From theory to practice: grid testing standards

Dr Uwe Jassmann, Digitalization Lead at R&D Test Systems, has played a key role in developing the IEC 61400-21-4 standard for grid compliance testing in wind turbines. By harnessing Hardware-in-the-Loop (HiL) technology, testing methods have advanced, improving accuracy and efficiency while reducing costs. This article highlights the impact of their work and the future of standardization in wind energy.

The development of international standards plays a vital role in ensuring reliable, efficient, and cost-effective solutions for the integration of wind energy.

Dr Uwe Jassmann, Digitalization Lead at R&D Test Systems, has contributed his expertise, alongside other professionals, to the creation of the IEC 61400-21-4 standard, which defines grid compliance testing for wind turbines on test benches.

With a specialization in Hardware-in-the-Loop (HiL) technology, Dr Jassmann enables the simulation of wind and electrical grid impacts on physically tested wind turbines. His experience highlights the significance of collaborative standardization efforts in advancing the methodologies used in wind turbine testing.

A passion for testing and standardization

Jassmann's work in standardization began in 2015 when he joined the German TR3 committee, later contributing to IEC 61400-21-4 in 2018. During his PhD at RWTH Aachen University, focusing on test bench control and HiL systems, he and others in academia and industry saw the transformative potential of large-scale test benches with HiL systems for grid compliance testing. These systems could dramatically shorten testing times and accelerate time to market.

'I believed, and still believe, that standardization in this area is crucial,' he says. 'Changing how an entire industry approaches grid compliance testing requires all stakeholders to be on board. Standardization is one effective way to achieve that.'

Beyond benefiting manufacturers and operators, standardization also strengthens wind energy's integration into global electricity markets. As grid codes evolve to accommodate higher shares of renewables, a harmonized approach to compliance testing ensures wind turbines meet strict regional requirements without costly redesigns.

For Dr Jassmann, one of the most exciting aspects of working in standardization committees, such as the IEC committee, is bringing together different stakeholders, that is manufacturers, certification bodies, researchers, and system operators, with often conflicting objectives. 'Understanding different perspectives, finding a compromise that everyone can agree with while maintaining technical diligence is not always easy, but it is incredibly rewarding,' he reflects.

The challenge is in aligning industry requirements with technical feasibility. Certification bodies demand precise validation methods, while manufacturers push for streamlined, lean and cost-effective testing procedures. By fostering open discussions, our working group managed to bridge these gaps, leading to a technical specification that balances accuracy with practicality.

'And in the end,' Dr Jassmann says, 'we successfully defined test bench types, technical requirements, and standardized test methods to replace field testing with bench testing while ensuring consistency and reliability in wind turbine conformity assessments.'

To achieve this, the working group behind IEC 61400-21-4, which is led by Björn Andresen, Aarhus University, has conducted more than 50 physical and virtual meetings across multiple countries. The participants came from manufacturers, e.g. Siemens Gamesa, Vestas, etc.; test bench operators, e.g. LORC Denmark; research institutes, e.g. Aarhus University, Fraunhofer IWES; certification bodies, e.g. FGH; and test laboratories, e.g. UL. Each contribution was invaluable to the success of these efforts.

Advancing grid compliance with Hardware-in-the-Loop

The newly published technical specification IEC 61400-21-4 establishes a framework for assessing the electrical characteristics of wind turbine components and subsystems in a controlled environment. By leveraging HiL systems, missing physical elements of a wind turbine, such as rotor dynamics, can be accurately emulated during physical testing, e.g. at nacelle, test benches.

'This approach allows for more precise, repeatable testing compared to field conditions, where aspects such as wind speed, grid strength, are often unpredictable or unchangeable,' Jassmann explains. 'It enables us to verify grid compliance faster and at a lower cost because there is for instance no waiting for the correct wind.'

On a more technical note, test benches with HiL systems and grid emulators allow us to simulate extreme wind events, such as gusts, and more importantly arbitrary grid conditions, such as voltage sags, frequency deviations, or weak grid situations, without exposing the actual wind turbines to potential operational risks.

This is done using real-time simulation models of the wind turbine and the grid. Based on advanced control methods, these real-time models are coupled with the physically tested components of the wind turbine.

This approach also facilitates early-stage debugging, allowing engineers to fine-tune turbine control systems before on-site deployment. 'Being able to test a turbine's response to a variety of grid disturbances in a controlled setting is a game changer,' says Jassmann. 'It significantly enhances our ability to meet compliance requirements before field deployment.'

Additionally, the converter-based grid emulators provide the opportunity to test scenarios that would be nearly impossible to replicate in the field, such as frequency variations or phase jumps. By running these tests in a laboratory setting, engineers can better understand how turbines behave under extreme conditions, leading to improved control strategies and more resilient wind power plants.

From research to implementation: the role of test benches

A significant outcome of the IEC 61400-21-4 standard is the structured classification of test benches, which helps define the appropriate setup for different compliance tests. These range from controller test benches, representing the least hardware-intense test setup, limited to assessing the turbine's control logic, to nacelle test benches, including all mechanical and electrical drive train components, which allow assessing the controller but also hardware capabilities and interactions.

Previous and parallel to the committee work several joint research projects of academia and industry were carried out, which conducted grid compliance tests with full-size wind turbines on test benches e.g. at Fraunhofer IWES or RWTH Aachen University.

The results were compared with field tests and even between different test benches to provide a meaningful basis for the IEC committee discussions. This ensures that the test results from test benches align with real-world compliance testing results and that testing quality remains high.

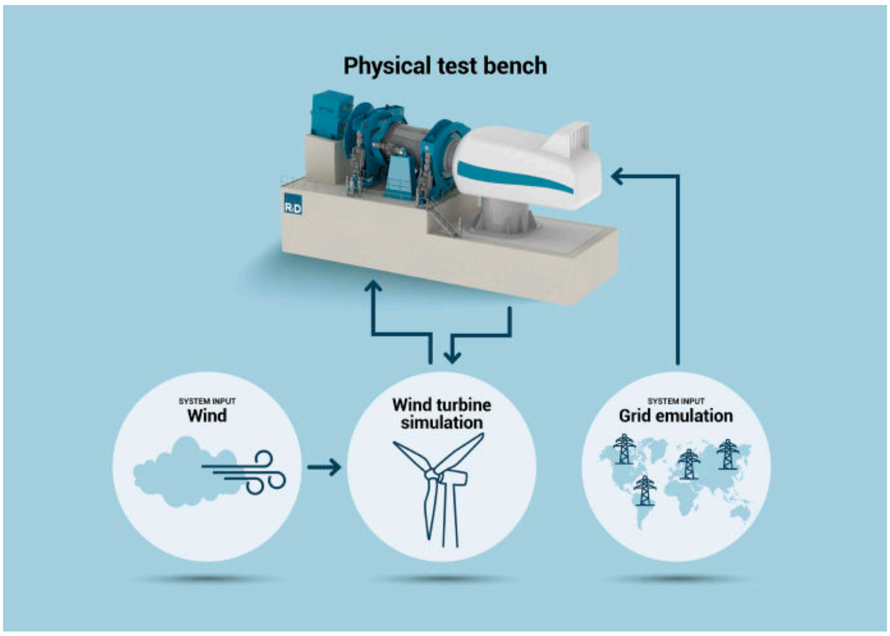
'One of the key questions we tackled was whether test bench results could truly replace field tests,' he explains. 'Through extensive validation across research projects, we demonstrated that properly designed test bench methods provide results that are as reliable as field testing.'

Conducting field tests can be expensive, time-consuming, and sometimes impractical, especially for offshore wind turbines. With test benches, manufacturers can conduct multiple tests efficiently, reducing downtime and accelerating turbine development.

The future of standardization in wind energy

Jassmann sees further potential for HiL-based testing to expand beyond its current scope. 'As wind turbines become more complex and grid requirements more stringent, standardized test procedures will play an even greater role' he notes. The IEC 61400-21 series is already referenced in various national grid codes and certification schemes, demonstrating its growing influence in the industry.

The increasing penetration of renewables into power grids will require more advanced validation methods for grid-forming inverters and hybrid energy systems. 'We're just scratching the surface of what's possible and needed' Jassmann says. 'Future iterations of the IEC 61400-21 series will likely address new challenges related to grid stability and renewable energy integration.'



Dr Uwe Jassmann studied Automation Engineering at the University of Rostock and earned his PhD from RWTH Aachen in 2018.

After working as a postdoctoral researcher and leading the CertBench project until 2020, he transitioned to self-employment as a consultant for several wind turbine OEMs.

Since 2023, he has been the Digitalization Lead at R&D Test Systems.

The seamless integration of digital twins, of the turbine and the test bench, in compliance testing as in any other testing will become more and more important in the future.

Ongoing advancements in test methodologies

His work in the IEC underscores a broader vision, one where collaborative standardization leads to more efficient, cost-effective, and technically robust solutions for the renewable energy sector. 'It's about creating a framework that benefits everyone, from turbine manufacturers to grid operators, by making compliance testing more reliable and accessible,' he concludes.

This personal experience report exemplifies how engineering expertise and collaborative standardization can drive progress in the wind energy sector. As wind power continues to evolve, such efforts will remain critical in ensuring the seamless integration of renewable energy into the global power grid.

This report highlights the power of collaboration and innovation in tackling complex engineering challenges across companies and stakeholders. It shall motivate experts all over the industry to support such initiatives, share their experience, and by that contribute to the further industrialization of wind energy.

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