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.

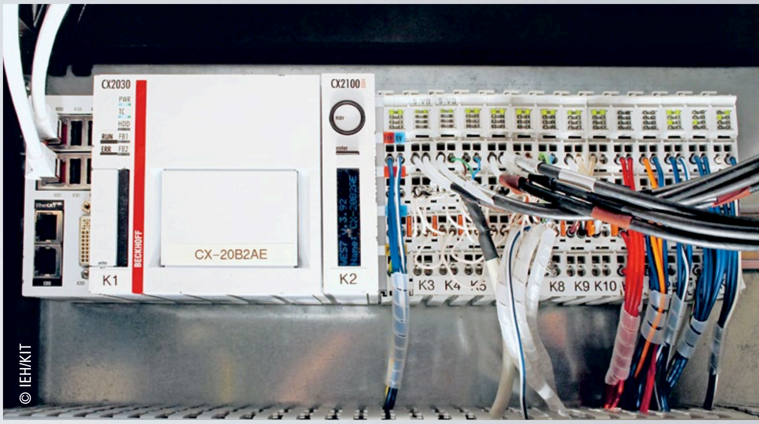
The closed-loop control was designed in MATLAB®/Simulink® using model-based design and, after compilation, executed in real time on the Embedded PC using TwinCAT 3 Target for Simulink®. A convenient user interface for operating the test bed was implemented with TwinCAT HMI. Control parameters, setpoint 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



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

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.

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:
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