor through to the control and management levels. The interface is characterized especially by the following functions: Data can be transmitted at up to 30 kHz where needed at high frequency and in a highly deterministic manner as well as in real time over a cable length of up to 100 m. As a bidirectional interface, it allows data to be read from a sensor and also transmitted to the sensor. The interface is based on the established and robust RS485 physical layer, which means that sensitivity to external interference is low. The cyclical redundancy checking (CRC) ensures data is transmitted securely and any errors can be detected reliably.

How is the associated gateway structured?

Matthias Finke: Our understanding of a gateway is that the signals from multiple ESR strain sensors can be implemented on the fieldbus over the EnDat 2.2 interface. It is unimportant in this respect initially whether the relevant bus couplers and I/O terminals are mounted on DIN rail in an existing control cabinet (e.g. pitch system) or are implemented as a stand-alone solution in robust IP65 design for installation in the rotor blade root. The advantage of the gateway concept is that the system design is as simple, robust and cost-effective as possible. The EL5032 EnDat 2.2 interface from Beckhoff offers ideal support for this approach, since it is extremely compact in design and can connect to two strain sensors. The small footprint is especially beneficial with a system design involving multiple strain sensors. In addition, the EtherCAT I/O terminal fulfills our strict standards of quality and reliability just as with the EK9300 PROFINET-RT Bus Coupler.

What is your experience of bus couplers and the EnDat interface in practice?

Matthias Finke: Our experience with use in wind turbines has been extremely positive – worthy of particular mention in this respect is the installation location in the root area of rotor blades. System commissioning proved to be extremely easy, in terms of connecting both the ESR sensors and the PROFINET interface to the higher-level data recording system. This is especially true in relation to connection of strain sensors since no separate commissioning is needed on behalf of EnDat 2.2.

Which software functionalities are available for evaluating the ESR data?

Matthias Finke: We see ourselves as a sensor and system supplier in this field of use. We offer a scalable solution, which covers many individual applications from the ESR strain sensor to the EMS strain measurement system. Where ESR is used

Leine & Linde focuses on status monitoring for primary components in wind turbines.

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Strain sensor in the ESR series

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exclusively, full access is provided to the measured raw data of each individual sensor, while plausibility and monitoring functions as well as functions for calibration and calculating bending moment are available with EMS in addition to the hardware components for installation in the wind turbine. The C++ function library ESR eXtended is ideal for this scalable solution offering. We provide this library free of charge for TwinCAT 3 software. ESR eXtended is designed both to support system control in series use and for frequently changing measuring campaigns. Time synchronicity, signal reliability and system maintainability are determining factors for use in system control in relation to sensor signals and the information generated. ESR eXtended supports this with the following functions: full integration in PLC projects including all task classes, evaluation of sensor self-diagnosis, online plausibility checking of measured values and automatic importing of the sensor-integrated, digital type plate. Factors such as integration in measuring projects, reproducibility and straightforward documentation are especially important for use in measuring campaigns. The task class-integrated querying of measured values, including synchronous time stamp, also helps here.

Which TwinCAT features are especially beneficial for you?

Matthias Finke: We relied fully on TwinCAT 3 as the development environment for creating ESR eXtended. A particularly positive aspect here is that with TwinCAT 3, our function library has been provided with a digital signature, which guarantees the user a high degree of quality and traceability. Another practical benefit is integration in the widely used Visual Studio® tool, which simplifies familiarization. TwinCAT support for C++ likewise simplified the implementation of our function library.

Which advantages does Beckhoff PC-based control technology offer in general?

Matthias Finke: The openness of PC-based control is paramount here. For example, this means that it is possible to access the hardware even without the TwinCAT development environment, thus making it easier to change basic settings or access diagnostic functions. Furthermore, optimum support is provided for creating graphical visualizations, since familiar development tools can be used here. From the perspective of a wind turbine manufacturer, PC-based control allows direct integration of condition monitoring in the system control. This is necessary since processor-intensive algorithms are frequently used for structure monitoring. Comprehensive monitoring can therefore be established, which allows the entire drive train to be monitored from generator to rotor – in parallel with system control and using the same hardware.

What is your experience so far with specific customer projects?

Matthias Finke: As regards the fieldbus gateway, a number of measuring campaigns have already been carried out with the ESR strain sensor and the EL5032 EnDat 2.2 interface. Our experience and that of our customers has been positive, especially with respect to the fast integration and commissioning. An experienced TwinCAT 3 user can start a measuring project after just five minutes, in which all information concerning measured values, diagnostics and documentation has been recorded and processed digitally.

The interview was conducted by Dirk Kordtomeikel,
Industry Manager Wind Energy at Beckhoff Automation.

More information:
www.leinelinde.com/wind
www.beckhoff.com/wind

Published in PC Control 03 | 2020

Retrofit and production solution extends wind turbine (WT) service life

PC-based control, paired with sensor and wind power expertise, optimizes wind turbines' service life

In a landmark achievement, the global installed capacity for wind energy generation surpassed 650 GW in the middle of 2020. However, operating wind turbines successfully over the longer term involves a significant challenge: During the next five years, more than one-third of turbines installed in Germany, Denmark and Spain will reach the end of their intended service lives. In light of this, solutions capable of optimizing wind turbines and prolonging their useful life – like a retrofit for pitch control systems, complete with rotor blade condition monitoring, co-developed by the companies fos4X and aerodyn – offer an important way forward.

Munich-based fos4X GmbH, founded in 2010, is an established industry player specializing in the use of data-driven approaches, including machine learning, to digitalize and optimize new and existing turbine systems. Its smart solutions, based on robust fiber-optic rotor-blade sensor technology, are deployed in today's best-performing, latest-generation turbine systems. Aerodyn Energiesysteme GmbH, headquartered in Rendsburg, Germany, is an engineering firm that develops wind turbine (WT) systems and rotor blades, provides WT redesign and optimization services, and licenses its turbine designs to third parties. The company's portfolio is based on its modular aeroMaster technology – a three-blade design with electrically powered pitch control and a variable-speed generator/converter system.

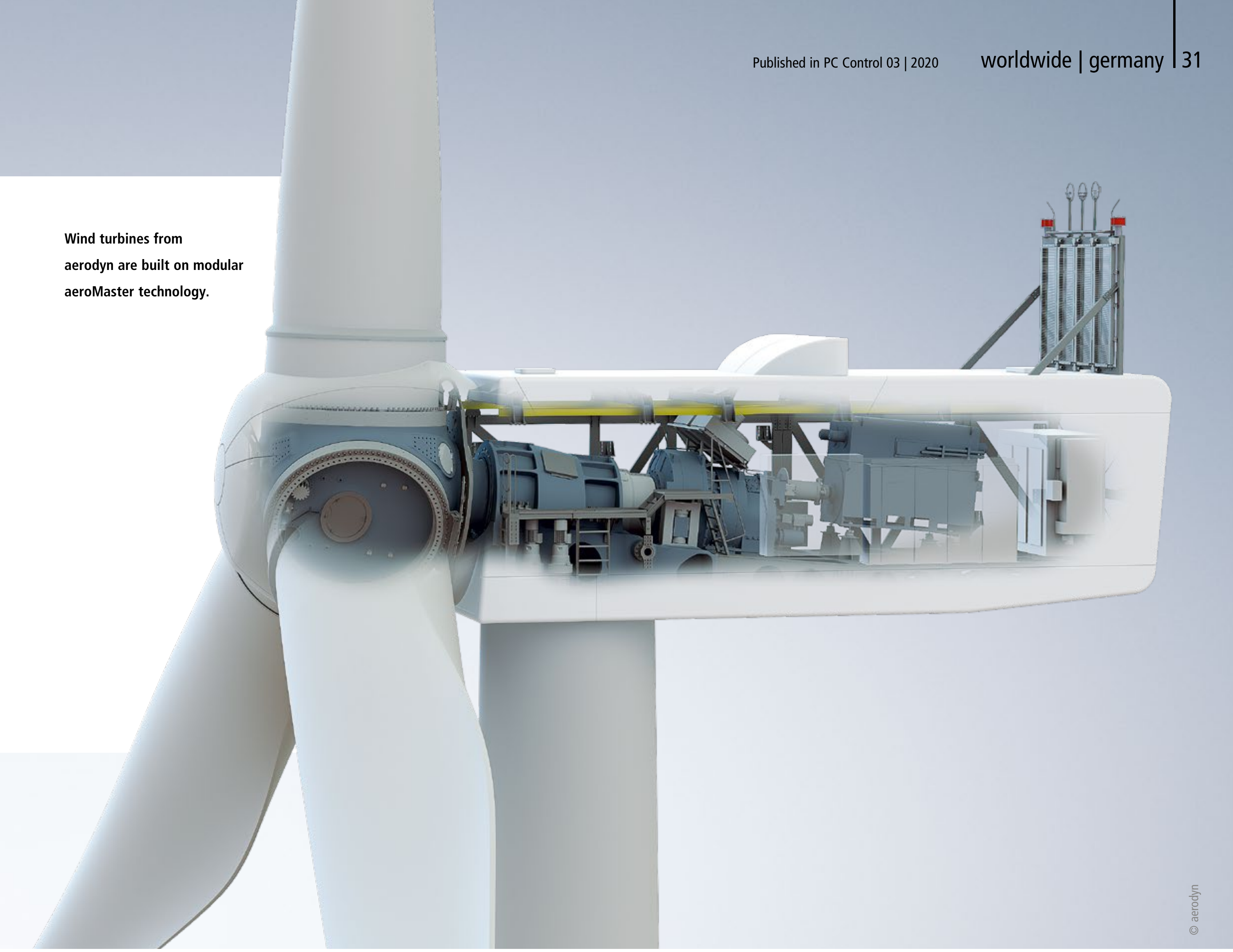
End-of-life solutions for maximum plant efficiency

End-of-life solutions are helping to extend wind turbines' service life while at the same time significantly increasing overall energy yields. Particularly at sites where regulatory constraints mean repowering is not an option, prolonging generating units' service life is sometimes the only way to preserve a wind farm. Extending turbines' useful life can also boost the financial appeal of wind power projects as well as bring down energy generation costs. This is underscored by the following figures for repairs and outages, and their financial impacts:

- Rotor blade faults account for around 7% of all wind turbine malfunctions. Repairs can be time-consuming, resulting in outages lasting several weeks.
- Experience in the field has shown that wind turbine components are likely to fail before they reach the end of their projected service life, which means that an appropriate repair budget generally needs to be set aside.
- Over a 10-year period, 2% of wind turbines, on average, needed to have their blades completely replaced. The ability to monitor the structural condition of rotor blades is therefore becoming increasingly important – not least because the blades' acquisition cost accounts for 15% – 20% of the total costs of a turbine system.

Ultimately, the key consideration here is what kind of financial benefit a project to extend a turbine's service life can deliver. One way to prolong the latter beyond a turbine's design life is to reduce the load on the main components, thus extending the relative service life without affecting the yield. For instance, a 10% reduction in damage-equivalent load at the rotor blade root results in a 50% longer service life. So if a system receives a retrofit in its tenth operating year that achieves such a reduction, its service life is extended by five years.

Comprehensive load monitoring gives wind farm operators consistent visibility into the impacts of discrete events on rotor blade service life. The same



Wind turbines from aerodyn are built on modular aeroMaster technology.

© aerodyn

indicators can serve as metrics for understanding differences in behavior between individual turbines within one and the same wind farm, enabling operators to identify wake effects (caused by wake currents in slipstreams) in turbines with higher levels of fatigue, as well as damage caused by tracking fluctuations in rotor blades' natural frequencies, and yaw and pitch errors due to uneven rotor loading.

A solution built on combined expertise

Solutions from fos4X bring down wind turbines' energy production costs by delivering the following:

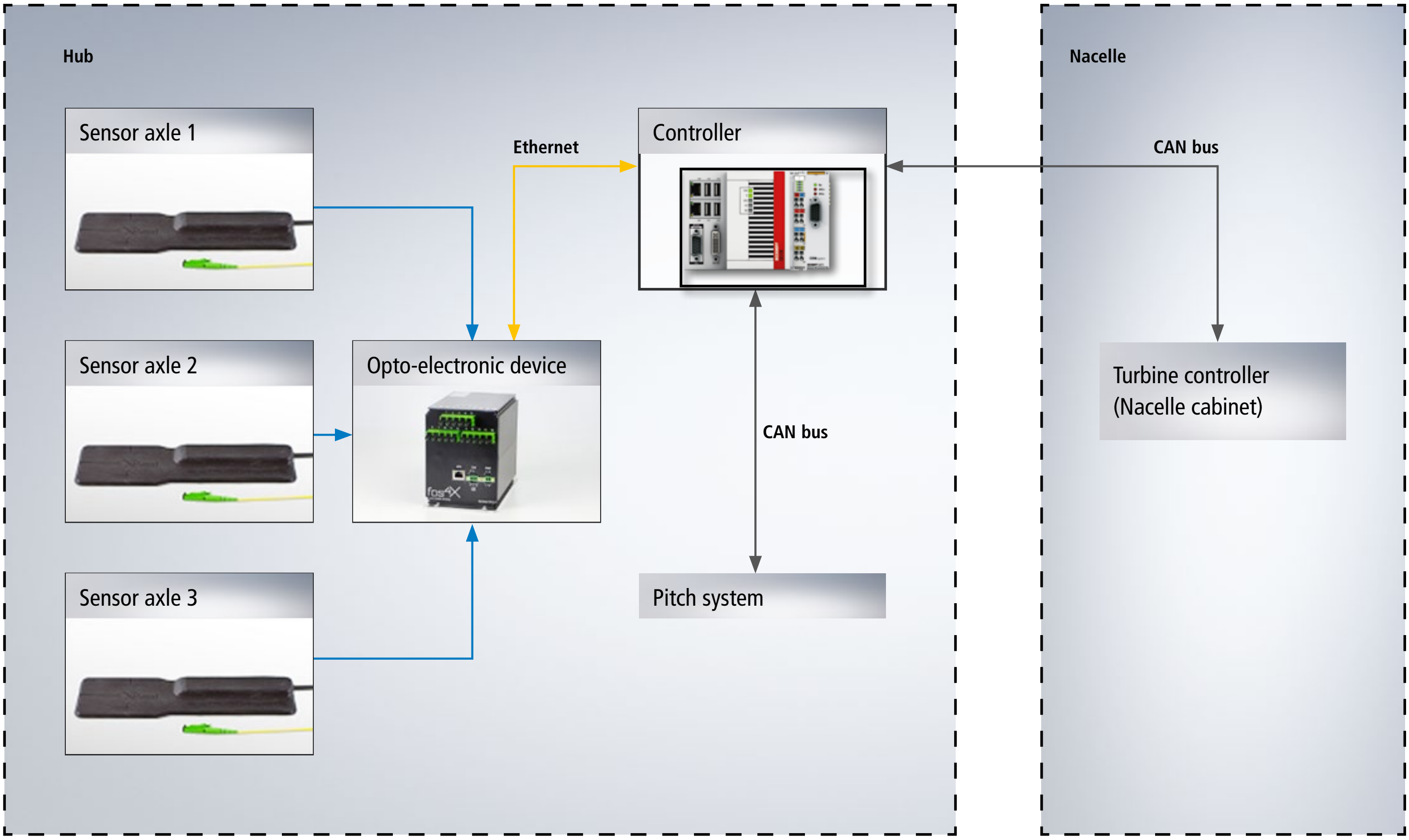
- higher annual power production
- lower operating costs
- minimized operation risk
- extended service life

The focus of these solutions is on rotor blade sensors and data analytics. Says Bernd Kuhnle, Chief Sales Officer at fos4X: "In our joint solution with aerodyn, we supply the hardware platform and the streaming analytics that serve as a basis for different approaches to optimizing wind turbine operation and extending service life. The wind turbines are fitted with our field-proven sensor system, which is installed inside the rotor blades to protect it from environmental impacts. The sensors reliably deliver valuable data over the entire WT service life."

© fos4X

For Bernd Kuhnle, Chief Sales Officer at fos4X, the openness of PC-based control technology is key.

The solution is calibrated autonomously during regular system operation using algorithms developed by fos4X. Much like a digital twin, the fos4X system produces high-quality data needed in subsequent processing. The real-time data captured and generated is read out by aerodyn and used to adjust each rotor blade's angle of attack in a specially developed approach known as individual pitch control.



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How the fos4X solution integrates with the turbine control system

But the system has more to offer in terms of value-add besides aerodyn's method of individual pitch control: While the basic version only measures loads, it can be augmented to generate a load history over the system's remaining service life. In addition, fos4X can detect yaw and pitch errors from the load data captured. Correcting these errors leads to a higher energy yield and reduced wear. The solution can also monitor the condition of blades to identify damage or ice build-up. These capabilities make the solution the first in the world to enable comprehensive rotor blade monitoring while at the same time delivering important data for use in digital twins and predictive maintenance.

Implementing individual pitch control

A variety of data needs to be captured in order to implement pitch control. This includes forces acting on the wind turbine, which are best measured directly at the rotor blades themselves. To accomplish this, fos4X installs sensors inside the turbine blades – a process that typically takes just a day to complete. Load data can then be captured continuously and fed to aerodyn's pitch control system.

The purpose-designed algorithm in the retrofit system allows each rotor blade to respond individually, in real time, to load fluctuations and to compensate for loads as they arise. This can substantially reduce the effective load borne, which has a beneficial effect on the wear and the durability of the various turbine components. Loads are managed using the aeroBalance method, which continuously computes the required angles of attack according to blade load. Timm Daunke, Load, Tower Design, aerodyn, explains in more detail: "Self-monitoring routines ensure that the loads are always reduced or, at minimum, never exceed the levels they would reach without individual pitch control. This means that the turbine doesn't need to be re-certified. Nor do the wind turbine's control parameters need to be modified. The load management process uses the unsecured bus communication between the turbine controller and the pitch system as this allows the wind turbine to automatically activate bypass modes and continue operating, even if an internal system error occurs."

Control system with integrated condition monitoring

For actual access to the wind turbine's control system, though, communication has to be secured. This, says Bernd Kuhnle, is where Beckhoff comes in as a strategic partner – and here, the openness of PC-based control plays a central role. With existing wind generating facilities in particular, which typically use a heterogeneous mix of components from different vendors, being able to integrate with the equipment already deployed is key. As an open platform that supports all common fieldbus standards, including EtherCAT, CANopen, PROFIBUS and PROFINET, PC-based control enables simple and flexible integration with solutions of any kind. The combination of modular hardware with the high-speed communication capabilities and flexible topology of EtherCAT means the system can adapt perfectly to the given requirements.

The solution from fos4X operates as an EtherCAT slave, so it is exceptionally simple to incorporate into a PC-based control system. However, it can integrate just as easily with any other controller, making it suitable both for retrofits to existing turbines and for installation in new turbine systems. If required, the system can also be expanded on a modular basis using Beckhoff EtherCAT Terminals – to capture strain, vibration and temperature information, for instance.

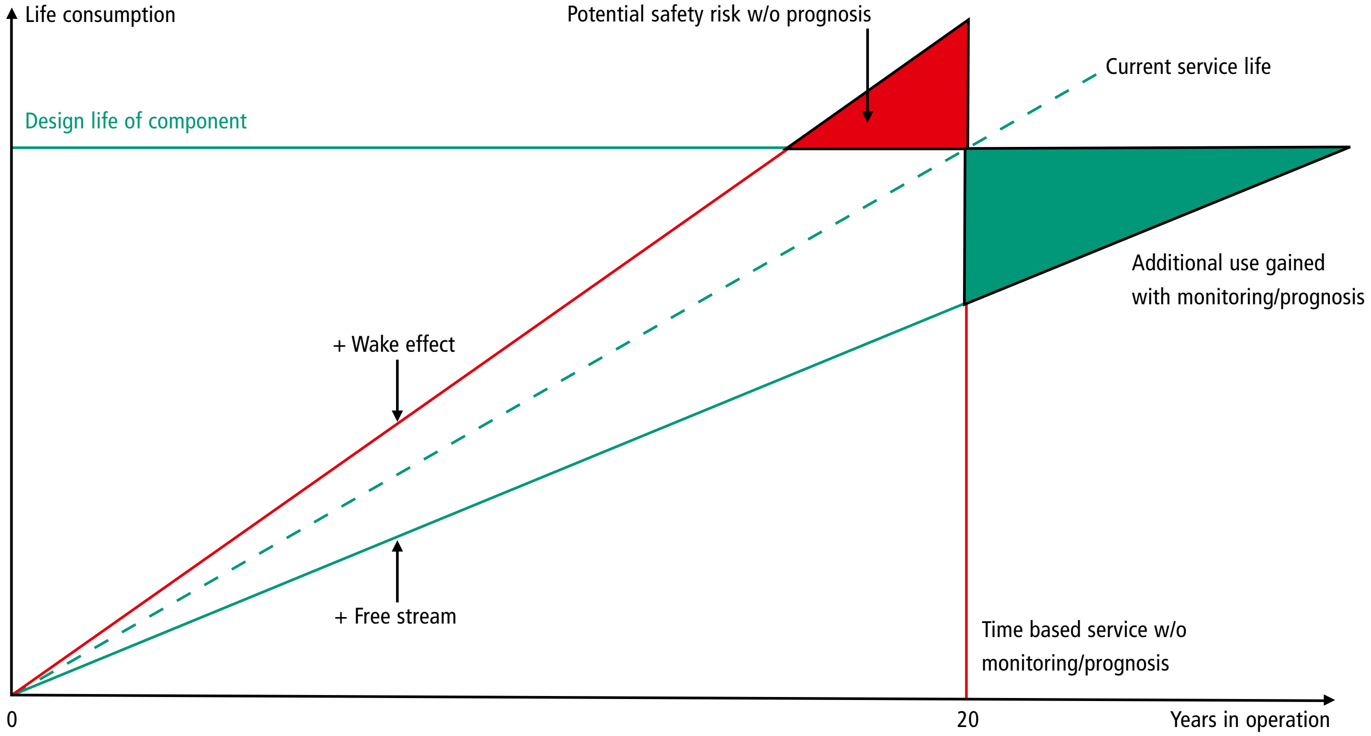
The controller developed by aerodyn is implemented as a TwinCAT TcCOM module, which means it will work on any Embedded or control cabinet PC running TwinCAT 3 software. TwinCAT also makes connecting fos4X sensors simple. Plus, by adding TwinCAT 3 functions for OPC UA, IoT and database connectivity, for instance, integration with existing SCADA systems can be accomplished with little effort.

More information:
www.aerodyn.de
www.fos4x.com/en
www.beckhoff.com/wind

A modern aerodyn wind turbine design using TwinCAT Wind Framework

Originally implemented in an initial project in 2014, aeroMaster 5.0 from aerodyn is the first wind turbine system to use the TwinCAT 3 generation of software and the new TwinCAT Wind Framework from Beckhoff. Modular control software based on the Wind Framework perfectly matches the turbine's modular hardware, which is designed to allow the sourcing of components such as the pitch controller, converter and generator from different vendors. TwinCAT 3 Wind Framework unites control technology with industry-specific expertise in a set of encapsulated modules and an application template. The modules offer a comprehensive range of services for automating wind turbines, as well as real-time access to a full range of data, plus long-term data retention in a database. The application template provides a modular architecture designed to enable efficient, highly focused engineering and to get users off to a quick and easy start.

More information:
www.beckhoff.com/twincat-wind



© fos4X

The benefits of continuous monitoring with fos4X rotor blade sensors: differences in linear service life consumption for a component's operating times (dashed line), including the potential safety risk and additional use gained, with or without monitoring.

Published in PC Control 03 | 2019

Online fault diagnostics improve wind turbine availability

TwinCAT Wind and oversampling technology enable highly efficient condition monitoring

High availability is a top priority for today’s wind turbines, especially if they have a high output in the MW range. Chinese turbine manufacturer Goldwind has therefore developed an online condition monitoring system with all functions based on PC Control technology and EtherCAT from Beckhoff. The control platform communicates in real-time, reduces maintenance costs and increases availability.

© Goldwind

The technology for wind turbines implemented by Goldwind and Beckhoff promotes the inexpensive, reliable and sustainable energy generation of the future.

For many years, Goldwind has been using online condition monitoring in its wind turbines to enable remote monitoring and determine the operating status of individual system components. Using appropriate sensors, the Condition Monitoring System (CMS) acquires and analyzes noise, vibration and temperature data, among other things, and warns of the possible failure of individual components in a timely manner. Anomalies that occur during wind farm operation are visualized for operators and maintenance staff on a convenient HMI. Impending faults can thus be predictively recognized and quickly rectified. As a result, wind turbine availability is increased and costly damage is avoided. This is particularly important for offshore systems on account of the poor accessibility at sea.

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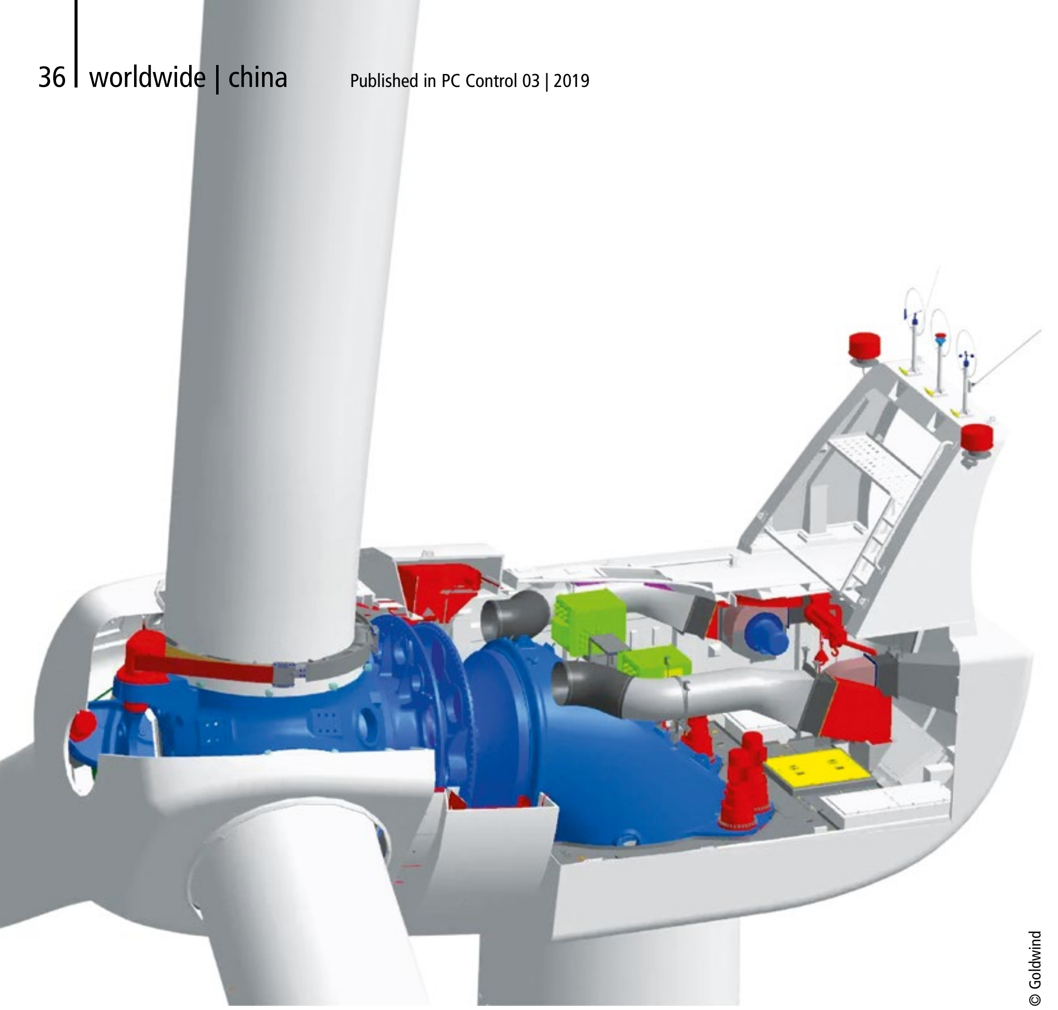

© Goldwind

Predictive maintenance with TwinCAT Wind Framework software uses ultra-fast EtherCAT communication to monitor the main components in a wind turbine nacelle (in this case with direct drive), such as rotor blades, hub, pitch system, generator rotor, generator stator, gear system, wind measurement system along with the foundation plate and tower frame.

Goldwind: focus on sustainable power generation

Goldwind, a Chinese provider of wind energy solutions, was established in 1998 and has delivered 28,500 wind turbines worldwide to-date, corresponding to more than 44 GW of installed wind capacity. Today, the company, which is a licensee and now majority shareholder of wind turbine manufacturer Vensys, stands out as a technology provider for renewable and green energy. Goldwind has been selected several times as one of the 50 most innovative companies in the world and was in the Top 100 list of the Global Challengers in 2016.

For the user the original CMS was merely a “black box”, because the soft--ware offered only limited openness. Another shortcoming: vibration data and condition values of the plant – such as wind speed, generator speed, gear or pitch angle – could not be recorded synchronously. Moreover, the trend towards increasingly high outputs and intelligent operational management of wind turbines made data evaluation for system optimization purposes more challenging. The consequence: the systems no longer met the present-day requirements with regard to technology and market needs.

Significant improvements of wind turbine availability

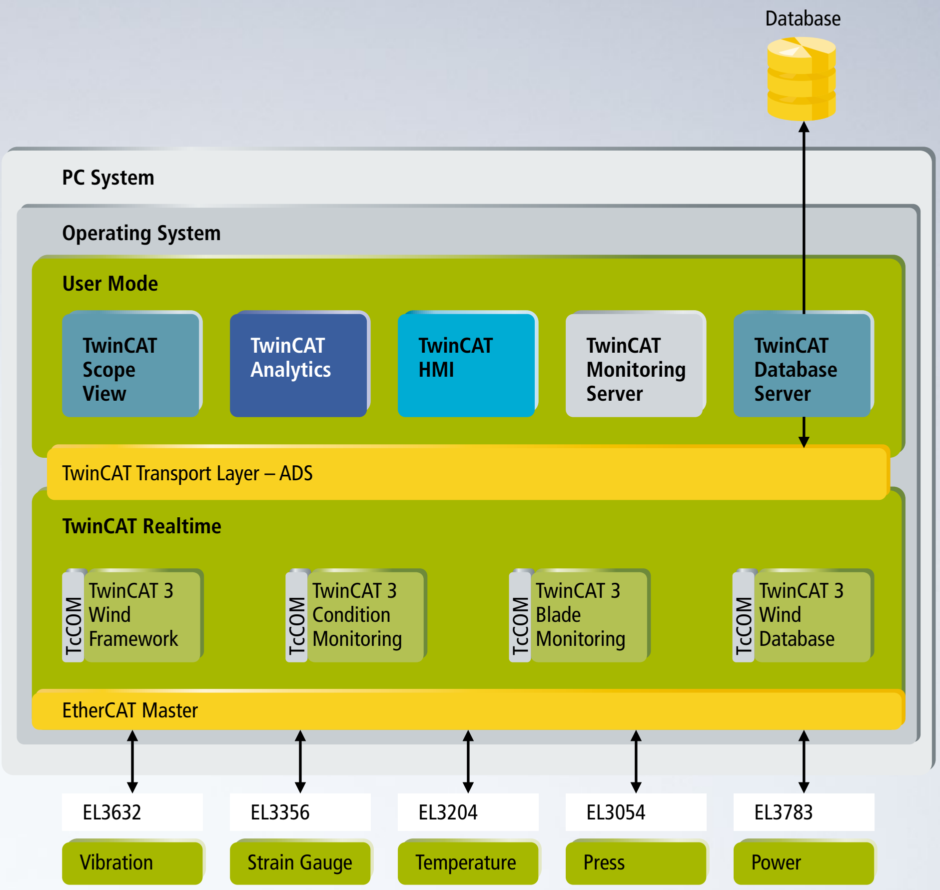
Goldwind has been using open automation technologies for years. Accordingly, when the Chinese wind turbine manufacturer started development of a new online monitoring system in 2014, they turned to PC-based control technology from Beckhoff for the implementation. The goals at the time included the ability to operate a wind turbine over its entire lifecycle with competitive costs and lower susceptibility to faults. It was also important to reduce maintenance costs and downtime. The first and foremost goal was to meaningfully improve wind turbine availability.

After completing detailed calculations and analyses of the operating behavior of large wind turbines, Goldwind researchers produced clear findings: In order to acquire all condition data synchronously from the generator bearings – including high-frequency acceleration data – the existing drive train monitoring system had to be developed into a state-of-the-art CMS. The new system records not only the acceleration and strain of the rotor blades and hub, but also those of the main bearing and the tower. These values are forwarded by the system to the database server via the network of the respective wind farm.

Real-time solution for intelligent wind turbines

The online CMS from Goldwind operates autonomously and is based on TwinCAT 3 automation software from Beckhoff. With regard to controls architecture and functionality, the CMS is built with the following functional components:

- The heart of the CMS is the CX5130 Embedded PC, which uses the 64-bit operating system Windows Embedded Standard 7 and an Intel Atom® multi-core processor with a clock frequency of 1.75 GHz.
- The oversampling-capable EL3632 XFC EtherCAT Terminal for Condition Monitoring (IEPE) records vibration and acceleration signals from the generator bearing with a sampling rate of up to 50 ksamples/s as well as a synchronization accuracy of < 100 ns per channel. The sampling rate and oversampling factor can be parameterized as required.
- All condition data of the wind turbine are acquired simultaneously via TwinCAT ADS communication.
- Raw data and condition data are collected synchronously via the TwinCAT Wind Framework in the controller. The original data and the results calculated from them are saved by the TwinCAT Database Server directly in the local relational database.



The TwinCAT-based CMS acquires and analyzes vibration data from the online generator bearing and saves it at high speed in a local database via TwinCAT Wind Framework.

© Goldwind

Application at a glance

Solutions for sustainable energy generation

- online condition monitoring for wind turbines

Customer benefit

- reduced maintenance requirements and increased system availability
- continuous acquisition of vibration and strain data incl. remote access capability

Applied PC Control

- CX5130: Embedded PC out of the finely scalable PC Control portfolio perfectly adapted to the application
- EL3632: highly precise signal data acquisition using oversampling technology
- TwinCAT 3 incl. Wind Framework, Condition Monitoring, Database Server: synchronous real-time acquisition of all data

- Streaming algorithms within TwinCAT Condition Monitoring analyze data such as power spectra and moment coefficients online and in real-time. The analysis results are also written to the database in real time and reported back to the main control system. In this way, meaningful diagnostic data can be generated for smart wind turbines.
- All information can be saved in a local or remote database. The Condition Monitoring Server can read the raw data and computed results for each wind turbine via remote access – a function that does not exist in a traditional CMS, according to Goldwind.

The openness of the software and flexible expansion of the Beckhoff control technology offer particular benefits for any condition monitoring system. This is incredibly important, because no two wind turbines are designed alike and it must be possible to adapt the functions of the turbine-specific control software to the respective needs quickly and optimally. Modularly expandable functions further simplify commissioning, because individual software functionalities can be added quickly in this way. Synchronous data acquisition can be implemented just as quickly as real-time communication and fault location tracking. All these features significantly simplify the creation of database structures and data storage functions.

PC-based control: the ideal platform for condition monitoring

Huang Xiaofang, Senior Engineer at Goldwind, who is responsible for the CMS development, summarizes: "The functions of the condition monitoring system based on Beckhoff technology facilitate future system expansions and upgrades. The CMS integrated into the main control system is cost-competitive and an ideal solution to support intelligent wind turbines."

Huang Xiaofang continues: "The CMS can communicate with wind turbines in real-time. Performance data from wind turbines and condition monitoring results can be acquired synchronously, which improves the scope of analysis and data insights. Due to the extremely high performance of the Beckhoff platform, the condition monitoring data can be acquired, stored and analyzed in real-time. Therefore, it is possible to implement continuous equipment health monitoring and real-time warnings for the state of key components in wind turbines."

More information:
www.goldwindglobal.com
www.beckhoff.com/wind

Published in PC Control 03 | 2018

Although the test bench weighs 4,000 tons, TwinCAT 3 software enables fast control sequences and the easy integration of advanced simulation models.

TwinCAT 3 controls a HALT test bench for wind turbines up to 10 MW

Wind turbine HALT enables rigorous testing

Denmark is setting a new standard for wind turbine testing technology. The Lindø Offshore Renewables Center (LORC) is capable of testing the nacelle of a wind turbine for all possible wind and torsion loads it will be subjected to during its service life of more than 25 years. The automation technology for the control of the test bench was supplied by Beckhoff.

© R&D Test Systems

As wind turbines become ever larger and more expensive, the need to minimize the risk of damage over their entire service life increases as well. This requires the execution of load tests on real turbines prior to starting series production of a new wind turbine. Providing the most rigorous Highly Accelerated Lifetime Test (HALT) possible is the mission of LORC, one of the world's largest test benches for wind turbines with a capacity of up to 10 megawatts, which went online in December 2017 in Munkebo, Denmark. The large wind simulator uses mechanical, hydraulic and electric functions to generate as many stresses and strains in six months as a wind turbine is subjected to over its entire 25-year service life. Such tests help identify weaknesses in design and construction so that any necessary changes can be made before the turbines are manufactured in volume.

Test bench with realistic conditions

As the facility's turnkey supplier, Danish engineering company R&D Test Systems was responsible for the entire project from designing and developing the mechanical components to programming and commissioning. The complex development and implementation processes took many years to complete. To ensure a smooth commissioning process and guarantee reliable test bench performance, all functions had to be thoroughly simulated and tested. The simulation models and test results were used for further software development and operator training.

At the testing center, the mechanical components of a wind turbine are subjected to realistic fatigue tests based on wind and weather data from wind farms all over the world. "The ability to simulate real-life conditions is becoming increasingly important for the wind power and other industries employing heavy-duty solutions. Manufacturers can save many resources over the long term if they know in advance how a wind turbine will react in real-world use," explains Michael Nielsen, General Manager, Beckhoff Denmark. With TwinCAT 3 software, powerful Industrial PCs and numerous EtherCAT I/O terminals, Beckhoff supplied the foundation for specification and monitoring of all test scenarios. Danish control cabinet supplier Tricon Electric A/S installed the components.

Each newly developed wind turbine must undergo testing as a complete system. Since this is very difficult considering the dimensions of modern turbines, manufacturers test the nacelle by itself, simulating the effects of the rotor, the electrical circuitry and other environmental conditions as realistically as possible on the test bench. To map all the forces and torque factors that affect the main turbine shaft and nacelle, the new HALT test bed required a unique design. Building the facility, which is 31 meters long, 8 meters wide and 13 meters tall, required 310 tons of steel, and 107 concrete pillars that had to be buried 16 meters deep into the ground. Weighing 4,000 tons, the test bench features a hydraulic bending system that can apply bending moments of up to 25 MNm to the turbine being tested. It generates these forces with hydraulic cylinders. A drive system with a torque of 14.5 MNm generates the wind force applied to the rotors.

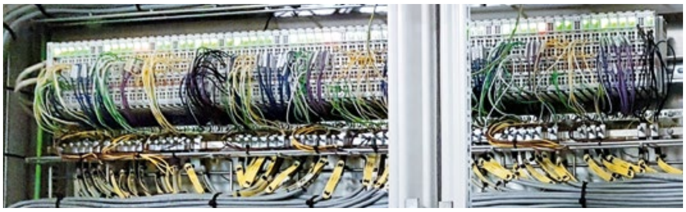
When wind shears, gusts or turbulences impact the rotor, this generates additional bending moments and thrusts. The test bench recreates these forces via hydraulic cylinders in a hexapod construction. Since the tower and rotor are missing, however, the system must model these real-life conditions as precisely as possible, which is why simulation models calculate the interactions occurring between nacelle and rotor in real time and send the corresponding signals to the hydraulic cylinders. The system is capable of simulating the widest possible range of operating conditions, such as the nacelle's behavior in gales or after grid failures and emergency stops.

Simulations in the millisecond-range

During test runs, the sensors must be able to acquire, process and transmit vast data quantities in the shortest possible time, which is why all test bench components and test objects were modeled in MATLAB®/Simulink® prior to commissioning. "Since the software must be able to respond to diverse test scenarios as quickly as possible, we wanted to achieve the shortest possible cycle time," says Allan Mogensen, Software Manager at R&D Test Systems. "We selected Beckhoff systems because the TwinCAT 3 automation software enables us to achieve a cycle time of 1 millisecond."

The MATLAB®/Simulink® software interface in TwinCAT 3 is another benefit, adds Allan Mogensen: "To ensure excellent operability and performance, we simulated all testing functions on a computer by creating MATLAB®/Simulink® models of all physical components of the test bench and test objects that LORC customers wanted to test in reality. The MATLAB® model simulations act as a benchmark for later real-life tests on the real physical mechanic system, without posing risks to the mechanic system. This enabled us to reach our goal faster than originally planned."

Allan Mogensen summarizes: "The test bench is a lighthouse project for Denmark and the Danish wind power industry. We delivered a HALT facility that enables us to test wind turbines faster and more effectively. Having sufficient computing performance was particularly important for our implementation. The hardware and software from Beckhoff satisfied these requirements in an ideal way." Morten Hauge, Sales Engineer at Tricon Electric, agrees: "Supplying such an advanced solution for a project as large as this one was an interesting job. Beckhoff hardware feature the level of intelligence you need for such demanding tasks."



© LORC

Installed in six control cabinets supplied by Tricon Electric, the Beckhoff hardware components communicate with each other over the powerful EtherCAT network.

More information:
www.lorc.dk
www.rdas.dk
www.tricon.dk
www.beckhoff.com/wind

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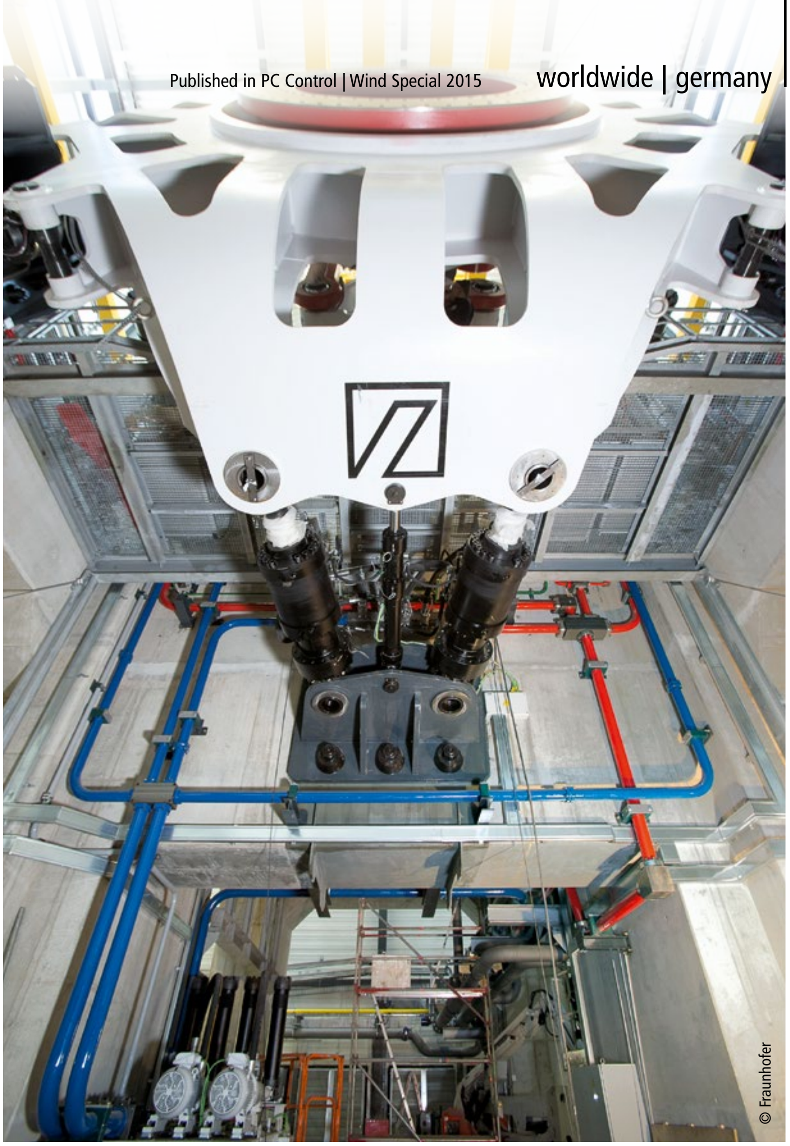
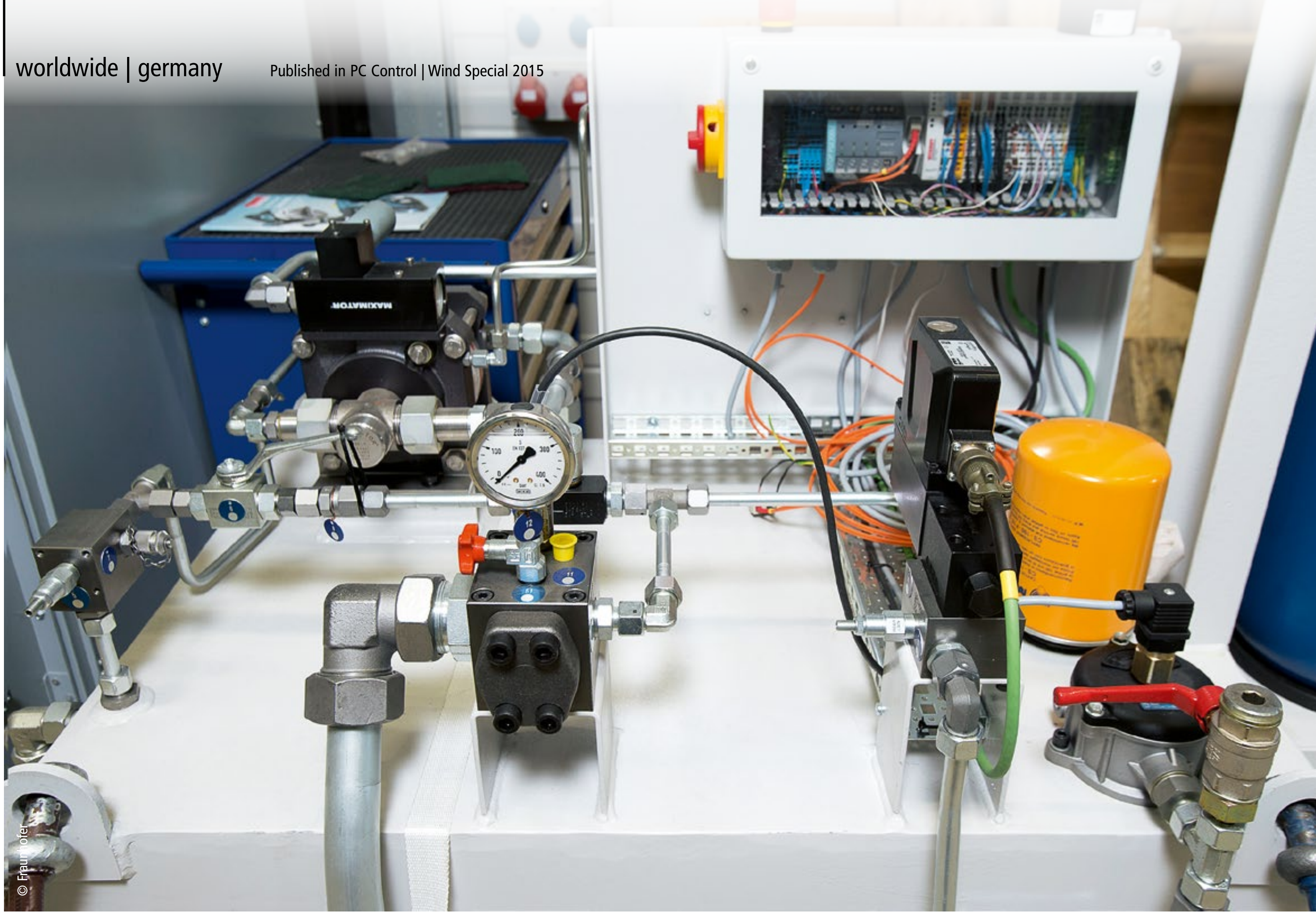


The Stewart platform for the load transmission to the wind turbine nacelle offers six degrees of freedom and uses six 3000 kN servo cylinders.

PC- and EtherCAT-based control technology in a feature-filled test bench system for wind turbines

Fast EtherCAT communication for distributed real-time controllers in a 10 MW test bench

The Dynamic Nacelle Testing Laboratory (DyNaLab) is the first test environment for complete wind turbine nacelles ever built in Germany. It features a test bench drive with a rated output of 10 MW, designed for testing wind turbine systems with a rated output of 4 to 8 MW. PC-based control from Beckhoff is used to control the complex system, and a high-speed EtherCAT communication ensures a consistent real-time solution as well as optimum consideration of the distributed subsystems from a control perspective.



© Fraunhofer

DyNaLab is located in Bremerhaven, Germany, at the "Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) Northwest". The research activities at the IWES cover the whole spectrum of wind energy technology, from wind physics to grid feed-in. The focus is on understanding wind turbines as systems with dynamic interaction between the individual components and environmental factors, which – according to Torben Jersch, group leader for plant and system technology – creates potential synergies in comprehensive approaches to these solutions. This is especially true in view of the fact that the Fraunhofer IWES in Bremerhaven already operates two continuously utilized rotor blade test rigs, and therefore offers a unique overall testing infrastructure.

Testing wind turbines comprehensively and under realistic conditions

DyNaLab offers wind system manufacturers a realistic test environment in the multiple-megawatt range, enabling meaningful laboratory tests that can contribute to the assessment and optimization of existing and future system concepts. The first tests were conducted in August 2015, in cooperation with a Spanish system supplier. The wind turbine nacelle from Jacobs Power Tec GmbH to be tested was connected via a hydraulic load application system in the form of a Stewart platform, and consisted of a hexapod with six 3,000 kN servo cylinders. One of DyNaLab's key features will be electrical certification of wind turbines on the test bench.

The load transmission structure for simulating mechanical wind loads, such as shear or bending moments, is linked to the flange adapter via a moment bearing. Moments and forces can thus be transferred from the non-rotating load disc to the rotating shaft. With this special configuration, it is possible to apply bending moments of approximately 20,000 kNm or shear forces up to 1,900 kN, and, moreover, it enables the dynamic simulation of radial loads. The wind torque is modelled via two externally excited synchronous machines in a tandem arrangement with a drive power of 5 MW each. For test operation, this enables a total drive power of 10 MW and the introduction of a rated torque of 8,600 kNm to the equipment under test.

The whole drive train of the test bench is tilted by 5°, which corresponds to the actual orientation of a wind turbine in the field, therefore simulating a real load situation. The wind load simulation can either mimic different static and dynamic operating conditions, or it can be run as a real-time simulation, as well. To test wind turbines as comprehensively as possible, pitch and yaw systems are integrated in the system test. For this purpose, the control values of the individual systems are implemented via actuators in the real-time simulation. A 36,000 V medium voltage grid simulation enables simulation of network faults and voltage dips during the nacelle test with a high repetition rate.

Real-time capable control system for the test bench

Torben Jersch explains the requirements for the control technology of the test bench: "Because we wanted to perform distributed real-time calculations and control simulations, a very fast and deterministic communication system was a must-have. EtherCAT has proven to be ideal for this purpose. Due to profound

PC-based control is modular and finely scalable, which means it can be used in all areas of the test bench as required.

The large hall of the test complex contains the actual test bench as well as the hydraulic and cooling systems; whereas the bulk of the electrical installation is housed in the building to the left.

EtherCAT expertise and the wide range of EtherCAT components available from Beckhoff, it made sense to completely rely on PC-based control."

In the meantime, this approach has been tried and tested in practice, as Torben Jersch explains: "The eXtreme Fast Control (XFC) characteristics of EtherCAT, such as Distributed Clocks and Timestamping, ensure time synchronicity across the whole test bench. As a result, we could easily configure the required distributed discrete control loops, consistently adhere to the real-time concept, and consider all sub-components from a control perspective. EtherCAT is therefore the main communication bus for controlling the key components of the test bench, such as inverters, motors, hexapod, simulation computers, set value specification and additional monitoring for the test object. Standard Ethernet is used for the non-real-time monitoring and control of auxiliary systems, such as cooling pumps."

The Beckhoff control technology includes TwinSAFE to ensure the system safety of the test bench. In addition, the Hexapod controller directs the six hydraulic cylinders in parallel, as well as the tasks performed by the central DyNaLab control computer and the real-time calculation of the wind turbine rotor model. Three Industrial PCs (IPCs) perform these tasks, specifically two 19-inch C5102 slide-in IPCs and a CX5010 Embedded PC. Torben Jersch explains the reasons for this configuration: "The physical separation into three computing devices was part of our specification, in order to provide a clear structure for the control system, with unambiguous interfaces. In addition, this architecture facilitates subsequent extensions or optimizations for various subsystems."

Simplified engineering through TwinCAT 3

DyNaLab uses the TwinCAT 3 automation software, which offers particular benefits because of the seamless interfacing with MATLAB®/Simulink® software, as Torben Jersch explains: "The integration of MATLAB® code enables the majority of our staff to program controllers themselves and therefore to focus on application development, without having to delve deeper into microcontroller or PLC programming." Other components used in the test bench include the base TwinCAT 3 software environment and additional functions such as TC3 PLC, TC3 Scope View Professional and Scope Server, and TC3 XML Server and Database Server.

More information:
www.windenergie.iwes.fraunhofer.de/en
www.beckhoff.com/ethercat
www.beckhoff.com/twincat3
www.beckhoff.com/wind

GfM staff engaged in testing acceleration sensors connected to the Peakanalyzer.

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High-end vibration analysis in wind turbines

Modular EtherCAT Terminals for scalable condition monitoring solutions

The Peakanalyzer by GfM, which is universally applicable for fully automatic vibration diagnostics, has been tried and tested for use in wind turbines. The raw data is processed by a Beckhoff CX5020 Embedded PC with integrated EL3632 EtherCAT Terminals for Condition Monitoring (IEPE). The system monitors the entire wind turbine drive train, and optionally the wind turbine foundations, reliably and with high precision.

GfM (Gesellschaft für Maschinendiagnose mbH), based in Berlin, specializes in vibration diagnostics for gear units mounted on roller bearings. Co-founder and managing director Dr. Rainer Wirth explains: "Our research and development work has always focused on the automation of diagnostic processes, since this is the key for widespread acceptance of these technologies. GfM actively promotes the combination of diagnostic services and device development, so that practical experience can directly feed into product development."

One of the devices that has benefited from this approach is the Peakanalyzer, designed for fully-automatic, high-end vibration diagnosis at up to 32 measuring points, with up to 32 further channels for slower process variables (1 kHz). At the heart is PC-based control technology from Beckhoff, which integrates Scientific Automation concepts for integrating measuring functions that go beyond standard automation, such as condition monitoring. In this way, the Peakanalyzer enables, among other things, order analysis through resampling for diagnostics of variable-speed drives, DVS (Drive Vibration Significance) analysis for automatic identification of significant spectra, characteristic value monitoring, and triggered data acquisition.

Typical areas of application for this versatile diagnostic device are for costly, low-redundancy drives, such as in mills for the building materials industry, drives in conveyor systems, where availability is a critical requirement, or safety-relevant drives in cable cars, for example. The Peakanalyzer is also frequently used for drives that are difficult to access and for which condition-based maintenance is therefore a prerequisite. Wind turbines are a prime example for such applications.

Application-specific and comprehensive monitoring of wind turbines

For monitoring wind turbine drive trains, an 8-channel Peakanalyzer is used, which can optionally also be used to monitor the foundations via two further channels, in order to detect loosening. The diagnostic device is installed in the wind turbine nacelle, either in the control cabinet or in a dedicated housing. The system analyzes the drive train based on the signals acquired by eight IEPE acceleration sensors: one sensor for the main bearing, two for the generator, and five for the gear unit. If required, the Peakanalyzer can be integrated into the existing communication structure (LAN interfacing in the nacelle, VPN access),

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Kai Uchtmann, Dr. Rainer Wirth, and Axel Haubold (left to right) have been working on machine diagnostics since 1985 and established the company GfM in 1999.

or communication can be established via wireless communication, optical fiber (tower), or via GHSDSL (copper cables between systems), as well as through DSL to the Internet provider.

GfM software developer Christian Reinke explains the benefits of the underlying PC-based control technology: "The modular control technology from Beckhoff enables us to offer customized and cost-effective diagnostic solutions that are highly scalable, based on a freely programmable, open system, and with globally available and exchangeable spare parts, if required. What's more, distributed solutions can be easily realized with the EtherCAT Terminal I/O system. Based on the high-performance communication via EtherCAT, the Peakanalyzer can be offered with up to 32 input channels for enhanced application flexibility. Moreover, a high channel sampling rate even with lower bus cycles can be achieved based on the oversampling functionality of the EL3632 and EL3702 EtherCAT Terminals, and this is how the Peakanalyzer is able to support such accurate vibration recording and evaluation."

The CX5020 Embedded PC performs measuring data acquisition and buffering based on TwinCAT software. The information is then passed via ADS (a communication protocol within TwinCAT) to GfM's proprietary analysis software for further processing. Christian Reinke continues: "The advantage lies in the direct control of the PLC. That is, the communication is based on a universal PLC, so that different system configurations with different numbers of channels and terminal types only need to be distinguished in our software." Remote access is also possible, and to this end, the GfM .NET application on the Embedded PC communicates with configuration and evaluation software on the corresponding network computer via TCP/IP.

Condition monitoring terminals as essential I/O equipment

Sensor data for drive monitoring is logged with high precision via the two-channel EL3632 EtherCAT Terminals, an essential component of the Peakanalyzer, according to GfM co-founder and managing director Axel Haubold: "The key for the implementation of our high-end vibration monitoring system is the acquisition of the IEPE sensor signals with a sampling rate of 50 kHz. An additional factor is the very wide sampling range between 1 Hz and 1 kHz, which enables the device to measure low-frequency vibrations (e.g. tower oscillations) and high-frequency vibrations (e.g. vibrations at the actual wind turbine) at the same time. In order to obtain a high-quality envelope signal for detecting roller bearing and gearing damage, all channels almost exclusively measure with a clock frequency of 50 kHz. Particularly in the wind industry, the 0.1 to 10 Hz mode is additionally used for logging characteristic values according to VDI 3834. A further benefit, particularly during commissioning, is the breakage detection feature offered by the EL3632 Condition Monitoring terminal."

The I/O range of the Peakanalyzer can be complemented by further interfaces, according to customer requirements. Christian Reinke elaborates: "Here, we benefit from the wide range of solutions in the modular EtherCAT I/O system. For example, via pulse time measurement, the EL5151 incremental encoder interface enables very precise speed measurement with several, non-equidistant pulses per revolution. The EL3702 analog input terminal with oversampling is ideal for recording oscillation movements via inductive displacement sensors for monitoring slowly moving roller bearings."

EL1002 digital input terminals are used for triggering measurements, and EL2004 digital output terminals handle the signaling of characteristic values and process parameter alarms. Important process variables such as power, wind, and torque can be integrated in the diagnostic system as analog voltage signals (±10 V) or current signals (0 to 20 mA) via the EL3702 or EL3742 EtherCAT Terminals. In addition, EL3356-0010 eXtreme Fast Control (XFC) load cell analysis units are available for torque measuring points, and high-precision EL3202-0010 PT100 input terminals are available for temperature measurements.

More information:
www.maschinendiagnose.com
www.beckhoff.com/el3632

Published in PC Control | Wind Special 2015

PC-based control in decentralized wind power generation

Open and modular controller for distributed power generation systems

Feeding power into the energy grid from renewable sources can result in strong fluctuations of network loads. These require intervention by the grid operators, in order to avoid power failures as well as voltage or frequency variations. German company ee technik GmbH has been involved in planning and designing electrical infrastructures of large wind farm projects for many years. They use a DEA controller (distributed power generation system controller), which, based on the openness and high level of integration of the control technology from Beckhoff, can be flexibly adapted to individual applications.

The community wind farm in Emmelsbüll-Horsbüll, Germany, was commissioned in late autumn 2014.

In power generation systems, special controllers direct the active and reactive power output, based on the current requirements of the network operator. Depending on how the actual values deviate from the specifications of the network operator, such a controller determines the respective set point value specifications for the individual power generation units. The challenge is that manufacturers of power generating plants have not yet come to an agreement on a standard protocol to exchange such data. Lack of standardization tends to necessitate a complex system of terminals and IT systems, in order to meet the requirements of the network operator at the grid connection point. A vendor-independent controller, offered by ee technik GmbH, based in Böklund, Germany, provides an efficient solution for the problem at hand. This controller for distributed power generation systems (DEA controller) is open for all common systems and enables the higher-level control of each individual power

© Bürgerwindpark Emmelsbüll-Horsbüll

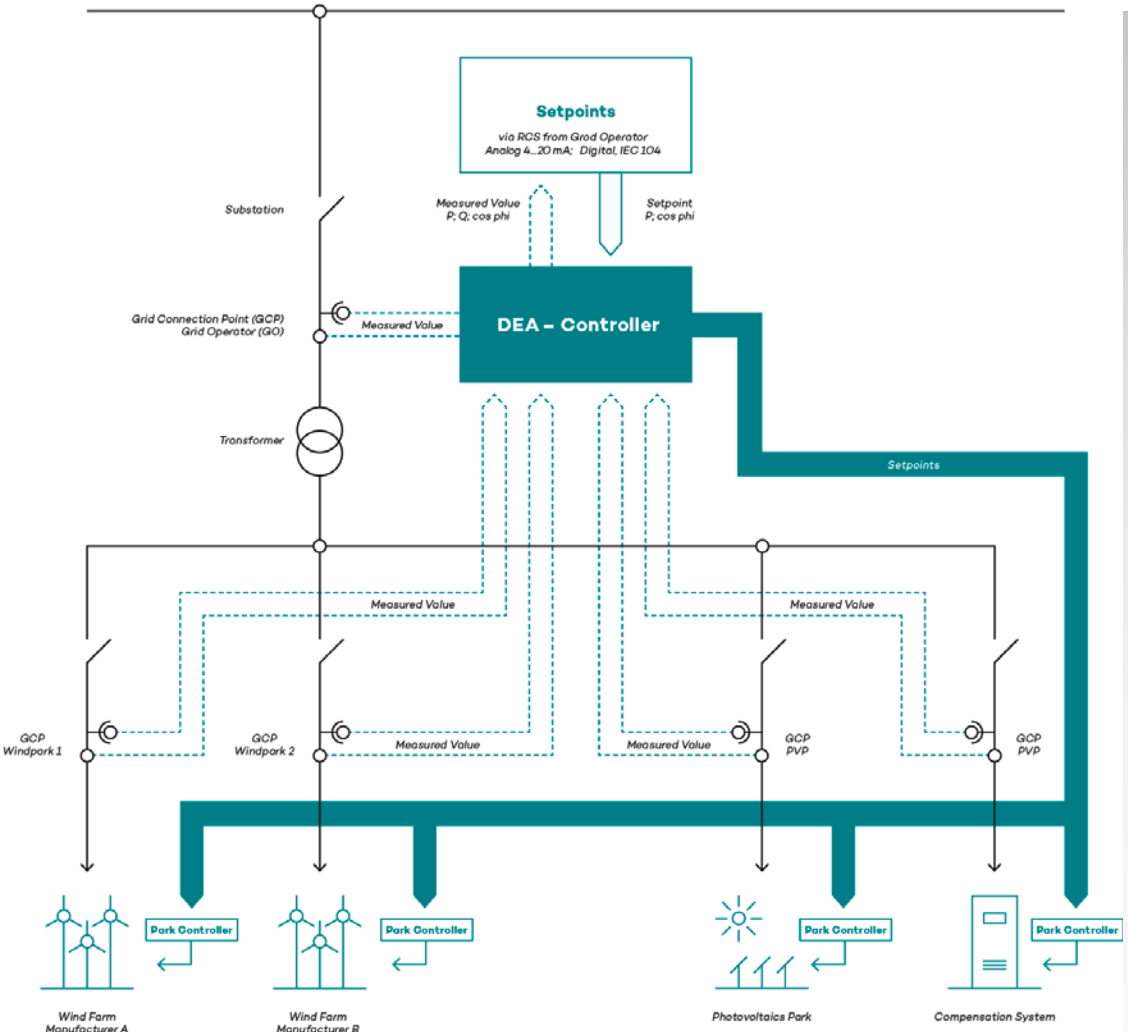
generation system at the grid connection point. In practice, it enables the preferential utilization of wind turbines with better tariff arrangements, for example, which has a positive effect on the yield.

Flexible DEA controller with PC-based technology inside

The DEA controller is available in different versions and is configured from a selection of core components. A high-performance PLC is used for storing, processing, and visualizing data. Next, a measurement transducer at the grid interfacing point provides actual value acquisition. The system is rounded off by analog and digital I/O components and Ethernet interfaces for reading the set value specifications of energy supply companies, for transmitting the control values to the power generation system and for integrating a visualization solution via OPC UA.

A flexible hardware and software configuration is implemented through a PC-based control system from Beckhoff. The open and integrated solution provides a cost-effective, system-integrated platform for the DEA controller, offering high computing power and modular expandability as key benefits. Karl-Friedrich Stapelfeldt from the Beckhoff branch in Lübeck, Germany explains the original selection criteria: “One of the decisive factors at the time was the high-performance CX2030 Embedded PC with Intel® Core™ i7 processor (1.7 GHz, dual-core). Because of its multi-core CPU architecture, it can easily run process visualizations and database applications in parallel with the PLC software on the same system, without any restrictions. An additional benefit was the high flexibility, due to fact that the system can be easily expanded. Key components here are the modular I/O system and the internal, PCI Express-based expansion bus, through which the system interfaces are connected with the full bandwidth of a PCI Express lane. In addition to two standard network connections, the CX2030 can be expanded via system modules with up to eight additional network adapters. In this way, the goal of implementing a customized network configuration for each wind farm is easily achievable.”

Devices used at the I/O level include analog Beckhoff EtherCAT I/O Terminals of the types EL3024 and EL4024 (4 to 20 mA) for capturing and feeding back analog set values from the network operator, and for transferring control signals to the wind farm. The digital EtherCAT I/Os EL1008 and EL2008 pick up the stepped stop signals and provide feedback via ripple control receivers. Additional system modules for the CX2030 include the dual Gbit Ethernet interface CX2500-0060, and the slide-in HDD/SSD CX2550-0020 unit. A CP2916 multi-touch Control Panel with 15.6 inch display is used for visualization. According to Karl-Friedrich Stapelfeldt, this flexible system is



A DEA controller can be used wherever generating units from different system manufacturers share a common grid connection point, e.g. in situations with a shared medium-voltage transmission line or a substation for high-voltage connection.

© ee technik

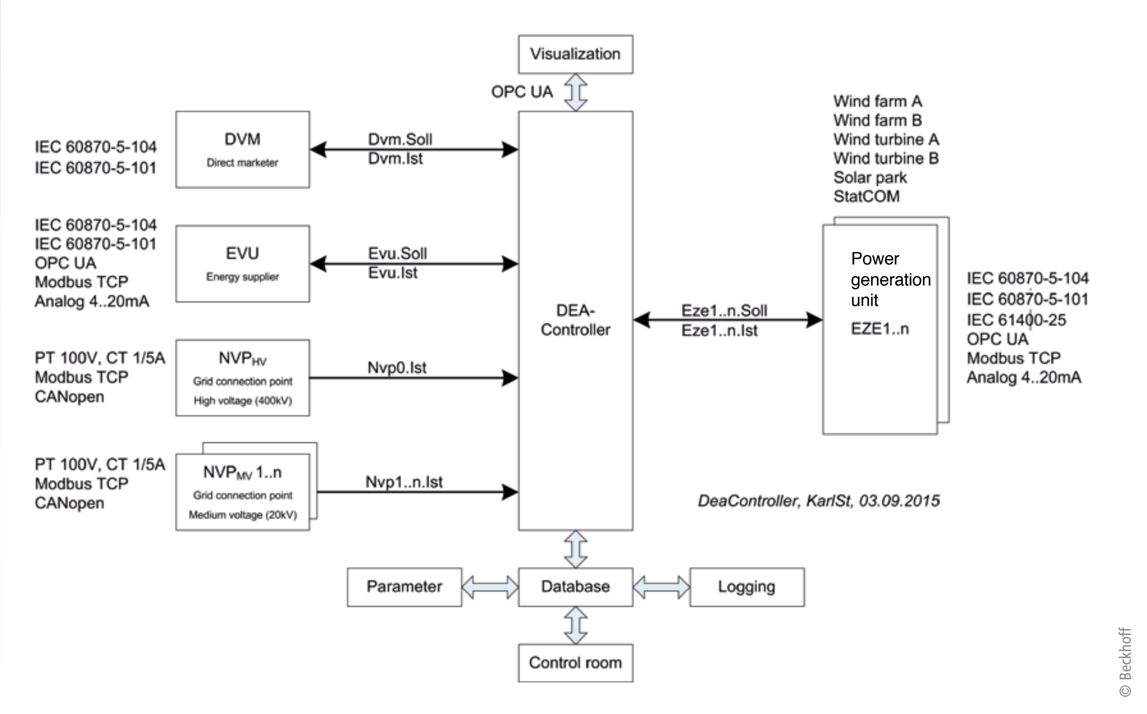
perfect for mastering the challenges inherent to the application: "Different standards and data point lists are used, generally analog 4-20 mA signals and established fieldbus protocols such as CANopen or Modbus. Telecontrol protocols such as IEC 60870-5-104, which are common in network control technology, are also becoming increasingly widespread. In addition, there is the IEC 61400-25 protocol – derived from IEC 61850 – which was specifically developed for wind power applications. As part of the TwinCAT 3 software platform, Beckhoff already offers ready-made function libraries to support all these communication protocols."

TwinCAT 3 with open communication and Wind Framework

In addition to the TwinCAT 3 functions for standardized communication via Ethernet (e.g. via Modbus, OPC UA) and the common telecontrol protocols (e.g. IEC 60870, IEC 61400-25), the recently developed TwinCAT 3 Wind Framework offers further major benefits. It builds on the modular architecture of TwinCAT 3 and supports the development of modular and object-oriented operational management software. Higher-level system services are provided via TcCOM modules. One example is a Status module, which enables monitoring of all components based on event management, error detection, troubleshooting, and reporting. Parameter and Command modules provide services for configuration and interaction with the system. The Capture and Statistics modules enable logging of signals and their statistical evaluation. The User module checks, manages, and records all user interactions. The Database module, which is based on an SQL database, documents all events and signals and is used for storing and loading the whole configuration.

The tool environment integrated into the TwinCAT 3 Wind Framework enables online and offline monitoring of recorded wind farm data, plus the inputs and outputs of the DEA controller. Database-driven offline analysis enables the display and combination of signal curves with a resolution up to 1 s. Trace logs with the resolution of the PLC task enable additional detailed analysis of the controller behavior, e.g. in the event of step changes in set values. ScopeView, the software oscilloscope integrated into TwinCAT 3, is ideal for ultra-fast logging into the µs range.

More information:
www.eetechnik.de
www.beckhoff.com/wind



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On the software side, each interface of the DEA controller is implemented as a modular function block with identical input and output interface. On the hardware side, various EtherCAT Terminals enable interface configurations that are optimized for the respective application.

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Ensuring that the expansion of the wind farm reliably supplies the major city of Glasgow, Scotland with power, the operator relies on fast EtherCAT communication together with the corresponding control components. The picture shows a group of Alstom ECO 100 wind turbines.

Fiber optic EtherCAT networking for efficient and flexible wind turbines

Real-time communication enables fast reaction times for wind farm applications

The European Wind Energy Association expects further dynamic expansion of wind power in Europe through 2020, predicting a 64% increase to installed wind power capacity. Part of this development includes dozens of turbines with a total output of 217 MW, recently installed on a wind farm in Scotland by the French company, Alstom. Fast EtherCAT communication and the corresponding Beckhoff I/O components form the backbone of this onshore project, one of the largest in Europe.

One of Alstom's latest wind power projects was put into service near Glasgow, Scotland, with the expansion of the Whitelee wind farm. The additional 217 MW of installed output is sufficient to supply 124,000 households with power. This onshore expansion set new standards for the entire European continent, in addition to being the first large-scale project for Alstom's powerful ECO 100 wind turbine. An installation totalling 69 of these 3 MW turbines is in operation at this site, along with six ECO 74s, each of which generates 1.67 MW.

Advanced control technology ensures reliable wind farm operation

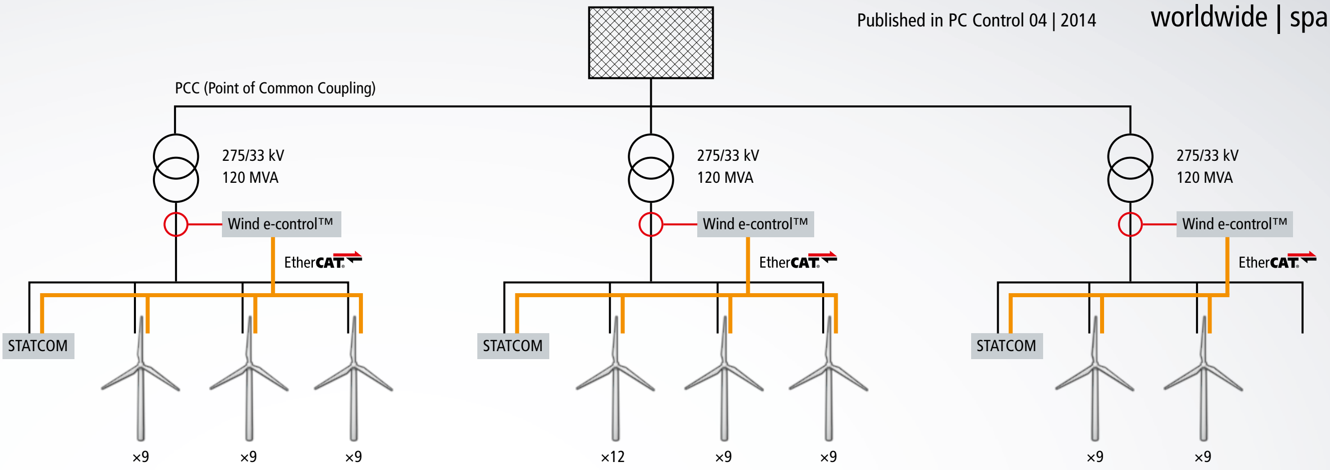
Alstom's Wind e-control™ system assumes the control tasks within the wind farm, e.g. with regard to voltage, power, and frequency control. For example, in order to check the reactive power at the transfer point of the wind farm to the grid, the Wind e-control™ system takes a wide range of measurements from the farm. The grid codes of each respective country can be reliably fulfilled through the control system. The requirements described in the grid code serve to stabilize the grid, which is imperative above all as the renewable energy industry continues to expand. Beyond that, the control system permits operational management on-site in the control room or remotely via data communication to the Scada system. The Wind e-control™ system was installed and successfully used for the first time in this wind farm.

Vicenç Casadevall, Grid Integration Design Engineer at Alstom, describes some key details about the control system: "On the one hand, we have the Reactive Power Control (RPC), which has three regulation modes. By controlling the reactive power in the 'Voltage control' mode, it is possible to adjust the voltage at the transfer point, i.e. the Point of Common Coupling (PCC), to the specifications of the wind farm operator. In the 'Power Factor control' mode, the power factor at the PCC can be controlled. The 'Reactive Power control' mode permits the wind farm operator to have a defined amount of reactive power. On the other hand we have the Active Power Control (APC), which has two regulation modes. By controlling the active power in the 'Active Power limitation' mode, it is possible to limit the active power output of the wind farm. In the 'Frequency control' mode the active power output is curtailed if the frequency goes beyond a certain level."

EtherCAT as the foundation for fast and cost-effective data communication

EtherCAT represents another core technology of the Wind e-control™ system. This powerful network for data communication is recommended not only for each individual wind turbine, it is also particularly important for farm networking. The 5 ms cycle times of the farm and turbine controls, which are synchronized to each other, enable response times lower than 200 ms for the wind farm voltage control.

Vicenç Casadevall recalls: "Because of the challenging time requirements that we had to meet, the R&D team from Alstom sought a communication protocol that operated deterministically. Ultimately, we chose the EtherCAT protocol. It fully meets our needs because of its reliable, high-speed operation."



A Wind e-control™ system is provided for each transformer station, securing the EtherCAT data transmission between the individual wind turbines in the wind farm.

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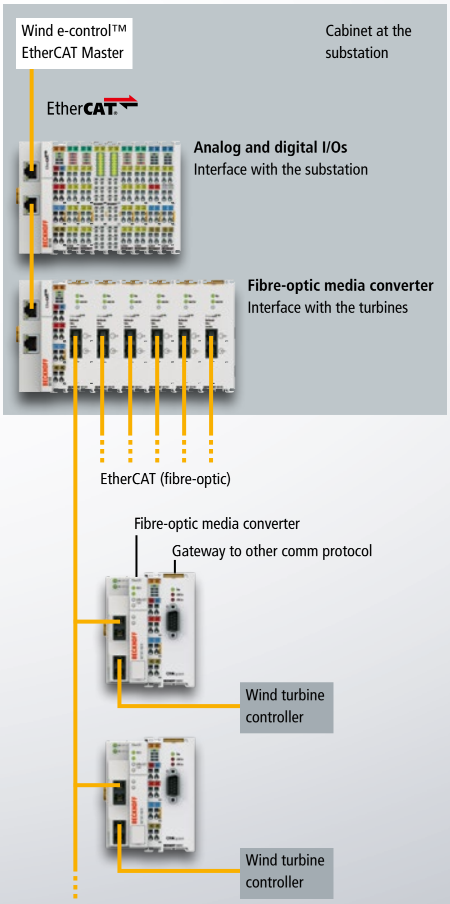
Dirk Kordtomeikel, Business Manager Wind Energy at Beckhoff, stresses the cost advantages of the EtherCAT system, in addition to its speed: "Today, wind farm networking equipment is largely based on fiber optic cables. These fiber optic cables are EtherCAT-compliant, allowing use of the existing cable network without auxiliary expenditure during set-up. In addition, our EtherCAT-based farm network meets the requirements for cable redundancy. In turn, interfaces to other bus systems also promote total system openness and flexibility. The operator gets all of these benefits at a lower cost than with other real-time Ethernet protocols."

EtherCAT capably spans long distances

An EK1100 EtherCAT Coupler connects the I/O level in the control station. The wide range of EtherCAT Terminals can process all signal forms occurring in the automated operation of wind farms. Another EK1100 Coupler communicates with various EK1521 EtherCAT optical fiber junction terminals. Together with the EK1501 EtherCAT Couplers with fiber optic connectors, these establish flexible and extensive fiber optic networks in the individual wind turbines. Whereas standard Ethernet cables permit a distance of up to 100 m between two stations, the distance between two optical fiber devices can be much longer: up to 2 km, due to the multimode glass fiber connection, and even up to 20 km with a single-mode glass fiber connection.

Hardware and software components working in harmony

In addition to the requirements for fast data communication, the operational reliability of hardware and software is absolutely vital, especially in wind turbines where harsh environmental conditions such as intense vibrations and work temperatures between –60 °C to +55 °C are common. Close cooperation with Beckhoff Automation was an important factor for Vicenç Casadevall: "Since Beckhoff invented EtherCAT, it was clear to us that the best hardware and software solutions would also be available from the company, optimally matched to this fieldbus system. Not only that, Beckhoff has a long history in automation technology, particularly in the wind industry, and a very good reputation at Alstom."



A general schematic diagram of the EtherCAT topology shows the functions handled by the individual modules in the wind farm.

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www.power.alstom.com
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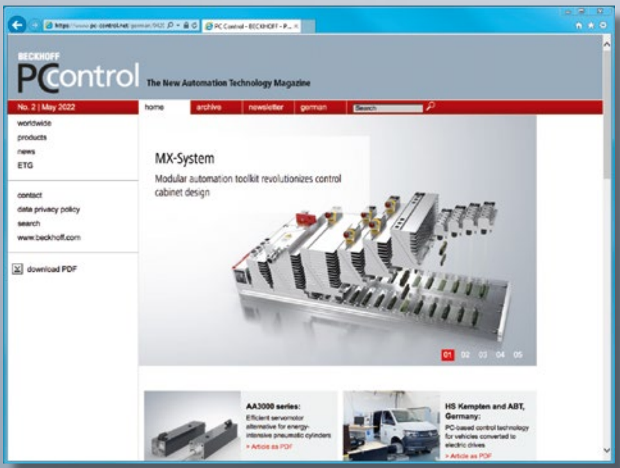

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