New methods of grid integration testing

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Offshore wind energy's expansion demands high-voltage transmission systems, creating together with the offshore wind farms converter-driven grids. The electrical challenges require validated electrical models in a higher frequency range and advanced validation methods for the stability studies in a converter-driven grid. Offshore grids face complexity and new requirements, necessitating innovative testing approaches. Fraunhofer IWES is developing specialized test benches for efficient validation, meeting future turbine demands.

The expansion of offshore wind energy and the required high-voltage direct current (HVDC) transmission systems as connection points to the transmission grid of offshore wind farms is creating a 100% converter-dominated offshore power grid in the North Sea. This poses electrical challenges that go beyond the classic approach to ensuring system stability and require valid electromagnetic transient models and harmonic models of the offshore wind turbines and HVDC systems.

Furthermore, the tasks of the systems for ensuring system stability are being expanded, which means new technological developments in wind turbines. Advanced testing and validation procedures on specialized test benches are needed to validate simulation models for system studies and to check the increasingly complex grid requirements within the development phase of wind turbines to minimize risks.

Transformation of the power grid

The ongoing transition from conventional power plants to decentralized renewable energy sources is transforming the power grid. On the generation side, onshore wind


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The HiL-GridCoP test bench for performing grid compliance tests on subsystem level of high-speed generator-converter systems and photovoltaic systems are being connected to the distribution grid, while increased use of electromobility, heat pumps, and electrolyzers is electrifying the load side.

These elements, linked to the power grid through power electronics, replace the stabilizing role of conventional power plants with synchronous generators.

Consequently, ensuring system stability becomes crucial, involving new actors like renewable energy systems, storage, and grid equipment. Voltage, frequency, angular stability, resonance, and converter- driven stability are key aspects, requiring a shift to electromagnetic transient investigations to capture high-frequency grid dynamics.

This transformation necessitates the development of renewable energy, storage, and grid equipment tasks, influencing overall grid characteristics. Simulation studies with validated models play a vital role in understanding and adapting to these electrical interactions for the future grids' successful conversion and operation.

The 100% converter-driven offshore power grid

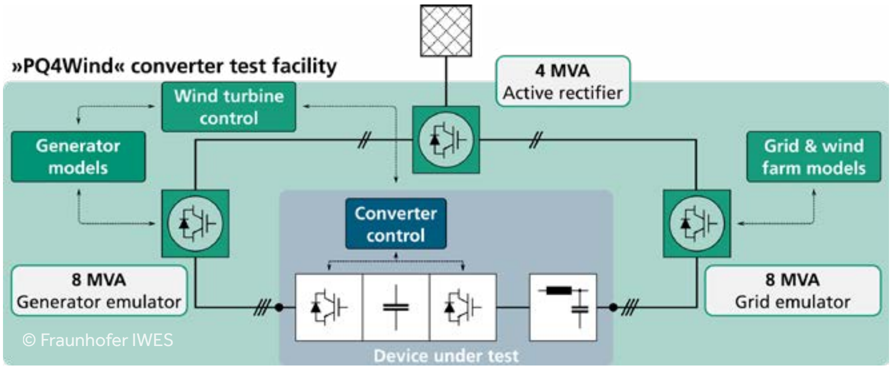
In contrast to the onshore power grid, offshore power grids already consist entirely of power-electronic converter systems, meaning that the difficulties and problems that onshore power grids will face in the future already have to be overcome for offshore grids today.

The offshore wind turbines are coupled to HVDC converter systems via passive equipment with low impedance in order to transmit the generated energy to the onshore power grid. The problem of resonance stability in offshore wind farms and HVDC systems is well-known among experts, and efforts are increasingly being made to overcome it.

Offshore power grid: complex operating behavior and new electrical requirements

The targets for the expansion of offshore wind energy in the German North Sea to 30 gigawatts of installed capacity by 2030, which has been increased and brought forward by the German government, makes it necessary to accelerate project implementation.

At the same time, the technical complexity of constructing the offshore power grid is increasing, as significant technological innovations are being implemented on the connection side and on the generation side, which increase the risk. This includes introduction of new types of 2-gigawatt HVDC systems, introduction of the 66- kilovolt voltage level with direct connection of offshore wind farms to the HVDC system, new standards from the technical requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (TAR HVDC) VDE-AR-N 4131, and new technological solutions due to the continued expected growth in offshore wind farm output.



Schematic setup of the 8 MW converter test bench PQ4Wind

Converter cabinets of the PQ4Wind test bench containing a total of 20 megawatt installed converter power for emulation

Testing the future: test benches instead of field measurement campaigns on wind turbine prototypes

Testing is the foundation for the validation of new and further developments of wind turbines as well as the generation of measurement data for a subsequent model validation process within turbine development.

Instead of conventional field campaigns, highly specialized laboratory test benches have been established to conduct grid integration tests which save costs and shorten development cycles despite increasingly challenging grid code requirements.

The background to this is that the unpredictable weather conditions lead to unreliable test conditions in the field and measurement campaigns therefore take a very long time. Furthermore, the field test methods, which have been in place for several years are no longer suitable for testing the new electrical requirements.

Modern laboratories rely on the power-electronic simulation of medium-voltage grids using grid emulators.

All the components which are not physically located on the test bench, such as the rotor blades and the tower of a wind turbine, are realistically simulated using the hardware-in-the-loop principle on nacelle test benches.

Modern wind turbines feature power electronic converters of up to 15 megawatts, while even 18-megawatt units are expected with the next generation of offshore turbines.

Construction of new nacelle test benches cannot keep up with this rapid growth of wind turbine size and power, as the necessary investment costs for test benches in the 25 to 30 megawatt range require high double-digit to low triple-digit million sums and involve considerable operating costs.

Other approaches to grid integration testing must therefore be established for the upcoming generations of wind turbines.

Cost-efficient approaches to testing at component level

The concept of component-based validation of electrical properties is used to combine these different developments efficiently. The aim is to carry out validation tests in accordance with the development methodology of the V-model at a low test level in the early development phase of the wind turbines using advanced test benches and to prequalify the power electronics in the laboratory at a very early stage of development and provide validated electrical models of the turbines for the market.

During the development of the wind turbine, individual worst-case tests in the field on the prototypes of the wind turbine are then used to check the entire design of the turbine and a reduced set of measurement data is generated to check the previously performed model validation.

In this way, a complete validation campaign can be carried out, which also corresponds to the state of the art and shortens the time-to-market of new turbines or facilitates recertification and saves costs.

The test and validation strategy employed by Fraunhofer IWES closely follows the V-model by designing test infrastructure suited to performing tests at each stage of the wind turbine development process as shown in figure 1.

Alongside the constructing of test benches, the development and establishment of new test and validation methods is a central focus of research. The technical foundations for this were established in the Hil-GridCoP and PQ4Wind research projects, and the normative specification of the new test procedure for component-based validation of electrical properties has already been defined internationally in IEC 61400-21-4.

The future of test benches for testing electrical properties

Fraunhofer IWES is currently building a facility to test future wind turbines with an output of up to 30 megawatts, thereby expanding the existing nacelle test bench system.

Compared to full system test benches, only the components relevant for grid integration are tested in the new test facility. The test specimen is reduced to the minimal use of large mechanical components of wind turbines.

The facility will be able to test wind turbines with medium-speed generator systems, so-called hybrid-drive wind turbines, as well as direct-drive wind turbines.

Therefore, the new test bench features two separate means of recreating the behaviour of a wind turbine's electrical generator: one using a mechanical prime mover and the other using power-electronic emulation of the generator's characteristics.

A mechanical prime mover with a maximum speed of 660 revolutions per minute and an output of 30 megawatts will be used to test hybrid-drive wind turbines, which will apply realistic loads to the generator converter system under test. The generator emulator method is used to test direct-drive wind turbines.

The components to be tested on the test bench are the converter system, the Transformer, and the control system of the wind turbine. Due to the large number of different generator types, two separate generator emulators are operated in parallel in order to adapt the test facility flexibly to the generators to be tested. Emulation of the generator is performed with the help of power electronic converters without the need for rotating mechanical machines.

Fraunhofer IWES is expanding the systems of the Dynamic Nacelle Testing Laboratory (DyNaLab) nacelle test bench in order to set up the test facility.

After the upgrade, the test facility will have a converter capacity of 36 megavolt-amperes (2 x 18 MVA). The grid behavior is emulated by the most powerful mobile grid emulator with an installed converter capacity of 80 megavolt-amperes.

The test facility can realistically emulate the behaviour of wind turbines and simulate complex offshore grid configurations using the grid simulator.

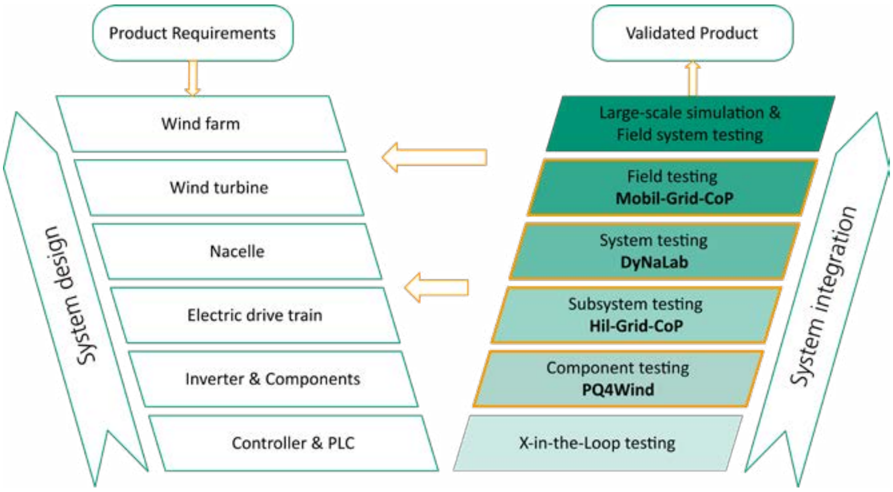


Figure 1: Wind turbine development process according to V-model and integration of the Fraunhofer IWES test infrastructure of Fraunhofer IWES in the field of grid integration into the development process © Fraunhofer IWES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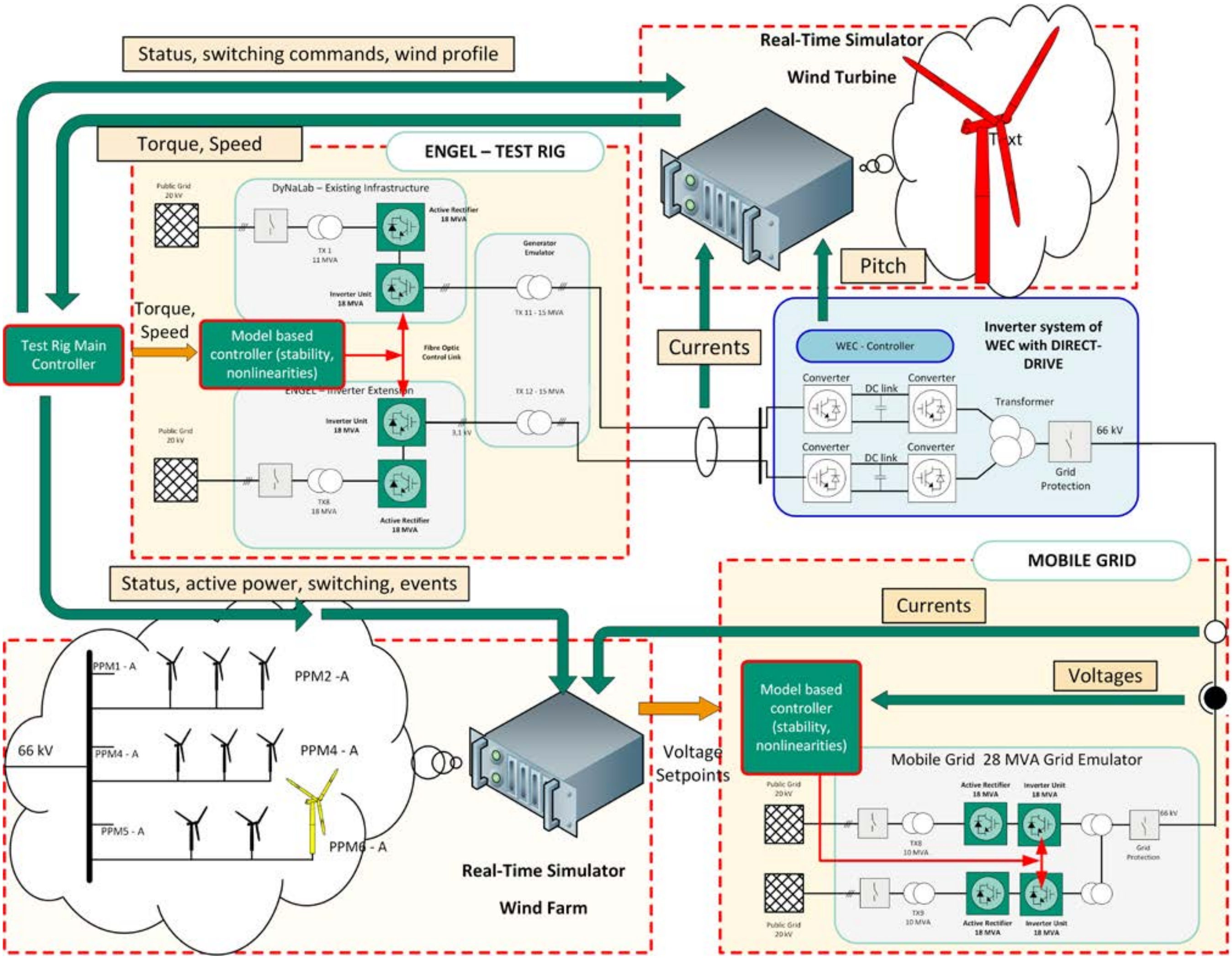
The 80 MVA mobile grid emulator. All components are housed in containers except the transformers



Operating principle of 30 MW grid integration test bench ENGEL (Emulated Nacelle Grid Testing Laboratory)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The DyNaLab test hall, converter system and filter bank of the nacelle test bench at Fraunhofer IWES in Bremerhaven

Summary

To meet future demands regarding new electrical requirements, costs, and development time, new procedures for verifying the grid code compliance of wind turbine must improve upon classic measurement and validation processes.

One approach is the component-based validation of electrical properties using specialized test benches. Based on the manufacturers' development process, Fraunhofer IWES develops these specialized test benches along with new test and validation methods at component level and tests them together with the manufacturers in order to create the basis for standardizing the procedures.

Fraunhofer IWES is currently developing a 30-megawatt hardware-in-the-loop test bench for testing converter systems of direct-drive wind turbines and generator-converter systems of hybrid-drive wind turbines.

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