EUDP Project on IEA Wind Task 35 – Full Size Ground Testing of Wind Turbines and their Components

Anand Natarajan, Kim Branner

DTU Wind Energy

Project Final Report

Project no. 64014-0141

Funded by the Energy Technology Development and Demonstration Programme (EUDP)

Project title	IEA Wind Task 35 – Full Size Ground Testing of Wind Turbines and their Components
Project identification (program abbrev. and file)	J.nr. 64014-0141
Name of the programme which has funded the project	Energiteknologisk udvikling og demonstration (EUDP)
Project managing company/institution (name and address)	DTU Vindenergi, Risø Campus, Frederiksborgvej 399, 4000 Roskilde
Project partners	DTU Mek, Vestas, LORC, Blaest, LM Wind power
CVR (central business register)	30060946
Date for submission	Dec 15, 2016

Contents

EUDP Project on IEA Wind Task 35 – Full Size Ground Testing of Wind Turbines and their Components 1

Project Final Report 1

Project no. 64014-0141 1

Funded by the Energy Technology Development and Demonstration Programme (EUDP) 1

1.0 Short description of project objective and results 4

2.0 Executive Summary 5

3.0 Subgroup 1: Nacelle Test Group 5

4.0 Subgroup 2: Blade Test Group 7

Work Sub tasks 7

Blade Test Methods 7

Nondestructive Inspection 9

Subcomponent Testing 10

Blade Test Uncertainty 10

Status of work in Blade sub task 11

Conclusions 12

1.0 Short description of project objective and results

The IEA Task 35 focuses on ground-based test rigs to evaluate wind turbine generator (WTG) nacelles and blades under reproducible, accelerated life conditions. To establish full size ground testing procedures and enabling the first steps for the standardization of test procedures, test rig operator, WTG manufacturer and other industry representatives (see table 1) came together within the IEA Task 35 to enhance full size ground testing for WTG nacelles and blades. The main objective was to provide recommended practices for standardized test procedures as well as proposals for uniform and qualitative analysis of test results for wind turbines components

Table 1. Countries Participating in Task

	Country	Institution(s)	Contact Name	Contact Email
1	China	Goldwind Science & Technology Co., Ltd.	Yang Jiongming	jiongmingyang@163.com
		Institute of Electrical Engineering, Chinese Academy of Sciences	Hu Shuju	hushuju@mail.iee.ac.cn
		Shanghai Electric Wind Energy Co., Ltd.	Zhu Zhiquan	zhuzhq@shanghai-electric.com
		China General Certification Center	Chen Leijie	chenlj@cgc.org.cn
		Zhejiang Windey Co., Ltd	Wu Genyong	wugy@chinawindey.com
2	Denmark	Technical University of Denmark (DTU), Wind Energy	Anand Natarajan	anat@dtu.dk
			Kim Branner	kibr@dtu.dk
			Federico Belloni	federbe@dtu.dk
		Technical University of Denmark (DTU), MEK	Christian Berggreen	cber@dtu.dk
		Lindoe Offshore Renewables Center (LORC)	Lars Rasmussen	lsr@lorc.dk
		Vestas Wind Systems A/S	Christian Fenselau	chfen@vestas.com
		LM Wind Power A/S	Scott Dydensborg	scdy@lmwindpower.com
			Torben Lindby	tl@lmwindpower.com
		R&D A/S	Morten Pedersen	msp@rdas.dk
			Carsten Vejby Møller	cvm@rdas.dk
			Christian Frier Hvejsel	cfh@rdas.dk
		Blade Test Center A/S	Erik Steen Jensen	esj@blaest.com
			Carsten Skamris	cas@blaest.com
		Bladena ApS	Find Mølholt Jensen	fmj@bladena.com
3	Germany	Center for Wind Power Drives (CWD), RWTH Aachen University	Dennis Bosse	dennis.bosse@cwd.rwth-aachen.de
			Tobias Duda	tobias.duda@cwd.rwth-aachen.de
		Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)	Martin Pilas	martin.pilas@iwes.fraunhofer.de
		Senvion GmbH	Olaf Tiedemann	olaf.tiedemann@senvion.com
		GE Energy Power Conversion GmbH	Uwe Vollmer	Uwe.Vollmer@ge.com
		MTS Systems GmbH	Sven Sagner	sven.sagner@mts.com
		Windtest Grevenbroich GmbH	Eric Effern	e.effern@windtest-nrw.de
		HBM- Hottinger Baldwin Messtechnik GmbH	André Schäfer	Andre.Schaefer@hbm.com
		Tüv Rheinland AG	Jens Kulenkampf	jens.kulenkampff@de.tuv.com
		Technical University of Berlin	Yuri Petryna	yuriy.petryna@tu-berlin.de
		Siemens AG (Winergy)	Dominikus Daners	dominikus.daners@siemens.com
4	United Kingdom	Offshore Renewable Energy Catapult	Chong Ng	chong.ng@ore.catapult.org.uk
		Lloyd's Register Group Services Ltd.	Steve Gilkes	Steve.Gilkes@lr.org
5	United States of America	National Renewable Energy Laboratory, National Wind Technology Center	Scott Hughes	Scott.Hughes@nrel.gov
			Marc McDade	Mark.McDade@nrel.gov
		Clemson University Wind Drivetrain Test Facility	Andrei Mander	andreim@clemson.edu
		McNiff Light Industry	Brian McNiff	brian@mcnifflight.com
		Sandia National Laboratories	Dennis Roach	dproach@sandia.gov
		MTS Systems Corporation	Bob Orange	bob.orange@mts.com

The results of the last couple of years in the task have enabled the compilation of documents on test cases and methods to reduce uncertainties or render robustness during testing. The work resulted in two conference publications and reports publicized on the IEA website. However it has not been able to develop standardized test procedures usable by the industry, for which an extension of the task is being sought.

2.0 Executive Summary

The IEA Wind Task 35 is coordinated by Aachen university and is divided into two sub groups: 1) Nacelle testing and 2) blade testing. The subgroup on nacelle testing is led by Aachen university and consists of DTU, LORC, Vestas, Senvion, Fraunhofer, GE, Clemson University and MTS as main participants from the beginning of the task in 2014, with other partners listed in Table 1 joining later on. The sub group on blade testing is led by NREL and consists principally of DTU, Blaest, LM Wind power, R&D, Fraunhofer, WMC, ORE Catapult, Sandia National Labs and McNiff along with other partners listed in Table 1.

The two subgroups function independent of each other, but have the common objective to review existing component test methods in a facility, suggest improved procedures and formulate a common best practice on component testing. While the subgroups have made great progress in documenting some test procedures and their associated details, the methods have not been conclusive nor validated and an extended activity is proposed from next year, for which an approval is sought from the IEA Executive committee. The extension may be needed from 1 -3 years.

3.0 Subgroup 1: Nacelle Test Group

The focus of nacelle testing is to be able to mount an entire wind turbine nacelle on a test stand connected to a prime move and to the grid so as to generate electricity similar to the actual wind turbine operation. The tests essentially cover:

- Type Certification (OEM). Focus on certification is needed before the installation of new wind turbines
- Design Validation of robustness, design assumptions and design methods (OEM, subsystem manufacturer
- Reproducing particular gearbox failure modes like White Etching Cracks or pitting etc. (subsystem manufacturer)

While the test nacelle is run using a prime mover which is essentially a motor, it may not produce the same stochastic dynamics as the wind turbine rotor nor possess identical coupled structural natural frequencies. Therefore it is required that the test setup be able to duplicate core dynamics of the actual setup through tuning and abstraction, most likely to the torsional natural frequency of the main shaft.

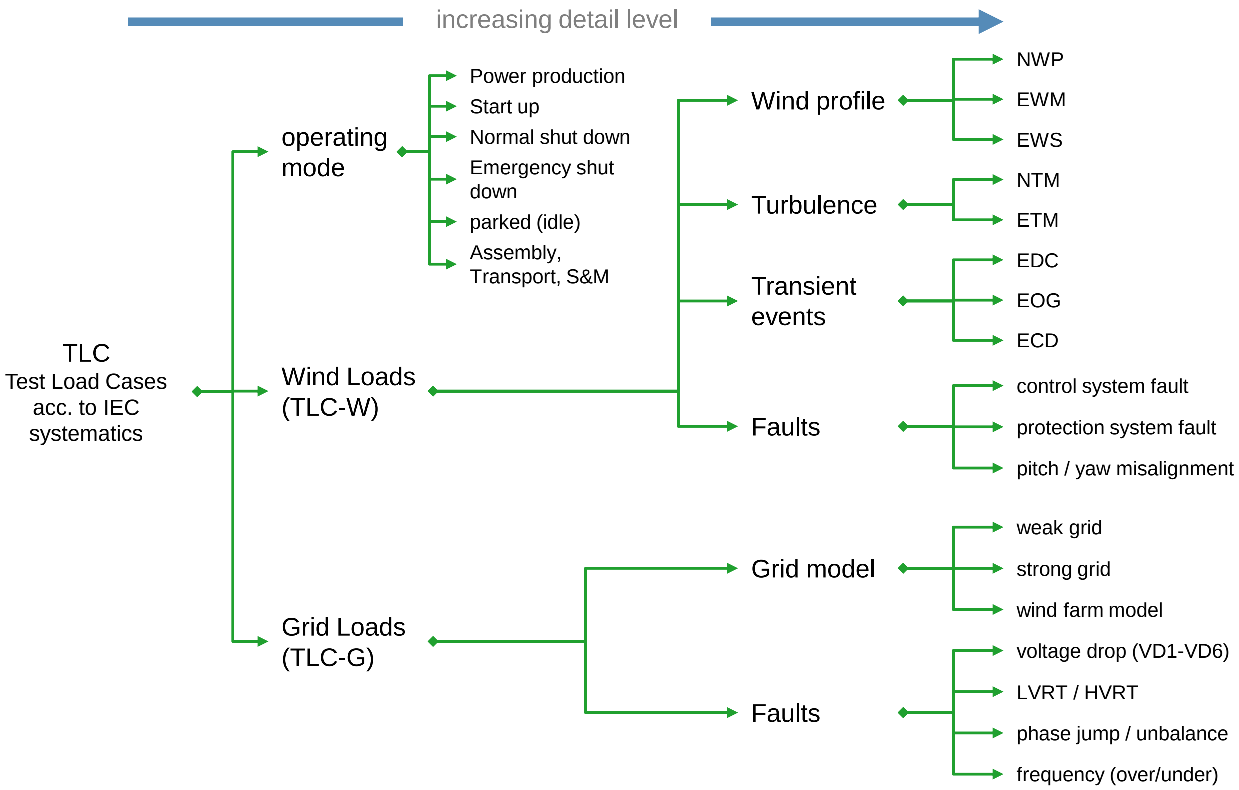
Test rig setup

Test setups that result in different behaviors of the subcomponents needs to be considered. Torque and bending modes are different and vary from turbine to turbine. Considering frequencies up to 3p (3 times the rotor harmonic) is usually sufficient. Dynamic performance capabilities are limited by the test rig actuators (max. displacement and hydraulic) and especially by the drivetrain stiffness. No general valid statements about critical load condition are possible. It highly depends on wind turbine configuration and controller.

The task has setup a matrix of possible test cases that need to be run for nacelle component cases, broadly divided into 1) mechanical loading tests, 2) electrical tests and 3) noise and electromagnetic tests. A key requirement to be considered was determined to be the robustness of the tests with regards to duplicating actual wind turbine operating conditions.

Test Schemes

While definite test procedures were not recommended, different partners determines several types of test schemes of relevance. One such test scheme proposition is provided below.



TLC Test load cases are descriptive parts of the test protocol for ground based tests of drivetrains and nacelles of wind turbines in which the kind, the intensity, (the time and duration) of the loading of the device under test (DUT) are determined. The loading of the DUT is done at the interfaces between test rig and DUT (e.g. hub, main shaft, point of common coupling). The TLC refer to the test objectives and ensure repeatable loading as well as reliable and meaningful measurements.

DLC Design load cases
ECD Extreme coherent gust with direction change
EDC Extreme direction change
EOG Extreme operating gust
EWM Extreme wind speed model
EWS Extreme wind shear
NTM Normal turbulence model
ETM Extreme turbulence model

NWP Normal wind profile model

detailed explanations are provided in 6.3 and 7.4 of IEC 61400-1 [1]

The final report of the IEA Task is expected to contain general procedures about nacelle testing including 1) Description of system tests for both electrical and mechanical sub components, 2) Robustness of tests, 3) Abstraction and tuning of test setup to actual turbine frequencies. Further objectives of the tests in terms of certification, failure mode analysis or developmental research will also be addressed. The milestones reported in the IEA Task 35 description, namely, M1 (Agreement of a work plan), M2 (Beginning of second project phase: working in subtasks), M3 (Determination of critical components), M4(First edition of test matrix for basic nacelle test procedures) and M5 (Second edition of test matrix for basic nacelle test procedures, Description of losses and benefits of system abstraction on test benches) have been completed and will be reported in the final report of the IEA Task 35 in Mar 2017. Milestones M6 and M7 on accelerated lifetime testing and recommended test procedures have not been completed and not fully initiated and are expected to be addressed during a possible extension of the IEA Task 35.

The subgroup has had two meetings at specific locations (Aachen, Germany and Blyth, UK) and several meetings over the telephone.

4.0 Subgroup 2: Blade Test Group

As part of the International Energy Agency (IEA) Task 35 Rotor Subgroup, a group of international wind turbine manufacturers and test laboratories intend to exchange data and information for the purpose of improving existing methods and developing new best practices for wind turbine blade testing. The scope of work including task obligations and responsibilities are described in the work plan, "IEA Wind Task 35 – Wind Turbine Testing. Full Size Ground Testing for Wind Turbines and their components". Each participant is expected to actively participate and contribute to discussions and documents resulting from this collaboration. The work in the group is coordinated by Scott Hughes, NREL National Wind Technology Center.

The work to date is progressing but another year is required to document all results. Therefore the sub task on blade testing is being planned to be extended at least by one year, that is till end of 2017.

Work Sub tasks

The Blade Test Group is currently working on a report consisting of 4 subparts:

1. Blade Test Methods (coordinated by Kim Branner, DTU Wind Energy)
2. Nondestructive Inspection (coordinated by Dennis Roach, Sandia National Laboratories)
3. Subcomponent Testing (coordinated by Arno van Wingerde, Fraunhofer IWES)
4. Blade Test Uncertainty (coordinated by Dave Snowberg & Nathan Post, NREL)

Blade Test Methods

For this subtask the purpose is to list the state-of-the-art in structural testing of rotor blades. Describe where improvement of existing methods is needed and suggest the best practices for wind turbine blade testing. The goal is to ensure that the same blade exposed to standard tests at different facilities result in the same measurements. The goal is also to recommend test methods that minimize field damage within the design load envelope.

Subpart report contents:

1. Introduction
2. Test facility layout and principles
3. Test stands and strong floor
4. Property characterization
   4.1. Mass, cog
   4.2. Stiffness
   4.3. Eigen frequencies, damping
   4.4. Functionality of lightning and mechanical systems
5. Static test methods
   5.1. Vertical test
   5.2. Horizontal test
   5.3. Torsional test
   5.4. Test direction and load combinations
   5.5. Load application and actuators
   5.6. Best practices
6. Fatigue test methods
   6.1. Exciters
   6.2. Single axis test
   6.3. Dual axis test
   6.4. Other methods
   6.5. Best practices
7. Processing of data
   7.1. Validations
8. Determination of test loads
   8.1. Static
   8.2. Fatigue
   8.3. Acceleration of test
   8.4. Materials with different S-N slopes
9. Measuring equipment
   9.1. Data acquisition
   9.2. Strain gauges
   9.3. Displacement
   9.4. Load cells
   9.5. Temperature
   9.6. Fiber Bragg Grating sensors
   9.7. Digital image correlation systems
   9.8. Acoustic emission
   9.9. …
10. Control of tests

11. Workplace safety aspects

Nondestructive Inspection

For this subtask the purpose is to list the state-of-the-art in NDI methods for rotor blade, describe improvements to existing methods that are needed and to suggest key best practices for NDI of wind turbine blades.

Subpart report contents that are planned are:

1. List of candidate NDI methods
   – UT, PA-UT, AC-UT, LA-UT, Shearography, Thermography, THz, AE, X-ray (see Force Tech), Tap testing, Visual (aided)
2. Usage
   – flaws to be detected
3. Description
   3.1. Equipment
   3.2. Physics - how it works
   3.3. Advantages
   3.4. Limitations
   3.5. Deployment
   3.6. Reliability (methods to ensure)
   3.7. Repeatability
   3.8. Sensitivity
   3.9. Signal Interpretation
4. Applications
   4.1. Quality assurance vs. in-service NDI
   4.2. Spar cap laminate
   4.3. Bond line
   4.4. Aero core regions
   4.5. Leading edge
   4.6. Trailing edge
   4.7. Root region
   4.8. Transition region - joint
5. Procedures
6. NDI Reference Standards – design and usage
7. Training
   7.1. Blade design overview (appreciation)
   7.2. Classroom
   7.3. On-the-Job
   7.4. Apprentice programs
   7.5. Recurring
   7.6. Lessons learned – operational & testing history

Subcomponent Testing

For this subtask the goal is to make subcomponent testing usable and understandable to the test engineer. Show options and problems to the test engineer and certification bodies.

Subpart report contents:

1. Introduction
2. Background
    2.1. Necessity
    2.2. Role of subcomponent testing in the design- and certification process
    2.3. Gaps in application to new standard
    2.4. Influence on load factors
3. Overview of current subcomponent tests
4. Evolving test methods
    4.1. Catalogue of ideas for subcomponent tests
    4.2. Load introduction and boundary conditions and comparison with analytic results
5. Implementation
    5.1. Practical considerations
    5.2. Best Practices
    5.3. Use in the development and certification process

Blade Test Uncertainty

For this subtask the purpose is to develop best practices for blade test measurement uncertainties with the goal to improve overall quality of wind turbine blade testing. In 2016 working drafts for uncertainty estimation in static and fatigue testing were developed. Developments included expansion of uncertainty estimates for multi degree of freedom cross-talk matrices and development for approaches to calculate the uncertainty of the damage equivalent loads applied during fatigue testing.

Subpart report contents:

1. Introduction
2. Background
    2.1. Necessity
    2.2. Benefits
    2.3. Gaps in application to new standard
3. Overview of uncertainty estimation
4. Property measurement and dynamic characterization
    4.1. Instruments
    4.2. Methods
    4.3. Influence of test rig
5. Static testing
    5.1. Instruments
    5.2. Geometry
6. Fatigue testing
    6.1. Instruments

    6.2. The blade as a sensor
    6.3. Reporting of DELs
    6.4. Example and comparisons
7. Evolving test methods
    7.1. Torque testing
8. Implementation
    8.1. Practical considerations
    8.2. Best Practices

Status of work in Blade sub task

First draft versions of the reports were presented and discussed at the in-person meeting in Albuquerque on September 1st, 2016. The work in the Blade Test Group is now, after a slow start, progressing very well and the partners in the group are dedicated and have a good collaboration. The work in the blade test group is currently planned to continue until the end of 2017. The group has monthly web meeting and in-person meetings two times a year. The latest in-person meeting were held:

September 1st, 2016 at Embassy Suites Hotel, Albuquerque, New Mexico, USA in connection with the 2016 Sandia Wind Turbine Blade Workshop organized by the Sandia National Laboratories, Wind Energy Technology Department. The meeting had participants from NREL, Sandia National Laboratories, WMC, Siemens WP, Envision, DTU Wind Energy & Bladena

December 3rd, 2015 at Maritim Hotel Düsseldorf, Germany in connection with the 6th annual international AMI conference on Wind Turbine Blade Manufacture.

The next in-person meeting will take place:

December 12th, 2016 at Maritim Hotel Düsseldorf, Germany in connection with the 7th annual international AMI conference on Wind Turbine Blade Manufacture.

Below is the status for EUDP project milestones related to the work by the blade test group. The formulation of the milestones has been changed in order to fit the work done by the blade test group within the objectives of the IEA Task 35 and as per the planned final report later in 2017.

Milestones for blade test work	**Status**
M1 - Details of turbine configuration and components to be covered	Completed
M2 - Definition of scope of work	Completed
M3 - Conclusions and best practice	Ongoing, expected done by Sep. 2017
M4 - Report on work	Ongoing, expected done by Dec. 2017

Conclusions

Subtask Nacelle

The focus was to determine test load cases for nacelle components. These tests will focus on each subcomponent needs, e.g. Generator, Converter System, Gearbox and Main Bearing. Beside the development for component tests, IEA Task 35's consortium can in the future analyze the certification procedures for WTGs and determine which of these certification tests could be adapted to full size ground test rigs. Subsequently Subtask Nacelle will summarize the findings of IEA Task 35's Nacelle Group and prepare a Final Technical Report, Final Management Report and an extension proposal by March 2017

Subtask Blade

The blade subcomponent activity work has focused on making subcomponent procedures and results useable and understandable to test engineers and blade designers. The reporting in the areas of blade test methods, subcomponents, uncertainty estimation, and NDI are planned to be completed and reported in 2017.