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Connection cable between grid emulator and transformer

Wind turbines: certification of grid characteristics

Words: Torben Jersch

The certification of the grid characteristics of wind turbines has been mandatory for a long time, in order to maintain grid stability and voltage quality, as well as to obtain the grid connection permit. Ever faster product development cycles lead to time-intensive qualification and validation tests in the field. Voltage dip tests are particularly critical in this regard. Some years ago, the Fraunhofer Institute for Wind Energy Systems IWES set itself the goal of bringing grid integration tests into the laboratory to accelerate product validation.

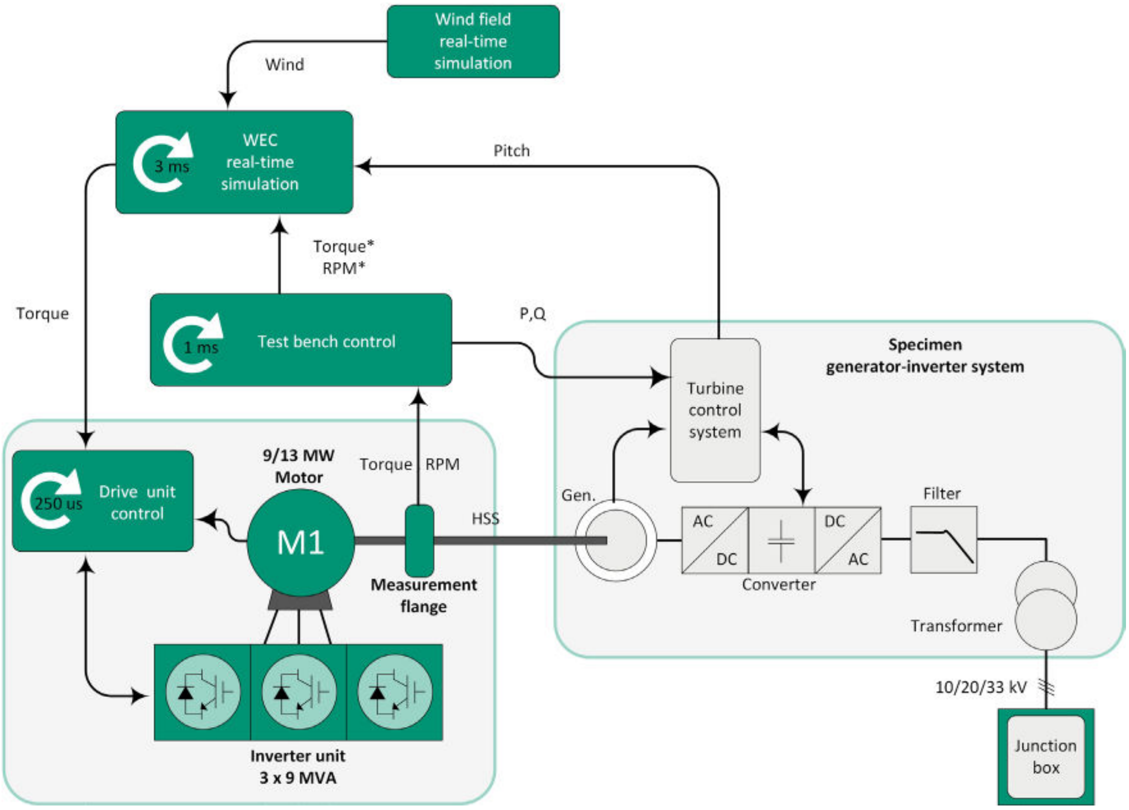

Image 1: mHiL Control Schema ©*Fraunhofer IWES*
Control framework for replicating realistic wind turbine behavior on the HiL-GridCoP test bench

Why are these tests important and how are they performed in the field?

For many years now, a transition relating to power generation has been under way in the grid, away from large-scale centralized power plants to smaller decentralized power generating units, predominantly employing renewable energy sources. To maintain grid controllability, stability and regulation, the requirements on power generating units, including wind turbines, are specified in the technical connection rules (TCR) for connecting electrical equipment to the grid for medium voltage and high voltage.

These stipulate the operating behavior in steady state, in other words the controllability with regard to active and reactive power. This results in requirements for the control quality of the entire wind turbine, including the correct control of the mechanical system. Furthermore, there are regulations to ensure that the power generating units cause only minor grid perturbations, with the result that the voltage quality in the grid remains guaranteed. These requirements can be verified in the field with comparatively little effort.

Not only that, the TCRs also specify or stipulate the dynamic operating behavior, in other words the reaction of the wind turbine to faults in the grid. To verify this, grid faults are tested at the medium-voltage level by means of 'voltage dip containers', so the turbines remain connected to the grid in the event of a grid fault and continue to support the voltage by feeding in reactive power. These short circuits have effects on the entire surrounding grid and thus also affect neighboring sites, which is why these tests can only be carried out at test sites with strong grids.

In addition to good wind conditions, test sites for wind turbine prototypes must also have a strong grid. However, the number of possible sites in Germany and Europe is severely limited. The short circuits generated during the tests represent an exceptional load for all the electrical systems of the wind turbine, as the abrupt loss of the grid produces oscillation in the wind turbines.

In contrast to standard development methods, these tests are now being performed in the field for the first time. Due to the combination of the aspects of a distant prototype site required, the final development in the field, and the unpredictable wind conditions, measurement of the electrical properties in the field over the entire power range takes many months and, additionally, can scarcely be planned from a time perspective. The result is that both the development times of new wind turbines and their validation take a similar period of time, which significantly delays the introduction of new products.

Bringing these tests into the laboratory provides a direct obvious added value. Unlike with other renewable energies such as solar power, grid integration tests of wind turbines on test benches were not considered for a long time. Due to the power range, which is currently 5.5 to 7 MW electrical connected load in new wind turbine development, and the replication of the mechanical load/oscillation in the realization, grid integration tests were not considered technologically feasible.

Fraunhofer IWES has now brought the grid integration tests into the laboratory and developed and constructed the HiL-Grid-CoP test bench, which offers the wind energy sector an alternative solution.

In addition, it has developed a cost-effective procedure for certification of the electrical properties. By the end of the project, it was possible to verify that the reproduction of grid fault tests is possible and that grid-wind turbine interactions can even be emulated for the most demanding wind turbines with doubly fed asynchronous generator.

The test bench was designed for testing generator-converter systems connected to the medium-voltage grid. The wind turbine's high-speed generators are bolted onto the strong floor and driven by the motor, with a drive power of 9 MW and an overload capacity of up to 13 MW. To provide sufficient control reserve and improve the torque control dynamics, the motor is fed by 27 MVA medium-voltage electronics.

The goal of realistic replication of the wind turbine behavior in the field (see Image 1: mHiL Control schema) is achieved by calculating the detailed aeroelastic model of the wind turbine in parallel to the test bench operation with a cycle time of 3 ms. This model is derived from the original manufacturer models for load calculation and compiled for a real-time system.

On the test bench, the wind turbine controller does not send the signal for blade pitch control to the pitch actuator, but rather it is fed to the real-time model so that the power is controlled. A torque measuring flange on the shaft between the motor and the test specimen measures the current torque, which is also fed to the real-time model. The virtual values of speed and torque from the real-time model are used as target values for the motor control.

The test equipment used in the field to generate grid short circuits has a very high overcurrent capability due to the technology employed, with the result that short-circuit currents of 4 to 8 times the nominal current, which are typical for the triggered events, can be generated. In the laboratory, in contrast, power electronic network emulators are used, which can be actively controlled and thus have optimal flexibility. However, power electronic semiconductors cannot tolerate overcurrent due to their technology. As such, the test equipment must be dimensioned for the corresponding overcurrent capacity.

With four converter systems connected in parallel, the Fraunhofer IWES grid emulator is designed for a power peak of 44 MVA, but test objects in the power range of 2 to 10 MW are tested. This has the advantage that the grid emulator can be operated with switching frequencies of 2.8 to 4.4 kHz and thus has exceptionally good control characteristics for a system in this power class. This system can be used to emulate any grid locations, weak/strong grid, 50/60 Hz, and grid faults on the test bench. A voltage dip container commonly used in the field is emulated specially for the test to determine the electrical properties.

Demonstration

It has now been possible to demonstrate using a 6 MW wind turbine with a doubly fed induction generator that field tests can be emulated in the laboratory with only minor deviations detectable in direct comparison. The course of the voltages coincides to within a few per cent in the pre-fault case, with the series impedance switched on, and in the fault case. The standard-conforming evaluation shows that the results are within the tolerance bands even when considering the dynamic behavior. Furthermore, mechanical oscillations with the dominant first coupled natural frequency are visible in the electrical power measurements.

For this test method to be applicable to the wind industry it is described in the German national technical guidelines (FGW TG3), in the European measurement/metrological regulations of EN50549-10, and in the IEC 61400-21-4 international standard. The manufacturers thus avoid the risk of product validation.

The course of the energy transition also includes a grid transition, in other words the ever-increasing use of power-electronically coupled power generating systems. In addition to testing the dynamic properties in the event of voltage dips, other issues relating to the safe operation of the grids are also coming into focus. The reduction of inertia in the grid results in stronger fluctuations of the grid frequency, to which the wind turbines must react. It is also expected that the power electronics will excite eigenfrequencies with little damping in the cables and the grid equipment.

The interaction of power electronic components is another major issue. If a critical condition is reached, the requirements in the grid connection guidelines will have to be made stricter and appropriate validation will be required.

Although the requirements for power generating units have not yet been defined, it is clear that grid integration tests can no longer be performed using simple test equipment in the field, but rather will be carried out with the aid of grid emulators. In the next few years, Fraunhofer IWES aims to procure more grid emulators so that special tests can also be performed to measure and validate harmonic behavior and the behavior of very large power generating units in converter-dominated power grids.

https://www.fraunhofer.de/en.html

Aerial view of Dynamic Nacelle Testing Laboratory (DyNaLab) and HiL-GridCoP test bench