



INTERNATIONAL ENERGY AGENCY

**Implementing Agreement for Co-operation in the Research,
Development and Deployment of Wind Turbine Systems
Task 11**

Topical Expert Meeting #94 on

Large Component Testing for Ultra-long Wind Turbine Blades

IEA Wind Task 11- Topical expert meeting

February 25-26, 2019

NREL, National Wind Technology Center, Boulder, CO, USA



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Executive Summary of TEM 94

Introduction

As turbine blades are expected to grow to 120-m or longer, current validation methods may not be scalable and test results may not achieve their intended purpose. Laboratory conditions and load regimes are expected to yield increasingly poorer representations of actual operating conditions. Wind turbine blade validation methods must keep pace with the scale and deployment needs for current and next generation wind turbines. Current methods for validating and certifying wind turbine blades, especially in fatigue, are time intensive and do not provide the realistic loading conditions needed to emulate in-field structural response.

Increasing deployment of turbines in extreme environments may necessitate validation and inspection methods that are not currently required. With time, cost, and technology barriers rapidly approaching it is timely to strategically review the current state of blade validation and what will be needed in the coming years.

The objective of the International Energy Agency (IEA) topical expert meeting (TEM) 94 was to identify near-term and future needs for validation of wind turbine blades and consider if existing test methods and test facilities can keep pace with industry needs. Group discussion focused on the challenges and potential enabling pathways for test methods and facility usage that enable high levels of reliability and reduced time to market.

Meeting Overview

The National Renewable Energy Laboratory (NREL) hosted TEM 94 on February 25th and 26th, 2019. The TEM was held at NREL's National Wind Technology Center (NWTC) located about 20 km south of Boulder, Colorado. Walt Musial and Scott Hughes of NREL, and Gary Nowakowski of the U.S. Department of Energy were the hosts of the TEM.

25 experts with expertise in wind turbine blade design, manufacturing and testing were in attendance. 17 presentations were provided by participants. The structure and timing of presentations was intended to identify:

- Where the wind industry is heading and what blades are on the horizon
- Existing validation capabilities
- New and emerging test methods
- New blade and turbine technologies that may influence future validation needs

The first day and a half was dedicated to presenting and discussing information. A tour of the NWTC was provided on the second day. The tour was followed by organizing breakout sessions for participants to explore specific details in several areas. The meeting concluded with a discussion of the results from the breakout sessions and discussions and identification of potential areas of collaborative research.

Main Results

The IEA TEM 94 covered the current state of the art for wind turbine blade validation and identified near-term challenges for testing ultra-long blades. The current pace of blade scaling will challenge the capabilities of existing test methods and test facilities unless new test approaches are developed and accepted as standard practices. Groups are selectively performing subcomponent testing to augment current complete-blade tests and to establish design allowables for near or full-scale components. Subcomponent test methods are a pathway to reducing or removing the need for validating a complete blade. However, the lack of guidelines and standardization is limiting the implementation of subcomponent testing. Subcomponent testing is only a general description, it may be used to describe testing of blade spanwise sections or testing of specific areas and features including trailing edges, panels, and root sections.

Following presentations, during discussions, and throughout the breakout sessions several topics emerged as reoccurring themes. Expanding or developing new test facilities was not a key point of discussion, rather improvements to the accuracy and fidelity of testing, and development of representative subcomponent testing, dominated discussions. Common themes identified during the meeting include:

- Blades are expected to outpace test laboratory capacities in the next decade
- There are blades on the horizon that cannot be efficiently tested under existing standards
- Subcomponent testing affords the potential to utilize existing facilities
- There is a lack of definition and guidance for conducting subcomponent tests, many approaches are currently being used and in development
- Analysis and demonstration of subcomponent testing is necessary to establish subcomponent testing as a viable alternative to complete blade testing
- Collaboration through sharing ideas and approaches will help enable subcomponent testing
- There are remaining questions on how accurately current test methods represent field conditions
- The length of time necessary for performing testing will be, if not already, a barrier to product deployment cycles.
- Adjustments or improvements to a safe-life design methodology may be needed to standardize subcomponent testing

Key outcomes of the meeting are summarized as:

- Identification of barriers of standard practices for ultra-long full-scale blades with existing facilities
- Identification of subcomponent testing as a pathway for testing ultra-long blades
- Identification of areas of collaboration that may enable subcomponent testing

Summary of Presentations

Presentations from the TEM94 are available on the IEA website. Information in this section provides an overview and select highlights of each of the presentations.

Nadine Mournir of Planair SA and Brian Smith of NREL provided an overview of the IEA and IEA Wind Task 11. Background information on the IEA and successful TEM's and tasks was presented. A history of IEA Wind tasks was presented and discussion of recent TEM's. Plans for moving recent TEM topics to full IEA wind tasks was presented. Discussion on expanding networks of experts and researchers by communicating findings between IEA and TCP (Technology Calibration Practice) was discussed in depth. Active participation of 20 communities with over 1300 users was highlighted

Scott Hughes of NREL provided an overview of the intent of the TEM and expected outcomes. Experience with running into facility limitations as blade sizes increase was discussed. First-order engineering principle blade scaling model information was presented to highlight potential facility and test equipment challenges if existing test practices are used for ultra-long blades. Recent work at NREL on partial-length blade testing, component testing, and multi-axial testing was described.

Walt Musial of NREL provided an overview of the status of offshore wind development in the U.S. Walt covered in detail the current state of offshore land leases and status of offshore projects along the Atlantic coast of the US. The installed power market for the Atlantic East Coast is approximately 17 GW. The weighted capacity of prototype turbines has been trending to approximately twice that of installed turbine capacity. Turbine blade length has also been growing with the trend towards lower specific power ratings. Industry trends point towards >120m blades for 15 MW turbines within a decade. Challenges and necessary innovations for large turbines may include flexible light-weight blades, increasing levels of reliability, and hurricane resistant designs. Increasing test fidelity while reducing the time to test will be necessary for meeting prototype to product cycles of only a few years.

Pasquale Braione of Vestas presented information on blade asset management. Information was provided on blade inspection and repair capabilities. Inspection capabilities include camera, telescope, drone and non-destructive testing. Common issues encountered during inspections include leading edge erosion, lightning damage, contamination, damaged or missing aerodynamic enhancements, and cracks. The ability to repair cosmetic and structural damage was also presented.

Christian Fenselau of Vestas presented on current testing capabilities at Vestas. Christian discussed the need for test capabilities to keep pace with increasing turbine scales. The importance of testing was highlighted as serving multiple needs including safety, standards compliance, and validation of repairs. Testing components covers in-house products and parts provided by suppliers. Considerable emphasis on testing that supports over 100 GW of installed capacity is realized by supporting 50 test rigs and total laboratory space of over 30 sq. km. Considering all the test facilities, test time capacity at Vestas is over 1500 hours per day. The amount of data collected from testing, fleet data, and a climate library is very large. The need for utilizing this data and hardware-in-the-loop is increasing. Maintaining and improving reliability is a key driver for test method improvement. Subcomponent testing was described as an increasingly important tool for strategic development. Reliability is key to ensuring customers realize a return on investment. Combined test loading including one example of combining edgewise and torsional loads as valuable for blade validation.

Michael Desmond of Envision presented an overview of Envision and recent work in the development of test methods and capabilities for testing large blades and components. Component testing was identified as an enabling capability for validating specific design features, statistical analysis of structures, and failure modes. In addition, component testing may reduce costs and the time required compared to full-blade testing. Gaps in available standardized methods for component testing was identified as well as the need for defining a path to realize viable component test standardization. Several blade areas that could be considered for component testing included blade roots, shear webs, novel aerodynamic geometries, and sectional blades. Current and future challenges that limit innovation and time to market should be addressed with advances in test methods. Future test facilities may not look like existing laboratory buildings. Being able to effectively test repairs was identified as an emerging need.

Peter Greaves of ORE Catapult presented on recent advancements of biaxial blade fatigue testing. Peter described evolutions that are necessary as test facility limitations are increasing as blade lengths become larger. Demonstration of biaxial testing of a new 83.5 m Samsung blade. Evaluation of optimization routines to progressively test different areas and different directions was presented. Challenges with the persistence of higher order modes for larger blades and how that impacts the controllability of biaxial testing was discussed. The fidelity of test results based on the detail of multi-axial was discussed in detail. Challenges with large aerodynamic forces and drag coefficients necessitate aerodynamic fairings, and the challenges associated with fabricating and building them.

Kim Branner of DTU and Martin Bonde Madsen of R&D presented ongoing activities of the BLATIGUE project. The project partners for the BLATIGUE project include many research, industry, certification, and owner operators. Kim described work in developing biaxial fatigue methods that can decrease the amount of time necessary to perform wind turbine blade testing. An overview of several excitation methods was described and how they can be used with existing international standards and how new methods can better represent design and field loading. Development of the new test system used to excite the blade was presented including demonstrations of single-axis and dual-axis system configurations. The evolution and timeline of demonstrating ground-based electromechanical excitation equipment was presented with pathways from simulation to availability of commercial test equipment for very large blades.

Kim Branner of DTU provided information on the development of subcomponent test methods. Kim identified gaps in the building block approach as applied to blades where only material coupon testing and full-scale blades are tested, lacking definition of intermediate scale testing. New DNV GL guidelines were identified as covering subcomponent tests however there remains a gap in how subcomponent testing can be realized for certification. Kim presented an analysis-to-demonstration method for testing of trailing edge composites. Model predictions were validated against full-scale components through subcomponent testing of a trailing edge section.

John Arimond of the University of Maine providing information on the UMAINE Composites Center. John provided an overview of the recent work testing large blades and additional components including towers. John presented information on the scaling and time challenges with current test approaches. John identified and discussed several interesting aspects and novel ideas. John reaffirmed that testing the root section of a blade was entirely possible and consideration of test methods that employ non-resonant means are fruitful and may increase the speed of testing to acceptable levels. John described in detail the development of a non-resonant test method employing electromechanical crank and

level test equipment that is being analyzed and evaluated as a possible forcing equipment. John reiterated the need to rigorously test the root section and joints.

Derek Berry of NREL presented the status of the IEC 61400-5 blade design and manufacturing standard for wind blades. The -5 standard seeks to ensure the engineering integrity of blades and inform appropriate levels of operational safety through the design lifetime. The -5 provides requirements for the design, material qualification, manufacturing, transportation, and repairs of turbine blades. The PT 5 will be working towards submitting a Final Draft International Standard to the IEC in July of 2019. **Scott Hughes** provided an overview of recent activities on the IEC 61400-23 maintenance team that is revising the standard covering full scale testing of blades. The -23 team is working towards updating the standard to integrate with new IEC standards and the IECRE operational documents. The -23 is updating the standard to reflect testing of non-scaled blades and blade components.

Todd Griffith of the University of Texas-Dallas presented on design specifications and testing considerations of extreme-scale wind turbines. Todd presented the design and analysis of the SUMR ultra-long blades of over 100 meters with scaling up to 250 meter blades for conceptual 50 MW blades. The development of gravo-aero-elastically scaled (GAS) blade models was presented. Design and validation challenges with increasing blade scale was discussed including very thick laminates, approaching 150 mm thick for very large blades. Information on the scaling of the 20.87 meter SUMR-demonstrator blade was presented, along with comparisons between 3-bladed and 2-bladed rotor configurations. Information on high-fidelity modeling and testing of blades was presented, including extensive dynamic characterization performed to identify both global and panel mode shapes on research blades. High fidelity testing of ultra-long blades was highlighted as quantifying global and local blade properties will be necessary for capturing low-frequency dynamics, including local panel modes, that may become increasingly important as blades increase in scale.

Josh Paquette of Sandia National Laboratories in the U.S. presented on durability and damage tolerant design approaches that may be applicable for wind systems enabling large rotors and improving reliability of all blade designs. Josh described the details and differences between safe-life, durability, and damage tolerance. Challenges and opportunities for application of damage tolerant approaches were presented including blade inspection, repair, and life extension. Josh provided information and outcomes of the IEA TEM 91 conducted in 2018 on durability and damage tolerant design. Information on recent research and development projects including inspection to multi-scale modeling at Sandia related to durability and damage tolerant design was covered.

Rick Damiani of NREL presented recent research and development work on downwind technologies. Rick described the benefits of downwind rotors including wake redirection, increased inboard and inclined flow power capture, flexible ultralight flexible rotors, yaw stability, and hurricane load mitigation. Rick described the work and advancements within IEA Wind Task 40 covering downwind rotor technology, providing benefits and challenges of downwind technology comparing upwind/downwind and 2 and 3 bladed rotors. Fatigue loads from turbulence and tower shadow effects as highlighted. Manufacturing and deployment of the Segmented Ultralight Morphing Rotor demonstrator on the Controls Advanced Research Turbine project was presented. The Gravo-Aero-elastically Scaled (GAS) blade is considered an enabling technology for ultra-long blades.

Nick Johnson of NREL presented ongoing research of the Big Adaptive Rotor (BAR). The BAR seeks to identify innovative technology for low specific power land-based machines. Key parameters of the BAR are a low specific power of 150 W/m² with very long blade

lengths of 100 meters. Land based turbine capacity may reach 5.5 MW by 2030 and identified the trend of growing the rotor as the average specific power rating continues to decline. Many innovative concepts that are being evaluated in the BAR project include 2-bladed rotors, downwind rotors, high flexible blades, and segmented blades. Evaluation of low-cost carbon fiber is also being evaluated within the project.

Robynne Murray of NREL presented research at the Composites Manufacturing Education and Technology facility. Recent work is advancing new materials and manufacturing processes that can transform blade technology and reduce LCOE. Projects include the demonstration of new thermoplastic materials, and novel manufacturing methods including thermal welding of turbine blade joints. Modeling and multi-scale validation methods were identified as an enabling capability for demonstrating and commercializing new materials. A description of coupon to component scale validation testing was presented, covering adhesive bond testing and component testing of spar subcomponents. Infusion of full-scale 9 m and 13 m blades with the new thermoplastic material was provided.

Breakout Session Notes

Three breakout sessions were held to brainstorm ideas and inform pathways for testing ultra-long blades. The outcomes of each breakout session were discussed with the full group of meeting participants. The breakout sessions focused on three general topics:

- Test facility utilization
- Component Testing
- Test Accuracy

The breakout groups were tasked with considering the following questions:

- How do we maintain (or increase) reliability as blade length increases?
- How do we validate all critical design features?
- How do we improve accuracy of test loading?
- How do we decrease test time?
- How do we maximize use of existing facilities?

The following sections provide a consolidated summary of the thoughts and notes from each of the breakout sessions. Raw notes from each of the breakout sessions is provided in Appendix Four.

Subcomponent breakout session

Notes – Subcomponent breakout session:

- Several subcomponent test approaches are possible. It may be possible to cut the blade in spanwise sections, say by cutting the blade in half. It may also be possible to cut the blade in smaller pieces. A fundamental challenge will be discretizing the inboard span of the blade between the root and maximum chord. Discretizing this region is difficult due to the complexity of geometry and materials, and modification to the natural boundary conditions
- The minimum necessary complexity of boundary conditions to achieve realistic test results is an unknown.
- Acceleration of fatigue testing is desirable to reduce the time to complete fatigue testing. As with complete blade testing, subcomponent testing may employ resonant testing at the eigenfrequency of the test system to reduce time. An upper limit to the frequency of testing, or a constraint with subcomponents with high natural frequencies tested at resonance, can be high test speeds resulting in self-heating and artificial weakening or damage to the test specimen
- If subcomponent test methods are not realized there will remain the need for large concrete blocks for all blade testing
- Standards do not provide guidance on subcomponent type or subcomponent test methods. Subcomponent testing is performed but in the absence of standards subcomponent test procedures are developed internally; these procedures and components currently vary between manufacturers and test laboratories
- Subcomponent testing can enable multi-directional loading. It may be possible to perform 6 DOF (degree of freedom) testing on blade sections with multi-directional loading equipment
- Relying upon a fixed setup or singular concrete block may not be the optimal configuration for subcomponent testing. At least one laboratory concluded that in order to enable subcomponent testing, modular space, strong structural floors, and

adjustable load mechanisms would be necessary as each subcomponent may have dissimilar restraint and loading requirements

- Wind turbine blade response from in-service loading, and factored and accelerated test loads, may include trailing edge buckling and out-of-plane deformation of large panels. These effects should be captured in the design of the subcomponent including representative boundary conditions
- Insufficient information is available to determine common failure modes in the laboratory or during in-field service. Understanding common or trending failure modes is needed to inform subcomponent test methods and the areas to be tested. Simulation of failure modes and the ability for test methods to replicate these failure modes may be an important benefit to subcomponent testing
- Cutting the blade tip would increase the speed of testing and reduce the length of time necessary to complete fatigue testing. It should be evaluated however, if removing the blade tip has unintended consequences or imposes additional simulation requirements as tip mass and the influence of tip stiffness has been removed
- If cutting the blade tip is an option for complete blade testing, then the sectioned blade becomes a subcomponent
- Similarity and scaling may be an important aspect for reducing the need to test blades and subcomponents similar in scale. Additional research is needed to understand how subcomponent testing of similar scale components may reduce the need for additional testing of additional blades and subcomponents. For example, if testing of a 60m blade is performed are the results applicable to a 70 m blade?
- The effectiveness of subcomponent testing needs to be demonstrated by comparing subcomponent and full-scale blade test results

Benefits – Subcomponent Breakout

- Destructive testing of subcomponents can be less expensive than load-based test methods
- Subcomponent validation enables a targeted approach to testing focusing on critical areas of a blade
- Structural and material similarity between multiple blade designs may enable subcomponent test results for different blades
- Increasing the test speed while at the same time decreasing the time to test should be a primary, achievable goal of subcomponent testing
- An issue or failure of one subcomponent during test will not affect test results for the balance of the complete blade
- Complex, multi-axial, time-series waveforms can be used as load inputs to a subcomponent. Hardware-in-the-loop experiments would be possible
- The transportation of subcomponents and prototypes between manufacturing and testing facilities is much easier and less expensive than transporting a complete blade

Challenges – Subcomponent Breakout

- Currently there are no standard or reference procedures for subcomponent testing. Procedures would need to be developed to enable subcomponent testing

- Subcomponent testing by itself may not test the entire structure. Areas that are thought to be robust may not be included in subcomponent tests. This may be a validation gap when considering the intent is validate a complete structure.
- Boundary conditions must be carefully considered for how they must create a proper representation of the complete structure and must not influence test results if additional reinforcements are used
- Regions of the subcomponent that are connected or bonded to test fixtures may be subject to very high point forces and susceptible to fatigue damage.
- Additional analysis is required to ensure results from sub-scale subcomponents or small subcomponent test article size is correctly interpreted. Analysis requirements increase as the subcomponent size decreases
- Standards used for certification purposes will need to allow for subcomponent testing
- Subcomponent test methods must provide a clear path for extracting results used to establish design allowables

Conclusions – Subcomponent Breakout

- There is no option yet to get around a large concrete block for testing the root to max chord span of the blade
- Additional benefits from subcomponent testing can be realized from more outboard sections
- Subcomponent testing is useful for testing different material systems and different design details

Test Facility Utilization Breakout Session:

Comments – Facility Utilization Breakout

- There will soon be a blade where existing facilities will be unable to perform structural testing using current practices considering facility dimensions and potentially the load capacities of test stands. At this point testing with existing standards and current facilities may be by necessity a compromise to accepted standards
- Scaling existing test practices to 150-meter blades imposes significant time-to-market restrictions and will be prohibitively expensive
- Existing test stands can provide the capability to fixture ultra-long blades for property testing including natural frequency, damping, and determination of stiffness distributions
- Accepted guidelines necessitate testing at least 70% of the blade span in static tests, and 40% of the blade span in fatigue tests.
- Structural testing of the blade root is important to validate the design and manufacturing of the blade in areas where large forces, changes in geometry, and variability of the composite laminate are present. The need for rigid test stands that support the rotor or blade may always be necessary for testing the root.
- Conducting testing inside environmentally controlled laboratories has advantages for ensuring a controlled, repeatable test environment. Accelerated testing does not test material ageing. Given the relatively short timeframe for testing, outdoor testing

can provide similar or equivalent results without the expense of new or expanded enclosed test space.

- Performing independent flapwise and edgewise fatigue tests is an accepted practice. Biaxial fatigue testing may provide a more representative laboratory test load. Biaxial testing is more complex even at modest blade lengths and consideration should be given to current and future implementation of biaxial test methods. Tri-axial loading including torsion may be needed for ultra-long blades.

Challenges – Facility Utilization Breakout

- Testing of complete blades that are cut into spanwise sections would allow use of existing facilities for larger blades. Reaction fixture capacity and relatively high point-loads needed for testing tip sections may limit the practicality of this approach. Additional work is needed to determine if the central span of the blade could become an untested area by sectioning the blade span.
- Structural testing consumes a considerable amount of energy from electro-mechanical or hydraulic test systems. Even considering the lower point-forces afforded by resonant testing, testing of ultra-long blades may be limited by the amount of energy required from the test system or by the point-forces applied during static and fatigue testing.
- Existing standards and guidelines require the complete blade to be structurally tested in a static, fatigue, then static sequence. Removal of the blade tip presents a challenge to performing the post-fatigue static test as well as potential impacts to fatigue loading. Modifying the sequence of testing may require a fundamental reassessment of the safe-life design philosophy. Applying principles from other approaches including durability and damage tolerant design should be evaluated.
- There is a lack of information to determine if existing test methods accurately represent field conditions and characterize in-service damage and failure modes. Development of future test methods and facility capabilities should be informed by needs to validate the blade considering extreme environmental conditions and unique load characteristics imposed on the next generation of ultra-long blades.

Potential Areas for Research and Collaboration – Facility Utilization Breakout

- Evaluation and comparison between safe-life and durability and damage tolerant design approaches
- Evaluation of spanwise-sectioned subcomponent test approaches
- Economic analysis of new and modified facility construction costs, including test equipment, compared for complete and subcomponent test methods
- Inter-laboratory comparisons for comparing test methods, both for complete blades and subcomponents
- Evaluation of single and multi-axial loading (biaxial, tri-axial with torsion, etc.)
- Evaluation of laboratory test results compared to blades in service

Test accuracy breakout session:

- Evaluation of Markov-based block loading may improve the accuracy of the test and potentially reduce the test time
- Ground-based dual actuator test is simpler and more accurate
- Test subcomponents along with full-scale to look at effects of torsion
- Subcomponent testing can be used to develop representative sample sets
- Work is needed to establish the connection between the partial safety factor for test-to-test or blade-to-blade variation and partial safety factors for defects and manufacturing variations

Conclusions & Next Steps

Participants expressed interest in collaborating on research to advance test methods for ultra-large blades. There was substantial interest in development of subcomponent test methods that may enable shorter testing timeframes and lead to improvement in blade and rotor reliability. Subcomponent testing of ultra-long blade components may be a necessity, and not an option, considering the increasing scale of blades and use of existing facilities.

Development of an IEA Wind task focusing on development of novel test approaches should be considered. One outcome of the meeting was that subcomponent testing is being performed by industry and research institutes, but there is not a clear path to establishing, standardizing or harmonizing validation approaches that are currently in use. An IEA Wind task focusing on bridging the gaps that may prevent the adoption of subcomponent test methods would support and enable validation of ultra-long blades. Outcomes of an IEA Wind task should provide the framework to support modifications or development of new standards. Reoccurring themes and key topics that should be considered for a task work plan, a non-exhaustive list of topics include:

- Establish framework for creation of a subcomponent test standard
- Compare methods that enable spanwise-sectional testing of blades
- Evaluate applicability of other design approaches including durability and damage tolerant design
- Determine required levels of fidelity for test methods and measurements
- Comparison of laboratory test results to in-service experience
- Subcomponent testing to bridge design allowable to complete structure validation

Key themes and outcomes from other recent IEA TEM's should be considered to determine if there is overlap of key topics and identify additional areas of collaboration or information exchange. TEM #91 focused on development of durability and damage tolerant design that may be relevant to realizing subcomponent testing. TEM #92 seeks to identify technologies that may improve the reliability of wind turbine blades through digitalization. TEM #93 considered lifetime extension of components covering relevant topics including data-based reliability methods, inspection methods, and changing environmental conditions.

APPENDIX ONE - TEM 94 Introductory Note

Walt Musial – National Renewable Energy Laboratory
Gary Nowakowski U.S. Department of Energy
Scott Hughes – National Renewable Energy Laboratory

BACKGROUND

As turbine blades are expected to grow to 120-m or longer, current validation methods may not be scalable and test results may not achieve their intended purpose. Laboratory conditions and load regimes are expected to yield increasingly poorer representations of actual operating conditions. Wind turbine blade validation methods must keep pace with the scale and deployment needs for current and next generation wind turbines. Current methods for validating and certifying wind turbine blades, especially in fatigue, are time intensive and do not provide the realistic loading conditions needed to emulate in-field structural response. Increasing deployment of turbines in extreme environments may necessitate validation and inspection methods that are not currently required. With time, cost, and technology barriers rapidly approaching it is timely to strategically review the current state of blade validation and what will be needed in the coming years.

OBJECTIVES

This topical expert meeting is intended for participants to exchange information and ideas that will help ensure validation capabilities for large turbine blades and components are available when needed. Topics that will be discussed include:

- Limitations of current practices and standards as applied to very large blades
- Evolution of blade design and manufacturing methods that may necessitate improvements in validation techniques
- Integration and evaluation of health monitoring systems for turbines in extreme environments
- Validation methods that reduce test duration
- Application of component and sub-article testing
- Improvements in test methods to capture extreme service conditions
- Maximizing the utilization of existing facilities

TENTATIVE PROGRAM

1. Introductions
2. Overview of the state of the industry
 - a. Existing validation capabilities
 - b. Testing and validation practices
3. Challenges and Opportunities
 - a. Time and complexity of testing
 - b. Emerging validation requirements
 - c. Support of nascent damage tolerant design approaches
 - d. Component and sub article testing
 - e. Sectional blade testing
 - f. Environmental testing
 - g. Harmonization of laboratory testing and field experiences
4. Identification of priorities
 - a. Utilization of existing test infrastructure
 - b. Areas for research

- c. Key opportunities
- 5. Framework of an IEA Wind Task

The Topical Expert Meeting will take place on February 25-16, 2019

INTENDED PARTICIPATION

- Wind Turbine OEM's
- Wind Turbine Owners and Operators
- Wind Turbine Blade Manufacturers
- Wind Turbine Certification and Validation Organizations
- Wind Turbine Service and Repair Providers
- Test System Design and Equipment Providers
- Research Institutions and Funding Organizations

EXPECTED OUTCOMES

A report will document the proceedings of the meeting. This report will provide:

- The state of existing rotor blade validation capabilities
- Challenges and opportunities for advancing test capabilities
- Definition of requirements for efficient validation of large wind turbine rotors
- Scope for proposed IEA Task for submission to IEA Executive Committee

APPENDIX TWO - Meeting Agenda

Location: National Wind Technology Center, 18200 State Highway 128, Boulder, CO 80303

Monday 25 February 2019

8:30 AM	Check-in, badging, coffee
9:00 AM	Introductions
9:20 AM	Welcome and Overview: <i>Scott Hughes, NREL</i>
9:40 AM	Introduction to IEA Wind: <i>Brian Smith, NREL</i>
9:50 AM	IEA Wind TCP and Task 11: <i>Nadine Mounir, IEA Wind</i>
10:00 AM	Trends in offshore wind: <i>Walt Musial, NREL</i>
10:30 AM	Blade Asset Management: <i>Pasquale Braione, Vestas</i>
10:50 AM	Break
11:00 AM	Discussion: Validation needs for ultra-long and offshore turbine blades
12:00 PM	Lunch
1:00 PM	Validation capabilities: <i>Christian Fenselau, Vestas</i>
1:20 PM	Validation capabilities: <i>Michael Desmond, Envision</i>
1:40 PM	Bi-axial fatigue testing of large wind turbine blade: <i>Peter Greaves, ORE Catapult</i>
2:00 PM	Recent results towards more realistic testing of wind turbine blades – BLATIGUE project: <i>Martin Bonde Madsen, R&D, and Kim Branner, DTU</i>
2:30 PM	Break
2:45 PM	Subarticle & subcomponent testing: <i>Kim Branner, DTU</i>
3:15 PM	Fatigue test acceleration through non-resonant methods: <i>John Arimond, University of Maine</i>
3:45 PM	Design, manufacturing, and validation standards: <i>Derek Berry and Scott Hughes, NREL</i>
4:15 PM	Discussion: Current and future validation methods
5:00 PM	Adjourn
6:00 PM	No-host dinner

Tuesday 26 February 2019

8:30 AM	Check-in and coffee
9:00 AM	Recap of Day 1
9:10 AM	Design specifications and testing considerations for large- and extreme-scale wind turbine blades at 100-meter, 200-meter, and beyond: <i>Todd Griffith, University of Texas - Dallas</i>
9:30 AM	Damage Tolerant Blade Design: <i>Josh Paquette, Sandia National Laboratories</i>
9:50 AM	Segmented Ultralight Morphing Rotor: <i>Rick Damiani, NREL</i>
10:10 AM	Big Adaptive Rotor: <i>Nick Johnson, NREL</i>
10:30 AM	Advanced Manufacturing: <i>Robynne Murray, NREL</i>
10:50 AM	Break
11:15 AM	Discussion: Evolution of design and validation practices
12:15 PM	Lunch
1:15 PM	Tour of the NWTC
2:15 PM	Breakout sessions: A: Utilization of existing capabilities and future needs B: Component and sub article testing
3:30 PM	Break
3:15 PM	Discussion: Areas for research and collaboration
4:15 PM	Day 2 wrap-up and next steps
4:30 PM	Adjourn

APPENDIX THREE - Meeting Participants

The meeting was attended by 25 participants from 8 countries. Following is the list of participants and their affiliations.



Name	Country	Company/Organization
Angelo Ricci	Italy	Vestas
Asier Oiz	Spain	CENER
Brian Smith	U.S.	NREL, National Wind Technology Center
Christian Fenselau	Denmark	Vestas
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APPENDIX FOUR - TEM 94 Raw Breakout Session Notes

IEA TEM#94 subcomponent breakout session notes

Notes:

Subcomponent options:

- Cut blade in half?
- Cut blade into pieces?
- Can area from root max chord be discretized?—may be difficult to discretize this section due to complexity contained within and boundary condition effects.

Boundary condition complexity?

Energy considerations for subcomponent testing—may need to test at eigenfrequency for energy requirements. But if frequency too high then may burn the laminate.

If can't do subcomponent testing then we will need large concrete blocks for all testing

Certification standards don't provide guidance, so procedures are developed internally

Section testing with 6 DOF

Fixed setup is not good approach and one lab concluded they needed modular approach with strong floor and adjustable load mechanisms because each subcomponent test is different.

TE buckling, panel breathing

Is there common failure modes in blade that could be replicated for subcomponent procedure validation?

How to simulate the mass and stiffness of tip that is removed from blade?—may not be any benefit to do this because it would slow test...

Cutting blade tip becomes a subcomponent.

If testing to 60m blade is done, then can results be applied to 70m blade?

Need to develop subcomponent procedures through comparisons with full-scale test results.

Benefits

- Destructive testing is less expensive
- Targeted approach to testing
- Use similarity in test sections to apply to multiple blade designs
- Hoping for quicker test time due to higher eigenfrequency
- An issue with one subcomponent during testing doesn't affect the testing to the overall blade.
- More complicated time series loading can be inputted.
- Prototype transportation is easier with subcomponents

Challenges

- Procedures need to be developed.
- may not test areas that were not expected to be an issue
- boundary conditions
- the fixation is tested in subcomponent versus the actual subcomponent (At least in fatigue)
- the smaller the subcomponent—the more analysis that needs to be done
- certification—standards need to allow it.
- How to extract design allowables from subcomponent test

Conclusions

- No option yet to get around large concrete block for testing root to max chord
- The more outboard sections, the more benefit to subcomponent testing
- Useful for comparisons of different design details (material systems)

IEA TEM#94 test facility utilization breakout session notes

Comments

- Soon be a blade we cannot test – will need to do what we can with what we have
- Scaling to 150 m with current tech too expensive
- Consider segment testing
- Consider outdoor testing
- Force/energy constraints
- Existing stands capable of model validation
- Capabilities for single or biaxial testing

Challenges

- Static-Fatigue-Static
- 70% span for static / 40% for fatigue
- Energy consumption
- Restraints for blade segment testing
- Is testing representative of in-service conditions

Areas for research

- Property-Static –Fatigue sequence
- Economic analysis of facility construction and test costs
- Improved ILC

- Tri-axial, Biaxial and single axis requirements
- Field to lab equivalency

IEA TEM#94 test accuracy breakout session notes

- Markov-based block loading for improved accuracy and possibly reduced test time
- Ground-based dual actuator test is simpler and more accurate
- Test sub-components along with full-scale to look at effects of torsion
- Use sub-component testing to develop representative sample set
- Connection between test-test variation PSF and defect PSF

APPENDIX FIVE - IEA Agreement

International Energy Agency Agreement Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems (IEA Wind)

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977 and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 26 contracting parties from 22 countries, the European Commission, and Wind Europe, participate in IEA Wind. Austria, Belgium, Canada, Denmark, the European Commission, EWEA, France, Finland, Germany, Greece, Ireland, Italy (two contracting parties), Japan, Republic of China, Republic of Korea, Mexico, Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Two Subtasks

The task includes two subtasks.

The objective of the first subtask is to develop recommended practices (RP). Recent developed RPs were on “Wind Farm Data Collection and Reliability Assessment for O&M Optimization (Task 33)” (RP#17) and “Floating Lidar Systems (Task 32 in coordination with the Offshore Wind Accelerator initiative)” (RP#18).

The objective of the second subtask is to conduct topical expert meetings in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, Topical Expert Meetings are arranged four times a year.

Documentation

Since these activities were initiated in 1978, more than 90 volumes of proceedings have been published. In the series of Recommended Practices 16 documents were published and six of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task.

Operating Agent

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COUNTRIES PRESENTLY PARTICIPATING IN THE TASK 11 (2018)	
COUNTRY	INSTITUTION
Belgium	Government of Belgium
Canada	Natural Resources Canada
Denmark	Danish Technical University (DTU) - Riso National Laboratory
Finland	Technical Research Centre of Finland - VTT Energy
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
Ireland	Sustainable Energy Ireland – SEI

Italy	Ricerca sul sistema energetico, (RSE S.p.A.)
Japan	New Energy and Industrial Technology Development Organization (NEDO)
Mexico	Instituto Nacional de Electricidad y Energías Limpias, (INEEL)
Netherlands	Rijksdienst voor Ondernemend Nederland (RVO)
Norway	The Norwegian Water Resources and Energy Directorate - NVE
Republic of China	Chinese Wind Energy Association (CWEA)
Republic of Korea	Korea Institute of Energy Technology Evaluation and Planning (KETEP)
Spain	Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas CIEMAT
Sweden	Energimyndigheten - Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy – SFOE
United Kingdom	CATAPULT Offshore Renewable Energy
United States	The U.S Department of Energy -DOE

