PC- and EtherCAT-based Control of hardware-in-the-loop test stand for wind farm controllers

Well prepared wind turbines on land or at sea!

Advanced wind farm control systems support the stable operation of the electrical grid. Hardware-in-the-loop tests are essential for fast and cost-effective commissioning of controllers in the field or at sea in the case of off-shore wind farms. Such tests are also very helpful for controller development. To this end a hardware-in-the-loop test stand for wind farm controllers was developed at the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) in Kassel, Germany. The wind farm controller and the wind farm communication system can be integrated as hardware in a real-time simulator, which models the behavior of the wind farm and the grid. The development of the test stand was supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The test stand was developed in cooperation with wind turbine manufacturer Areva Wind.

Control systems for wind farms and wind turbines play a key role in the availability and therefore the economic efficiency of wind farm projects. For this reason the quality requirements for the control hardware and software are continuously increasing, particularly in conjunction with offshore systems. Certification bodies recently started calling for documented quality management in controller development, i.e. the certification no longer covers just the control algorithms, but also the development and testing processes for the control hardware and software [1].
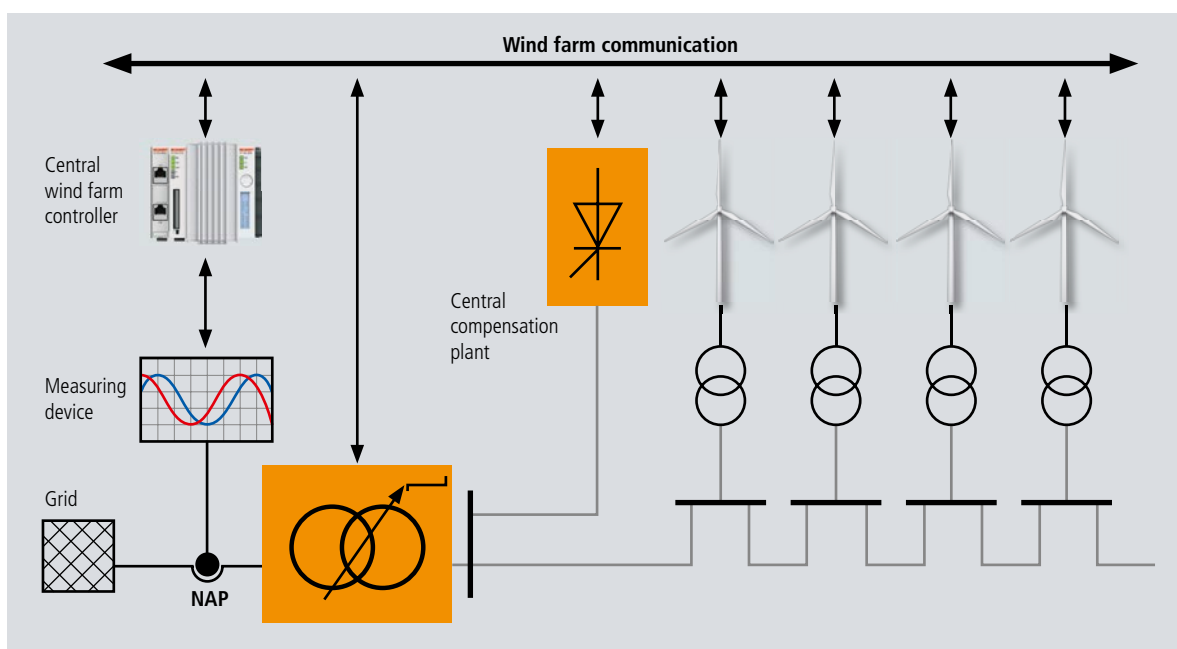
Software or hardware-in-the-loop (HIL) tests, during which the control system and its interaction with simulation models of wind turbines or wind farms are tested under realistic conditions, form an important part of such a development process. The key benefits of the HIL procedure are:

– Functional controller tests, covering all relevant operating situations
– Reproducible ambient conditions, particularly wind velocities and grid conditions
– Safe testing of the controller functionality, even in critical situations
– Significant reduction of commissioning efforts in the field

HIL tests, in which the actual controller hardware is coupled with a real-time simulator via a hardware interface, are particularly demanding for simulation models.

The Fraunhofer IWES in Kassel created a modular model library based on the Matlab®/Simulink® simulation software for this purpose, which can be used to configure suitable models for individual wind turbines and wind farms. Automatic code generation enables real-time models to be derived, which can be executed directly in a real-time, Industrial PC-based simulation environment

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Offshore wind farm Alpha Ventus off the German North Sea coast

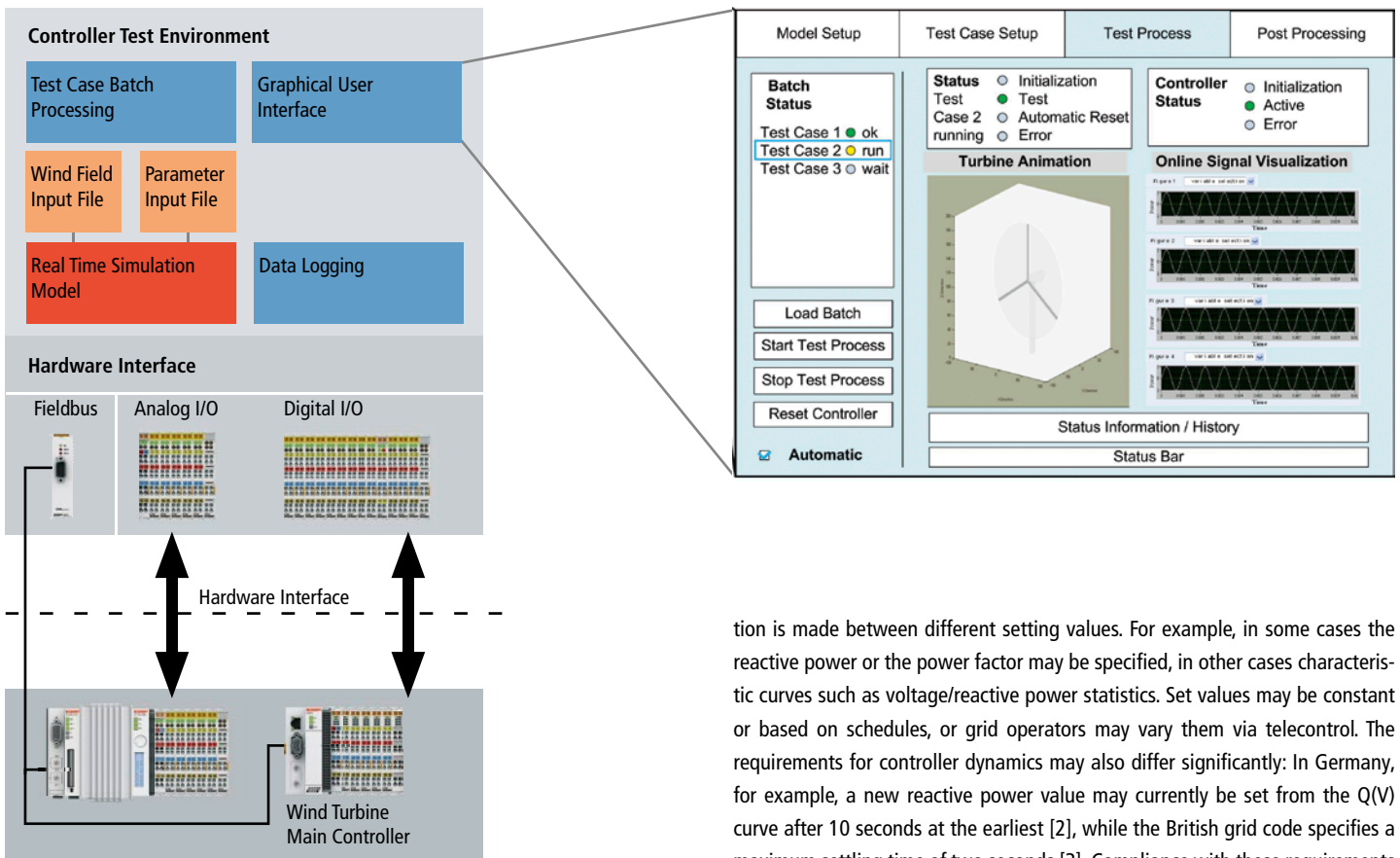**Figure 1: Diagram of a wind farm control system**

Figure 2: Diagram and user interface of the hardware-in-the-loop test environment for wind turbine controllers

through integration in the TwinCAT 3 automation software platform from Beckhoff. The actual models are embedded in an environment for automated processing of a large number of test cases. For each test the external conditions such as wind speed and grid voltage, and also the occurrence of defined faults in a turbine or the wind farm can be specified. In conjunction with the modular model structure, the configuration of a real-time simulator based on Beckhoff hardware enables a high degree of flexibility for matching customer requirements with the test challenge. Figure 1 shows the structure and the user interface of the hardware-in-the-loop test environment for the control system of a wind turbine.

Hardware-in-the loop test environment for wind farm controllers

In advanced wind farms it is essential to have a wind farm controller as a central control unit. This enables support of stable grid operation through system services. Active power control supports frequency stability in the grid, while reactive power control is important to ensure voltage stability at the wind farm connection point. The wind farm controller is supplied with measured data from the grid connection point and controls the different actuators via a wind farm communication system. Actuators include the individual wind turbines and additional compensation systems such as capacitor banks or STATCOMs. Transformers with variable ratios can also be used as actuators (see Figure 2).

General requirements of grid operators

The required system services are specified in grid codes. They vary from country to country and between grid operators. For voltage-supporting control a distinc-

tion is made between different setting values. For example, in some cases the reactive power or the power factor may be specified, in other cases characteristic curves such as voltage/reactive power statistics. Set values may be constant or based on schedules, or grid operators may vary them via telecontrol. The requirements for controller dynamics may also differ significantly: In Germany, for example, a new reactive power value may currently be set from the Q(V) curve after 10 seconds at the earliest [2], while the British grid code specifies a maximum settling time of two seconds [3]. Compliance with these requirements is generally verified during commissioning of a wind farm. However, starting in 2014 wind farm controllers for the German market will also have to be certified.

Challenges for hardware and controllers

High dynamic requirements are a challenge for the control system and for the wind farm communication. Crucial factors for the achievable dynamics are the discrete delays in the control loop [4]. These are caused by the measurement of electrical parameters, the processing in computers and the communication between wind farm controllers and turbines. Fast communication processes and processing sequences within the controlled system, which should ideally by synchronized, are therefore required. Faced with high dynamic requirements, the controller itself should be precisely synchronized with the controlled system. In addition to the discrete delays, this also includes the dynamic behavior of the actuators and the steady-state gains through electrical components in the wind farm and the grid.

The final step before simulations become the real thing

A universally applicable wind farm controller has a complex structure and an extensive parameter set. It must be adapted to the hardware, the precise behavior of which can in many cases only be determined with significant effort and through simulations. Before commissioning wind farm controllers, it is therefore advisable to test them in the laboratory under realistic conditions. With such a development step it is possible to avoid time-consuming and expensive adaptation measures in the field or at sea.

To this end an HIL test stand for wind farm controllers was developed at Fraunhofer IWES in Kassel. The wind farm controller and the wind farm communication system can be integrated as hardware in a real-time simulator, which models the behavior of the wind farm with the required level of detail. The real-time simulator consists of different submodels, which are distributed
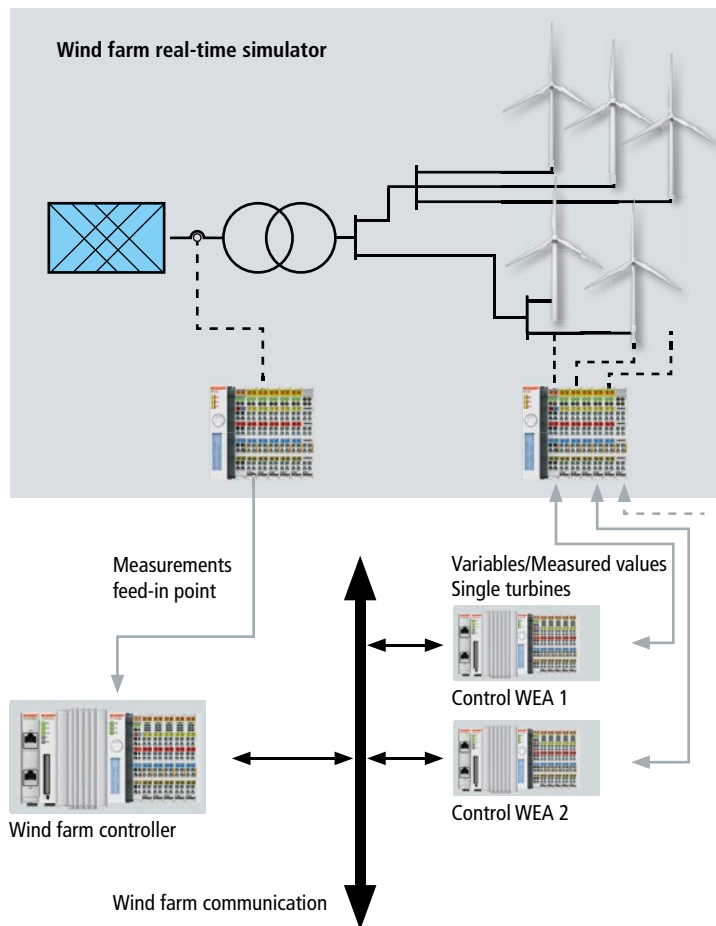
Figure 3: Diagram of the real-time simulator with wind farm controller and turbine control systems

Fraunhofer Institute for Wind Energy and Energy System Technology

The Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) was established in 2009, with main locations in Kassel and Bremerhaven, Germany. Research areas include the whole spectrum of wind energy and the integration of renewables in the supply structures. The institute has 370 staff and an annual budget of around 30 million euros (2011 figures).

Figure 3 shows a diagram of the real-time simulator and the linked hardware. The simulator transfers the electrical parameters calculated for the grid connection point to the wind farm controller via an EtherCAT Terminal, for example. The controller sends its set values via the wind farm communication system to the individual turbine controllers, which are connected with the turbine models in the simulator via further terminals. The turbine controllers can optionally be integrated as software, either in part or fully.

The application options of the HIL test stand include controller development and adjustment of the controller to a particular wind farm. In this way the controller functionality and the correct signal exchange between the hardware components (assignments, scaling) can be verified. The controller dynamics can be assessed taking into account the actual hardware characteristics and adapted, if necessary. In contrast to adaptation in the field, the input conditions (wind speed, grid conditions) can be set in a reproducible manner, and extreme events such as grid failure can also be considered.

The test stand can also be used as part of any future certification process for wind farm controllers. Due to the influence of the hardware characteristics on the controller dynamics, measurements on the HIL test stand provide a good basis for assessing the controller characteristics. A range of standard wind farm models can be used, and different characteristics of the grid connection and the actuators can be taken into account.

Author: Dipl.-Ing. Melanie Hau, Wind Farm Control and Real-time Simulator Group, Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

[1] Germanischer Lloyd Industrial Services GmbH, Rules and Guidelines Industrial Sevices – Guideline for the Certification of Wind Turbines, 2010

[2] Bundesverband der Energie- und Wasserwirtschaft e.V., Technische Richtline Erzeugungsanlagen am Mittelspannungsnetz, 2008

[3] National Grid Electricity Transmission plc, The Grid Code, 2010

[4] M. Hau, M. Shan, Windparkregelung zur Netzintegration, 16th Kassel Symposium Energy Systems Technology, 2011

across several Industrial PCs. Specifically, it includes the following components:
– An electrical model of the wind farm network including cables, transformers and grid connection. Of particular significance is the model for the coupling between the reactive power feed and the voltage at the grid connection point.
– Turbine models, including aerodynamics, generator and converter. Turbine controllers can be integrated as real-time models or as hardware.
– A model of the wind field, which is coupled with the aerodynamic turbine models in order to take into account shading effects within the wind farm.

The computing cycles of the individual submodels and the communication between the submodels are adapted to modeled physical properties. The real-time simulator has a modular structure for maximum flexibility in terms of the wind farm size. The individual turbine models can be distributed across several Industrial PCs.

Beckhoff Industrial PCs from the C51xx series were chosen as hardware for the simulator. The number of required PCs depends on the size of the wind farm to be simulated and the level of detail of the models. System-wide input and output signals of the individual models are exchanged via the EtherCAT Automation Protocol. In parallel, the clocks of all simulation computers are synchronized with EtherCAT. For the I/O, EtherCAT Terminals are connected via EtherCAT couplers. The simulation models are compiled using the TwinCAT 3 target for Matlab®/Simulink®, so that they can be transferred directly to the Industrial PCs. Simple PLC programs coordinate the start and finish of the distributed simulation.

Further information:
www.iwes.fraunhofer.de
Areva Wind GmbH: www.areva-wind.com