INTERNATIONAL ENERGY AGENCY

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

IEA R&D Wind Task 11 - Topical Expert Meeting

"ADVANCES IN WIND TURBINE AND COMPONENTS TESTING"

February 21st – 22nd, 2012

Tagungsraum Süd, Manfred Weck Haus

Steinbachstraße 19, 52074 Aachen (Germany)

CENER - Drive Train Test Facility

Organized by:

Institut für Maschinenelemente und Maschinengestaltung, RWTH Aachen University, Germany.

Scientific Co-ordination:

Félix Avia Aranda

CENER (Centro Nacional de Energías Renovables)

Urb. La Florida C/ Somera 7-9, 1ª

28023 - Madrid – Spain

Copies of this document can be obtained from:

CENER
Félix Avia Aranda
Urb. La Florida. C/ Somera 7-9, 1ª
C.P.: 28023 - Madrid – Spain
Phone: +34 91417 5042
E-mail: favia@cener.com

For more information about IEA Wind see www.ieawind.org

International Energy Agency

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, 24 contracting parties from 20 countries, the European Commission, and the European Wind Energy Association (EWEA) participate in IEA Wind. Australia, Austria, Canada, Denmark, the European Commission, EWEA, Finland, Germany, Greece, Ireland, Italy (two contracting parties), Japan, the Republic of Korea, Mexico, the Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, 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) for wind turbine testing and evaluation for each topic needing recommended practices. In June 2011 was edited the RP on “Consumer Label for Small Wind Turbines”. A new RP about “Performance and Load Conditions of Wind Turbines in Cold Climates” is expected to be edited this year.

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 65 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five 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

CENER
Félix Avia Aranda
Urb. La Florida. C/ Somera 7-9, 1ª
C.P.: 28023 - Madrid – Spain
Phone: +34 91417 5042
E-mail:favia@cener.com

COUNTRIES PRESENTLY PARTICIPATING IN THE TASK 11	
COUNTRY	**INSTITUTION**
Canada	National Resources Canada
Denmark	Risø National Laboratory - DTU
Republic of China	Chinese Wind Energy Association (CWEA)
European Commission	European Commission
Finland	Technical Research Centre of Finland - VTT Energy
Germany	Bundesministerium für Unwelt , Naturschutz und Reaktorsicherheit -BMU
Ireland	Sustainable Energy Ireland - SEI
Italy	Ricerca sul Sistema Energetico – RSE S.p.A.
Japan	National Institute of Advanced Industrial Science and Technology AIST
Republic of Korea	POHANG University of Science and Technology - POSTECH
Mexico	Instituto de Investigaciones Electricas - IEE
Netherlands	SenterNovem
Norway	The Norwegian Water Resources and Energy Directorate - NVE
Spain	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas CIEMAT
Sweden	Energimyndigheten
Switzerland	Swiss Federal Office of Energy - SFOE
United Kingdom	Uk Dept for Bussines, Enterprises & Regulatory Reform - BERR
United States	The U.S Department of Energy -DOE

Blank page

CONTENTS

INTRODUCTORY NOTE

a) Background

The rate of development of wind turbines (WT) – particularly regard to turbine size – is very high compared to other technological products and systems. The system power has increased tenfold within the last 15 years. Aside from few exceptions, the operation period of WT in use today is still far away from the required service life of 20 years. Consequently, little service life relevant experience in the field exists, the knowledge of these experiences however would be utterly helpful for the redevelopment of WT. The high rate of development and the lack of field experience, in particular with the current plant sizes in combination with the dynamic operating conditions of WT and its highly networked components often leads to unexpected system shutdowns.

Common causes for downtime of WT are unexpected bearing failures, gear damages and breakdowns of control and power electronics. Investigations of Germanischer Lloyd have shown increasing the system size also attracts an increase in downtime. The calculation models used during the development to explore the dynamic loads within the drive train, as well as the test procedures to determine acceptable strain of machine elements and groups of components, apparently do not deliver sufficient results in their existing, often standardized form.

Today's wind turbines are composed of numerous, individually developed components such as the gearbox, the generator, the aerodynamic rotor system and control system using adequate interface specifications. To analyze the system performance of WT, the interactions in between the single components and their influence on the particular function need to be reproduced on test benches. For this, system test rigs which are capable of loading the drive trains of WT not only with rotatory but with all relevant loads, are set up around the world. Using the system test rigs, it is possible to define the occurring wind and network loads on WT in a reproducible manner in order to measure the actual sectional strain in between the components. Thus realistic load collectives can be generated from the resulting knowledge of the system.

b) Topics to be addressed

System Test

- Expected results and benefits
  - Identification of local stress and critical load cases
  - Validation of simulation models and results
  - Development accompanied by system tests
  - Release test and certification
- System test rig designs, capabilities, requirements
  - Value of Load Application Systems, 5 DOF
  - Dynamic requirements for Load Application Systems
  - Types and advantages of couplings on the high torque side
  - Slave gearbox vs. direct drive for torque input
  - Reduced system test e.g. mainframe, gearbox and main bearing
  - Hardware requirements for HIL integration
  - Necessary input data (load application grid and wind)
- System test procedures (standardization)
  - Method to test and compare design variants
  - Generic test cycles vs. measured data vs. HIL-Simulation of loads
  - Definition and standardization of Wind Turbine system tests

Component Test

- Blades: test rigs and procedures
- Generator incl. power converter: test rigs; HALT procedures; climatisation
- Gearbox: end of line test and transfer of results to real WT conditions; R&D test rigs
- Bearings: Main bearing/direct drive bearing test rigs; gearbox bearing test rigs
- Pitch and yaw: bearing systems; brakes; drives

CENER Test Bench for Blades

c) Expected outcomes

One of the goals of the meeting will be to gather existing knowledge on the subject and come up with suggestions and recommendations on how to proceed with future developments. Based on the above, a document will be compiled, containing:

- Presentations by participants
- A compilation of the most recent information on the topic
- Main conclusions reached in the discussion session
- Definitions IEA Wind RD&D's future role in this issue

d) Agenda

Tuesday, 21st February

9:00 Registration. Collection of presentations

9:30 Introduction by Host
Georg Jacobs, Institute of Machine Elements & Machine Design, , RWTH Aachen University, Germany

09:45 Recognition of Participants

10:00 Introduction by AIE Wind Vice Chair and Task 11 Operating Agent.
Topics to be addressed
Joachim Kutscher, Forschungszentrum Jülich Gmbh, Germany
Felix Avia, Operating Agent Task 11 IEAWind R&D

- *10:15 Coffee Break*

1st Session Individual Presentations:

10:30 RWTH Aachen research program on wind power drive testing
Georg Jacobs, Institute of Machine Elements & Machine Design, , RWTH Aachen University, Germany

10:55 How much Testing do you need? - Different Test Rig Designs for different Testing Requirements
Armin Diller, Renk Test System Gmbh, Germany

11:20 System test rig designs, capabilities
Zuohui Liu, Sinovel Wind Group Co.Ltd., China

11:45 Sub-System and Component Testing - An OEM Approach…
Sven Sagner, RETC Gmbh, Germany

12:10 Development in full-scale, sub-structure and component blade testing at DTU Wind Energy
Christian Berggreen, Technical University of Denmark, Department of Wind Energy

12:35 Testing of wind turbine components
Mark Capellaro, Universität Stuttgart, Germany

- *13:00 Lunch*

2nd Session Individual Presentations:

14:00 Blade and Component test development at the National Renewable Energy Laboratory
Hughes Scott, National Renewable Energy Laboratory (NREL), USA

14:25 Full-scale Structural Testing of Rotor Blades – Ultimate Type Testing Design
Zheng Lei, China Genera Certification, China

14:50 Challenges in nacelle and rotor blades testing
Hans Kyling, Fraunhofer IWES, Germany

15:15 Testing and Optimization of Support Structures for Wind Energy Turbines
Maik Wefer, Leibniz Universität, Hannover, Germany

15:40 Introduction of Wind Turbine LVRT testing in China
Li Qing, China Electric Power Research Institute, China

16:05 End of the Tuesday meeting

17:15 Visit Aachen cathedral, Meeting point Mainportal, Domhof

18:15 Informal dinner in the city centre, Restaurant Ratskeller, Markt 40

Wednesday, February 22nd

3rd Session Individual Presentations

09:00 How to validate, verify and certify a prototype WTG gearbox.
Brian Niff, Mc Niff Industry, USA

09:25 Wind Turbine Gearbox Test
Li Ximei, China Genera Certification, China

09:50 Type testing and modeling for reliable integration of wind farms
Martin Brennecke, FGH Certification, Germany

10:15 Test of a High speed shaft
Thomas Stalin, Vattenfall, Sweeden

- *10:30 Coffe Break*

11:00 Validation Requirements of WTGs
Jan-Bernd Franke, RWE Innogy Gmbh, Germany

11:25 Testing facilities in Spain

Emilien Simonot, AEE; Spain

11:50 Discussion

- *12:30 Lunch*

13:15 Summary of Meeting

14:00 End of the meeting

- *14:00-16:00 Optional tour:*

Visit the RWTH System Test Rig for wind turbines (under construction). In addition we will visit the EON Research Center nearby the test rig, which compromised a Real Time Digital Simulator for grids and a prototype of a 5 MW DCDC converter for offshore grid connection.

PRESENTATIONS

slide 1

Institut für Maschinenelemente und Maschinengestaltung
RWTH AACHEN UNIVERSITY
Univ.-Prof. Dr.-Ing. G. Jacobs

Welcome at RWTH Aachen University

Topical Expert Meeting #68

Advances in wind turbine and component testing

21th February 2012

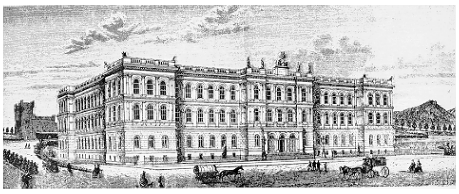
Univ.-Prof. Dr.-Ing. Georg Jacobs
Dr.-Ing. Ralf Schelenz

slide 2

RWTH Aachen University

History of RWTH Aachen

- est. 1870: Polytechnic School
- since 1880: Royal Technical Academy
- since 1945: RWTH Aachen University



RWTH Aachen University today

- biggest employer in the City of Aachen
- 262 Institutes and Chairs
- 465 Professorships
- about 32,000 Students

Institut für Maschinenelemente und Maschinengestaltung
RWTH AACHEN

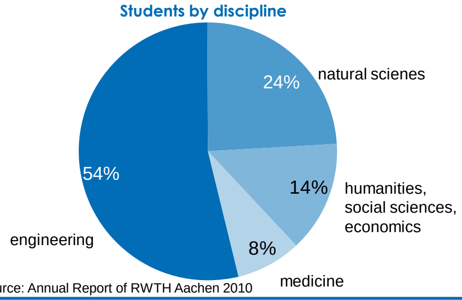
slide 3

RWTH Aachen University: Facts and figures 2010

- Budget: 705 Mio. €
- Third party funds: 258 Mio. €
- Affiliated institutes: 35 Mio. €

- 465 professorships
- 262 institutes
- including 20 major institutes and 4 Fraunhofer Institutes

- 13 affiliated institutes
- 9 Research Training Groups
- >32.000 students



Source: Annual Report of RWTH Aachen 2010

RWTH is the leading third party fundraisers among German universities raising 258 million € per year

slide 4

Wind energy research at Aachen University

Network

- AIA - Aerodynamics
- ACS - Grid structures
- ISEA - Power Converter
- IEM - Generator
- **IME - Drive train**
- WZL - Gears
- IRT - Control Systems

- IFAS - Fluidtechnic
- IMB - Foundation
- LSF - Steelconstruction
- IKV - GRP, CFP
- IFHT - High Voltage Systems
- IWM - Material science
- WZL - Production technics

- more than **300 publications** about wind energy
- each year **5 Mio € third-party-funds** for wind energy projects
- each year **10 Mio € aditional third-party-funds** for projects with relevance to wind energy (30 Mio € in 2012)
- about **70 scientific associates** working on wind energy projects
- several lectures about wind

IME - Institute for machine elements and machine design
RWTH Aachen University

slide 5

Institut für Maschinenelemente und Maschinengestaltung
RWTH AACHEN UNIVERSITY

Board of the Institute

- Univ.-Prof. Dr.-Ing. G. Jacobs
  Director of the Institute
  Head of Non Road Machinery
- Dr.-Ing. Ralf Schelenz
  Head of Transmission Technology
- Dipl.-Ing. Christoph Henschke
  Head of Tribology

31 scientific associates
80% financed by third-party funds

27 non-scientific staff
Machine-shop, Measurement-engineering, Administration

90 student assistants
Reseach and teaching

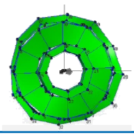
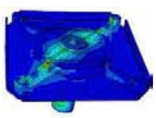
IME: Areas of research

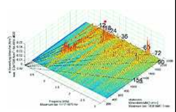
slide 6

Areas of Research

Tribology	Drive Train	Drive Train Non Road Machinery	Wind power drives
▪ Journal bearings ▪ Roller bearings ▪ Free wheels ▪ Coatings ▪ Lubricants ▪ Filter systems	▪ Dynamics of machines ▪ Multi-body simulation ▪ Rotary oscillations ▪ Structure analysis with FE ▪ Acoustics ▪ Couplings ▪ Gears	▪ Modeling of drive trains ▪ Modeling of vehicles ▪ Continuously variable transmission (CVT) ▪ Recuperation ▪ Stress Analysis ▪ Power Loss Analysis	▪ **Test methods** ▪ **FE structure analysis** ▪ **Multi-body simulation** ▪ **Acoustics** ▪ **Gears**

Research expertise in conception, modeling und validation

Heavy Drive Train Conference
Conference for Wind Power Drives

slide 7

19.- 20. March 2013
Eurogress Aachen

CONFERENCE FOR WIND POWER DRIVES
CWD 2013

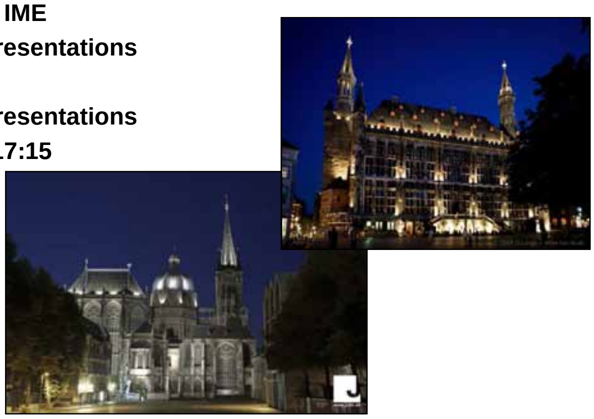
ANTRIEBSTECHNISCHES KOLLOQUIUM
ATK 2013

IME Institut für Maschinenelemente und Maschinengestaltung
RWTH AACHEN

Agenda TEM#68

slide 8

- **Advances in Wind Turbine and components testing**
- **Today**
  - **Introduction by IEA and IME**
  - **1st Session Individual Presentations**
  - **Lunch**
  - **2st Session Individual Presentations**
  - **Visit Aachen cathedral 17:15**
  - **Informal dinner 18:15**

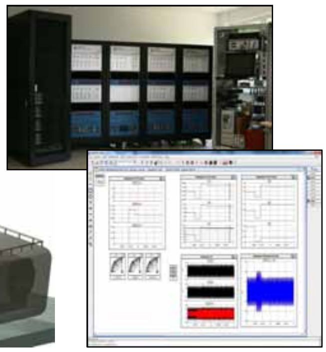


IME Institut für Maschinenelemente und Maschinengestaltung
RWTH AACHEN

Agenda TEM#68

slide 9

- Advances in Wind Turbine and components testing
- Tomorrow
  - 3rd Session Individual Presentations
  - Lunch
  - Summary of Meeting
  - Technical tour



Institut für Maschinenelemente und Maschinengestaltung
RWTHAACHEN

Structure of presentation

slide 10

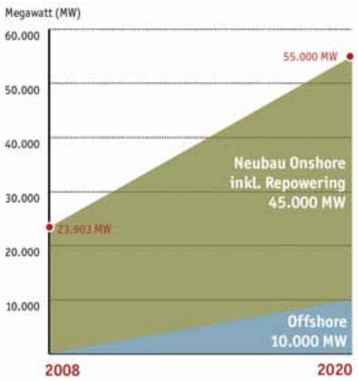
1. RWTH Aachen University
2. Institute for Machine Elements and Machine Design
3. **Center for Windpower Drives and 4 MW Nacelle Test Rig**
4. Windturbine Research Projekt Hightech.NRW

Institut für Maschinenelemente und Maschinengestaltung
RWTHAACHEN

On-shore wind power: social meaning and expected profitability

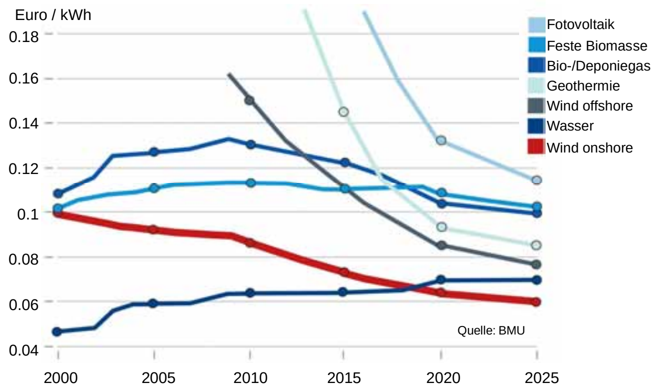
slide 11

Developement of installed wind power capacity in Germany



Quelle: BEE e.V., Repowering, 2010

Cost trend of power generation with renewable energy: scenario on the price basis 2009



Europe-wide expected engine power rate of on-shore wind power over 90%

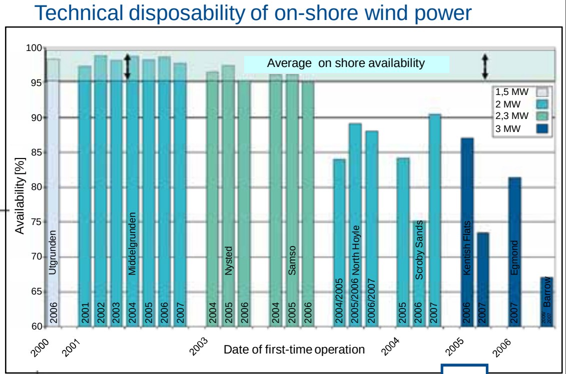
Enormous, world-wide pressure on the profitability of on-shore wind power necessitates research-effort to improve the reliability and the power efficiency.

RWTH AACHEN

On-shore wind power: damage frequency and disposability

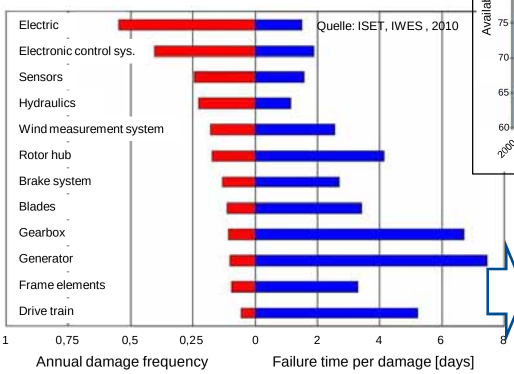
slide 12

Technical disposability of on-shore wind power



Quelle: Erhöhung der Verfügbarkeit von Windkraftanlagen, 2009

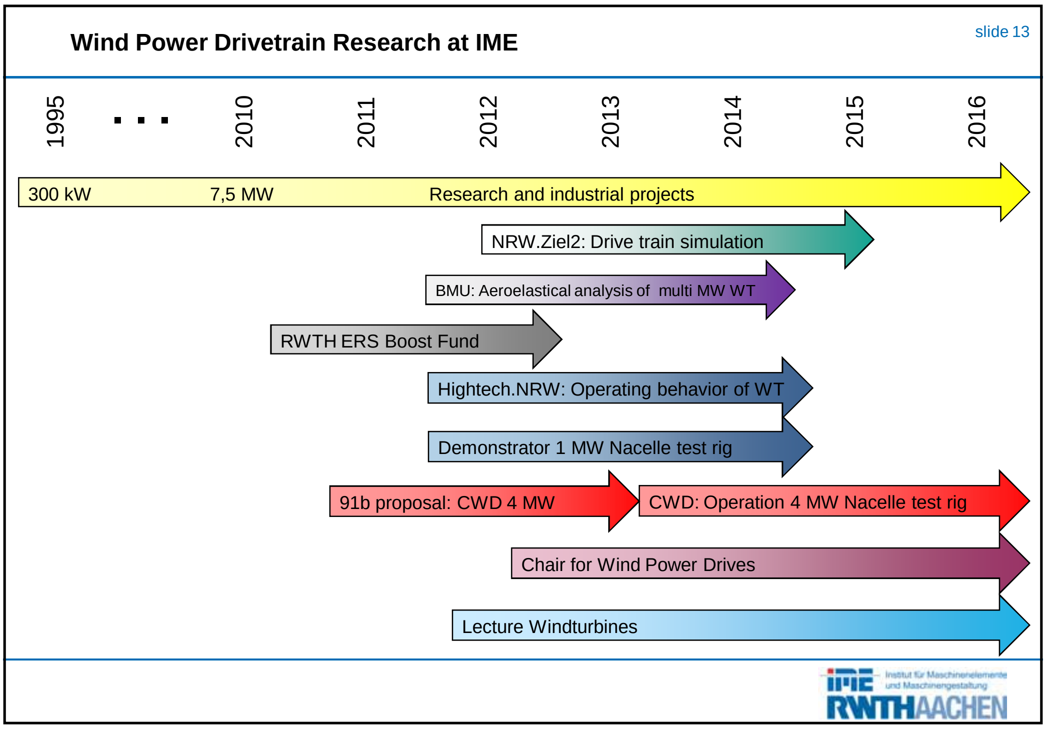
Damage frequency and failure times of components

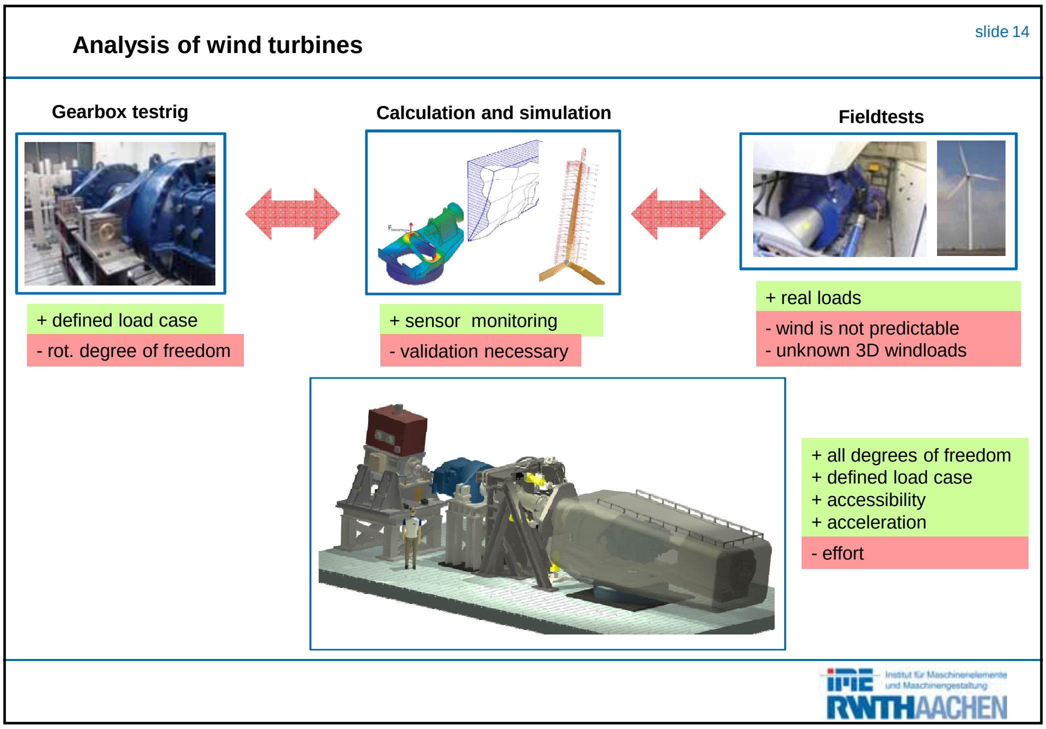


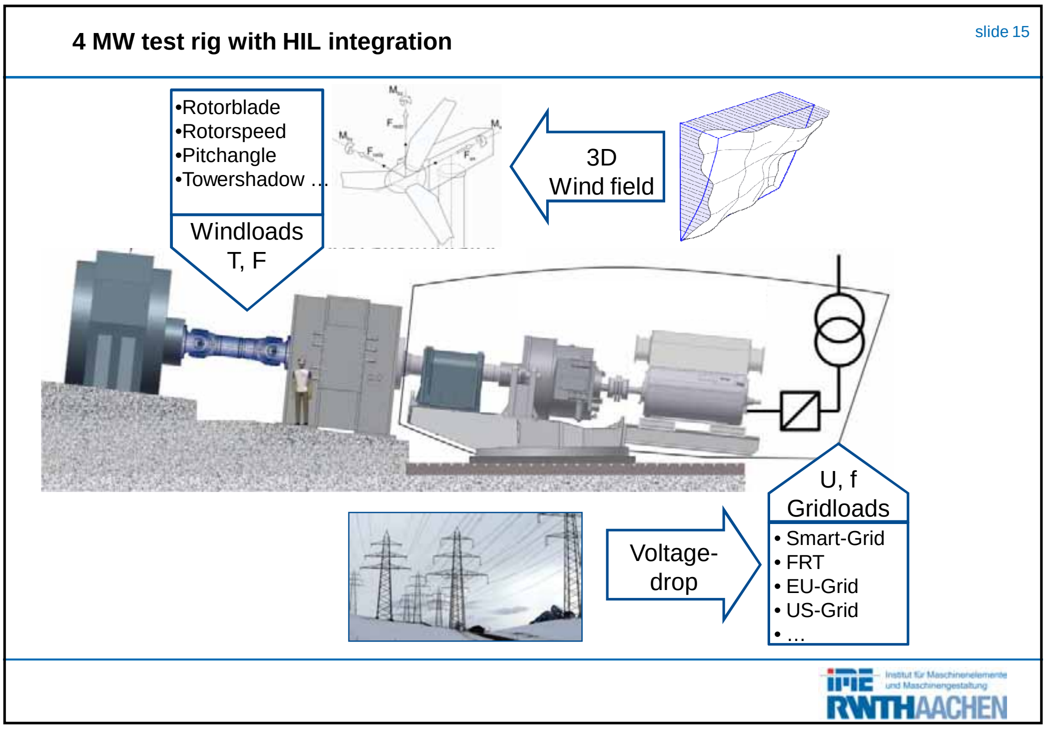
Drive train and its components are decisive for the disposability of wind power

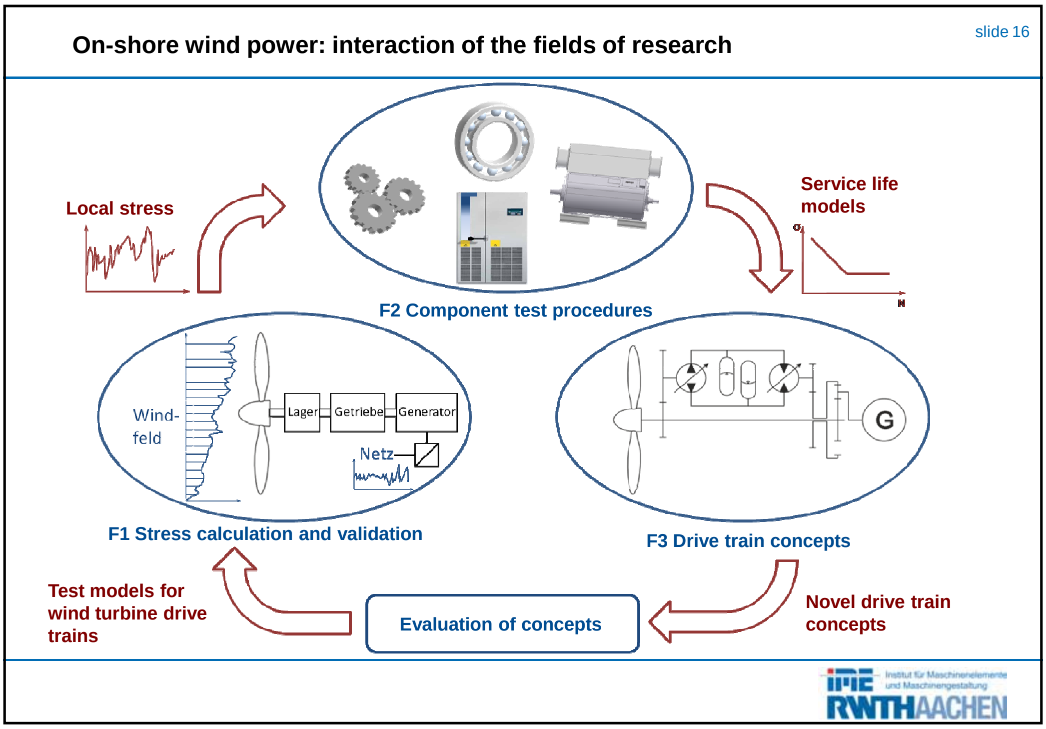
Decreasing disposability with increasing plant size

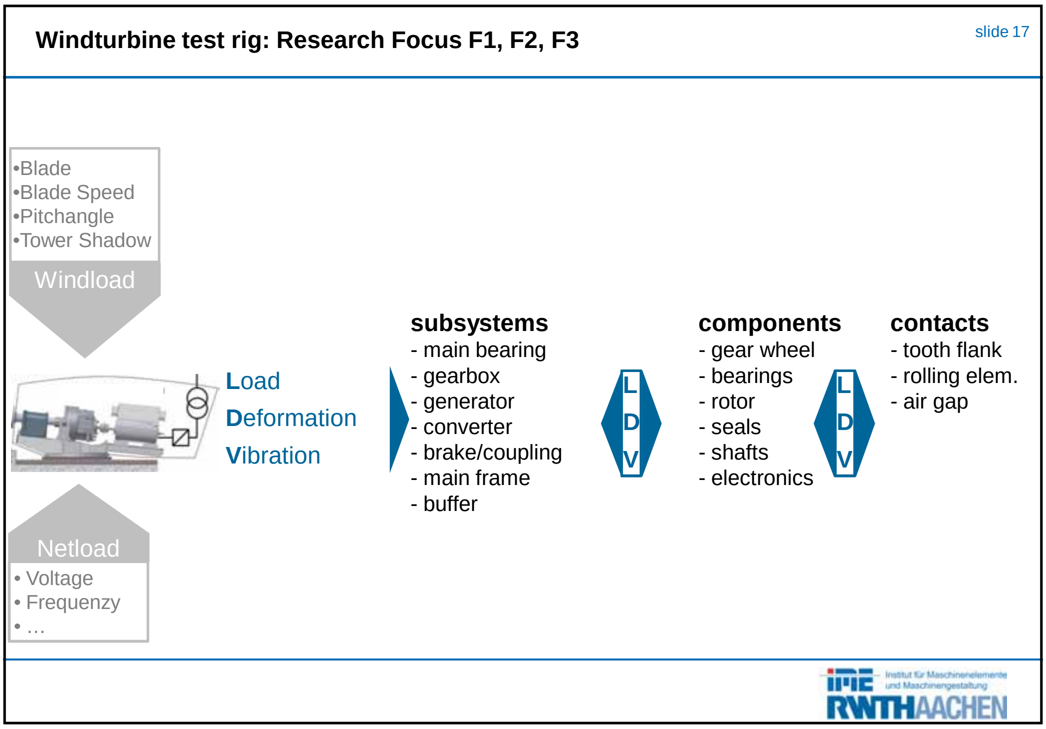
RWTH AACHEN

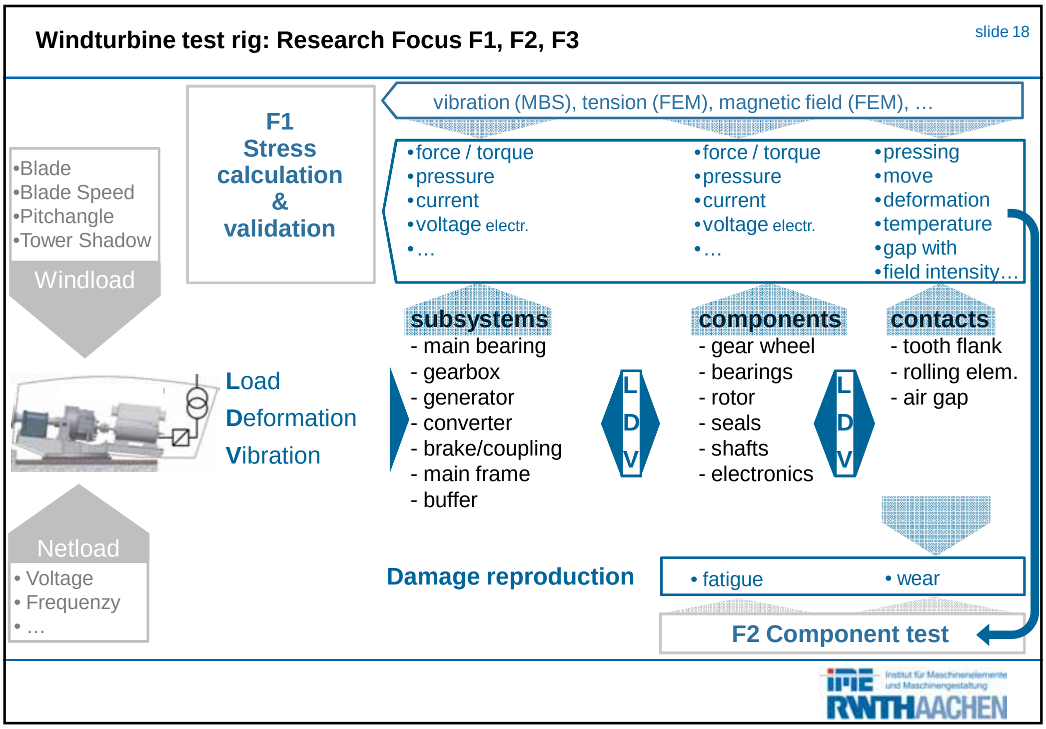

Wind Power Drivetrain Research at IME
slide 13
1995
...
2010
2011
2012
2013
2014
2015
2016
300 kW
7,5 MW
Research and industrial projects
NRW.Ziel2: Drive train simulation
BMU: Aeroelastical analysis of multi MW WT
RWTH ERS Boost Fund
Hightech.NRW: Operating behavior of WT
Demonstrator 1 MW Nacelle test rig
91b proposal: CWD 4 MW
CWD: Operation 4 MW Nacelle test rig
Chair for Wind Power Drives
Lecture Windturbines
RWTH AACHEN

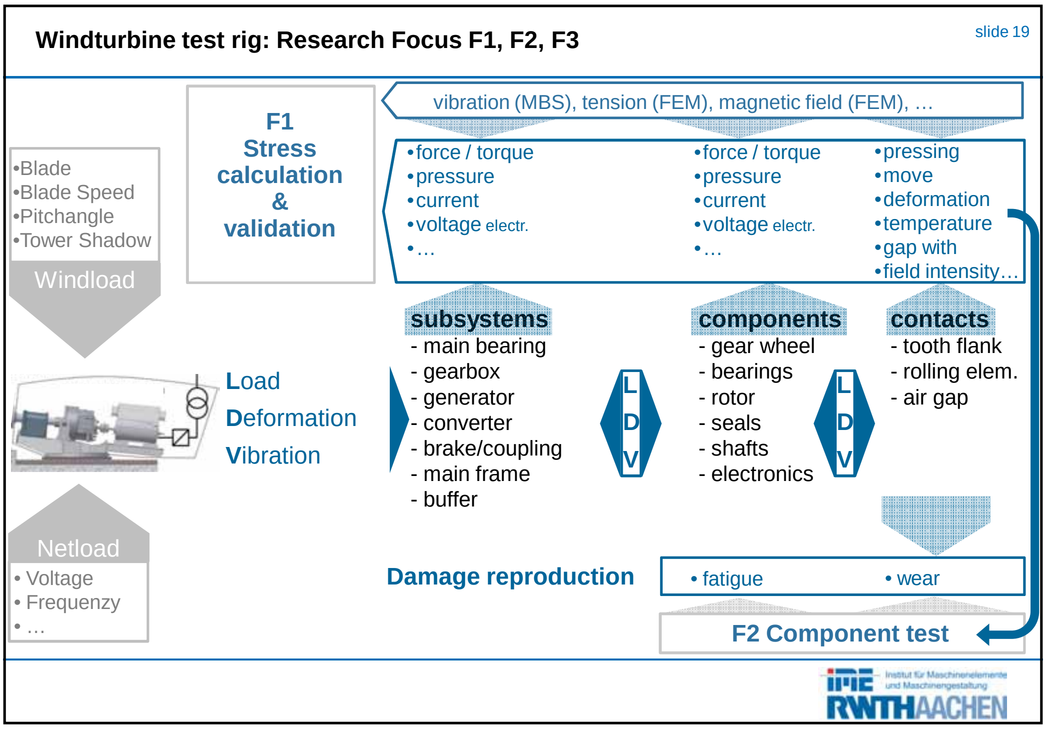

Analysis of wind turbines
slide 14
Gearbox testrig
Calculation and simulation
Fieldtests
+ defined load case
- rot. degree of freedom
+ sensor monitoring
- validation necessary
+ real loads
- wind is not predictable
- unknown 3D windloads
+ all degrees of freedom
+ defined load case
+ accessibility
+ acceleration
- effort
RWTH AACHEN

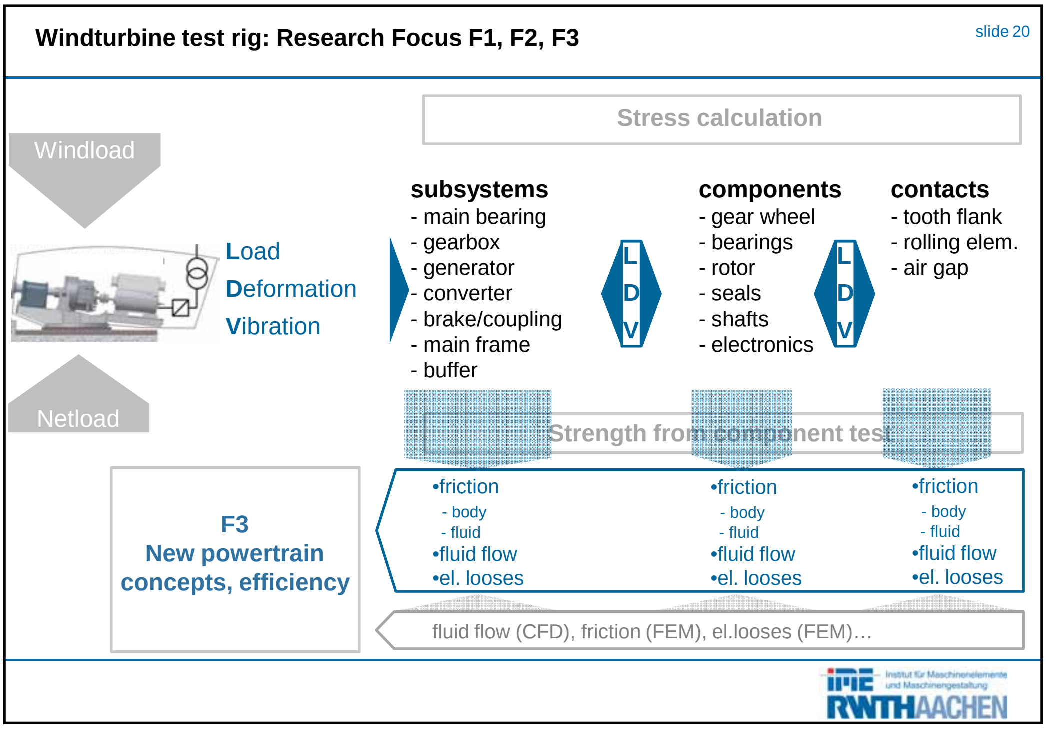

4 MW test rig with HIL integration
slide 15
•Rotorblade
•Rotorspeed
•Pitchangle
•Towershadow ...
Windloads
T, F
3D
Wind field
U, f
Gridloads
• Smart-Grid
• FRT
• EU-Grid
• US-Grid
• ...
Voltage-
drop
RWTH AACHEN

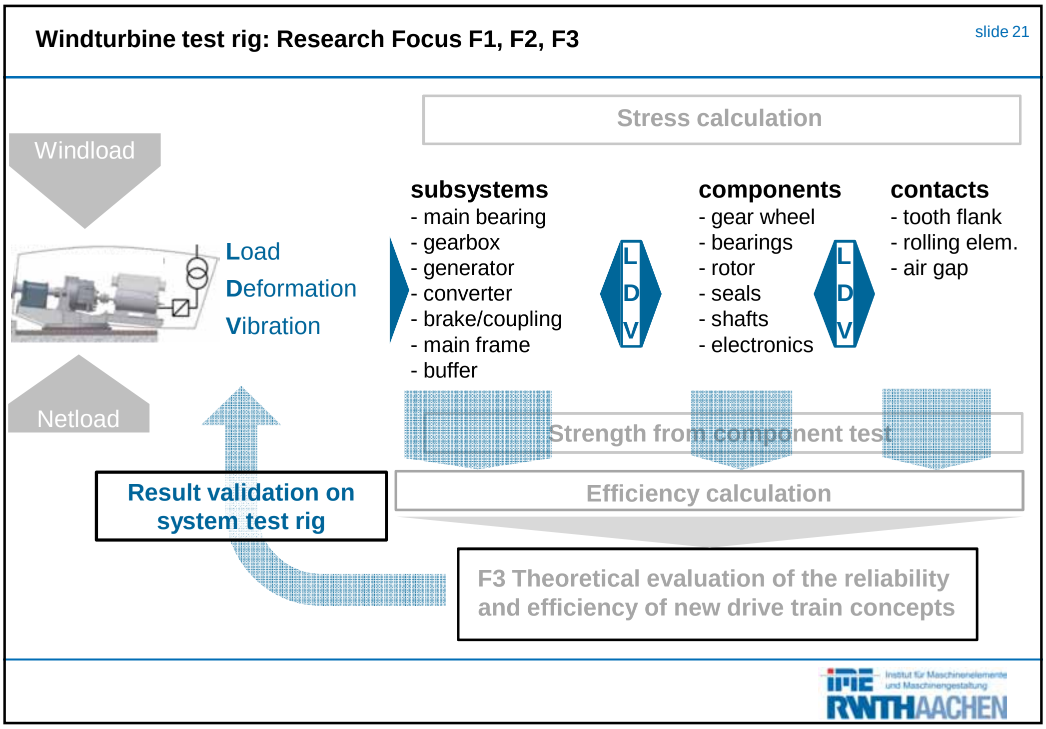

On-shore wind power: interaction of the fields of research
slide 16
Local stress
Service life
models
F2 Component test procedures
Wind-
feld
Lager
Getriebe
Generator
Netz
G
F1 Stress calculation and validation
F3 Drive train concepts
Test models for
wind turbine drive
trains
Evaluation of concepts
Novel drive train
concepts
RWTH AACHEN

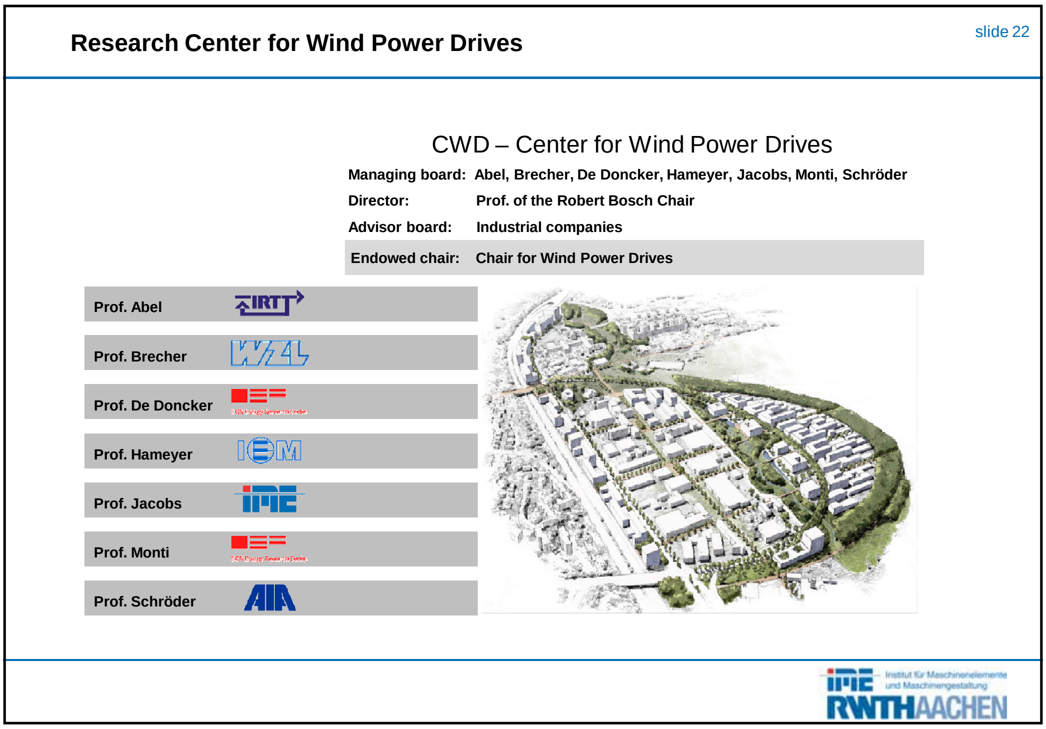

Windturbine test rig: Research Focus F1, F2, F3
slide 17
•Blade
•Blade Speed
•Pitchangle
•Tower Shadow
Windload
Load
Deformation
Vibration
Netload
• Voltage
• Frequenzy
• …
subsystems
- main bearing
- gearbox
- generator
- converter
- brake/coupling
- main frame
- buffer
L D V
components
- gear wheel
- bearings
- rotor
- seals
- shafts
- electronics
L D V
contacts
- tooth flank
- rolling elem.
- air gap
RWTHAACHEN


Windturbine test rig: Research Focus F1, F2, F3
slide 18
F1
Stress calculation
&
validation
vibration (MBS), tension (FEM), magnetic field (FEM), …
•force / torque
•pressure
•current
•voltage electr.
•…
•force / torque
•pressure
•current
•voltage electr.
•…
•pressing
•move
•deformation
•temperature
•gap with
•field intensity…
•Blade
•Blade Speed
•Pitchangle
•Tower Shadow
Windload
Load
Deformation
Vibration
Netload
• Voltage
• Frequenzy
• …
subsystems
- main bearing
- gearbox
- generator
- converter
- brake/coupling
- main frame
- buffer
L D V
components
- gear wheel
- bearings
- rotor
- seals
- shafts
- electronics
L D V
contacts
- tooth flank
- rolling elem.
- air gap
Damage reproduction
• fatigue
• wear
F2 Component test
RWTHAACHEN


Windturbine test rig: Research Focus F1, F2, F3
slide 19
F1 Stress calculation & validation
vibration (MBS), tension (FEM), magnetic field (FEM), …
•Blade
•Blade Speed
•Pitchangle
•Tower Shadow
Windload
•force / torque
•pressure
•current
•voltage electr.
•…
•force / torque
•pressure
•current
•voltage electr.
•…
•pressing
•move
•deformation
•temperature
•gap with
•field intensity…
subsystems
- main bearing
- gearbox
- generator
- converter
- brake/coupling
- main frame
- buffer
components
- gear wheel
- bearings
- rotor
- seals
- shafts
- electronics
contacts
- tooth flank
- rolling elem.
- air gap
Load
Deformation
Vibration
L D V
Netload
• Voltage
• Frequenzy
• …
Damage reproduction
• fatigue
• wear
F2 Component test
RWTHAACHEN


Windturbine test rig: Research Focus F1, F2, F3
slide 20
Stress calculation
Windload
subsystems
- main bearing
- gearbox
- generator
- converter
- brake/coupling
- main frame
- buffer
components
- gear wheel
- bearings
- rotor
- seals
- shafts
- electronics
contacts
- tooth flank
- rolling elem.
- air gap
Load
Deformation
Vibration
L D V
Netload
Strength from component test
F3 New powertrain concepts, efficiency
•friction
- body
- fluid
•fluid flow
•el. looses
fluid flow (CFD), friction (FEM), el.looses (FEM)…
RWTHAACHEN


Windturbine test rig: Research Focus F1, F2, F3
slide 21
Stress calculation
Windload
Load
Deformation
Vibration
Netload
subsystems
- main bearing
- gearbox
- generator
- converter
- brake/coupling
- main frame
- buffer
L D V
components
- gear wheel
- bearings
- rotor
- seals
- shafts
- electronics
L D V
contacts
- tooth flank
- rolling elem.
- air gap
Strength from component test
Result validation on system test rig
Efficiency calculation
F3 Theoretical evaluation of the reliability and efficiency of new drive train concepts
RWTHAACHEN


Research Center for Wind Power Drives
slide 22
CWD – Center for Wind Power Drives
Managing board: Abel, Brecher, De Doncker, Hameyer, Jacobs, Monti, Schröder
Director: Prof. of the Robert Bosch Chair
Advisor board: Industrial companies
Endowed chair: Chair for Wind Power Drives
Prof. Abel
Prof. Brecher
Prof. De Doncker
Prof. Hameyer
Prof. Jacobs
Prof. Monti
Prof. Schröder
RWTHAACHEN

CWD building with 4 MW test rig

slide 23

- 477 m² Officearea
- 1773 m² Laboratoryarea
- 181 m² Workshop
- 81 m² Meeting rooms

Structure of presentation

slide 24

1 RWTH Aachen University

2 Institute for Machine Elements and Machine Design

3 Center for Windpower Drives and 4 MW Nacelle Test Rig

4 Windturbine Research Projekt Hightech.NRW

slide 25

Windturbine Research Projekt Hightech.NRW

Test rig construction P_N = 1 MW
RWTH Aachen
Bosch Rexroth
GE (Converteam)
FIS (Schaeffler)
Vestas

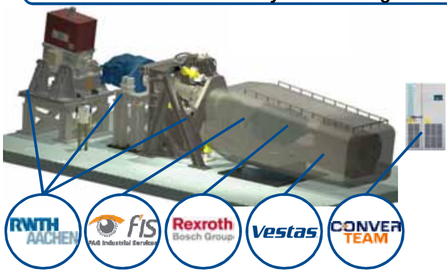
Certification
RWTH Aachen
Bosch Rexroth
FIS (Schaeffler)
TÜV Rheinland
Vestas

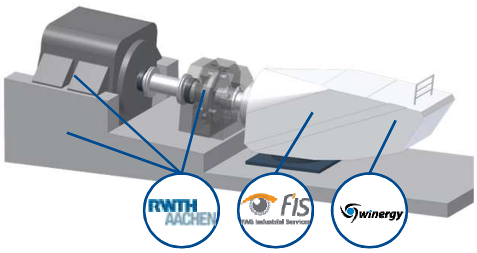
Condition monitoring
RWTH Aachen
Bosch Rexroth
FIS (Schaeffler)
Vestas

New drive train concepts
RWTH Aachen
FIS (Schaeffler)
Winergy

Part I Research for and with the **1 MW-system test rig**

Part II Research with the **4 MW-system test rig**





slide 26

1 MW demonstrator nacelle test rig in Aachen

Input Machine		
Power	P_n	= 1 MW
Input Speed	n_{max}	= 3800 rpm
Torque	M_{max}	= 6360 Nm

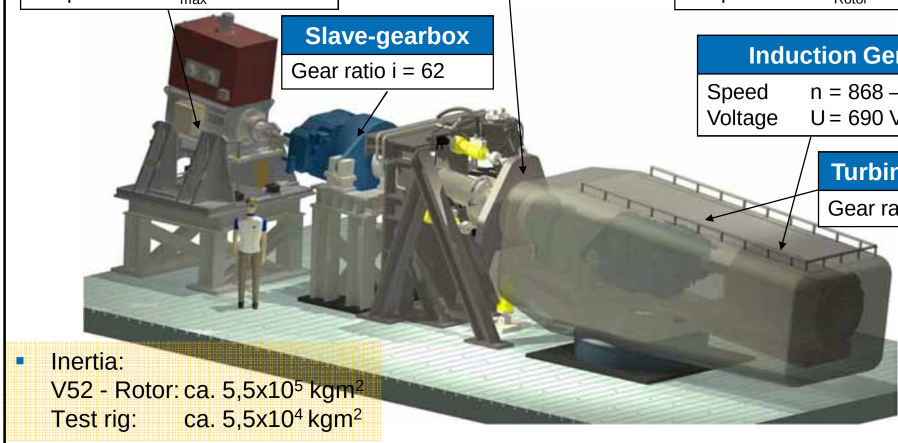
Loadunit		
Axialforce	F_{axial}	= 300 kN
Verticalforce	$F_{vertical}$	= 150 kN

Vestas V52 Test Object		
Power	P_n	= 850 kW
Speed	n_{Rotor}	= 14 - 32 rpm
Torque	M_{Rotor}	= 35 - 330 kNm

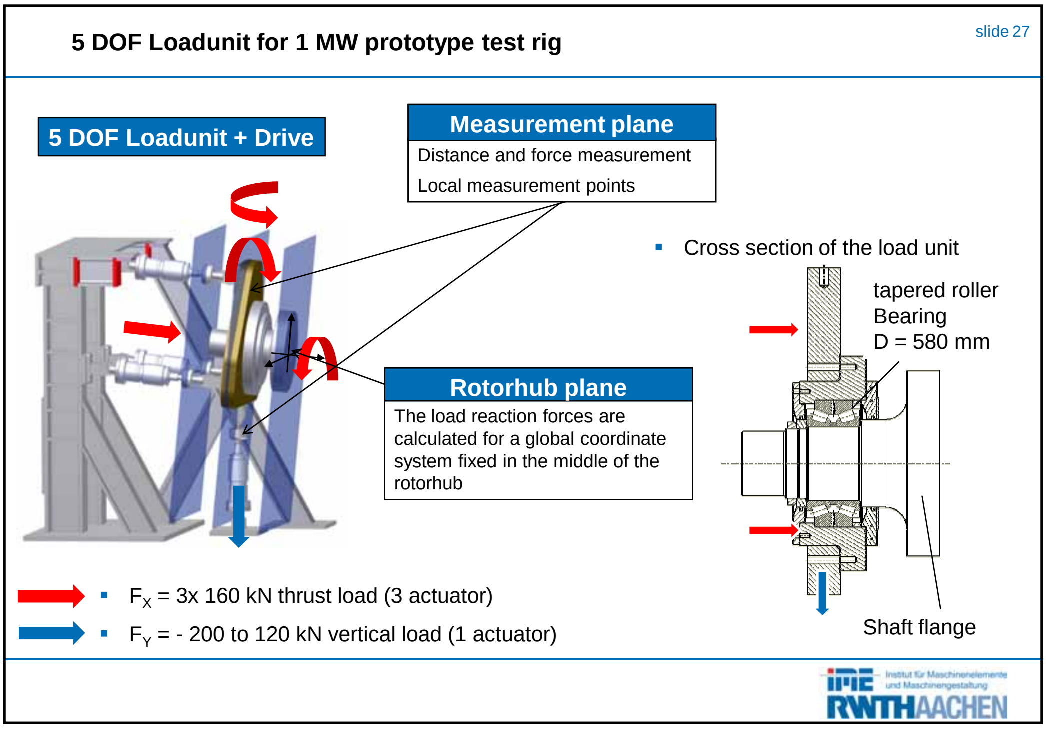
Slave-gearbox
Gear ratio i = 62

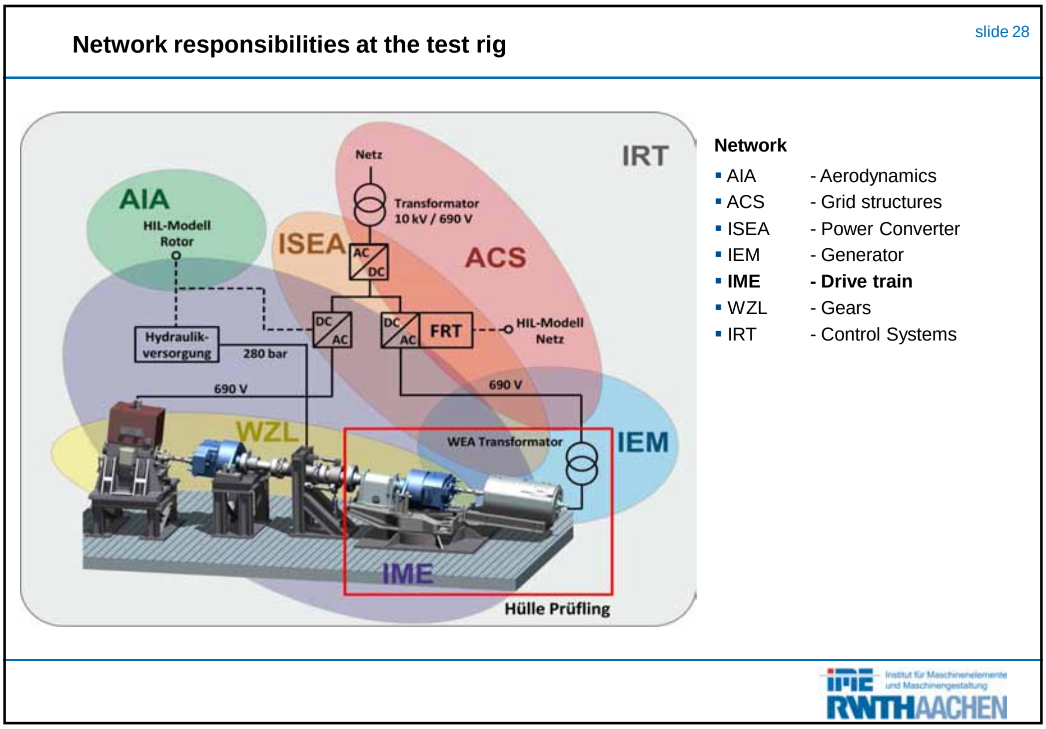
Induction Generator	
Speed	n = 868 – 1946,8 rpm
Voltage	U = 690 V

Turbine gearbox
Gear ratio i = 62



- Inertia:
  V52 - Rotor: ca. $5{,}5 \times 10^5$ kgm^2
  Test rig: ca. $5{,}5 \times 10^4$ kgm^2


5 DOF Loadunit for 1 MW prototype test rig
slide 27
5 DOF Loadunit + Drive
Measurement plane
Distance and force measurement
Local measurement points
Cross section of the load unit
tapered roller
Bearing
D = 580 mm
Rotorhub plane
The load reaction forces are calculated for a global coordinate system fixed in the middle of the rotorhub
Shaft flange
F_X = 3x 160 kN thrust load (3 actuator)
F_Y = - 200 to 120 kN vertical load (1 actuator)
RWTHAACHEN


Network responsibilities at the test rig
slide 28
Netz
IRT
AIA
HIL-Modell
Rotor
Transformator
10 kV / 690 V
ISEA
ACS
FRT
HIL-Modell
Netz
Hydraulik-
versorgung
280 bar
690 V
690 V
WZL
WEA Transformator
IEM
IME
Hülle Prüfling
Network
AIA - Aerodynamics
ACS - Grid structures
ISEA - Power Converter
IEM - Generator
IME - Drive train
WZL - Gears
IRT - Control Systems
RWTHAACHEN

slide 29

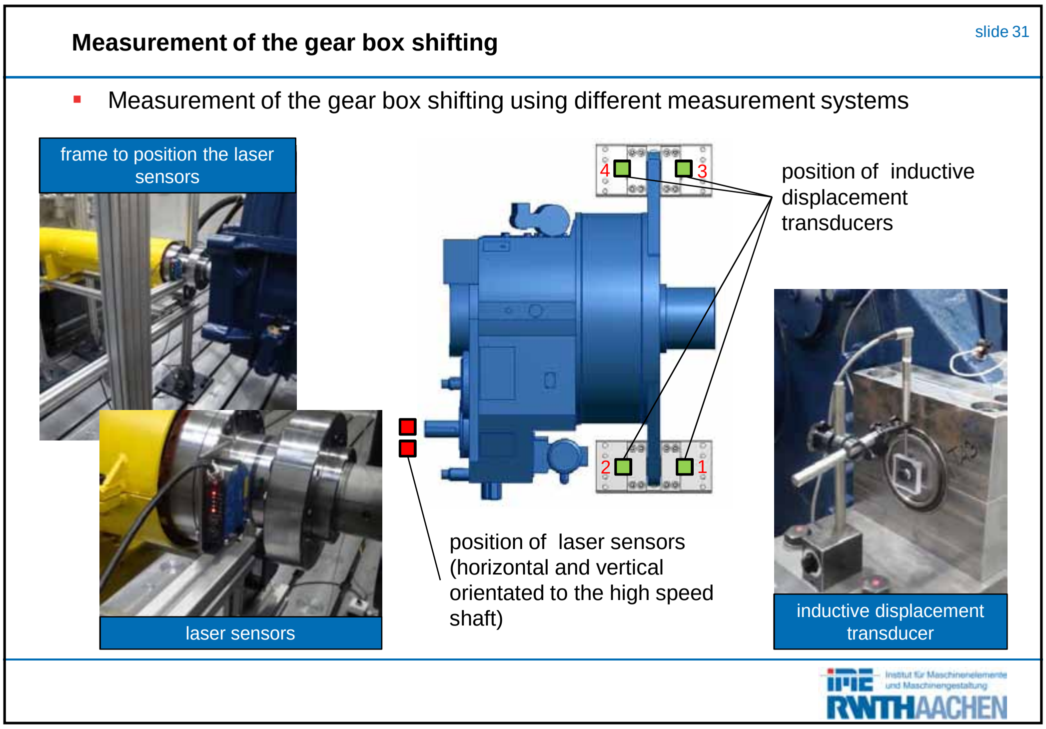
1MW test rig in Aachen

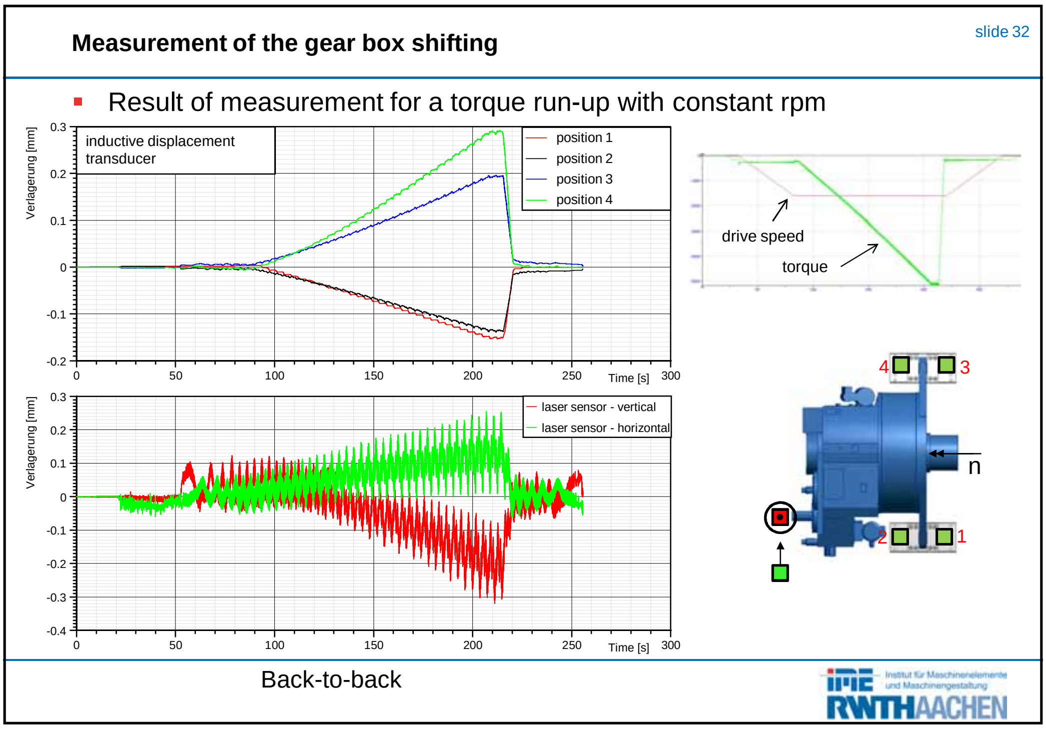
IME Institut für Maschinenelemente und Maschinengestaltung
RWTHAACHEN

slide 30

Component testing: Back to back gearbox qualification

IME Institut für Maschinenelemente und Maschinengestaltung
RWTHAACHEN


Measurement of the gear box shifting
slide 31
Measurement of the gear box shifting using different measurement systems
frame to position the laser sensors
position of inductive displacement transducers
4
3
2
1
laser sensors
position of laser sensors (horizontal and vertical orientated to the high speed shaft)
inductive displacement transducer
RWTHAACHEN


Measurement of the gear box shifting
slide 32
Result of measurement for a torque run-up with constant rpm
inductive displacement transducer
position 1
position 2
position 3
position 4
Verlagerung [mm]
Time [s]
laser sensor - vertical
laser sensor - horizontal
drive speed
torque
4
3
n
2
1
Back-to-back
RWTHAACHEN

slide 33

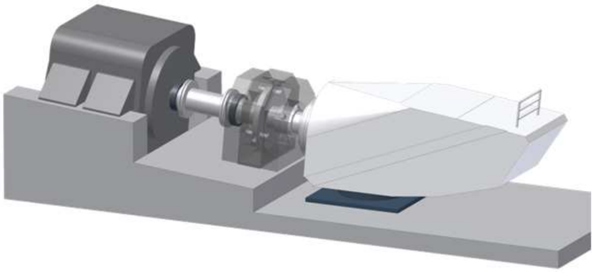
Institut für Maschinenelemente und Maschinengestaltung
RWTH AACHEN UNIVERSITY
Univ.-Prof. Dr.-Ing. G. Jacobs

Thank you for your attention!

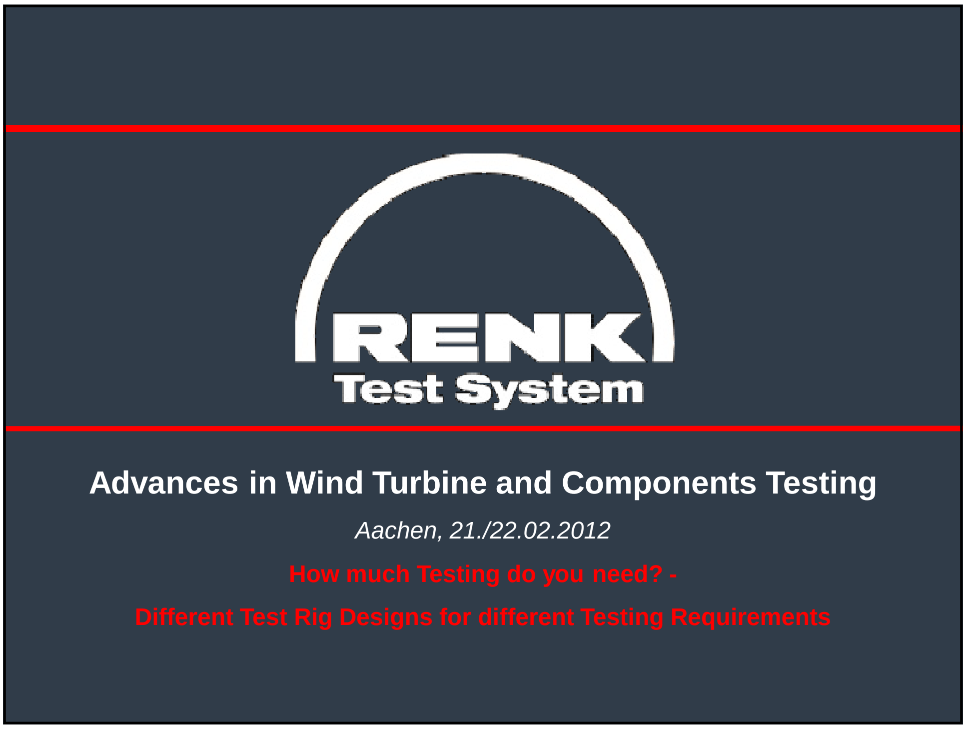
Windturbine Powertrain Research

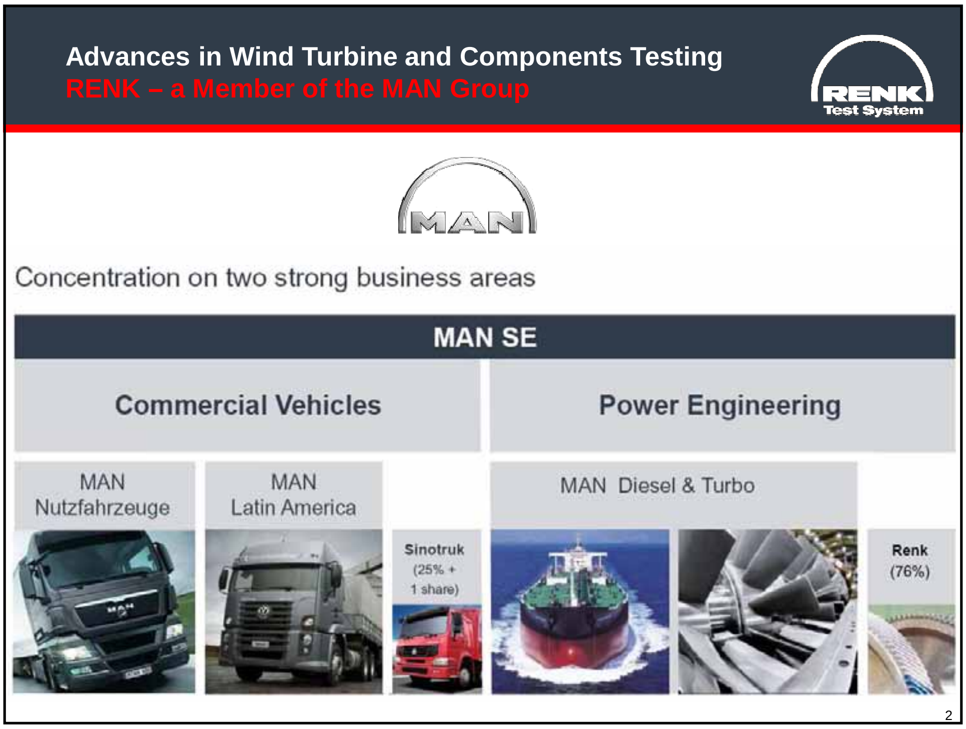
Institute for Machine Elements & Machine Design

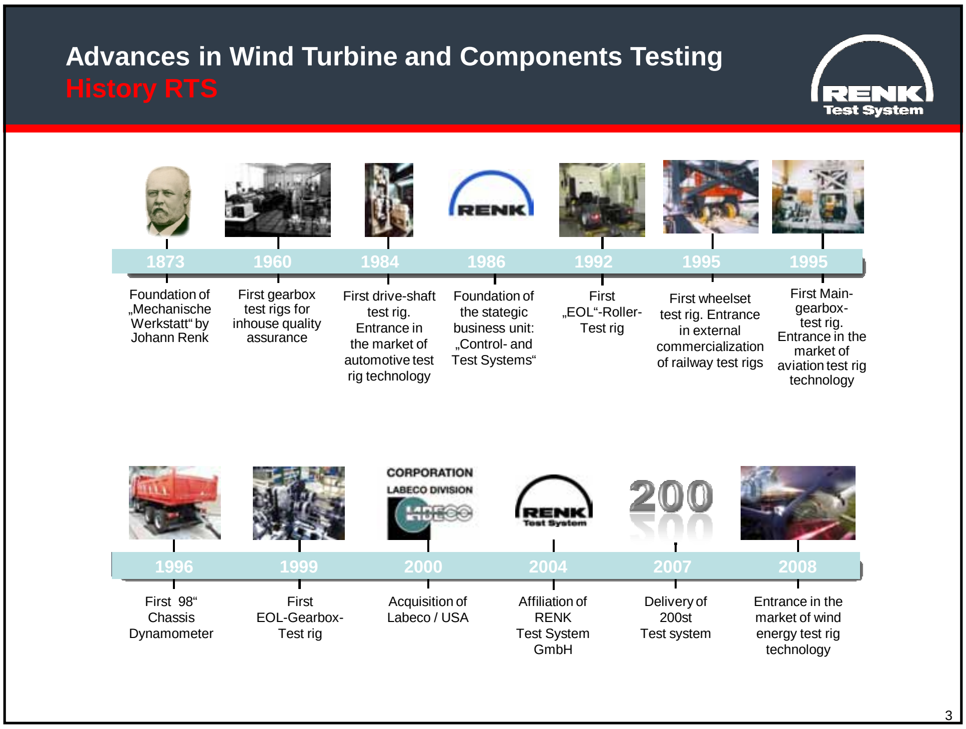
21th February 2012

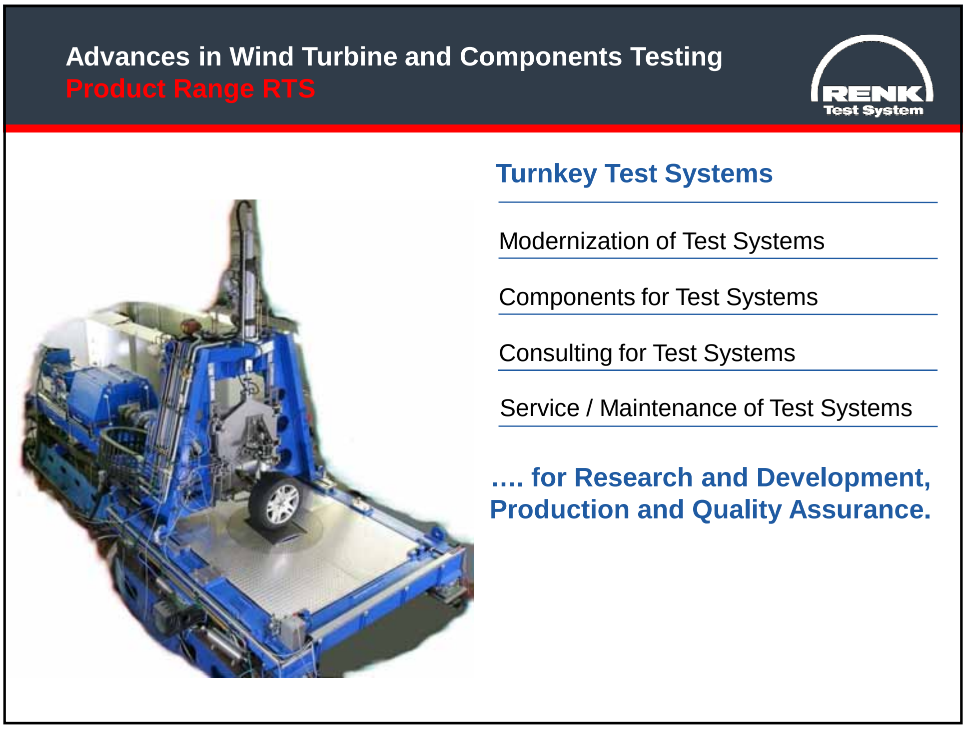


Univ.-Prof. Dr.-Ing. Georg Jacobs
E-Mail: Jacobs@ime.rwth-aachen.de
Telefon: 0241-80-95635
Dr. Ralf Schelenz
E-Mail: Schelenz@ime.rwth-aachen.de
Telefon: 0241-80-95679


RENK
Test System
Advances in Wind Turbine and Components Testing
Aachen, 21./22.02.2012
How much Testing do you need? -
Different Test Rig Designs for different Testing Requirements


Advances in Wind Turbine and Components Testing
RENK – a Member of the MAN Group
RENK
Test System
MAN
Concentration on two strong business areas
MAN SE
Commercial Vehicles
Power Engineering
MAN Nutzfahrzeuge
MAN Latin America
Sinotruk (25% + 1 share)
MAN Diesel & Turbo
Renk (76%)
2


Advances in Wind Turbine and Components Testing
History RTS
RENK Test System
1873
Foundation of „Mechanische Werkstatt“ by Johann Renk
1960
First gearbox test rigs for inhouse quality assurance
1984
First drive-shaft test rig. Entrance in the market of automotive test rig technology
1986
Foundation of the stategic business unit: „Control- and Test Systems“
1992
First „EOL“-Roller-Test rig
1995
First wheelset test rig. Entrance in external commercialization of railway test rigs
1995
First Main-gearbox-test rig. Entrance in the market of aviation test rig technology
1996
First 98“ Chassis Dynamometer
1999
First EOL-Gearbox-Test rig
2000
Acquisition of Labeco / USA
2004
Affiliation of RENK Test System GmbH
2007
Delivery of 200st Test system
2008
Entrance in the market of wind energy test rig technology
3


Advances in Wind Turbine and Components Testing
Product Range RTS
RENK Test System
Turnkey Test Systems
Modernization of Test Systems
Components for Test Systems
Consulting for Test Systems
Service / Maintenance of Test Systems
…. for Research and Development, Production and Quality Assurance.

Advances in Wind Turbine and Components Testing
Product Range RTS

RENK Test System

Examples of Test Systems
Automotive

Drive Train Test Rigs
for Endurance Testing

Chassis Dynamometers
for Research on Noise, Vibration and Climatic Conditions

Cardan Shaft Test Rigs
for Endurance Tests

AUDI, BMW, Claas, Daimler, Eberspächer, Fast Gear, GKN, MAN, MTU, GM, Porsche, Schaeffler, SCANIA, Valeo, Volkswagen, ZF

Advances in Wind Turbine and Components Testing
Product Range RTS

RENK Test System

Examples of Test Systems
Military

Hydraulic Components Test Rigs
for Quality Assurance

Gearbox Test Rigs
for Quality Assurance

Al Masaood, Ashot Ashkelon, BEML, GIAT, RENK AG, US Army

Advances in Wind Turbine and Components Testing
Product Range RTS

RENK Test System

Examples of Test Systems
Railway

5 Breake Test Rigs
with shiftable Flywheels for System Development

Wheelset Test Rigs
for Endurance and Material Testing

China Academy of Railway Sciences, China South Railway, CoFren, Deutsche Bahn, Knorr-Bremse, Schaeffler, Yuijin Machinery

Advances in Wind Turbine and Components Testing
Product Range RTS

RENK Test System

Examples of current Projects
Aviation

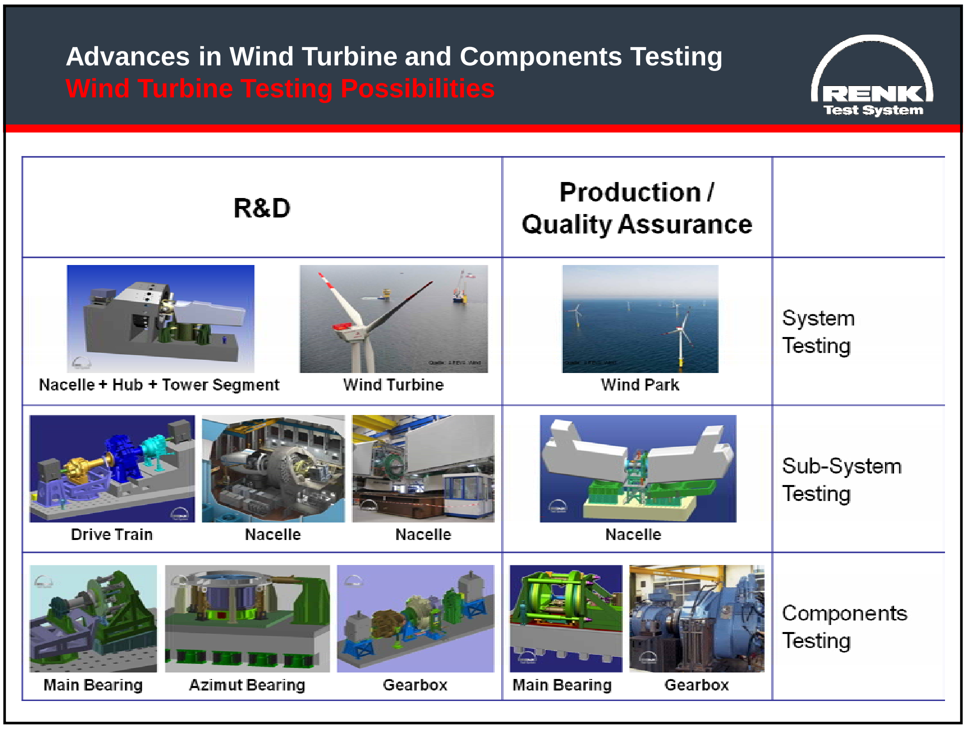
Gearbox Test Rigs with mechanical Power Recovery
for Development and Quality Assurance

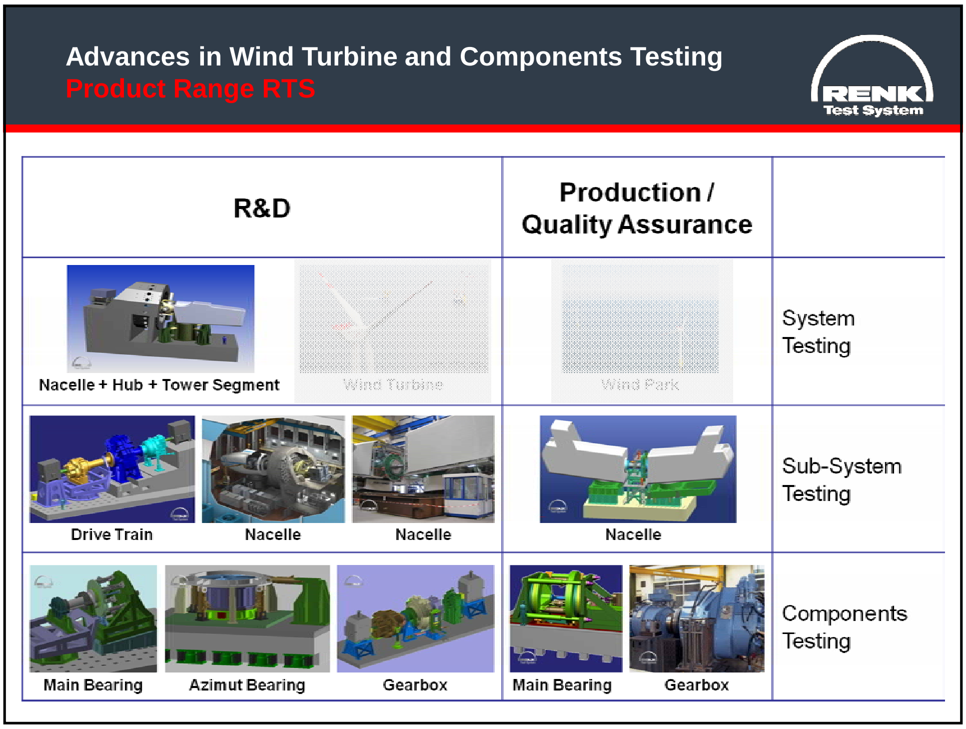
3,7 MW

7,5 MW

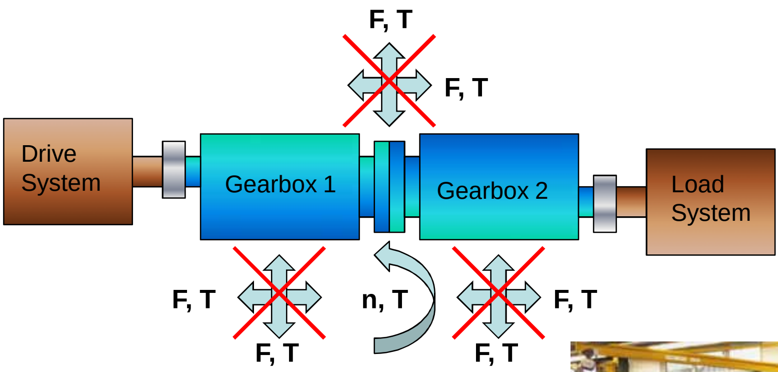
18,6 MW

AMRL, Agusta Westland, Boeing, Eurocopter, HAL, Harbin Dongan, Heli One, RUAG, Schaeffler, Sikorsky, US Army CCAD


Advances in Wind Turbine and Components Testing
Wind Turbine Testing Possibilities
RENK Test System
R&D
Production / Quality Assurance
Nacelle + Hub + Tower Segment
Wind Turbine
Wind Park
System Testing
Drive Train
Nacelle
Nacelle
Nacelle
Sub-System Testing
Main Bearing
Azimut Bearing
Gearbox
Main Bearing
Gearbox
Components Testing


Advances in Wind Turbine and Components Testing
Product Range RTS
RENK Test System
R&D
Production / Quality Assurance
Nacelle + Hub + Tower Segment
Wind Turbine
Wind Park
System Testing
Drive Train
Nacelle
Nacelle
Nacelle
Sub-System Testing
Main Bearing
Azimut Bearing
Gearbox
Main Bearing
Gearbox
Components Testing

Advances in Wind Turbine and Components Testing
Conventional Gearbox Test Rig



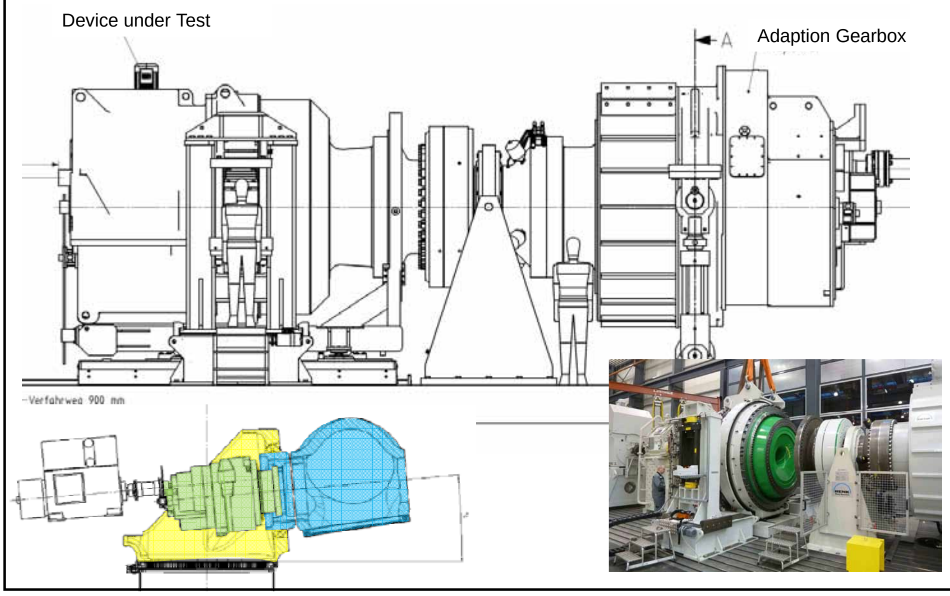
Advances in Wind Turbine and Components Testing
7 MW RENK Gearbox Test Rig

Primary Missions:

- EoL Testing of 5 MW Gear Set for AREVA M5000
- R&D of various Wind Turbine Gearboxes up to 7 MW
- Additional vertical Loads on Specimen
- High Flexibility

Advances in Wind Turbine and Components Testing
7 MW RENK Gearbox Test Rig

RENK Test System



Advances in Wind Turbine and Components Testing
2 MW AREVA Nacelle Test Assembly

RENK Test System

Primary Mission:

• Testing and Commissioning of 6 Turbines for the Alphaventus Test Field

AREVA

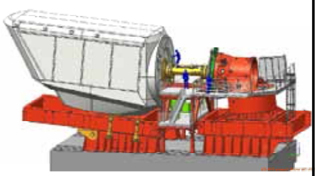
Advances in Wind Turbine and Components Testing
5 MW AREVA Nacelle Test Rig

RENK Test System

Primary Mission:

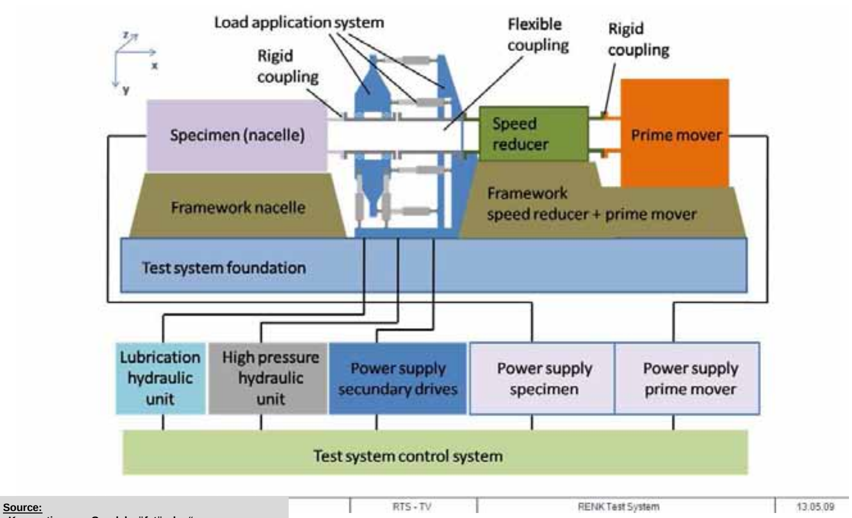
- EoL-Testing and Commissioning of 100% M5000 AREVA Turbines

AREVA

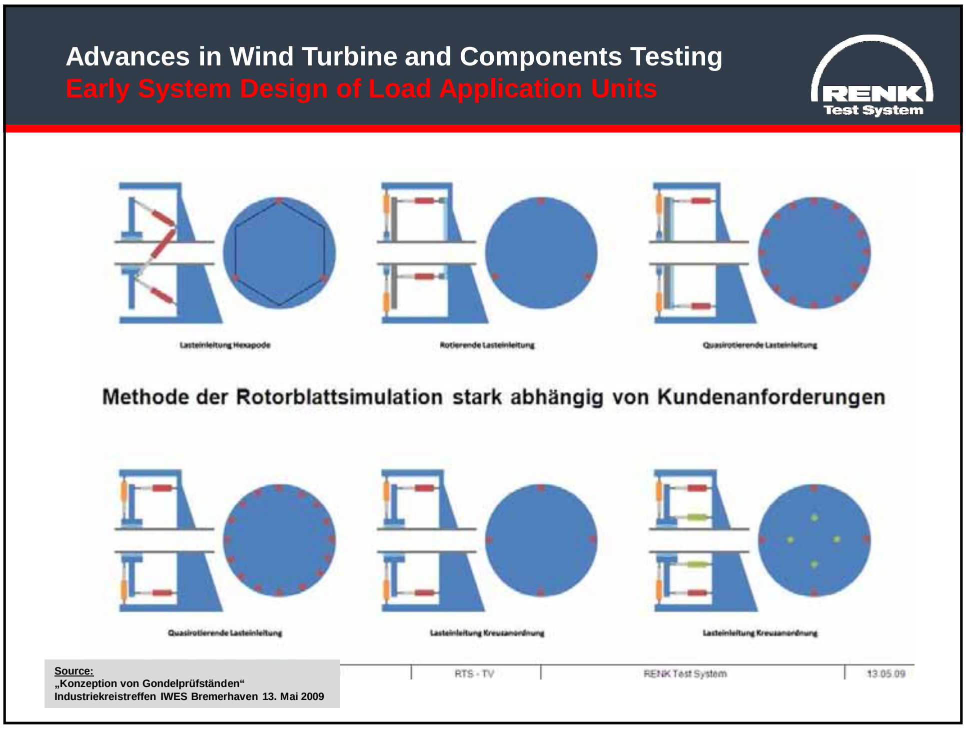


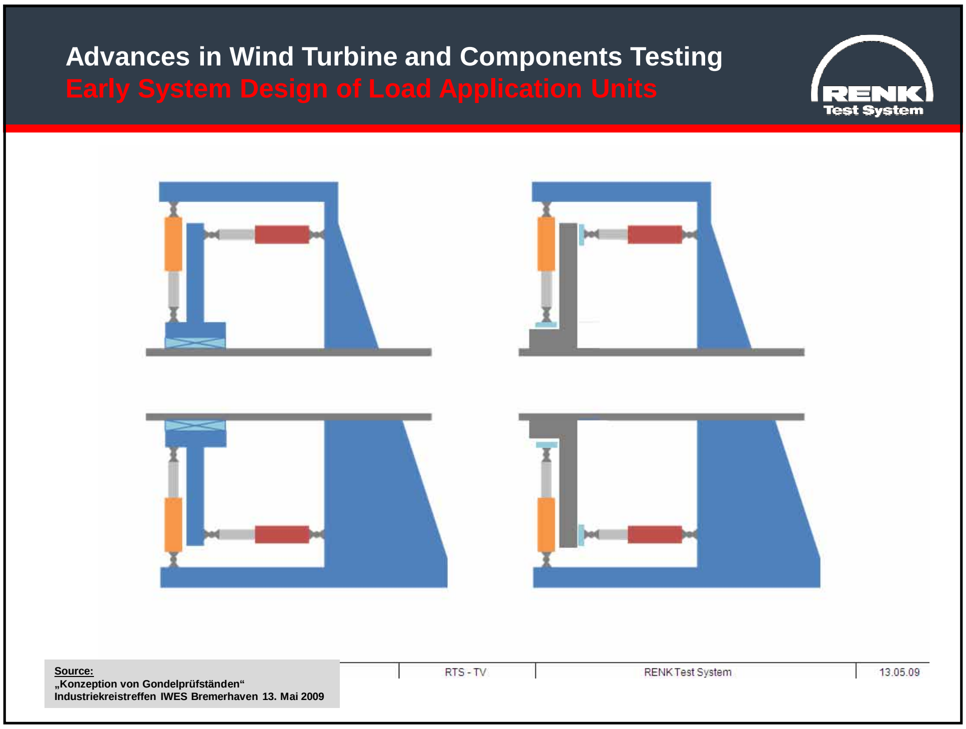
Advances in Wind Turbine and Components Testing
Early System Design of Nacelle Test Rigs

RENK Test System

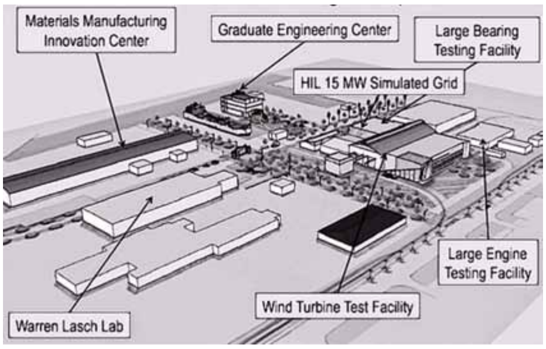


Source:
„Konzeption von Gondelprüfständen“
Industriekreistreffen IWES Bremerhaven 13. Mai 2009


Advances in Wind Turbine and Components Testing
Early System Design of Load Application Units
RENK Test System
Lasteinleitung Hexapode
Rotierende Lasteinleitung
Quasirotierende Lasteinleitung
Methode der Rotorblattsimulation stark abhängig von Kundenanforderungen
Quasirotierende Lasteinleitung
Lasteinleitung Kreuzanordnung
Lasteinleitung Kreuzanordnung
Source:
„Konzeption von Gondelprüfständen“
Industriekreistreffen IWES Bremerhaven 13. Mai 2009
RTS - TV
RENK Test System
13.05.09


Advances in Wind Turbine and Components Testing
Early System Design of Load Application Units
RENK Test System
Source:
„Konzeption von Gondelprüfständen“
Industriekreistreffen IWES Bremerhaven 13. Mai 2009
RTS - TV
RENK Test System
13.05.09

Advances in Wind Turbine and Components Testing
Wind Turbine Test Facility Clemson University

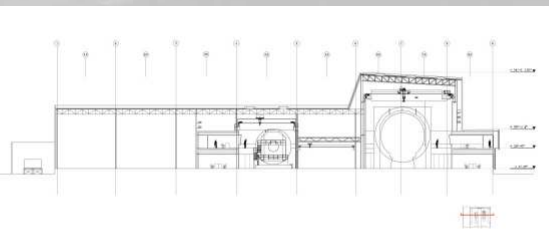


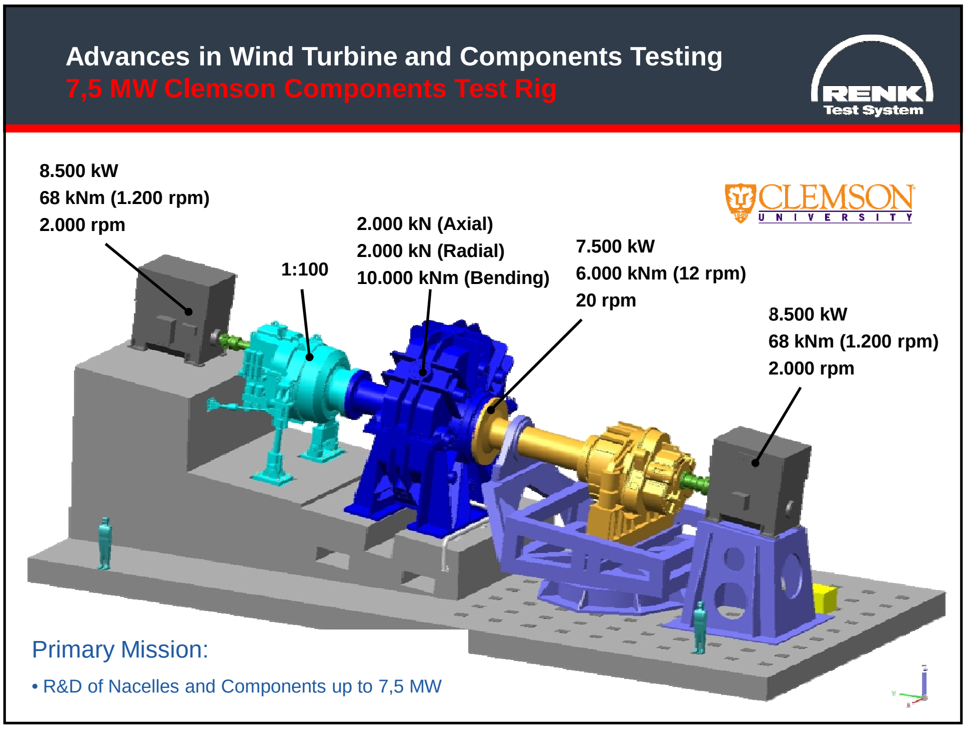
US DOE EERE: DE-FOA-000012 : $98M Project
$45M US DOE EERE, $53M Matching Funds

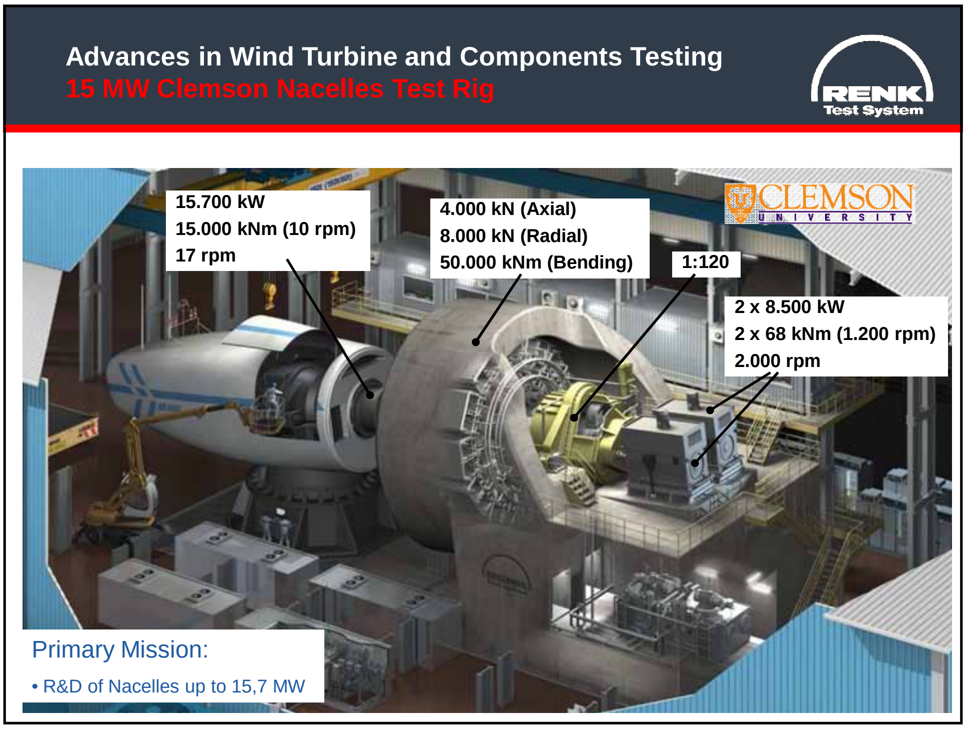
Primary Mission: Provide high quality testing services to wind turbine industry for up to 15 MW turbines, drivetrains or gear boxes.

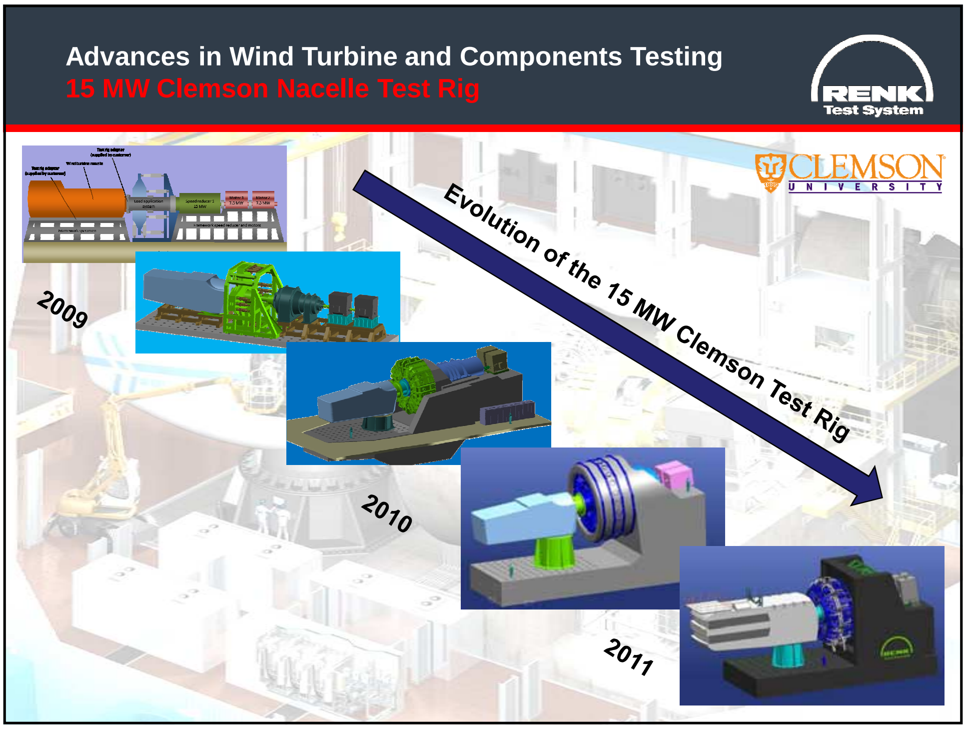
Secondary Mission: Establish long term partnerships with industry for work force development, research and education.

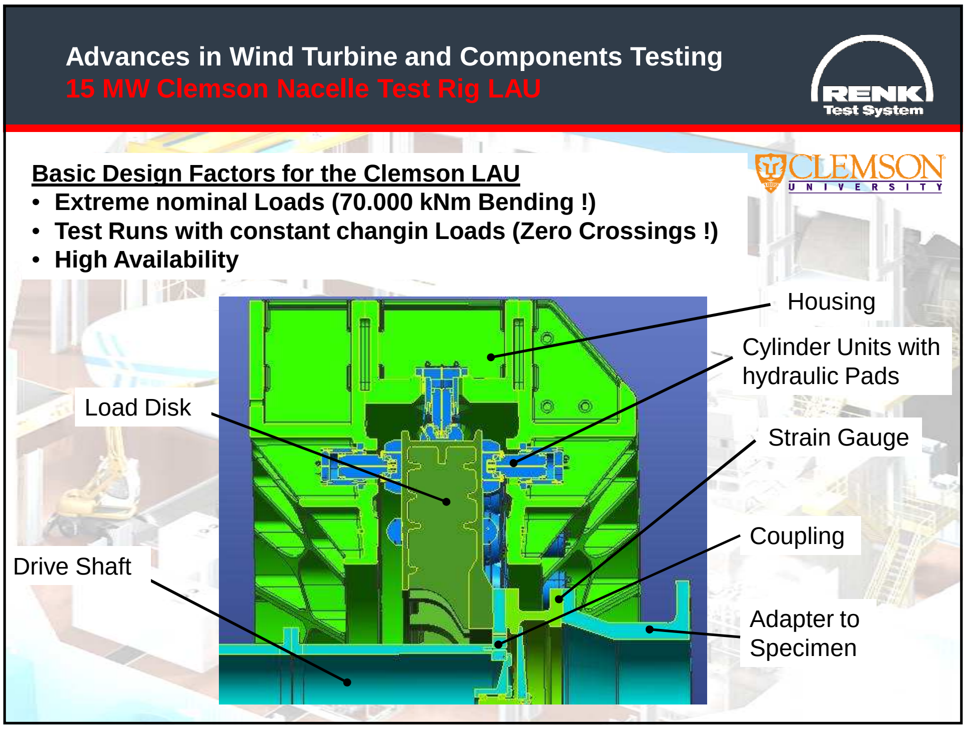
Advances in Wind Turbine and Components Testing
Wind Turbine Test Facility Clemson University

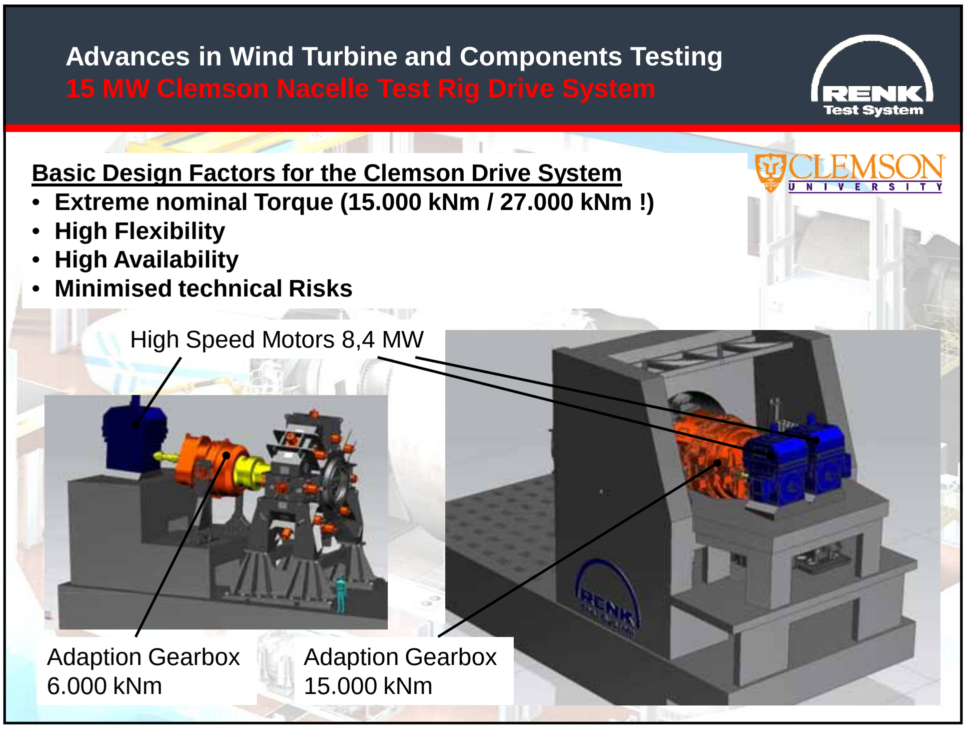


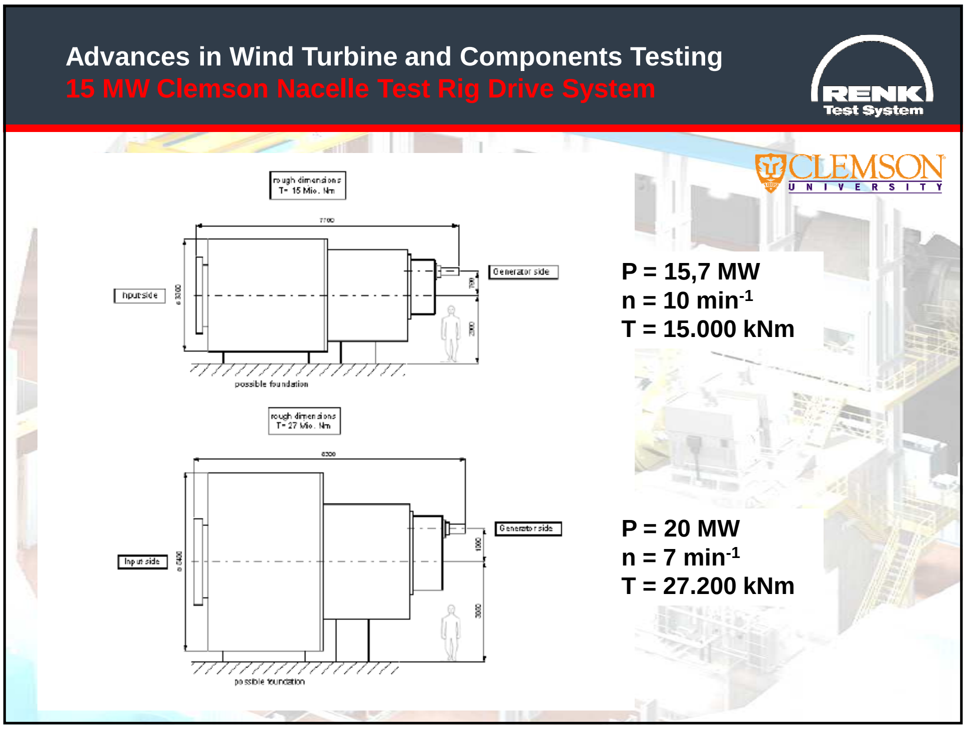

Advances in Wind Turbine and Components Testing
7,5 MW Clemson Components Test Rig
RENK
Test System
CLEMSON
UNIVERSITY
8.500 kW
68 kNm (1.200 rpm)
2.000 rpm
1:100
2.000 kN (Axial)
2.000 kN (Radial)
10.000 kNm (Bending)
7.500 kW
6.000 kNm (12 rpm)
20 rpm
8.500 kW
68 kNm (1.200 rpm)
2.000 rpm
Primary Mission:
• R&D of Nacelles and Components up to 7,5 MW

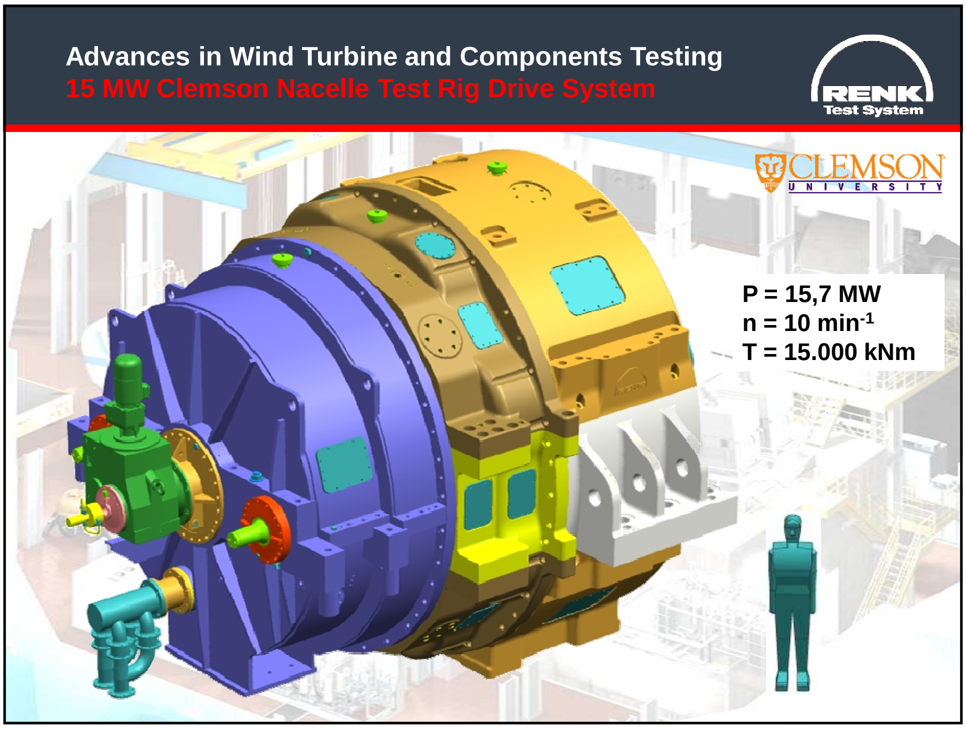

Advances in Wind Turbine and Components Testing
15 MW Clemson Nacelles Test Rig
RENK
Test System
CLEMSON
UNIVERSITY
15.700 kW
15.000 kNm (10 rpm)
17 rpm
4.000 kN (Axial)
8.000 kN (Radial)
50.000 kNm (Bending)
1:120
2 x 8.500 kW
2 x 68 kNm (1.200 rpm)
2.000 rpm
Primary Mission:
• R&D of Nacelles up to 15,7 MW

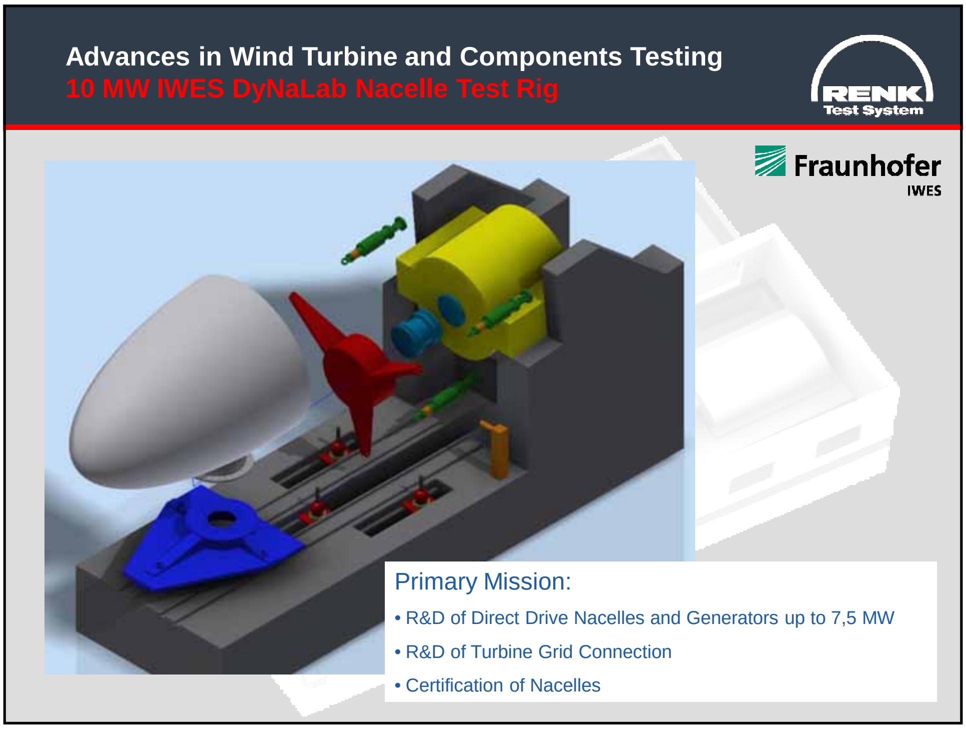

Advances in Wind Turbine and Components Testing
15 MW Clemson Nacelle Test Rig
Evolution of the 15 MW Clemson Test Rig
2009
2010
2011


Advances in Wind Turbine and Components Testing
15 MW Clemson Nacelle Test Rig LAU
Basic Design Factors for the Clemson LAU
• Extreme nominal Loads (70.000 kNm Bending !)
• Test Runs with constant changin Loads (Zero Crossings !)
• High Availability
Housing
Cylinder Units with hydraulic Pads
Load Disk
Strain Gauge
Coupling
Drive Shaft
Adapter to Specimen


Advances in Wind Turbine and Components Testing
15 MW Clemson Nacelle Test Rig Drive System
RENK Test System
CLEMSON UNIVERSITY
Basic Design Factors for the Clemson Drive System
• Extreme nominal Torque (15.000 kNm / 27.000 kNm !)
• High Flexibility
• High Availability
• Minimised technical Risks
High Speed Motors 8,4 MW
Adaption Gearbox 6.000 kNm
Adaption Gearbox 15.000 kNm


Advances in Wind Turbine and Components Testing
15 MW Clemson Nacelle Test Rig Drive System
RENK Test System
CLEMSON UNIVERSITY
possible foundation
P = 15,7 MW
n = 10 min-1
T = 15.000 kNm
P = 20 MW
n = 7 min-1
T = 27.200 kNm

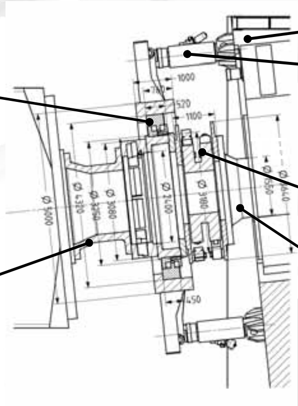

Advances in Wind Turbine and Components Testing
15 MW Clemson Nacelle Test Rig Drive System
RENK
Test System
CLEMSON
UNIVERSITY
P = 15,7 MW
n = 10 min-1
T = 15.000 kNm


Advances in Wind Turbine and Components Testing
10 MW IWES DyNaLab Nacelle Test Rig
RENK
Test System
Fraunhofer
IWES
Primary Mission:
• R&D of Direct Drive Nacelles and Generators up to 7,5 MW
• R&D of Turbine Grid Connection
• Certification of Nacelles

Advances in Wind Turbine and Components Testing
10 MW IWES DyNaLab Nacelle Test Rig LAU

RENK Test System
Fraunhofer IWES

Basic Design Factors for the IWES LAU
- **Real Loads of existing Turbines (20.000 kNm Bending)**
- **Test Runs with infrequent changin Loads (Zero Crossings !)**
- **Periodical Spare Parts Replacing Acceptable**



Advances in Wind Turbine and Components Testing
10 MW IWES DyNaLab Nacelle Test Rig Drive System

RENK Test System
Fraunhofer IWES

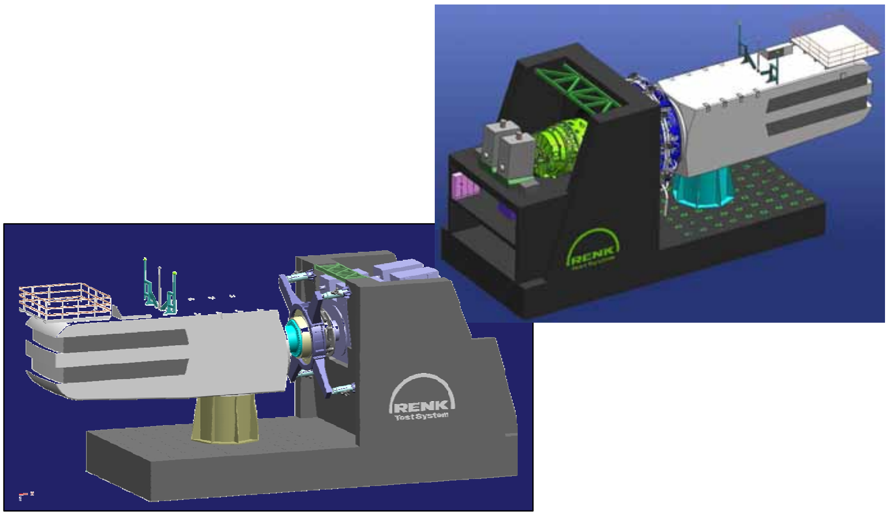
Basic Design Factors for the IWES Drive System
- **High nominal Torque (8.6.000 kNm)**
- **High Speed Dynamic**

P = 10 MW
n = 11 min^{-1}
T = 8.600 kNm

Advances in Wind Turbine and Components Testing

Different Test Rig Designs for different Testing Requirements

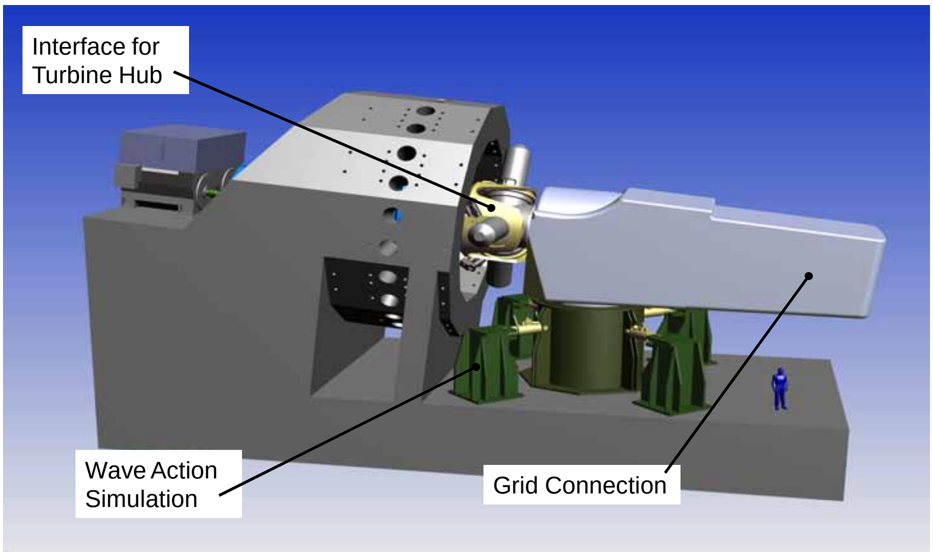
RENK Test System



Advances in Wind Turbine and Components Testing

Examples for future Topics in Test Rig Development

RENK Test System



Thanks for your Attention!

RENK Test System

Armin Diller
RENK Test System GmbH
Gögginger Straße 73
86159 Augsburg

Tel.: +49 (0)821 / 5700-479
Mobil: +49 (0)151 / 57 14 31 26
Fax: +49 (0)821 / 5700-610
armin.diller@renk.biz

SINOVEL

Laboratory Testing for Wind Turbine and Components

Zuohui Liu

SINOVEL WIND GROUP Co., Ltd.

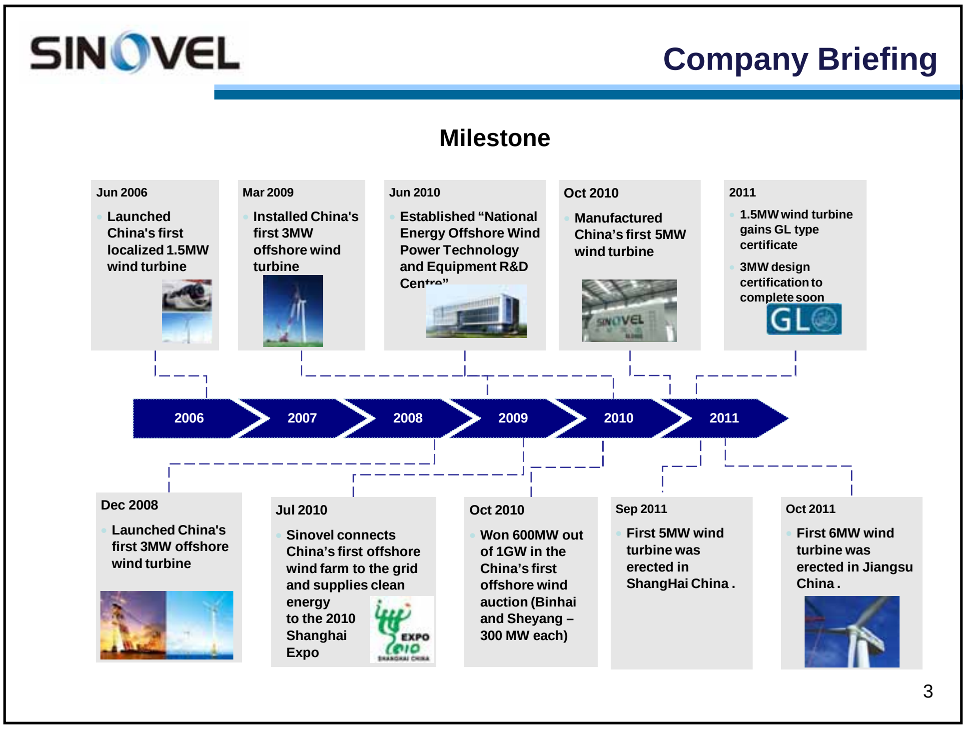
February, 2012

SINOVEL

Company Briefing

- Wind turbine manufacturer, headquartered in Beijing, China.
- Engaged in development and manufacture of onshore and offshore WTGS
- In 2010, successfully held its ground as No.1 in China and No.2 in the world, with a newly installation of 4386MW
- In 2011 the newly installation more than 3000MW

2



SINOVEL

Company Briefing

Productions

Series	Rotor Diameter	Types
SL1500	SL1500/70; SL1500/77; SL1500/82; SL1500/89 …	Onshore; 50HZ; 60HZ; Cold Climate
SL3000	SL3000/90; SL3000/105; SL3000/113 …	Onshore; Offshore; 50HZ; 60HZ; Cold Climate
SL5000	SL5000/128	Onshore; Offshore; 50HZ; Cold Climate
SL6000	SL6000/128; SL6000/155	Offshore; 50HZ;

4

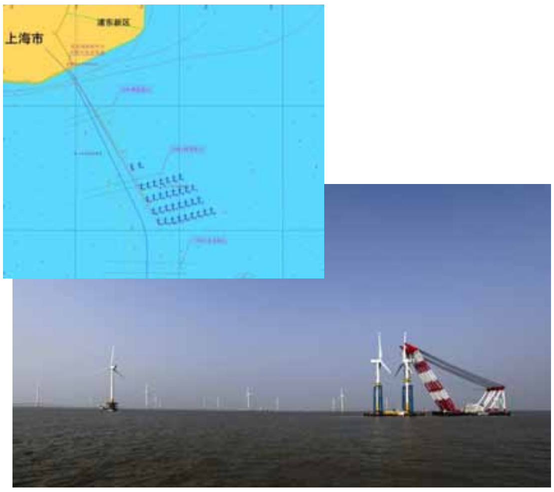
SINOVEL

Company Briefing

Offshore Projects

---Shanghai Donghai Bridge offshore project

- The first offshore project in China
- with 34 units of Sinovel SL3000, total 102MW
- The wind farm is near Shanghai, the water depth is 10 meters, and turbines lay out 8km to 13 km from the land



5

SINOVEL

Company Briefing

R&D Centre and Manufacture Base

R&D Center

"National Energy Offshore Wind Power Technology and Equipment R&D Centre"

Manufacture Base

Assembly for 1.5 MW and 3MW .

6

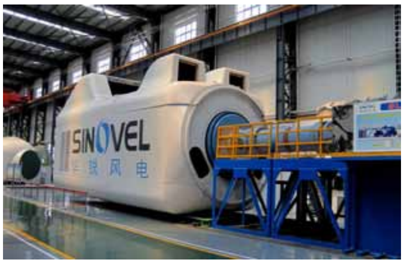
SINOVEL

Factory Testing

Factory Testing for Wind Turbine

Testing items

- **Full power production test**
- **Driver train performance test**
- **Systematic function test**



Test bench for 3MW wind turbine

Test bench for 1.5MW wind turbine

7

SINOVEL

Factory Testing

Factory Testing for Wind Turbine

Test bench for 5MW and 6MW wind turbine

8

SINOVEL

Factory Testing

Factory Testing for Pitch Systems

- Testing items
  - **Pitch bearing test include the sealing frication and lubrication**
  - **Pitch motor and converter test**

Test bench for pitch system

9

SINOVEL

Laboratory Testing

"National Energy Offshore Wind Power Technology and Equipment Experimental Sub-centre"

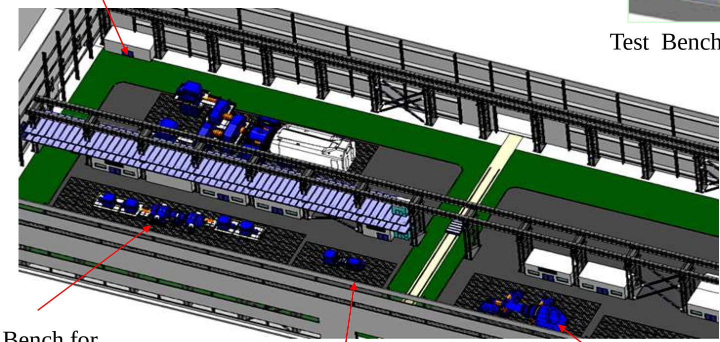
- Supported by National Energy Bureau, China.
- Prototype testing for large scale offshore wind turbine and components
- 5 testing and research sub-centre , include the gearbox, generator, converter, blade, and bearings.

10

Laboratory Testing

Test Bench for wind turbine and components

Test Bench for Wind Turbine



Test Bench for Blade

Test Bench for Gearbox

Test Bench for Generator, converter, and control system

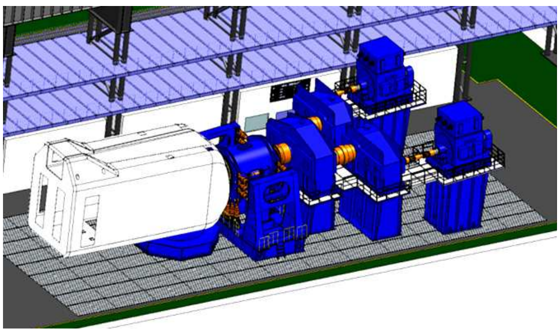
Test Bench for the Bearing

11

Laboratory Testing

Test Bench for Large Scale Wind Turbine

- Testing items
  - **Design Load Case simulation**
  - **Durability and fatigue test**
  - **System function test**
  - **Environmental test**
  - **Driver train test**
  - **Power production test**

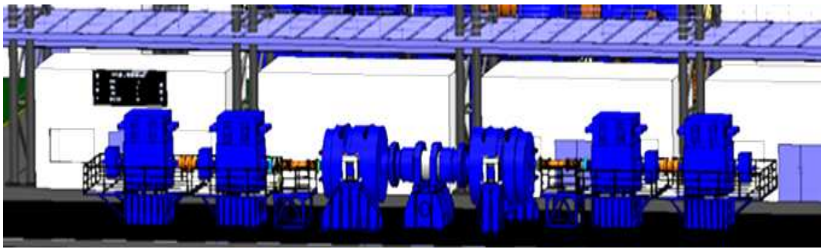


12

SINOVEL

Laboratory Testing

Test Bench for Gearbox



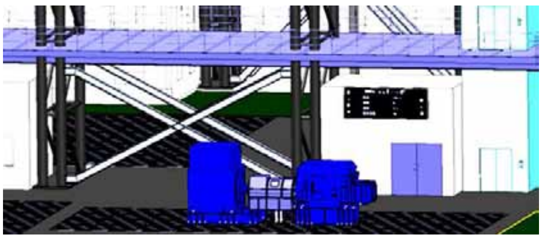
- Testing items
  - **Efficiency test**
  - **Extreme and fatigue load test**
  - **Over speed test**
  - **Environmental test**

13

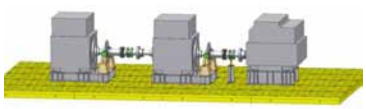
SINOVEL

Laboratory Testing

Test Bench for Generator, Converter and Control System



- Testing items
  - **Efficiency ,vibration and noise test for generator**
  - **Over load test for generator and converter**
  - **Over speed test for generator**
  - **Temperature rise test for generator and converter**
  - **Withstand voltage test**
  - **LVRT test**

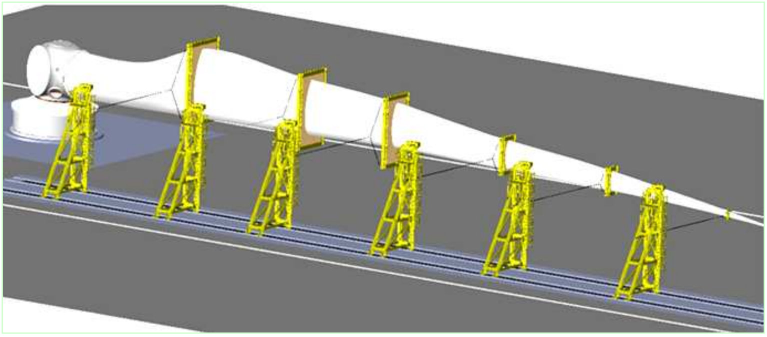


14

SINOVEL

Laboratory Testing

Test Bench for Blade



- Testing items
  - **Static loads test**
  - **Fatigue loads test**

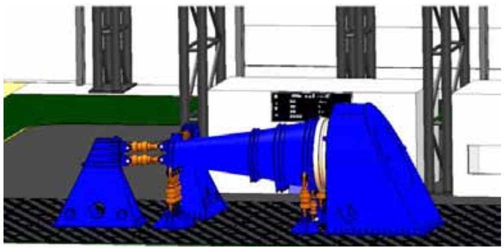
15

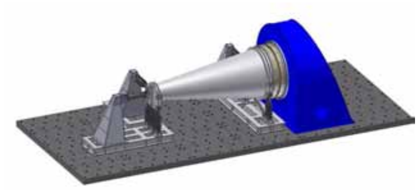
SINOVEL

Laboratory Testing

Test Bench for Pitch Bearings

- Testing items
  - **Temperature rise test for the pitch motor and converter**
  - **Vibration and noise test**
  - **Lubrication,sealing and friction test**
  - **Pitch driver performance test**



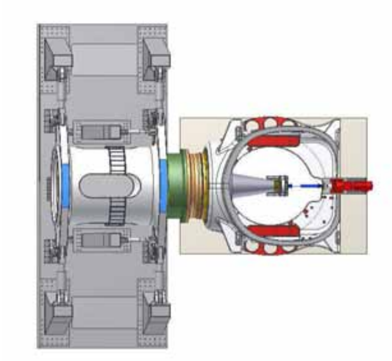


16

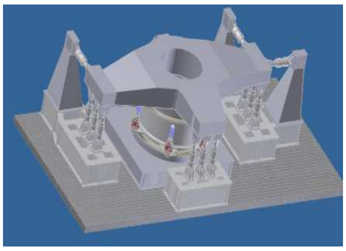
SINOVEL

Laboratory Testing

Test Bench for Main Bearing and Yaw Bearing



Test bench for Main bearing



Test bench for Yaw bearing

17

Sub-System and Component Testing

An OEM Approach…

IEA Wind TEM #68, Aachen

RETC Test and Measurement, Sven Sagner 21.02.2012

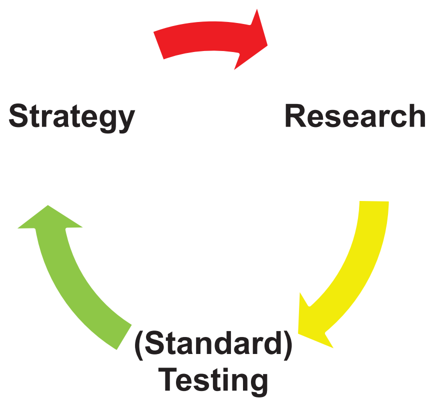
Topics

1. RETC Test & Measurement Center
2. REpower and Suzlon Initiatives
   - Drivetrain Testing: Pre-Study and Benchmark
   - Monitoring of Test Facilities
   - Nacelle Testing
   - Component and Sub-System Testing

Sven Sagner, TMC 21.02.2012

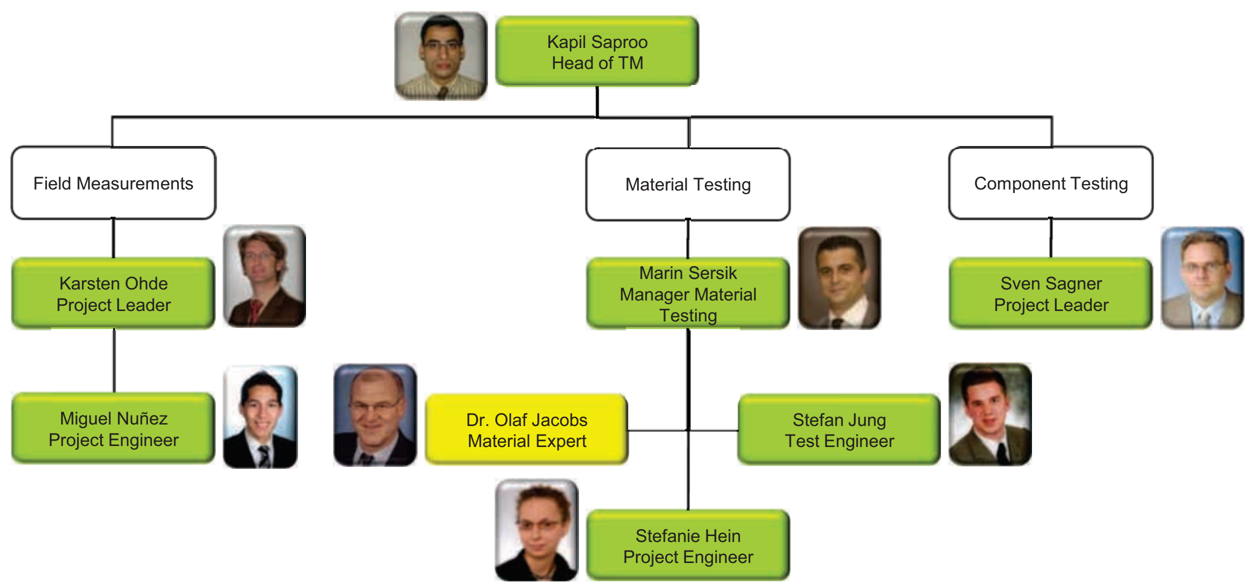
RETC Test & Measurement

- Development of new test methods and improvement of existing procedures for material, component and system testing
- Implementation of test methods from mature industries
- Building up of strategic partnerships with suppliers and external institutes
- Set-up and execution of key-tests and key-measurements within RETC
- Implement trainings and train best business practices throughout the organizations



Sven Sagner, TMC 21.02.2012

RETC Test & Measurement Organizational Structure



4

RETC Test & Measurement
Departments and Activities

Material Testing

- Static strength tests
- Dynamic tests
- Characterization of materials
- Damage analysis
- …

Component Testing

- Component testing
- Sub-system testing
- System testing
- Fatigue testing
- Virtual testing
- …

Field Measurements

- Noise & vibration
- Grid connection
- LVRT/HVRT
- Ice detection
- Non-destructive testing
- …

Validation

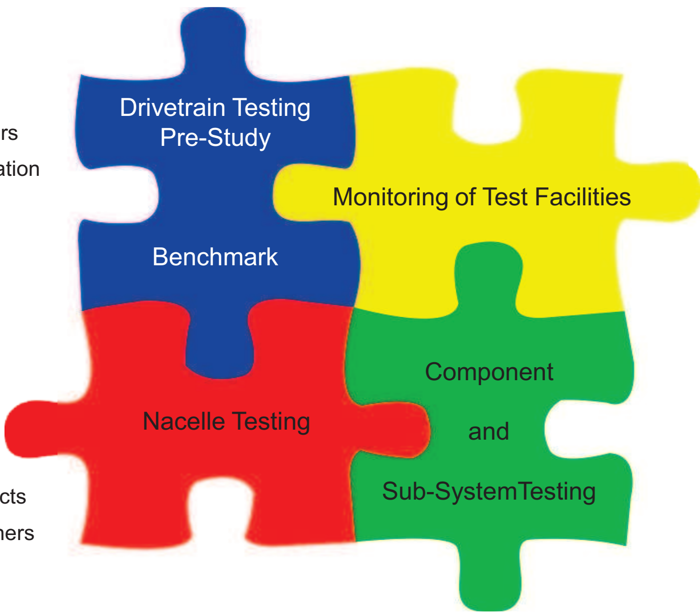
- Lab quality/accreditation
- Seminars
- Tools & methods, e.g. Design of Experiment
- BBP Best business practice
- …

Sven Sagner, TMC 21.02.2012

REpower and Suzlon Initiatives

- Study the „Market“
- Identify Suppliers
- Identify possible Partners
- Get a rough cost estimation
- Compare Internal and external testing efforts

- Identify R&D needs
- Set Priorities
- Specify Requirements
- Derive Projects
- Precalculation for Projects
- Compare possible partners

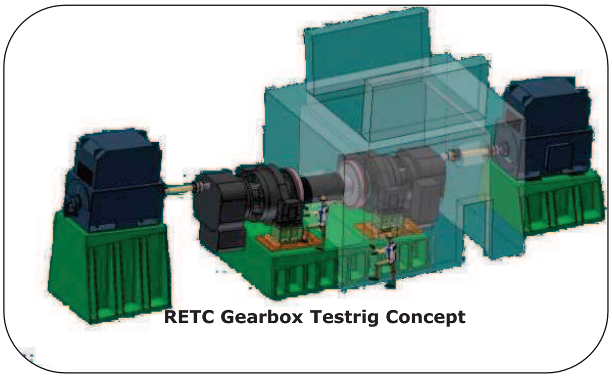


- New Testing Opportunities
- Place Stakeholder Requirements in Projects
- Benchmark

- Align stakeholders efforts
- Identify „test-valuable“ Sub-Systems
- Inventory of all internal testing facilities
- Specify future Requirements for various testing needs

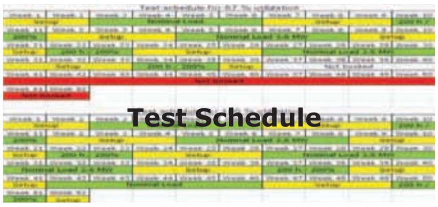
Sven Sagner, TMC 21.02.2012

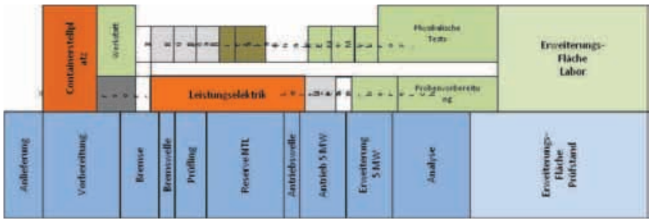
Pre-Study



Comparison Basis: 3.5MW Gearbox Testrig

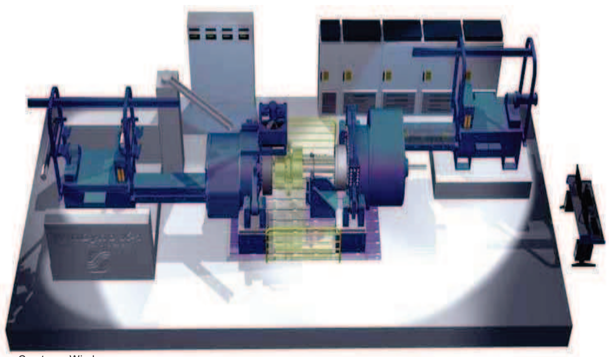
- Testing Costs and Invest
- Test Center Concept
- Internal or external Testing
- Comparison of Locations
- Specification



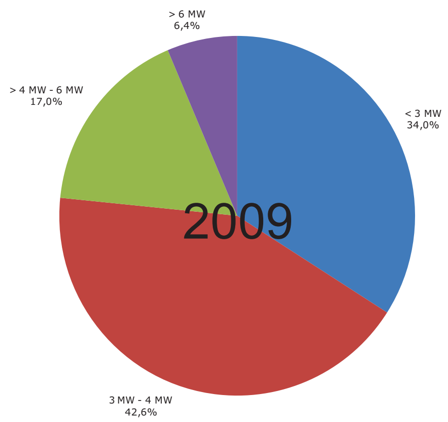


Sven Sagner, TMC 21.02.2012

Benchmark Production Testrigs



Courtesy : Windyno



Worldwide more than seventy wind turbine drive train related testrigs were in operation or planned.

Most of them are utilized as end of line test equipment at gearbox manufacturer facilities.

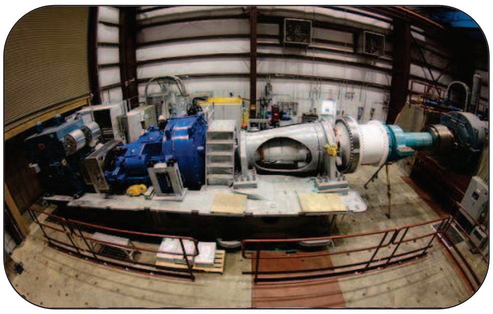
Even testrigs primarily designed for development issues will be used for production and development tests.

The power loop of approximately 70 % of production testrigs is electrical.

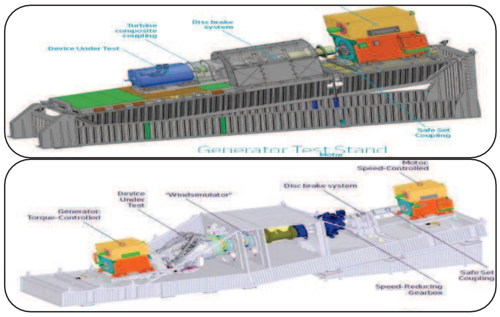
Sven Sagner, TMC 21.02.2012

Benchmark

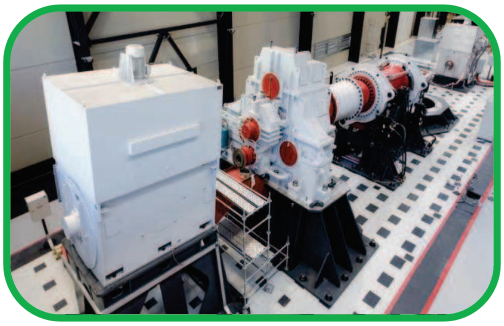
RETC
Renewable Energy Technology Center



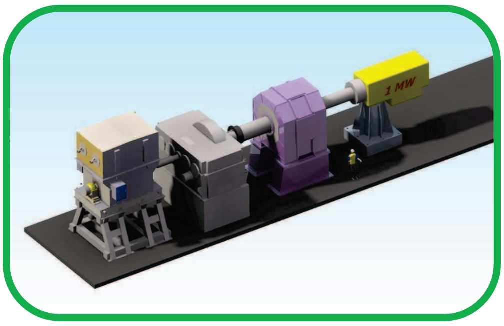
NREL 2.5 MW, 2000



Vestas Generator and Nacelle each 12 MW, ≈2006



Cener 8 MW, 2007

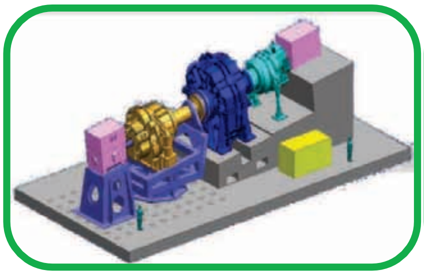


narec 3 MW, Q4 2011

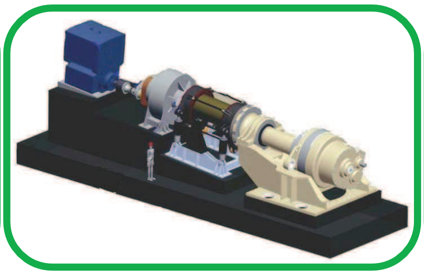
Sven Sagner, TMC 21.02.2012

Monitoring of Test Facilities

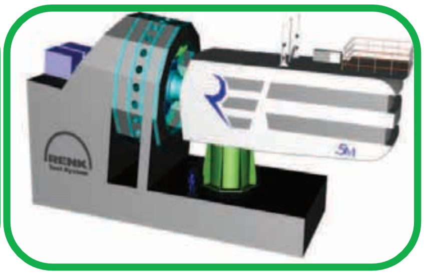
RETC
Renewable Energy Technology Center



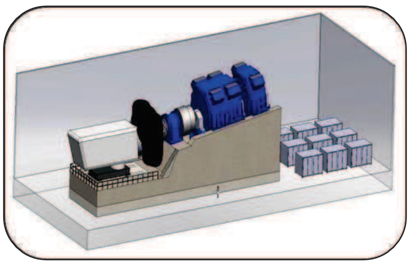
Clemson 7.5 MW, Q2 2012



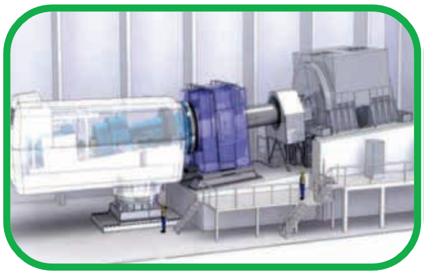
NREL 5 MW, Q3 2012



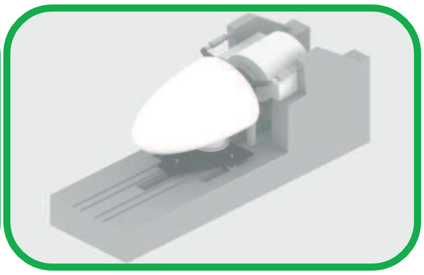
Clemson 15 MW, Q4 2012



LORC 20 MW, Q1 2013



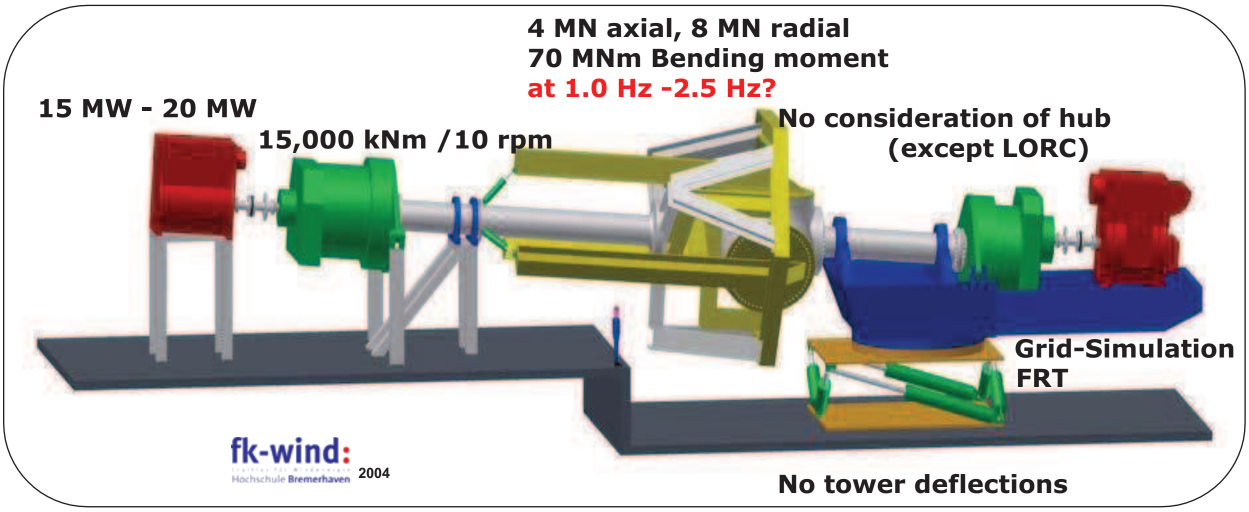
narec 15 MW, 2013



Fraunhofer IWES 10 MW, Q1 2014

Sven Sagner, TMC 21.02.2012

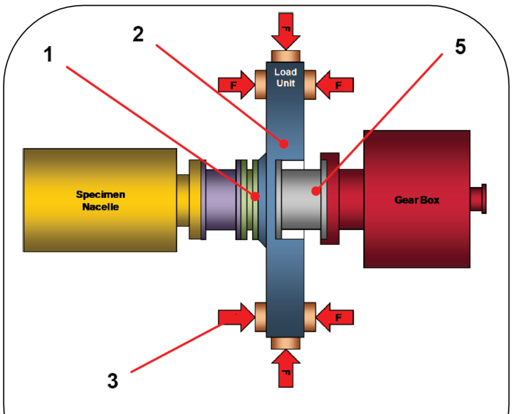
Monitoring of Test Facilities



- Discussions about cold-start and operation under different climates
- Usually fixed tilt angle at 6°

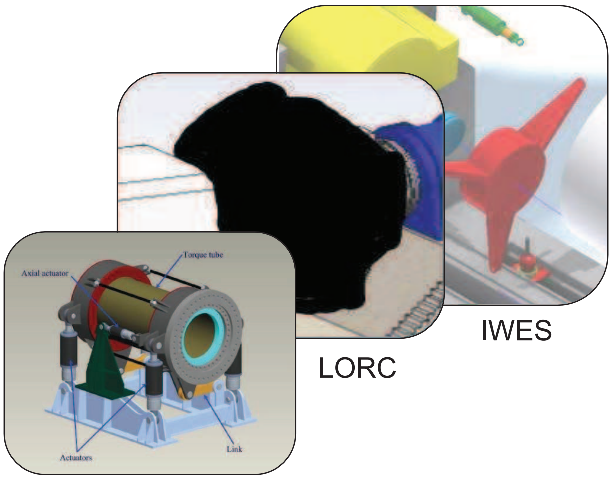
Monitoring of Test Facilities

Non torque Loads: Mandatory but seen as research task!



1	Central shaft	2	Load disc
3	Hydraulic actuators	4	Load reaction block
5	Coupling	-	-

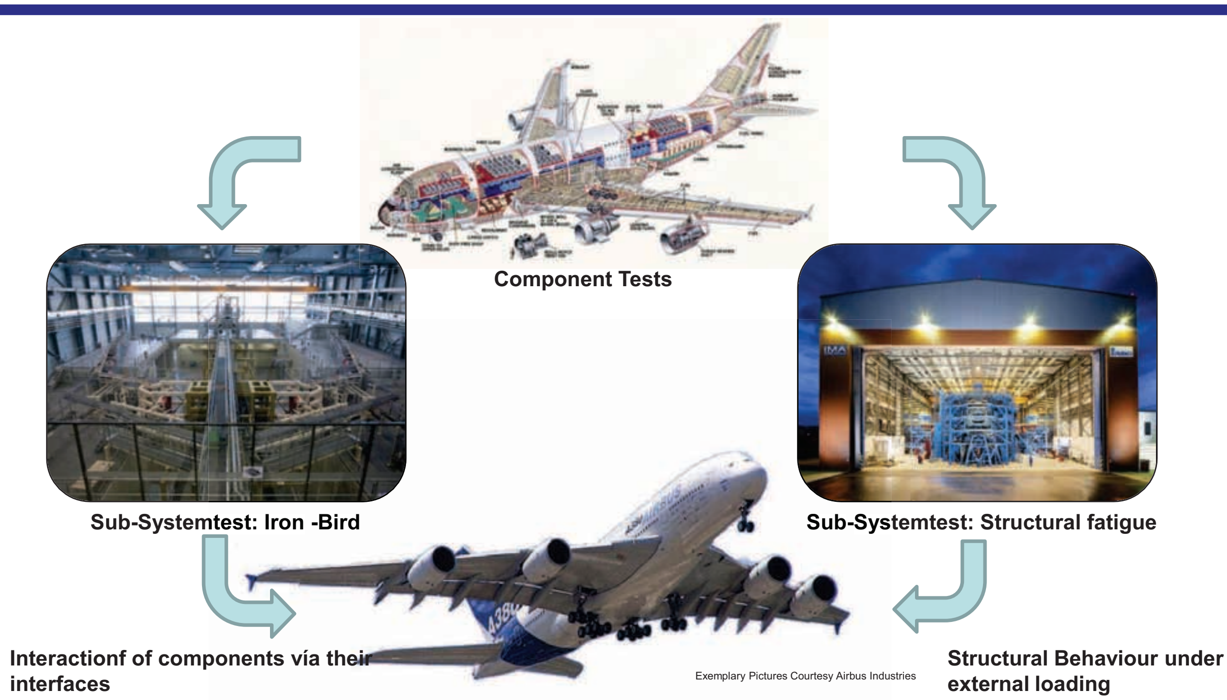
Hydrostatic
(Courtesy of Renk Test Systems)



NREL (similar to Cener)

Nacelle Testing
Traditional Wind Industry Approach

Nacelle Testing
Aerospace Approach



Nacelle Testing
Some obvious statements

- We define the Nacelle as **Sub-System**
- Structural and functional tests are difficult or not to separate
- Interferences of wind, grid and turbine control are leading to structural loads
- Rotor Loads including pitch and yaw effects have to be simulated

Seen that way, a Nacelle test is comparable to an Iron-Bird within the real Aeroplane-Structure under external loads but…

Without engines!!!

Sven Sagner, TMC 21.02.2012

Nacelle Testing
Testing Interests

- Every possible Operating Condition
- Evaluation of local component load profiles resulting from rotor induced load
- Development of grid products and functions (LVRT,HVRT and frequency response) according to different international grid codes
- Software Verification
- Verification of control- and operational management concepts
- Development of load collectives to generate specific failure modes

Sven Sagner, TMC 21.02.2012

Nacelle Testing
Workshop Results

RETC Renewable Energy Technology Center

Top five of the internal priority Analysis:

1. System Behaviour
2. Test Scheduling (Knowing WHAT and WHEN!!)
3. Early Failure Detection
4. Grid Simulation
5. Supplier Participation

Sven Sagner, TMC 21.02.2012

Nacelle Testing
Workshop Results

RETC Renewable Energy Technology Center

Are smaller testrigs suitable?

Which features have priority?

Who could be a partner?

Grid simulation?

Overseas Testing?

90%

Certification?

Testing needs?

Integration in development strategy

Long term partnerships?

Testing Costs?

Schedules?

answered

First project ideas?

Accelerated Tests?

Environmental Chamber?

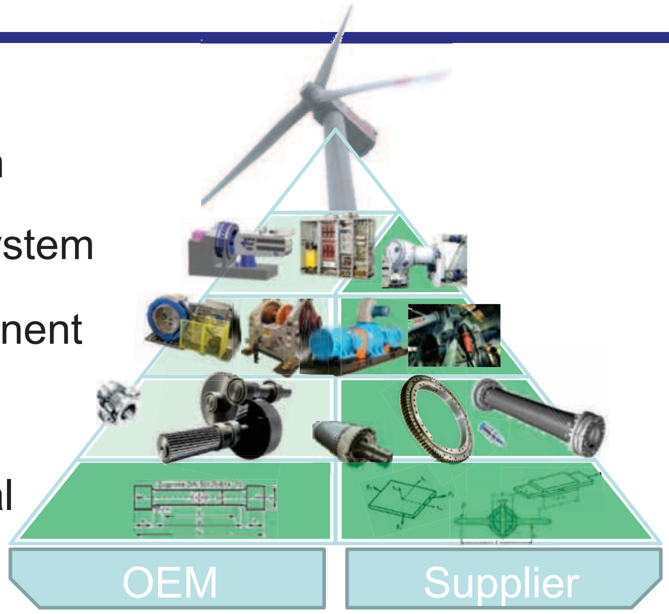
Which turbine has to be priorized?

Which departments have to be involved?

Need of Corporate Testing Strategy

Sven Sagner, TMC 21.02.2012

Component and Sub-System Testing

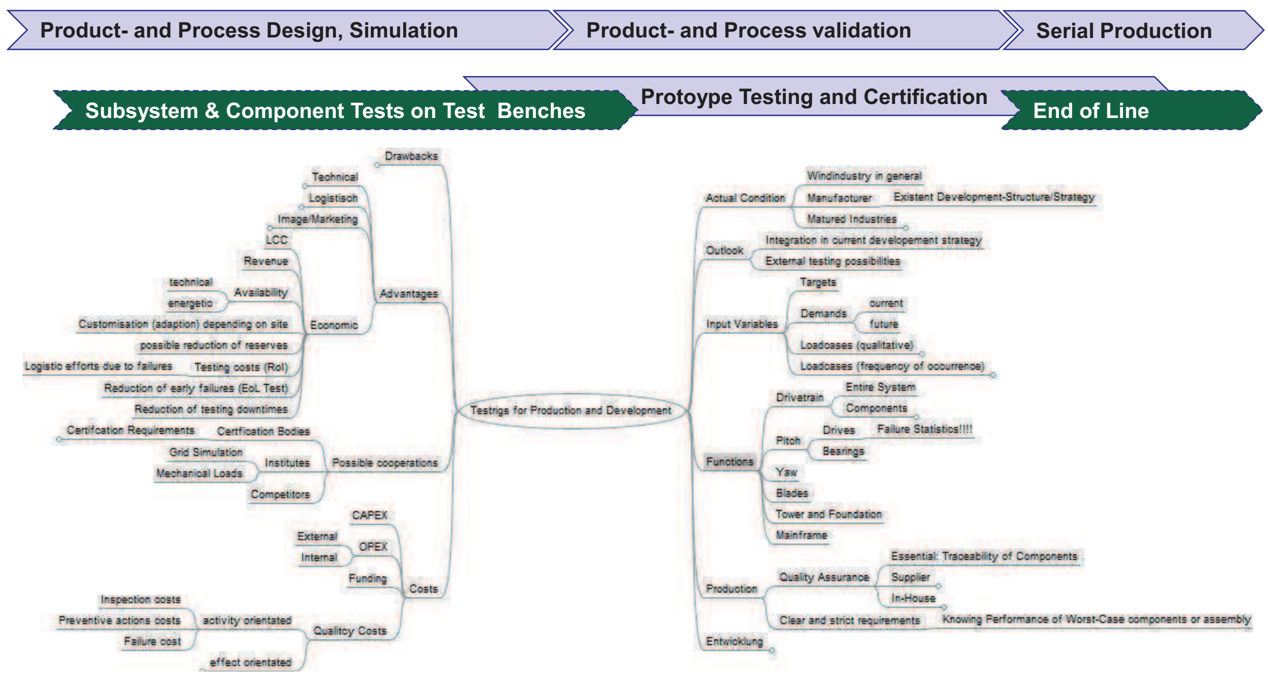


Define ONE Corporate Testing Strategy considering the full Testing Pyramid

Exemplary Pictures taken from different Sources:
RTS, Rothe Erde,ZF Transmissions, SKF, FAG

Sven Sagner, TMC 21.02.2012

Test Bench Integration & Benefits



Sven Sagner, TMC 21.02.2012

Contact

RETC Renewable Energy Technology Center GmbH
Überseering 10 / Oval Office
D-22297 Hamburg
GERMANY

T: +49 40 5555 13 – 7000
F: +49 40 5555 13 – 7010

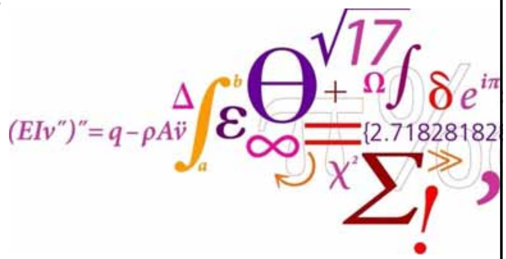
- Department Head kapil.saproo@retc.de -7300
- Component Test sven.sagner@retc.de -7301
- Material Test: marin.sersik@retc.de -7302
- Field Measurements: kasten.ohde@retc.de -7304

Sven Sagner, TMC 21.02.2012

Developments in full-scale, sub-structural and blade component testing at DTU Wind Energy

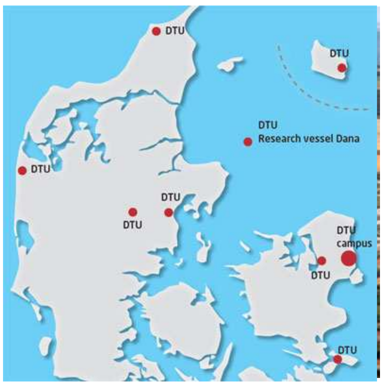
IEA RD&D Task 11 Topical Expert Meeting #68
Institute of Machine Elements & Machine Design,
RWTH Aachen University, Germany
February 21-22, 2012

Christian Berggreen
Head of Group Composite Mechanics
Associate Professor, PhD



DTU Wind Energy
Department of Wind Energy

DTU - Det bli'r til noget



- The **Technical University of Denmark (DTU)** was founded by H.C. Ørsted in 1829
- **DTU** has approx. 4500 employees (of these are 700 PhD-students and over 50% researchers)
- 7000 students on bachelor and master level
- Campuses spread all over Denmark
- Main campus in Lyngby, just north of Copenhagen
- Approx. 250 employees (of these 70 PhD-students and 50 technical staff)

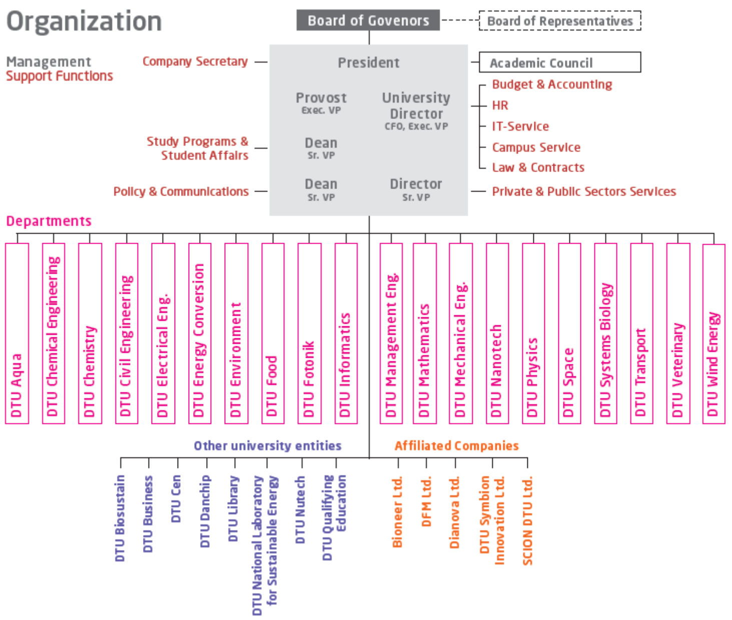
DTU 2012 re-organisation

As of January 1st 2012, DTU was re-organized with the following consequences:

- **Risø DTU** was discontinued as a national laboratory for sustainable energy!
- **DTU Wind Energy** was formed as a new department consisting of:
  - Wind Energy Division from **Risø DTU**
  - The Composite and Metal Materials programs of the Material Research Division from **Risø DTU**
  - The Fluid Mechanics and Composite Mechanics groups from **DTU Mechanical Engineering**
- **DTU Energy Conversion** was formed as a new department consisting of parts of two old **Risø DTU** divisions
- Remaining parts of **Risø DTU** was distributed on other existing DTU departments
- Various re-organizations between other DTU departments

3 **DTU Wind Energy, Technical University of Denmark** IEA RD&D Task 11 meeting 21/2/2012

Organization



4 **DTU Wind Energy, Technical University of Denmark** IEA RD&D Task 11 meeting 21/2/2012

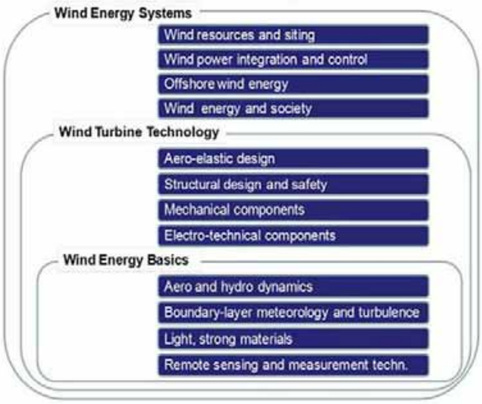
DTU Wind Energy

DTU Wind Energy - a mission orientated department!

240 employees distributed on 8 sections:

- Aero-elastic Design
- Composite Materials
- Fluid and Composite Mechanics
- Metallic Materials
- Meteorology
- Test and Measurements
- Wind Energy Systems
- Wind Turbines

(*a section re-organization is planned!*)



5 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

Section for Fluid and Composite Mechanics
Composite Mechanics Group

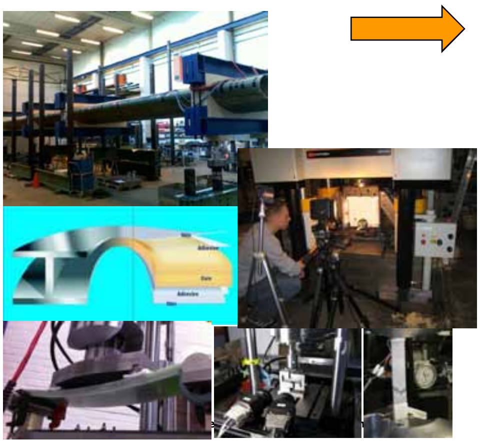
- Staff: (at the moment approx. 13-18 persons)
  - Christian Berggreen, Assoc.Prof., PhD (head of group)
  - NN, Researcher, PhD
  - Konstantinos Anyfantis, Researcher, PhD
  - Ramin Mosl
  - Vladimir Fe
  - Benjamin Ri
  - Leif A. Carls
  - Niels Jørgen
  - Rasmus Erik
  - Søren Giver
  - Marcello Ma
  - Olafur Olafsson, PhD-cand.
  - Jacob Herold Høgh, PhD-cand.
  - Nikolay Dimitrov, Industrial PhD-cand. (with *Siemens WP*)
  - Andrei Costache, Industrial PhD-cand. (with *NKT Flexibles*)
  - Zuzana Andrlová, PhD-cand. (with *Wind Turbine section*)
  - Danial Ashouri Vajari, PhD-cand. (with *Mech. Engineering*)
  - Jacob Waldbjørn PhD-cand. (with *Civil Engineering*)

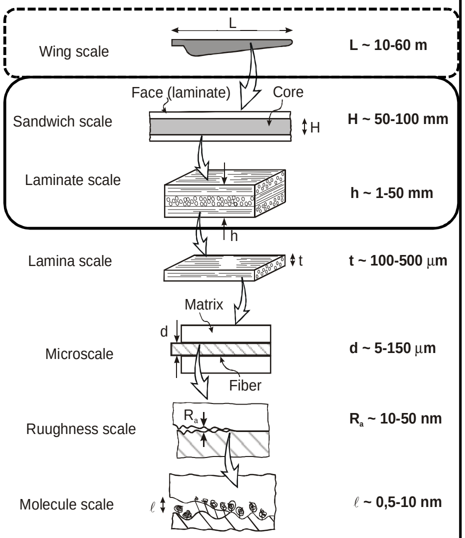
In total: 13 (18+)
- **5 faculty/research staff members**
- **2 external/visiting staff members**
- **1 lab. engineer**
- **7 (10) permanent PhD-candidates**
- **+ varying number of MSc/BSc/BEng candidates**

6 DTU Wind Energy, Technical University of Denmark IEA RD&D Ta

Composite Mechanics Group
Research areas

Length scales: *(From 1 mm to 15 m)*
Laminate, component to sub-structural





IEA RD&D Task 11 meeting 21/2/2012

Composite Mechanics Group
Research areas

Focus areas:

- Damage tolerance & fracture mechanics of composites, especially sandwich
- Advanced structural analysis and modeling/simulations
- Design of *smart* structures, morphing, sandwich structures
- Protective engineering, blast/impact, high strain rates
- Reliability and probabilistic design
- Experimental mechanics – characterisation, multi-axial structural loading, DIC etc.
- Advanced structural testing of composites – hybrid testing
- Application:
  - Wind turbine blades
  - Military vehicles
  - Off-shore structures
  - Ships
  - Airplanes and helicopters

8 DTU Wind Energy, Technical University of Denmark

DTU Structural Lab – Lyngby Campus
Facts and facilities

Facts:

- History: Integrated cooperation between DTU Mechanical and DTU Civil Engineering from year 2000 within material and structural testing facilities
- 2011: Formalized cooperation through establishment of **DTU Structural Lab**, *Center for Mechanical Testing of Structures and Materials*
- 2012: DTU Wind Energy joins **DTU Structural Lab** as the third department partner.
- *Largest facility of this type in Northern Europe!*

Facilities: (also for consultancy testing!)

- **Purpose**: Material, component and structural testing
- Servo-hydraulic (20) & Non-servo hydr. (9)
- Large-scale strong floors (up to 40 m length)
- Static capacity up to 1000 tons in compression, 500 tons in tension + multi-axial control
- Advanced optical deformation measurement systems
  - ARAMIS 2M, 2 x ARAMIS 4M
  - ARAMIS HHS + analysis server/licenses
- Advanced climatic mechanical test environments

9 DTU Wind Energy, Technical University of Denmark

DTU Structural Lab – Lyngby Campus
Facts and facilities

Locations:

- B119: *Main location*
  - Materials/component testing
  - Two strong floors (up to 40 m)
  - Climatic testing environments
- B373: *Maybe from medio 2012 (?)*
  - Strong floor (20 m)
- B414:
  - Materials testing

10 DTU Wind Energy, Technical University of Denmark

DTU Structural Lab – Lyngby Campus
Material & structural laboratory facilities

Material & component testing (low force):

- Load levels below 100 kN
- Electro-mechanical machines (6): [Static]
  - 1 kN, MTS QTest/1
  - 5 kN, MTS QTest/5
  - 10 kN, Instron 6022
  - 30 kN, MTS Sintech 5/G
  - 100 kN Instron 6025 (x 2)
- Servo-hydraulic machines (13): [Static/dynamic]
  - 10 kN, MTS 858 with MTS FlexTest 60
  - 10 kN/160 Nm, Instron 8511 with MTS FlexTest 60
  - 25 kN, Instron 8872 with Instron 8800
  - 25 kN/100 Nm, Instron 8874 with Instron 8800
  - 25 kN/200 Nm, MTS 858 with MTS FlexTest 60
  - 40 kN, Instron 8511 with Instron 8500+
  - 50 kN, DTU-design high-speed (up to 5 m/s) with MTS TestStar II
  - 100 kN, MTS 810 with MTS TestStar IIs
  - 100 kN, MTS 810 with MTS FlexTest SE (B414)
  - 100 kN, Instron 8516 with Instron 8800
  - 100 kN, Instron 8521 with MTS TestStar IIs
  - 100 kN + 2 x XX kN, MTS 810 with MTS FlexTest 60
  - 100 kN, MTS 809 high-speed (up to 25 m/s) with MTS TestStar II and additional controlling
- 3 climatic chambers for temperature/humidity variation

DTU Structural Lab – Lyngby Campus
Material & structural laboratory facilities

Material & component testing (high force):

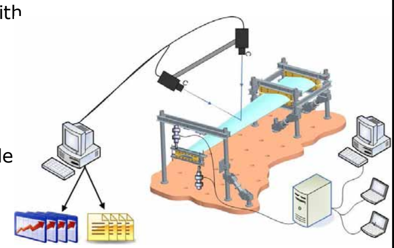
- Load levels above 100 kN
- Hydraulic non-servo (3): [Static]
  - 600 kN, MFL
  - 2000 kN, MFL
  - 10000 kN, MFL
- Servo-hydraulic machines (7): [Static/dynamic]
  - 155 kN/XX Nm + 50 kN, DTU-design with Instron 8800 (bi-axial) integrated with large climatic chamber (temp/humidity)
  - 250 kN, MTS 810 with MTS TestStar IIs
  - 250 kN, Instron 8502 with Instron 8800
  - 250 kN, Schenck PBS-25 with Instron 8500+
  - 500 kN, Instron 1343 with Instron 8500+
  - 500 kN, MTS 810 with MTS TestStar IIs
  - 5000 kN + 500 kN, Instron 8508 with Instron 8580
- Possibility to build "tailor made" machines on strong floor using a wide range of separate servo-hydraulic actuators
- Advanced large climatic chamber (temp/humidity) integrated in 3 axis loading rig (see above)
- Application of DIC-systems (ARAMIS) possible!

12 DTU Wind Energy, Technical University of Denmark IEA RD&

DTU Structural Lab – Lyngby Campus
Material & structural laboratory facilities

Structural lab. (strong floor):

- 31 m + 10 m strong floors with 2 MN single point loading capacity+multiple rigging possibilities (B119)
- 20 m strong floor (B373)
- Single point active load levels up to 1 MN (5 MN)
- Range of (45) hydraulic non-servo actuators [Static/dynamic]
- Servo-hydraulic actuators [Static/dynamic]
    - 50 different actuators ranging from 5 kN up to 1000 kN
    - 5000 kN using the Instron 8508 combined with the strong floor
    - Advanced multi-axial control
    - Additional adhoc test machines possible!
- Ring main central hydraulic supply system with a capacity of approx. 700 l/min.
- Hybrid-testing of sub-structural specimens possible
- Application of DIC-systems (ARAMIS) possible!

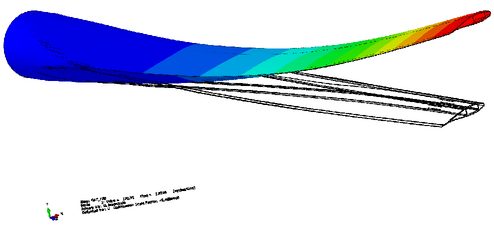


13 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

Risø Campus
Full-scale blade testing facility

Full-scale blade lab.:

- Located at Risø Campus
- Steel root fixture for mounting blades of up to 30-35 m
- Static testing with hydraulic winches
- 2D combined flap/edge-wise loading possible
- Focused on research activities



Opening of the test facility:

25.11.2008

34m blade from SSP Tecnology A/S

Cut at 25 m.

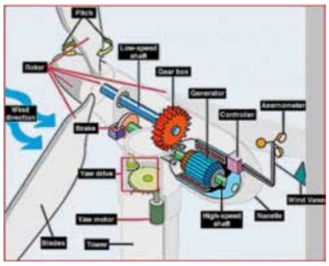
14 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

Risø Campus
Drive-train test center

Partners:
- Aalborg University
- Force Technology
- Danish Technological institute
- Dong Energy A/S

The main focus of the center should be:

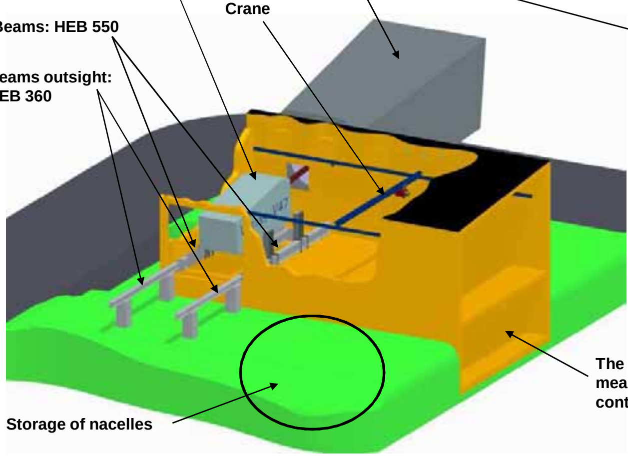
- Systems and their function and operation in the wind turbine, rather than the component itself
- Test and demonstrations as system tests, rather than component tests
- Develop test methods/procedures and the representative load paradigms required to experimentally test a wind turbine drive train
- Contribution to development and formulation of requirements for component tests, verification and certification



15 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

Risø Campus
Drive-train test center – 1 MW

The test-setups motor and gear (the drive unit) is a 1MW nacelle, which has been modified with a frequency control drive system such that it is capable of applying variable-torque and variable-speed.



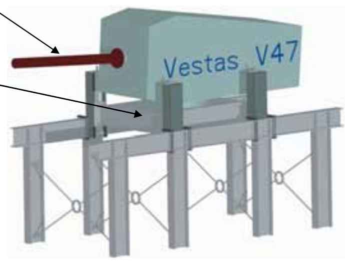
16 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

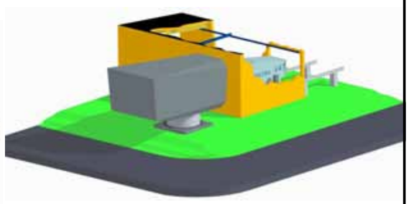
Risø Campus
Drive-train test center – 1 MW

Long flexible coupling

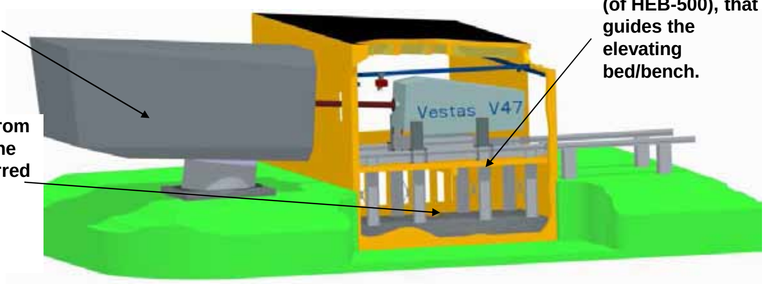
Elevation bed/bench, which has a vertical adjustment span of approximately 1.8m.

The 1MW nacelle which weighs 92-ton is mounted on a heavily steel reinforced foundation.





Eight HEB-550 columns support the stiff rail-beams (of HEB-500), that guides the elevating bed/bench.



Dynamic loading from the setup insight the building is transferred to a heavily steel reinforced plate-foundations in the basement

17 **DTU Wind Energy, Technical University of Denmark** IEA RD&D Task 11 meeting 21/2/2012

Conditions through which the test nacelle can be impacted

1. Variation of drive shaft rotation
2. Grid connection manipulation
3. Environment conditions surrounding test nacelle

1) Test situations for variation of drive shaft rotation
- User input of wind speed pattern/profile and characteristics (speed, turbulence intensity…)
- User input of rotational speed/power/torque profile (over-speed tests…)
- Standard (IEC?) test profiles to be selected from a menu.

2) Test situations for grid connection manipulation
- Grid faults
- Frequency variation
- Grid voltage variation
- Emulation of grids of various strengths/weaknesses

3) Test situations for the environment conditions
- Vibration/twisting of nacelle (replication of response of turbine tower)
- Temperature variation
- Humidity variation
- Salinity levels
- Loading device which can apply 3 forces and 3 moments to the main shaft (will be implemented)

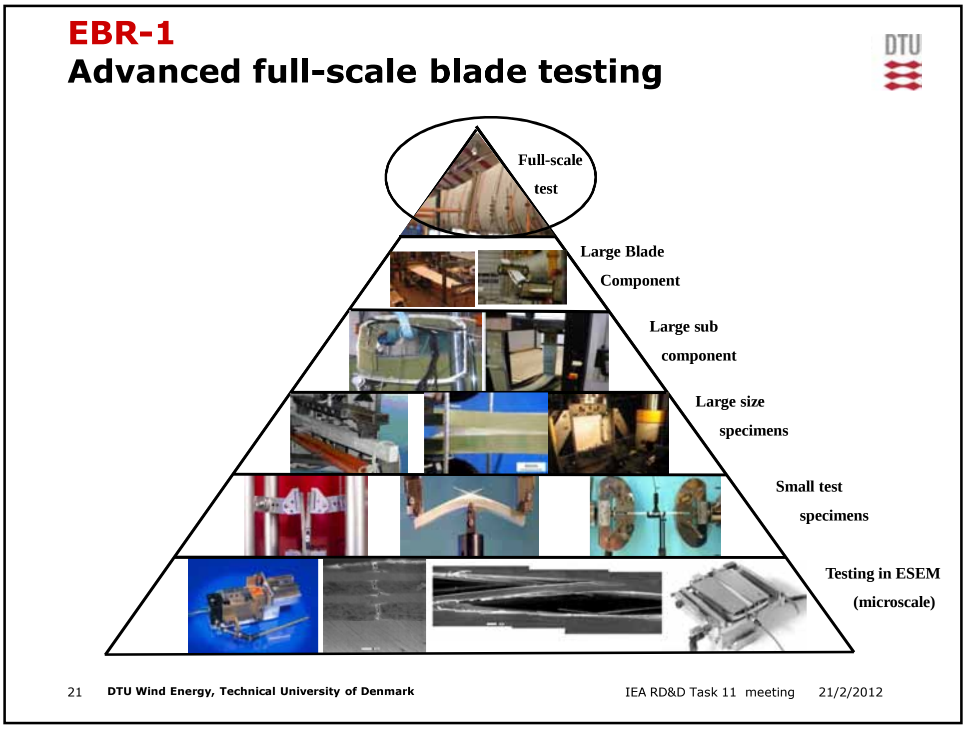
18 **DTU Wind Energy, Technical University of Denmark** IEA RD&D Task 11 meeting 21/2/2012

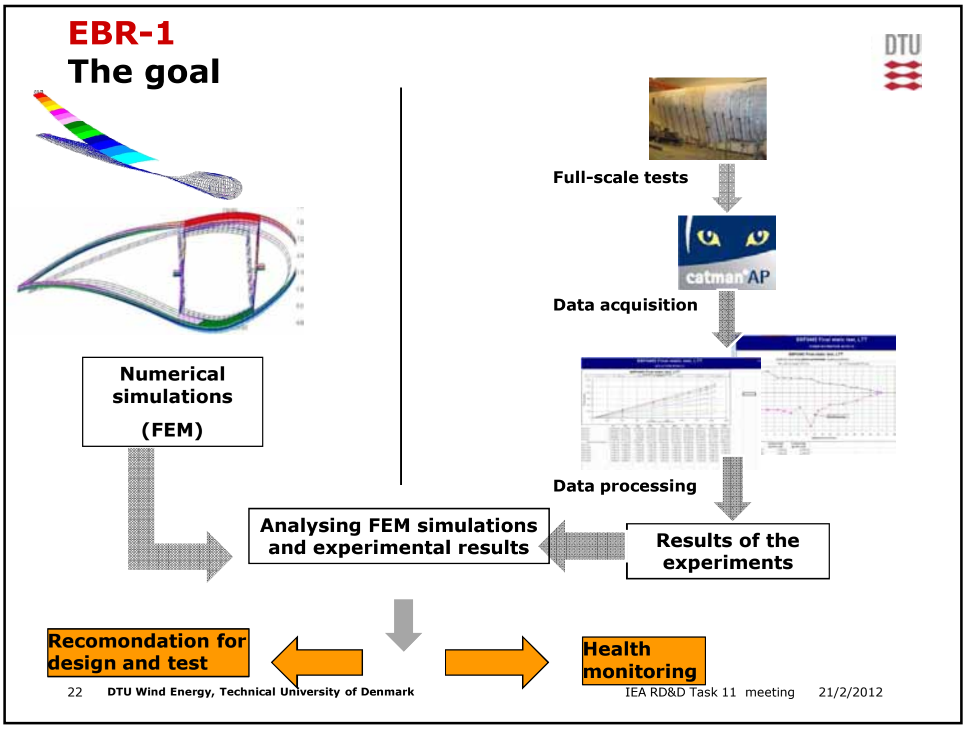
Selected glimses of research activity within:

Wind Turbine Blade Testing

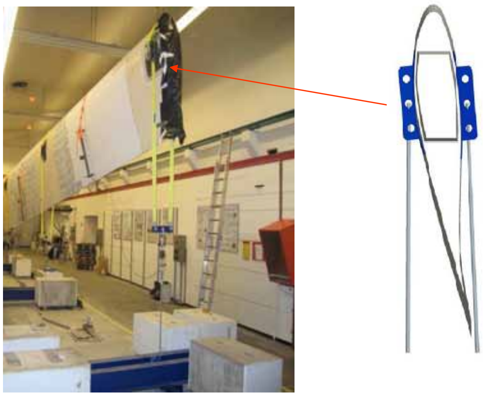
Full-scale blade testing

Full-scale blade testing facility (Risø Campus)


EBR-1
Advanced full-scale blade testing
DTU
Full-scale
test
Large Blade
Component
Large sub
component
Large size
specimens
Small test
specimens
Testing in ESEM
(microscale)
21 DTU Wind Energy, Technical University of Denmark
IEA RD&D Task 11 meeting 21/2/2012


EBR-1
The goal
DTU
Full-scale tests
Data acquisition
Data processing
Numerical
simulations
(FEM)
Analysing FEM simulations
and experimental results
Results of the
experiments
Recomondation for
design and test
Health
monitoring
22 DTU Wind Energy, Technical University of Denmark
IEA RD&D Task 11 meeting 21/2/2012

EBR-1
Edge-wise load test

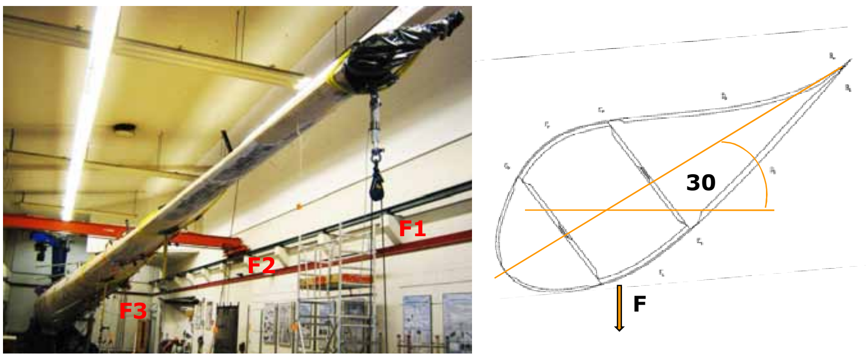


- 3 load application points on the blade F1, F2 and F3 (3 pulley systems)
- Anchor plates is used for the load application

Load application	F3	F2	F1
Risø edgewise load [N]	40013	31675	58099
Distance from root	13.21	18.61	24.91

23 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

EBR-1
Combined load test

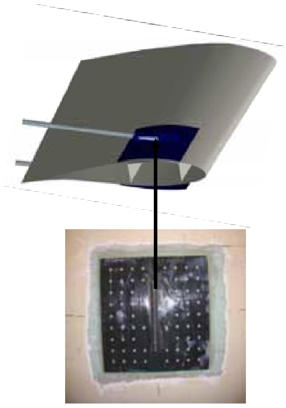


Load application	F3	F2	F1
Risø combined load [N]	86642	80507	142928
Distance from root	13.21	18.61	24.91

24 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

EBR-1
Load application

Loading clamps tyoically used in commercial blade testing



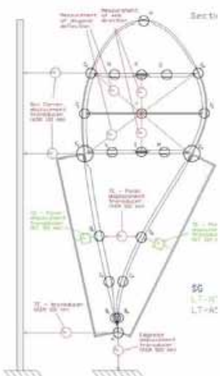
Anchor plates are used in the full-scale test facility at DTU Wind Energy instead of conventional load clamps.

25 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

EBR-1
Instrumentation

The blade is heavily instrumented with mechanical measuring equipment.

- 56 distance transducer are mounted inside and outside on the structure to monitor both the global and local deformations.
- 376 strain gauges are mounted on structure

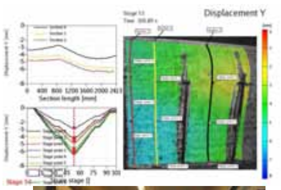


26 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

EBR-1
Instrumentation

A DIC-system (Digital Image Correlation)

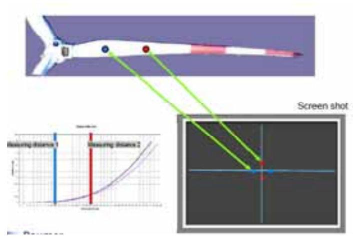
The system is used to measure large scale areas (volumes ~ 3m*3m*3m) Tests has shown a out-of-plane precision within 0.1mm.



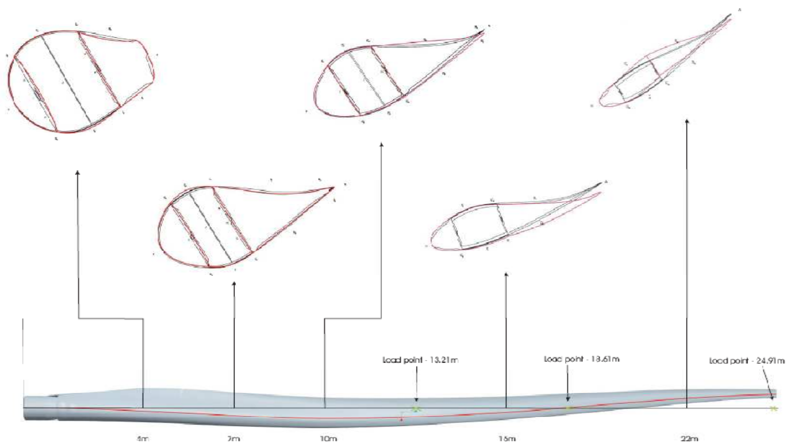
Acoustic Emission is used to detect damage during testing.

Optical blade monitoring system:

Can measure natural deflection, torsion and global displacement



EBR-1
Combined load (Deformation of the blade)



Sub-structural blade testing

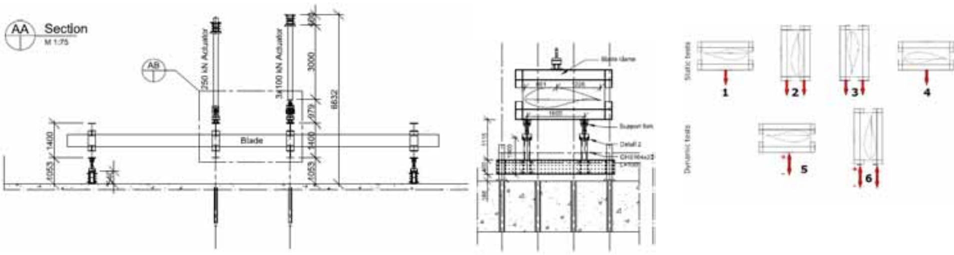
DTU Structural Lab (Lyngby Campus)

29 **DTU Wind Energy, Technical University of Denmark** IEA RD&D Task 11 meeting 21/2/2012

COMMERCIAL PROJECT

Sub-structural 4PB static and fatigue testing of a blade section

- Motivation: *Fast* and *cheap* static and fatigue evaluation of new blade construction details
- Advanced strong floor 4PB-test rig developed at DTU Structural Lab (for 15 m section - flexible)
- Servo-hydraulic controlled loading system making advanced loading possible
- Flap-wise as well as edge-wise loading
- Static: Up to 2 MN, Fatigue: Up to +/- 500 kN



30 **DTU Wind Energy, Technical University of Denmark** IEA RD&D Task 11 meeting 21/2/2012

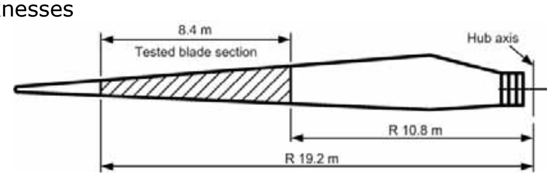
ANBAVI
Experimental investigations on bend-twist coupling in wind turbine blades

- **Motivation**
  - Modern wind turbine blades become very long (60-120 m)
  - Bend-twist coupling is an achievable option for passively controlled load mitigation (e.g. due to sudden wind gusts)
  - There is an interest in possible practical applications of couplings in medium to large turbine blades
- **Studies on a 23 m Vestas wind turbine blade**
  - The original blade is tested in a set of load cases
  - The original blade is then modified by application of extra biased UD layers to introduce the coupling
  - FE analyses on the blade are validated against the experiments
- **Studies on composite beams with coupling behaviors**
  - Simpler geometries with open and closed cross-sections are tested
  - The beams are designed with different layups to study the coupling effects
  - FE models are validated against the experiments

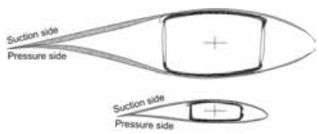
31 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

ANBAVI
Sub-structural tests on a blade section

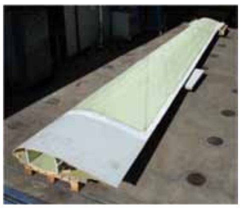
- 8.4 m blade section of a 23 m Vestas wind turbine blade
- Box spar configuration with minimum complexity
- Thin to moderate wall thicknesses
- Extra 25°biased UD layers



600 kW Vestas wind turbine with 47m rotor diameter



Root and tip cross-sections of the blade section



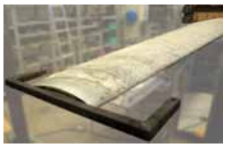
Modified blade section with extra UD layers

32 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

ANBAVI
Test setup for blade section tests

- Clamped boundary conditions applied by two root clamps
- All the loads are applied at the free end:
  - through a load clamp
  - through a special handle
- Multi-axial hydraulic system is used for load application

Load clamp with hydraulic actuators at the blade section free end



Special handle for torque application

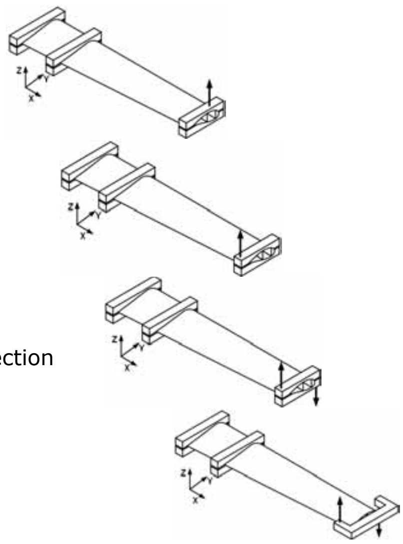
3D model of the test rig with mounted blade section

The blade section mounted in test facilities

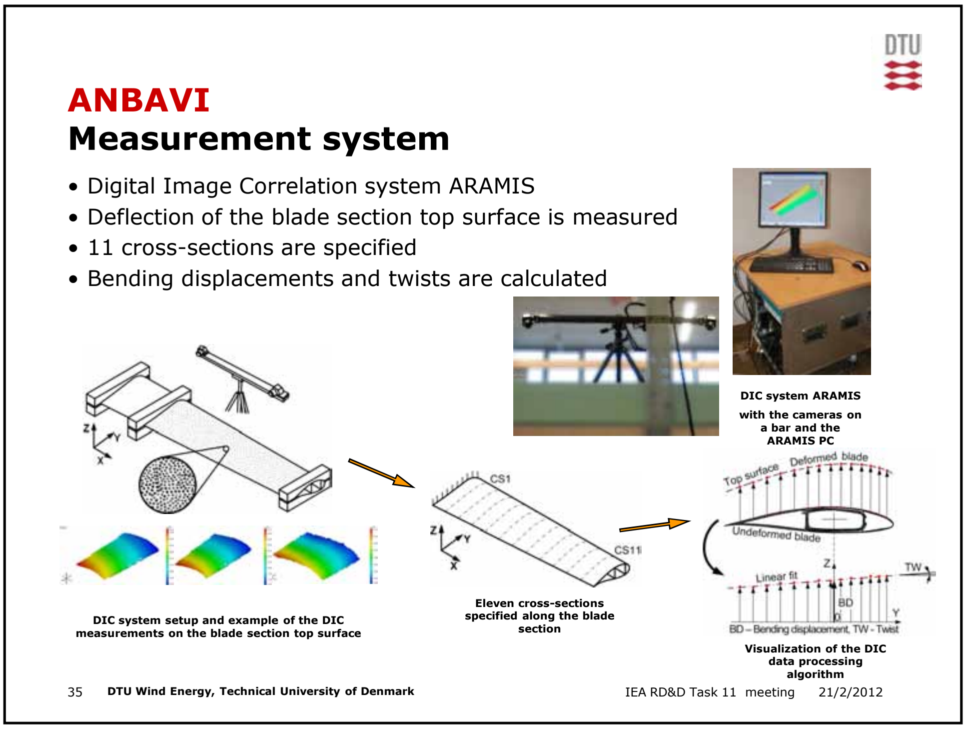
33 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

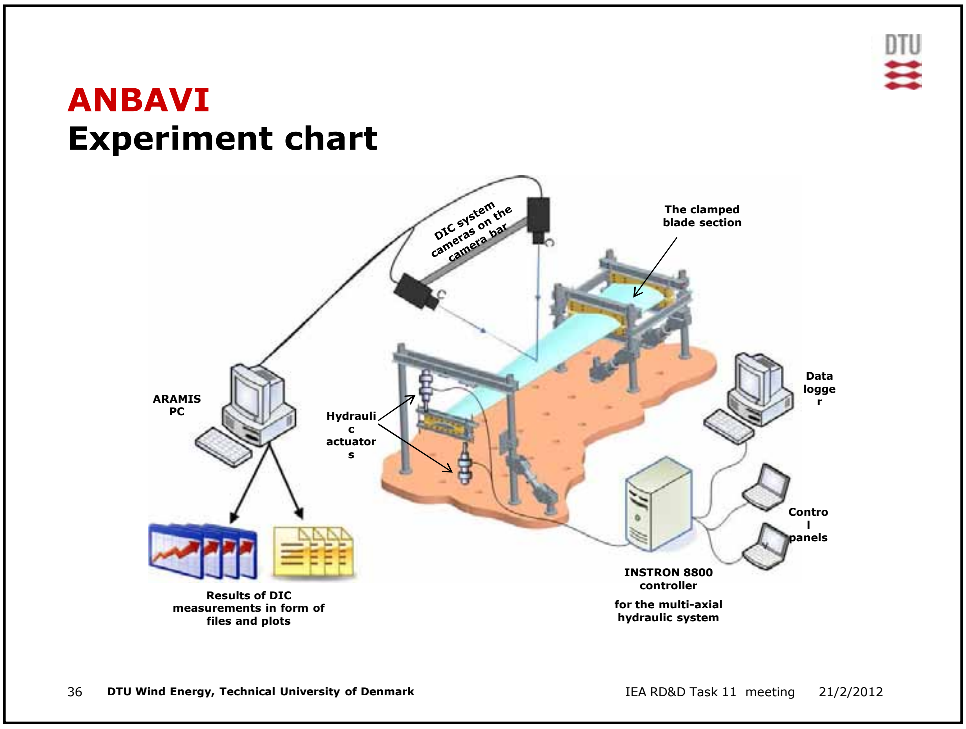
ANBAVI
Load cases

- Flap-wise shear force bending:
  - Constant shear force distribution
  - Linear bending moment distribution
- Flap-wise shear force bending:
  - Constant shear force distribution
  - Linear bending moment distribution
  - Constant torque distribution
- Pure torsion:
  - Constant torque distribution
  - Torque applied to the entire cross-section
- Spar torsion
  - Constant torque distribution
  - Torque applied only to the spar



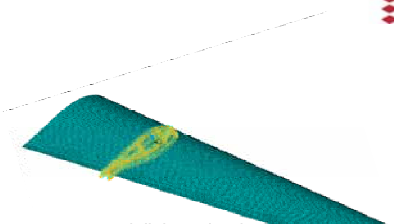
34 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012


ANBAVI
Measurement system
• Digital Image Correlation system ARAMIS
• Deflection of the blade section top surface is measured
• 11 cross-sections are specified
• Bending displacements and twists are calculated
DIC system ARAMIS with the cameras on a bar and the ARAMIS PC
DIC system setup and example of the DIC measurements on the blade section top surface
CS1
CS11
Eleven cross-sections specified along the blade section
Top surface
Deformed blade
Undeformed blade
Linear fit
BD
TW
BD – Bending displacement, TW - Twist
Visualization of the DIC data processing algorithm
35 DTU Wind Energy, Technical University of Denmark
IEA RD&D Task 11 meeting 21/2/2012

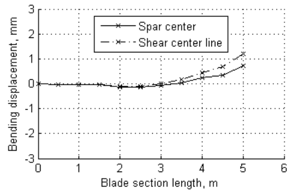

ANBAVI
Experiment chart
DIC system cameras on the camera bar
The clamped blade section
ARAMIS PC
Hydraulic actuators
Data logger
Control panels
Results of DIC measurements in form of files and plots
INSTRON 8800 controller
for the multi-axial hydraulic system
36 DTU Wind Energy, Technical University of Denmark
IEA RD&D Task 11 meeting 21/2/2012

ANBAVI
FE models and results

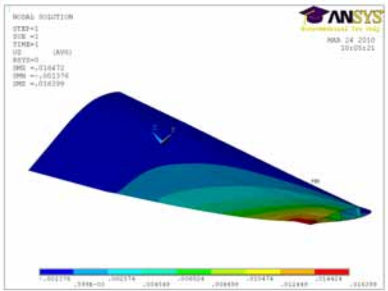
- A set of FE models is developed:
  - NASTRAN Shell/Solid model
  - ANSYS Shell model
  - ANSYS Shell model with offsets
- Accuracy problem of the offsets techniques is demonstrated
- The bend-twist coupling effect in the modified blade section is studied



ANSYS shell element based FE model of the blade section



Experimentally measured bending of the blade section in pure torsion induced by bend-twist coupling



FE results of the global blade section deformation in pure torsion load case

37 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

Blade component testing

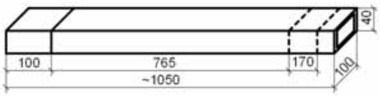
DTU Structural Lab (Lyngby Campus)

38 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

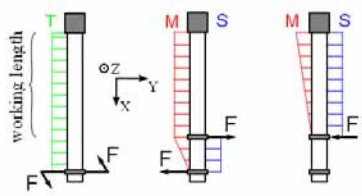
DTU

ANBAVI
Tests on coupled composite beams

- Straight forward geometries
- Open and closed cross-sections
- Biased UD layers for bend-twist coupling:
  - Full UD flanges with 0°,15°,25°
  - Biax shear webs
- A set of load cases:
  - Shear force bending
  - Pure bending
  - Pure torsion



Composite Box-beam specimen geometry



Load cases for the composite beams
T – torque, M – bending moment, S – shear force


Box-beam cross-section

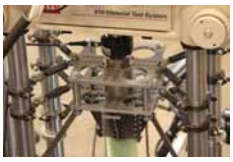

I-beam cross-section

39 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

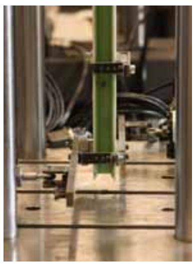
DTU

ANBAVI
Test setup

- Four-column testing machine as a foundations
- Clamped boundary conditions
- A special protective setup for the vertical actuator
- Multi-axial hydraulic system for load application
- Two ARAMIS DIC systems for global measurements (bending, twist) and local measurements (warping)


Special protective setup for the vertical actuator


Setup for experiments on the composite beams. The beam is clamped at the top, the load is applied at the lower tip

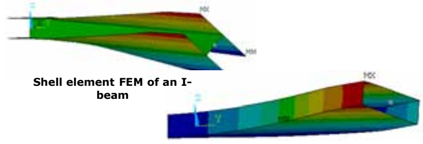

Load application at the beam tip


Setup of two DIC systems: Left – for warping measurements, right – for global response measurements

40 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

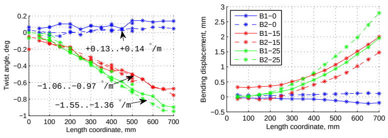
ANBAVI
Short results

- A set of FE models of different detail levels are developed and validated:
  - Shell element models
  - Solid element model
  - Continuum shell element model
- Bending and torsion load cases studied
- Warping along the beam wall studied numerically and experimentally



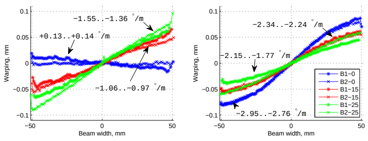
Shell element FEM of an I-beam

Shell element FEM of a Box-beam



Experimentally measured Box-beam twist response in pure bending

Experimentally measured Box-beam bending response in pure torsion



Experimentally measured warping of a Box-beam in pure bending

Experimentally measured warping of a Box-beam in pure torsion

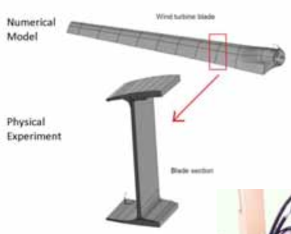
41 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

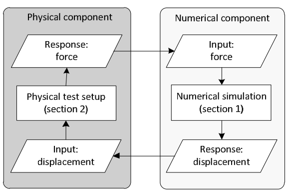
DCCSM
Hybrid testing of wind turbine blade components

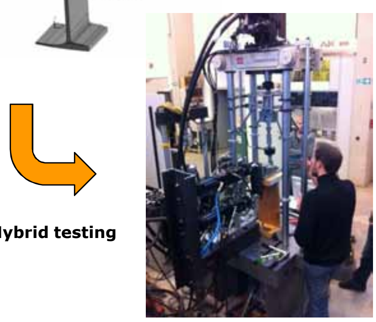
Concept:

Divide structure into two sections:

- ***Section 1***: full structured blade modeled in e.g. FEM
- ***Section 2***: sub-part of structure, tested in experiment with complex local phenomenon, e.g. fracture, buckling etc.





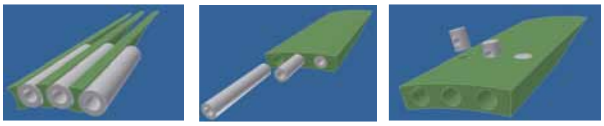


Hybrid testing

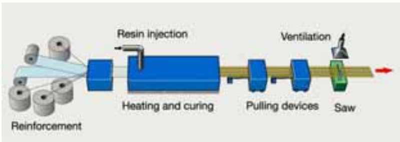
42 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

INNO-JOINT

Component testing of new blade root joint solutions

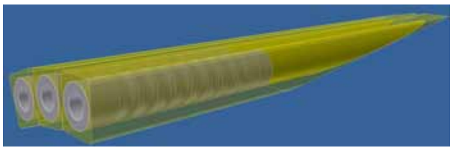


Existing root solutions



Root joint sub-component manufacturing using pulltrusion

Patented new sub-component root joint element solution (by Fiberline Composites)

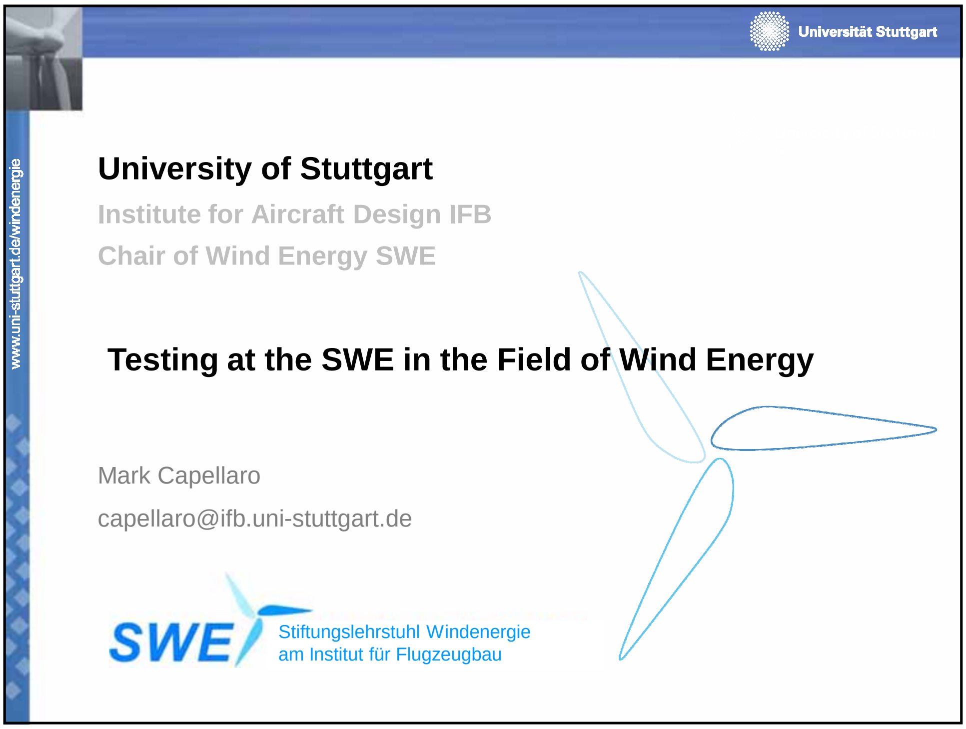


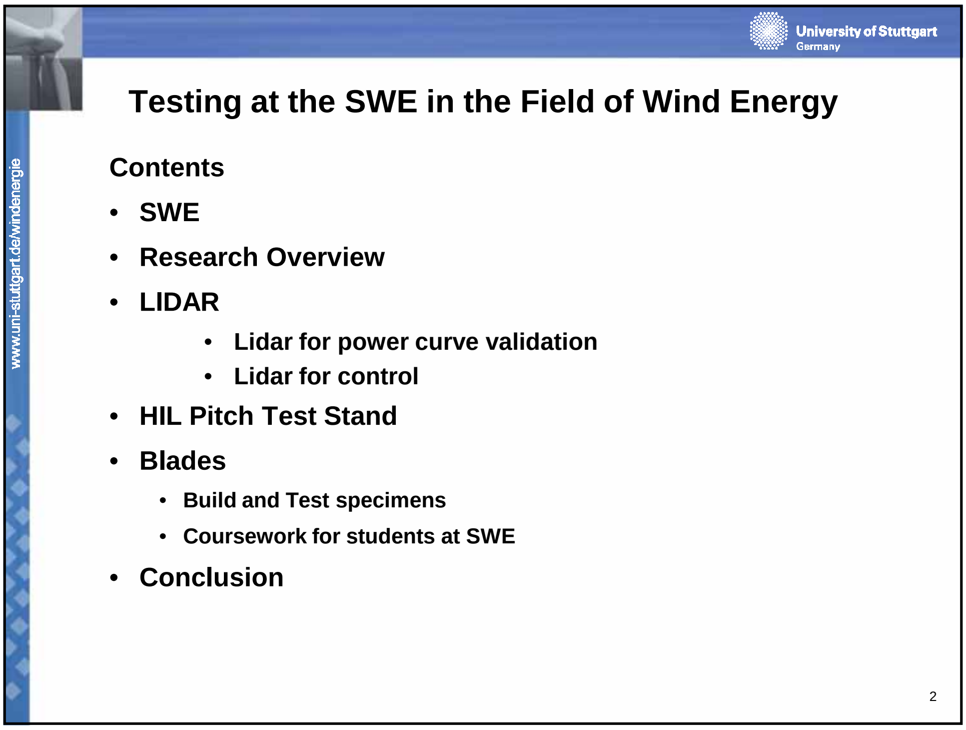
43 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012

THE END

Thank you for your attention!

44 DTU Wind Energy, Technical University of Denmark IEA RD&D Task 11 meeting 21/2/2012


Universität Stuttgart
www.uni-stuttgart.de/windenergie
University of Stuttgart
Institute for Aircraft Design IFB
Chair of Wind Energy SWE
Testing at the SWE in the Field of Wind Energy
Mark Capellaro
capellaro@ifb.uni-stuttgart.de
SWE
Stiftungslehrstuhl Windenergie
am Institut für Flugzeugbau


University of Stuttgart
Germany
www.uni-stuttgart.de/windenergie
Testing at the SWE in the Field of Wind Energy
Contents
• SWE
• Research Overview
• LIDAR
• Lidar for power curve validation
• Lidar for control
• HIL Pitch Test Stand
• Blades
• Build and Test specimens
• Coursework for students at SWE
• Conclusion
2

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Testing at the SWE in the Field of Wind Energy

SWE

- **Germany's first research chair in wind energy (2004)**
- **Professor Po Wen Cheng (formerly of GE offshore research)**
- **14 Phd Researchers + associated staff**
- **Research topics:**
  - **Multi body simulation and floating turbine dynamics**
  - **Offshore structures for WTG**
  - **Lidar (control, power curves, offshore...)**
  - **Load monitoring**
  - **IPC (HIL test stand)**
  - **Composite blade design**

3

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Lidar: Power Curve Measurement

1st Class anemometer

Temperature sensor and 3D-sonic anemometry

Large Scale Testing
Goal is to improve IEC standard

Measurement project
- Power curve and load measurement
- Met mast (102 m height)
- Meteorological sensors
- Data acquisition system
- LIDAR device

[Fig. SWE]

4

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Lidar: Scanner development for nacelle-based LiDAR system

Modifications for nacelle installation

- Laser beam orientated almost horizontally
  → Replacement of the internal beam deviation (mirror)
- Development of a scanning system
- Integration of scanner unit
- Software development

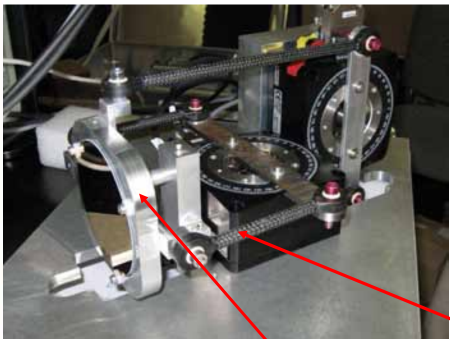
Scanner system requirements

- Flexible trajectories (max. 50 points per trajectory)
- For each direction: 5 measurement points (line-of-sight) in 5 distances
- High speed and acceleration
  → Complete trajectory every 5–9s
- Repeatability accuracy

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Lidar: Scanner - single mirror with 2DOF



Specs of rotation stages

• Resolution	0.00001
• Reversal Value	0.0001 °
• Absolute Accuracy	0.01 °
• Maximum Speed	720 °/s
• Maximum Acceleration	1000 °/s²
• Maximum Torque (Mz)	0.42 @ 0°/s Nm
• Maximum Inertia (Iz)	0.032 kgm²

Source: Newport ®

Carbon fiber rods, additionally braided

Lightweight frame and mirror

[Fig. SWE]

6

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Lidar: Installation on AREVA Wind M5000

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Lidar: Installation of nacelle-based LIDAR

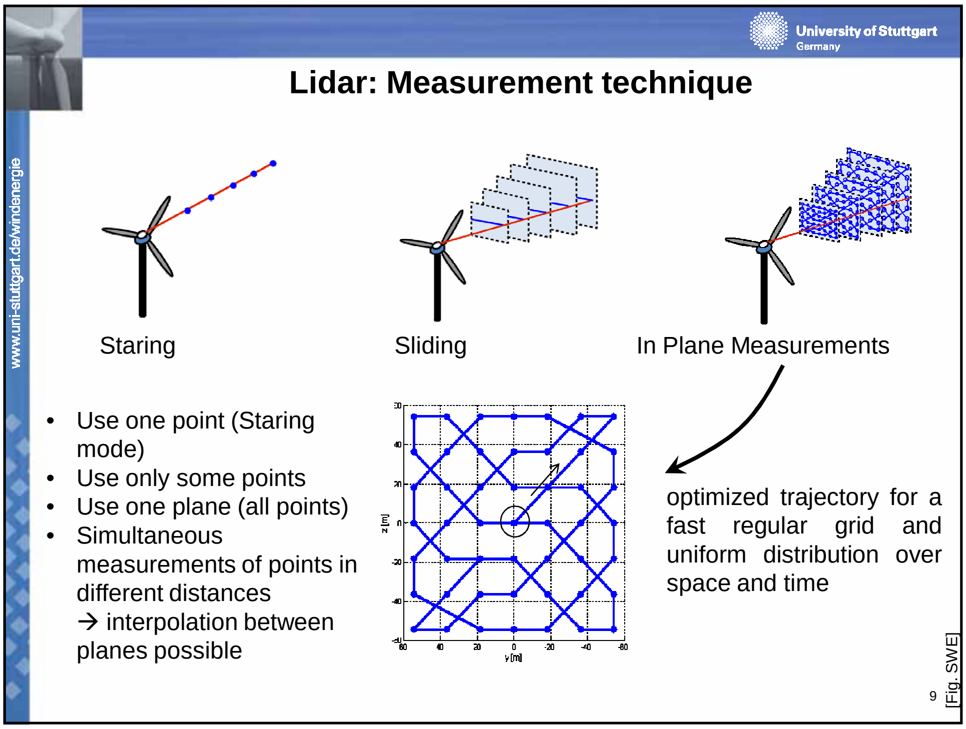
AREVA-Multibrid M5000 prototype

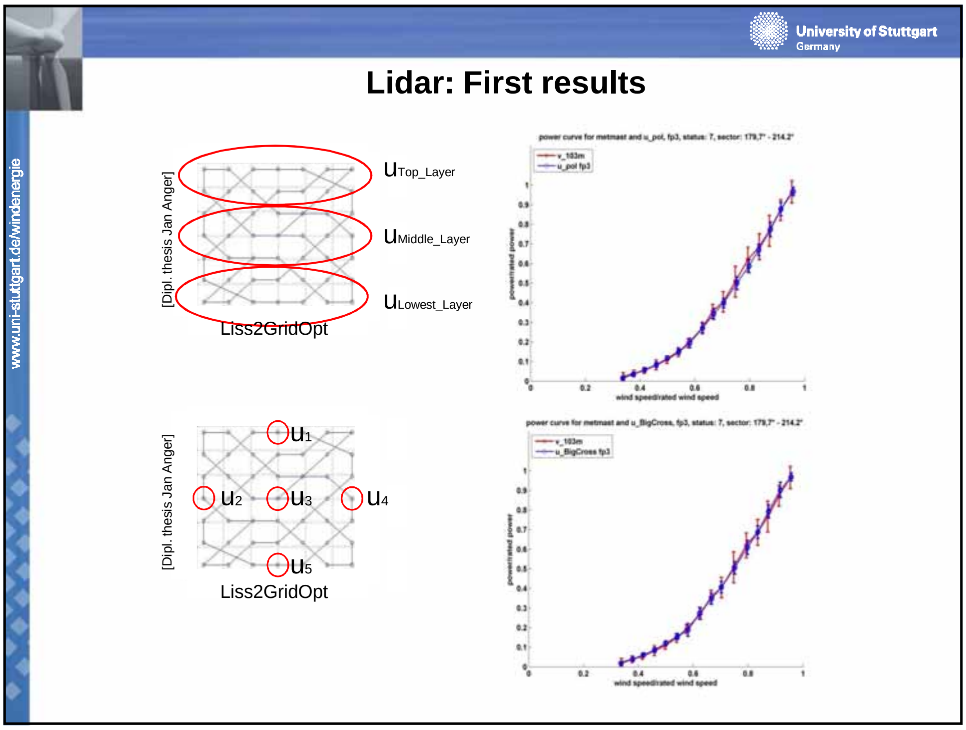
- 5 MW with 116m rotor diameter
- 102m hub height
- Heavily equipped with sensors
- Mounted LIDAR system + scanner
- Met mast with meteorological sensors

LIDAR system + scanner

[Fig. SWE]

8

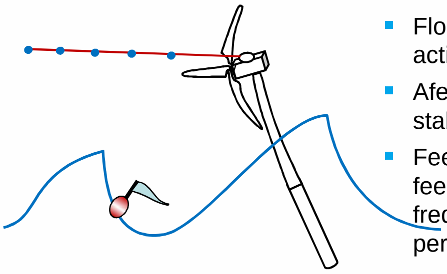

University of Stuttgart
Germany
www.uni-stuttgart.de/windenergie
Lidar: Measurement technique
Staring
Sliding
In Plane Measurements
• Use one point (Staring mode)
• Use only some points
• Use one plane (all points)
• Simultaneous measurements of points in different distances
→ interpolation between planes possible
optimized trajectory for a fast regular grid and uniform distribution over space and time
z [m]
y [m]
[Fig. SWE]
9


University of Stuttgart
Germany
www.uni-stuttgart.de/windenergie
Lidar: First results
[Dipl. thesis Jan Anger]
u_{Top_Layer}
u_{Middle_Layer}
u_{Lowest_Layer}
Liss2GridOpt
u_1
u_2
u_3
u_4
u_5
Liss2GridOpt
[Dipl. thesis Jan Anger]

University of Stuttgart
Germany

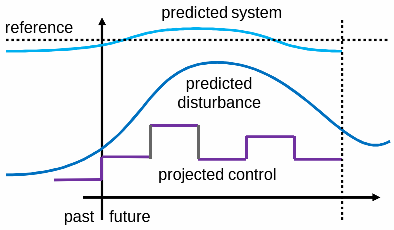
www.uni-stuttgart.de/windenergie

Lidar: Model Predictive Control



- Floating turbines are stabilized if the pitch action is slow compared to the tower motion
- Afeedforward controller cannot destabilize a stable system
- Feedforward (e.g. LIDAR and waveform) + feedback controller with lower natural frequency = simple update, good performance and stability

- Motion of floating turbines is highly nonlinear
- Waves and wind changes are important but measurable and predictable disturbances
- Sophisticated control strategies as Nonlinear Model Predictive Control can be applied more effective with knowledge about future disturbance



[Fig. SWE]

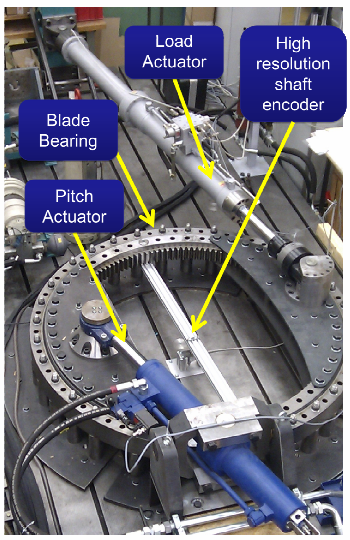
11

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

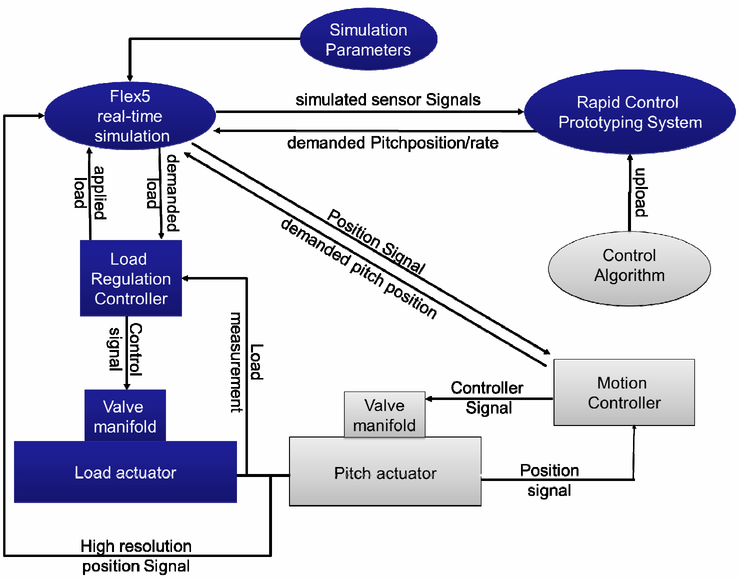
Hardware-in-the-Loop-Simulation of Individual Pitch Control Systems

- Proof of concept on close-to-production-hardware
- Validation and optimization of standard motion controllers with special respect to advanced control algorithms
  Validation of pitch control systems under realistic loading
- Validation and optimization of signal processing for advanced controls



12

HIL Pitch Test Stand: Signal Flow Chart



13

HIL Pitch Test Stand: Technical Data

- Real time Version of Flex5 (cycle time: 5ms)
- Simulation of IEC design load cases
- Test of electric or hydraulic pitch systems up to 2.5MW wind turbine class
- Integration of arbitrary control systems
- synchronous hydraulic load actuator system with a rated force of 220kN and total hydraulic power of 165kW
- Integration of 'in the loop' blade root load sensor Systems (e.g. Fiber optics, strain gauges)

14

University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

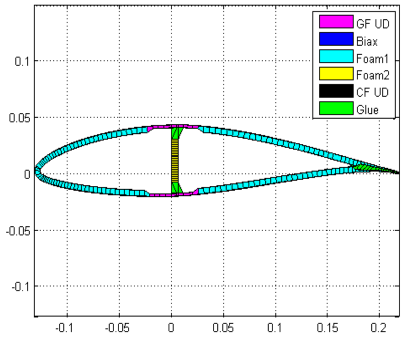
Blades and Composite Testing:

Wind turbine blades are extensively tested.

- *no one trusts composite materials or design tools used in blade design.*

Lamina material properties vary and testing is necessary, along with healthy safety factors, to ensure safety.

To test a blade design code/method and to determine potential for building a coupled blade (anisotropic), a 2m blade specimen was built and tested at Stuttgart.



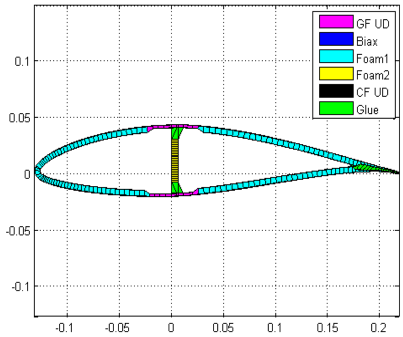
University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Blades and Composite Testing: Modelling of Test Blade with VABS FE code

Optimization Analysis:

- 2-D FEM Program VABS
- Sectional properties in a short amount of time (EI_1, EI_2,GJ,...)
- Inputs are geometry, material properites (E_1,E_2..) and location (lamina schedule)
- Short analysis time allows for possibility to loop optimization (stiffness optimization).



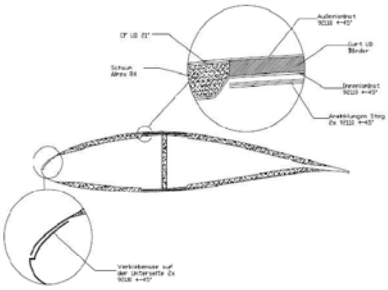
University of Stuttgart
Germany

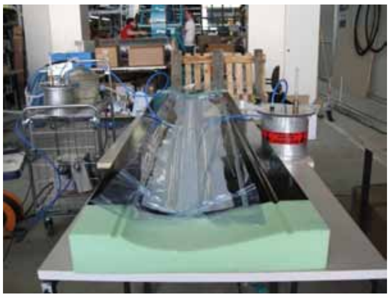
www.uni-stuttgart.de/windenergie

Blades and Composite Testing: Design of Test Blade

– The test specimen was scaled, as much as possible, from the UpWind reference turbine model.

- Uniform blade section (no twist or chord change) allowing for better test results.





[Dipl. thesis Florian Henne]

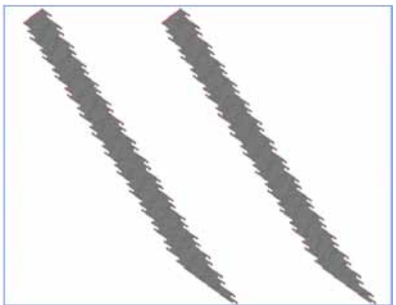
University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Blades and Composite Testing: Manufacture of Test Specimen

Carbon fiber coupling material (to produce bend twist coupling

- Fibers applied with tailored fiber placement stitching machine (1200k HT-Rovings)
- Fibers held in place with thermoplastic layer and threads
- These melt out during the process (no degradation in material properties).
- Wrapping of fiber ends to control load path.



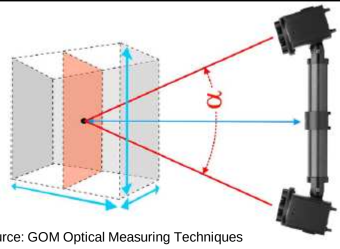
University of Stuttgart
Germany

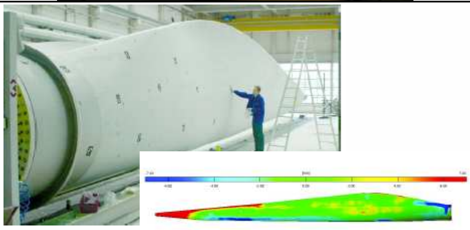
www.uni-stuttgart.de/windenergie

Blades and Composite Testing: Equipment

Aramis Optical Measurement system.

- Stereo cameras create a three dimensional image of the blade
- Contrast (B&W points) on blade is used as focus points for cameras





Source: GOM Optical Measuring Techniques

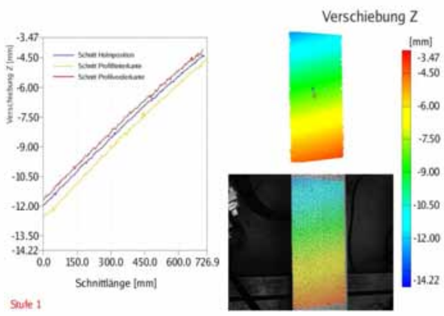
University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Blades and Composite Testing: Results

Optical Measurement Results

- Determination of the bending deflection across the blade section.
- From the bending, the blade stiffness (EI_2) can be determined.
- BTC Torsional deformation from shear load is clear
- Loading/deflection calcuated stiffness matched well with FE predicted values (including coupling stiffness).



	Units	Test Results	FE Results Corrected	Diff-erence	FE Results	Diff-erence
Bending Stiffness	[Nm²]	15064	15780	5%	16745	11%
Torsion Stiffness	[Nm²]	6107	5292	13%	6685	9%
α (coupling)	[-]	-0.225	-0.207	8%	-0.206	8%

Shape	Test Results	Analytical Results Corrected	Diff-erence	Analytical Results	Diff-erence
[Units]	[Hz]	[Hz]	[%]	[Hz]	[%]
1st Flap	13.51	13.55	0.3	13.9	3.2
2nd Flap	82.5	85.1	3.2	NA	NA
1st Edge	34.1	NA	NA	NA	NA
1st Torsion	90.1	89.5	0.5	100.6	11.7

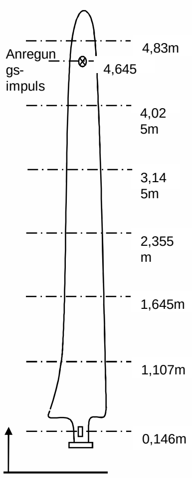
Teaching to Test

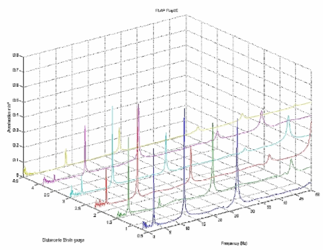
The SWE also offers a course called Windenergie Labor.

This is a course designed to give students some hands on experience with methods and tools used in the wind turbine industry.

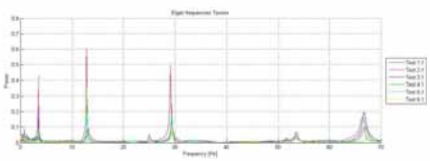
- Power curve calcuation (from local turbine and mast according to IEC).
    - Blade Testing
    - Static test (max load)
    - Mode testing (to determine 1st, 2nd flap, 1st edge and 1st torsion)
    - Design of fatigue testing (using first two test results).
- Drive train testing

Teaching to the Test





By using our accelerometers and some simple signal processing, students develop the eigen frequencies, including torsion, and the eigen shapes of the Hütter blade.



University of Stuttgart
Germany

www.uni-stuttgart.de/windenergie

Other ongoing projects...

- ProTEST (Determination of load cases for wind turbine gear boxes ECN)
- LIDAR for control installed (?) on the NREL CART (Controls Advanced Research Turbine) in USA.
- Offshore floating Lidar buoy.
- *Blade manufacturing automation - IFB*
- *Uniform Test Specimen (expanded blade mould for manufacturing automation and testing of new materials, validation of design codes).*

Thank you for your attention

Mark Capellaro

capellaro@ifb.uni-stuttgart.de

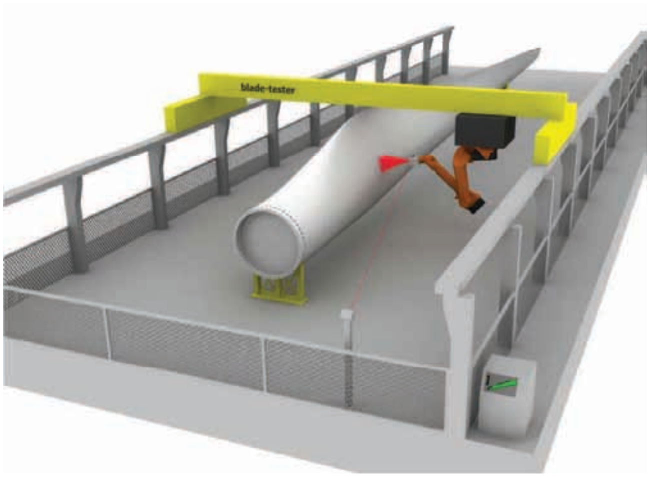
Stiftungslehrstuhl Windenergie

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

BladeTester

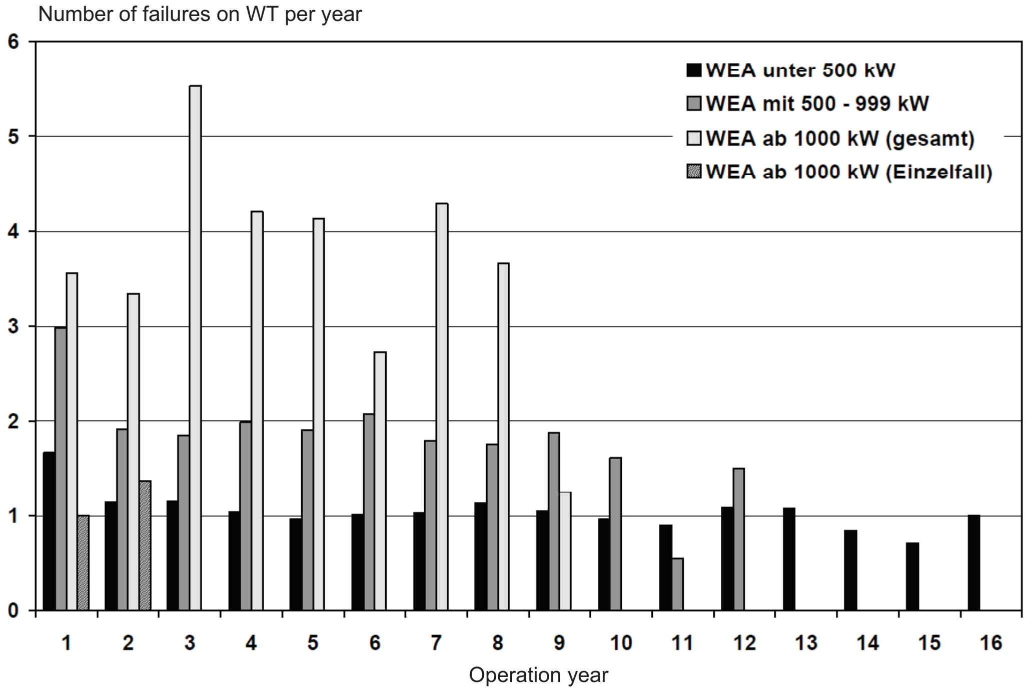
Automated approach for serial integrity tests of rotor blades

Y. Petryna, Technische Universität Berlin



Availability WT

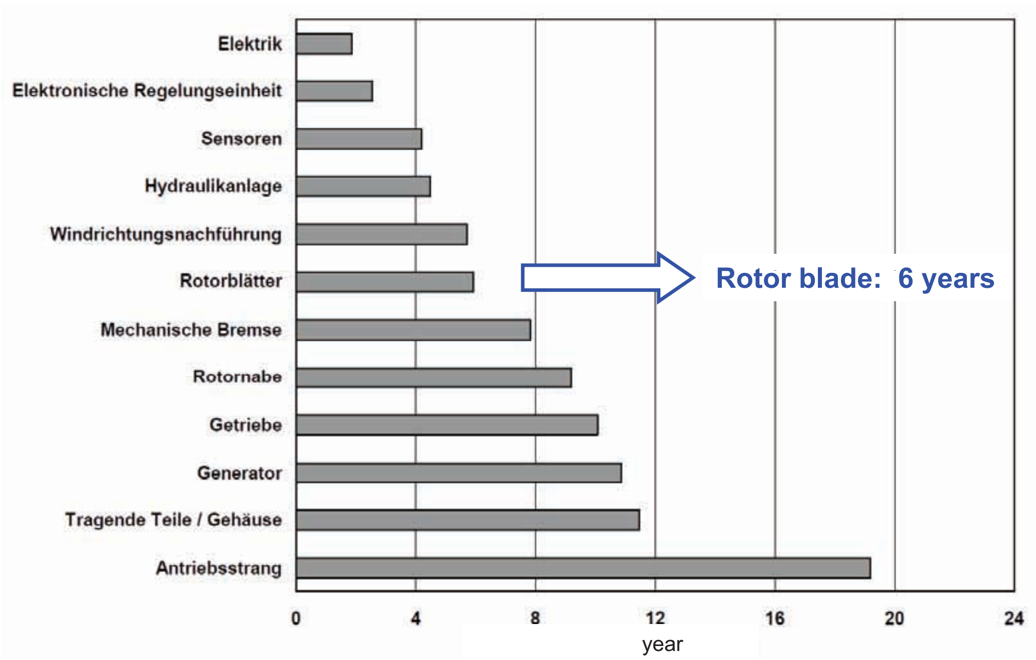
Technical availability 98-99%



Ref.: Windenergie Report Deutschland 2006

Damage statistics for WT components

Average (statistical) time interval between two failures



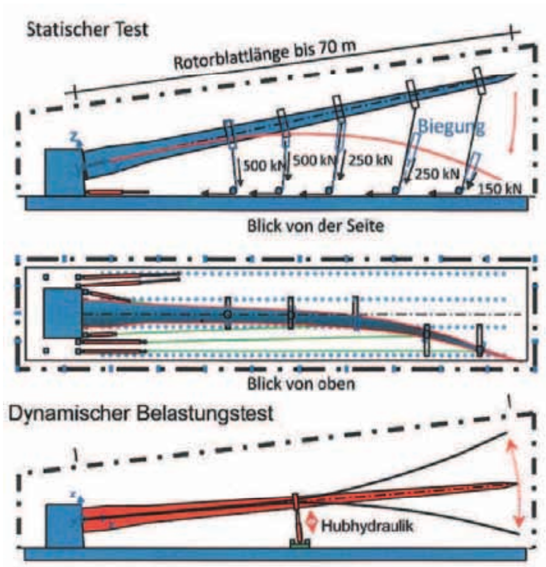
Ref.: Windenergie Report Deutschland 2006

Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* 3

Rotor blade testing: Fraunhofer IWES

Goals: Verification of operational safety
Integral tests of carrying capacity
Verification of operational service life
Type test, i.e. 1-2 RB for each series

Full-scale static and dynamic tests (single blades)



Test duration: month(s)

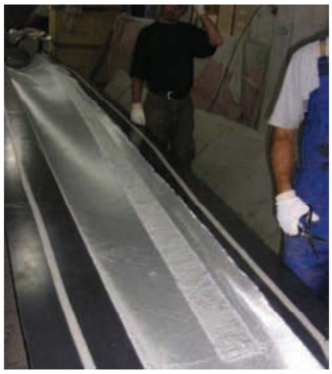
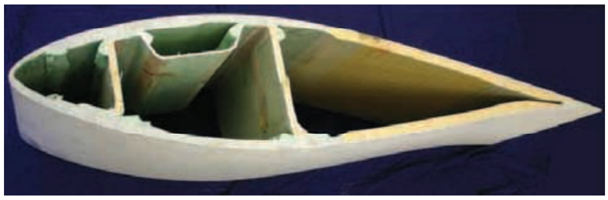
Ref.: Fraunhofer IWES

Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* 4

Motivation

Manufacturing conditions:

- increasing automation, but still much hand work
- human factor = high error rate
- production technology aspects:
  blind gluing
  laminating / layering
  impragnating
  curing
  etc.
- Price policy reduces quality

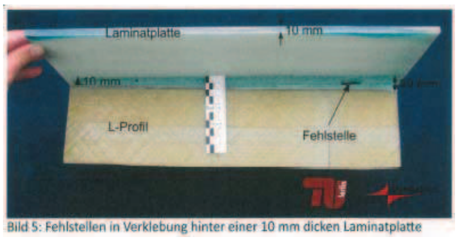




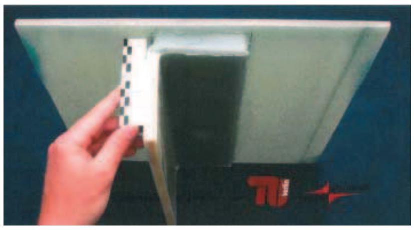
- Rotor blade possess individual manufacturing defects and need to be individuallly tested
- Fast serial tests of each rotor blade are a good complement to the full-size IWES tests
- Serial testing is a responsibility of manufacturers and their individual know-how

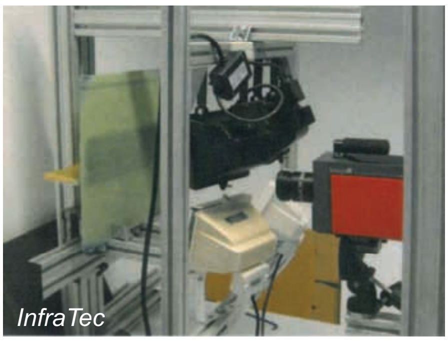
Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* 5

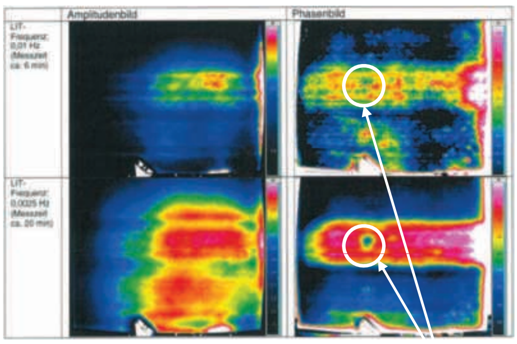
Testing methods: Thermography

Spesimen with defects









Drawbacks:
- Interpretation of measurements
- Depth limitations
- Time of testing, especially for thick components and large surfaces

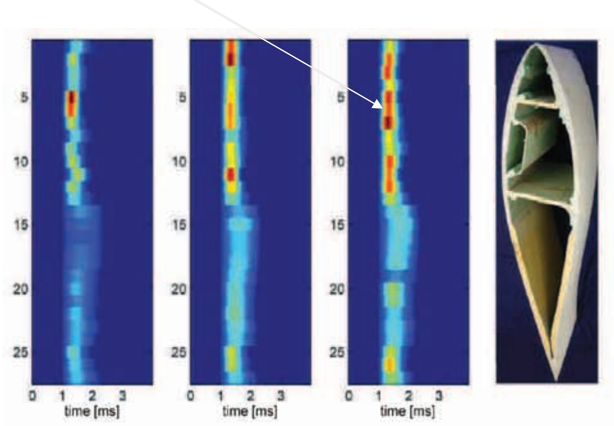
Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* 6

Testing methods: ultrasound

- reflection of US signals on material interfaces
- strong damping in layered structures
- wave length to defect size ratio

Resonance spectroscopy

Signal difference = structure change



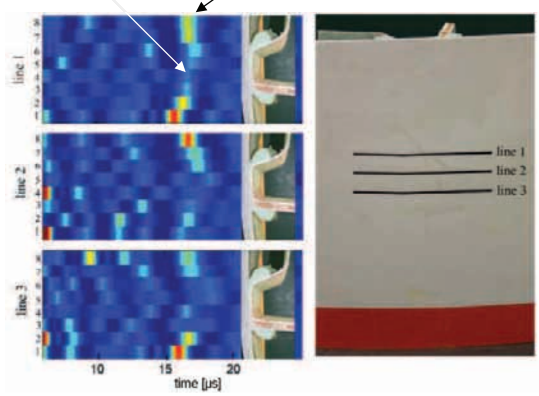
Force signals (impulse excitation)

Acoustic wave (tapping)

Ultrasound echo

Intact cohesion

Back surface echo

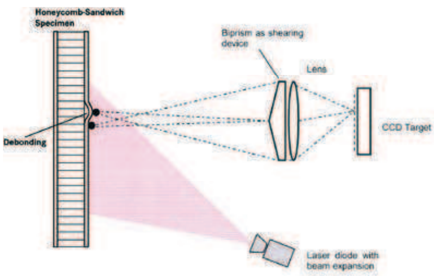


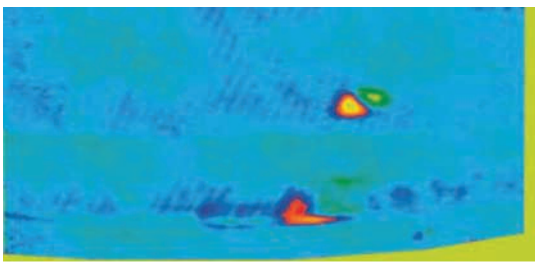
Time-energy diagrams

Ref.: MPA Stuttgart

Testing methods: Shearography

Interferometry: overlapping of state images with and without loading
= image correlation approach
- Loading type: thermal, pressure or vacuum loading
- calibration required for various defect types and depths





Ref.: Steinbichler

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Joint Research Project Bladetester

„ Automated approach for serial integrity tests of rotor blades“

Goals:
- cheap and serial integrity tests on production site
- automated detection of manufacturing defects and their localisation
- prediction of defect influence on rotor blade integrity resp. fatigue and life-time
- statistical data base of manufacturing defects for quality management

Main features:

- intelligent non-destructive testing (i-NDT)
- in combination with specific static and dynamic loading (detection improvement)

- Use of verified computer model
- arbitrary position of rotor blades, no expensive clamping facility
- special test rotor blades - tuners - with known / pre-defined defects

- test facility on production site, no transport costs for testing
- testing rate = production rate

Duration: October 2011 – September 2014
Budget: 3 M€

Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* 9

Joint Research Project Bladetester

Project partners

Project Coordinator	Technische Universität Berlin Chair of Structural Mechanics
BAM Bundesanstalt für Materialforschung und -prüfung	Federal Institute of Material Research and Testing Department V.64 Mechanics of polymer materials
steinbichler	Steinbichler Optotechnik GmbH

Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* 10

Joint Research Project Bladetester

Partners

SINOI GmbH Manufacturer

Fraunhofer Institut für Windenergie und Energiesystemtechnik

Automated Precision Europe GmbH

WindNovation Engineering Solutions GmbH

DEWI-OCC Offshore and Certification Center GmbH

Ingenieurbüro
Werkhausen

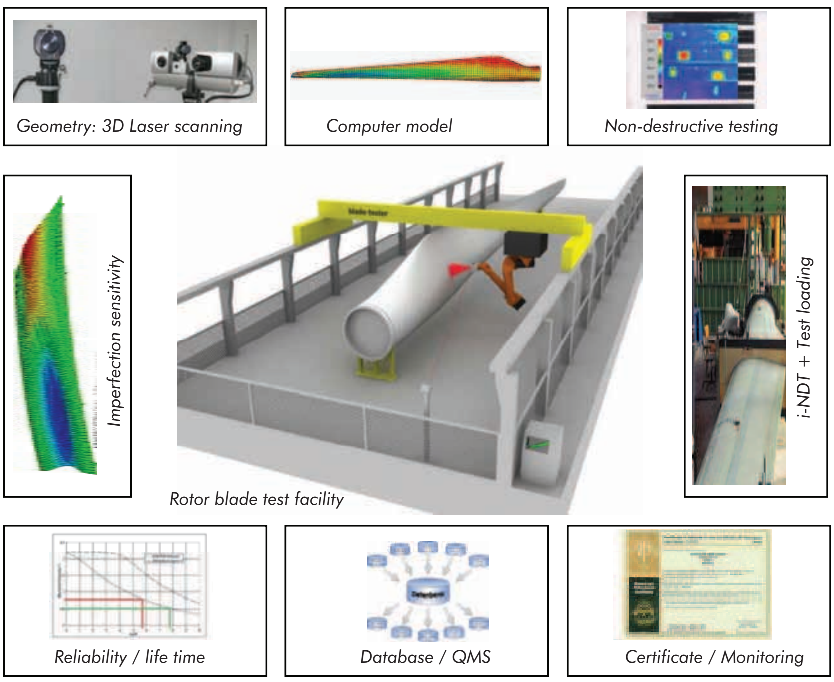
Ingenieurbüro Werkhausen

Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* *11*

BladeTester

Working packages:

WP1: virtual blade testing
WP2: smart testing approaches
WP3: integral test facility



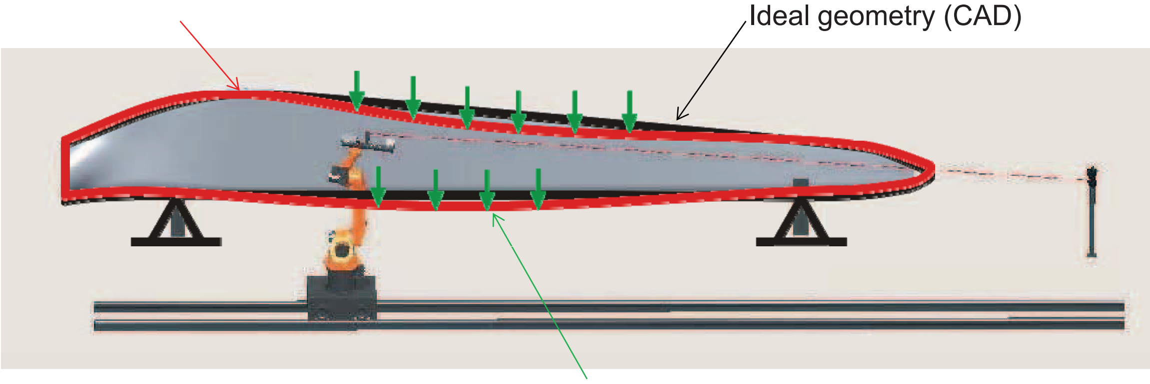
Y. Petryna, BladeTester *IEA R&D Wind, Task 11, TEM #68, Aachen, 21-22 February, 2012* *12*

Computer model & geometry scanning

• A verified computer model serves as a gap between the ideal geometry (CAD) and the measured geometry (3D scanning).
• Specific feature: scanning is possible only in a deformed state (dead load). At that, imperfections / defects are much smaller than deflections. This deformation must be taken into account .

3D-Scanning of the surface, accuracy:
100 μ to 25 μ (surface quality)

Ideal geometry (CAD)

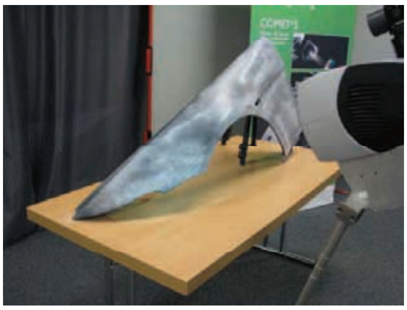


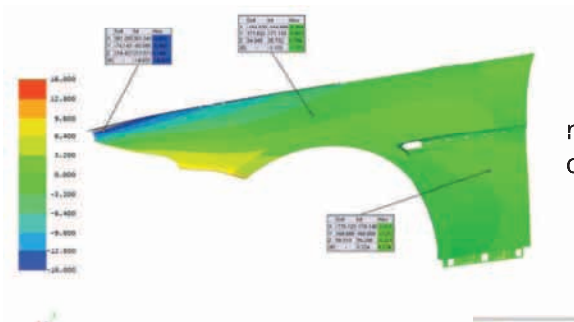
3D deformation due to dead weight:
(bending and torsion)

3D scanning of flexible structures

The same specimen in

vertical position | horizontal position

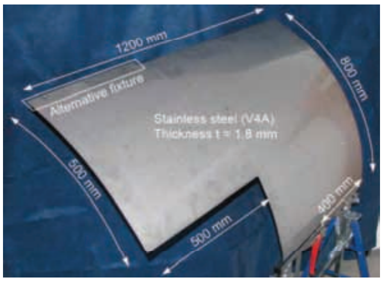


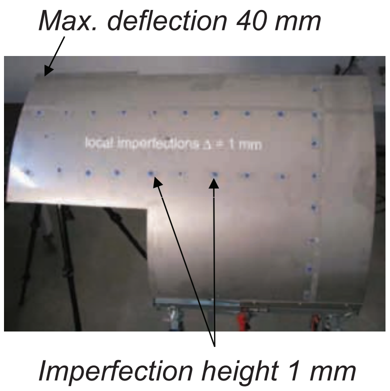


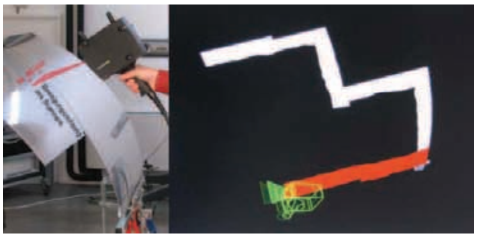
measurement accuracy < 0.1 mm
deformation: 16 mm

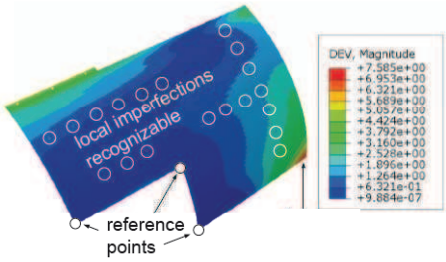
Measurement support by: steinbichler

Identification of imperfections by 3D scanning and simulation





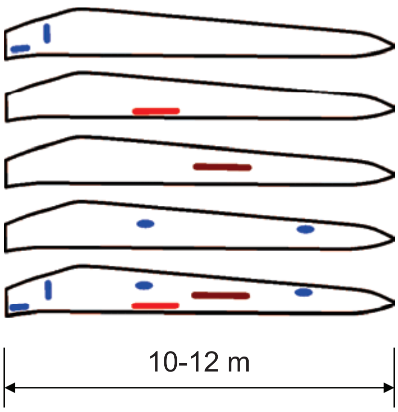




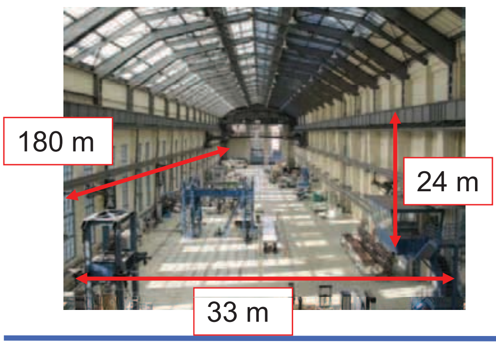
Measurement support by: steinbichler

Ref.: F.Vogdt

Tuners and testing facility



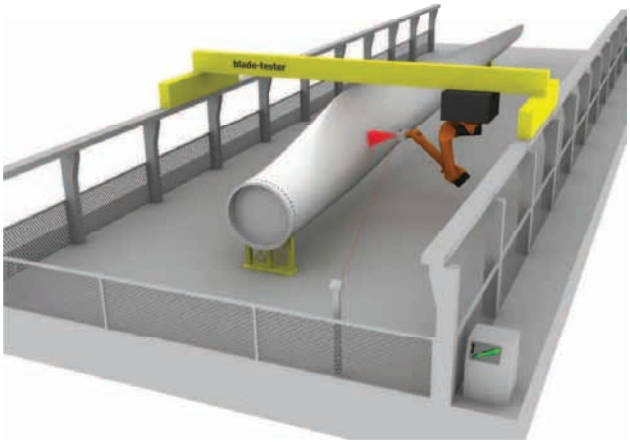
- rotor baldes with installed (built-in) pre-defined manufacturing defects serve as specimen (tuners) for NDT techniques and approaches
- typical structure of rotor blade
- type, location, depth, orientation of individual manufacturing defects and their combination
- know-how and experience of manufacturer, designer and certifier (project partners)
- long-term use of tuners for development and testing of new NDT techniques



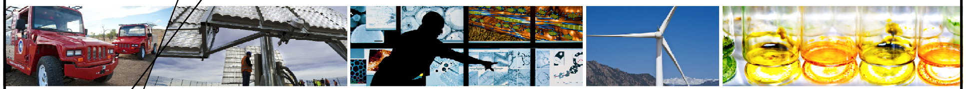
- Smart Testing Center STC, Technische University Berlin, Institute for Civil Engineering

BladeTester

Contact: Prof. Dr.-Ing. Y. Petryna
Technische Universität Berlin, Sekr. TIB1-B5
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
Tel.: +49 30 314 72320
yuriy.petryna@tu-berlin.de
http://www.statik.tu-berlin.de/
Project web page: coming soon



Blade and Component Test Development at NREL



IEA meeting #68 – Advances in Wind Turbine and Components Testing

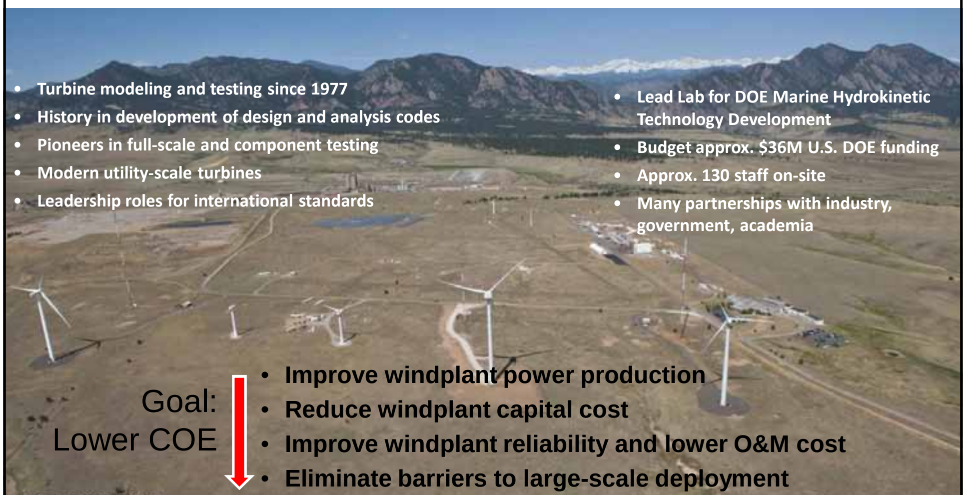
Aachen, Germany

Scott Hughes

February 21, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

National Wind Technology Center (NWTC)



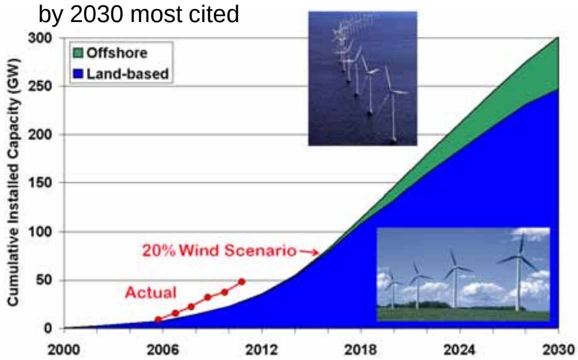
- **The NWTC will be an essential partner for the technical development and large-scale deployment of wind and water power systems.**

NATIONAL RENEWABLE ENERGY LABORATORY 2

Operation and Approach

Operation model:

- Funded by the US Department of Energy EERE Wind and Water Power Program
- Projects and tasks are negotiated with DOE
- Competitive funding through DOE Funding Opportunity Announcements
- Several cost and deployment metrics, 20% wind by 2030 most cited



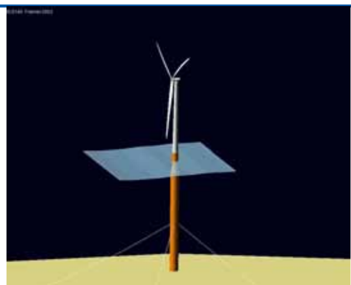
Approach:

- Provide essential test facilities
- Provide reliable, comprehensive engineering models and economic analyses
- Develop innovative new technologies
- Develop robust solutions to deployment barriers
- Partner with all stakeholders

NATIONAL RENEWABLE ENERGY LABORATORY 3

Modeling and analysis work

- **Performance**
  - WT_PERF: performance optimization
  - Windplant aerodynamics: major new HPC initiative
- **Loads**
  - FAST: World standard for offshore and floating platforms
  - Advanced structural modeling
- **Controls**
  - Enormous potential for loads reduction
- **Systems Engineering**
  - Comprehensive model of entire windplant
  - Need to embed engineering models
  - Supports optimization
- **Cost models**
  - Guides R&D activity for COE impact



NATIONAL RENEWABLE ENERGY LABORATORY 4

Turbines at NWTC

DOE 1.5 MW GE
- Model: GE 1.5-SLE
- Tower Height: 80 m, Rotor Diameter: 77 m
- DOE owned; to be used for research and education

Siemens 2.3 MW
- Model: SWT-2.3-101
- Tower Height: 80 m, Rotor Diameter: 101 m
- Siemens owned and operated
- Multi-year cost-shared R&D CRADA; aerodynamics and rotor performance

Alstom 3 MW
- Model: ECO 100
- Tower Height: 90 m, Rotor Diameter: 100 m
- Alstom owned and operated

Gamesa 2 MW
- Model G97
- Tower Height: 90 m, Rotor Diameter: 97 m
- Gamesa owned and operated

Controls Advanced Research Turbine (CART):
- Two 600-kW Westinghouse-based turbines; open platform
- Feed-forward controls using look-ahead wind sensing
- UPWIND Controls Testing (Risoe MOU)
- Closed loop system ID

Multiple Distributed Wind (<100-kW) Turbines on Site

NATIONAL RENEWABLE ENERGY LABORATORY 5

NWTC Blade Testing Capabilities

- Test blades to 50-m
- Three test cells
- Large blade component testing
- Base for test technology development
  - UREX
  - Phased locked dual-axis fatigue
  - Base Excitation
  - Health monitoring and data acquisition
  - 9-m research blades
- Regular use by industry, overflow commercial testing
- Operating since 1990

NATIONAL RENEWABLE ENERGY LABORATORY 6

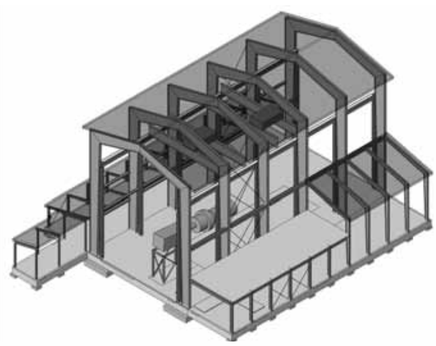
Current NWTC Drivetrain Testing Capabilities

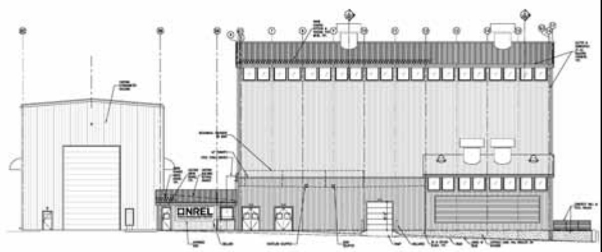
- **225-kW Dynamometer**
  - Distributed wind testing
  - 100-KW turbine size
  - Commissioned June 201
- **2.5 MW Dynamometer**
  - Commissioned 1999
  - Steady use by industry
  - Used in R&D activities
  - **Brian McNiff will provide much more detail on Wednesday**

NATIONAL RENEWABLE ENERGY LABORATORY 7

New 5-MW NWTC Dynamometer Upgrade

- $10M Recovery Act funding
- NTL (Non-Torque Loading)
- HALT testing for 2.5 to 3.5 drivetrains (depending on method used by manufacturers)
- Torque transients for HIL embedded in control
- Static loads for 3.5 MW
- Dynamic load NTL for 4.5 MW
- Test Articles up to 6-m in diameter
- Commissioning in 2012
- Future augmentations due to manufacturer needs



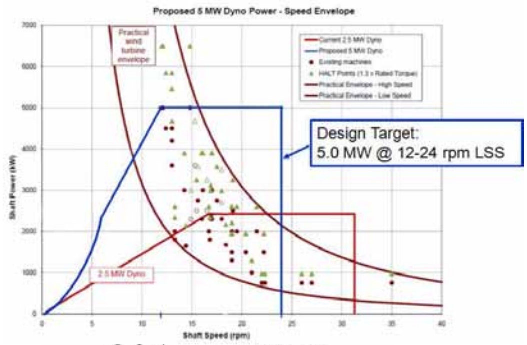


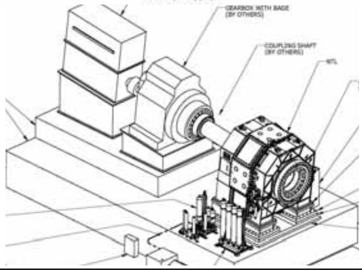
NREL Contact: Hal Link and Jim Green

NATIONAL RENEWABLE ENERGY LABORATORY 8

New 5-MW Drivetrain Specifications

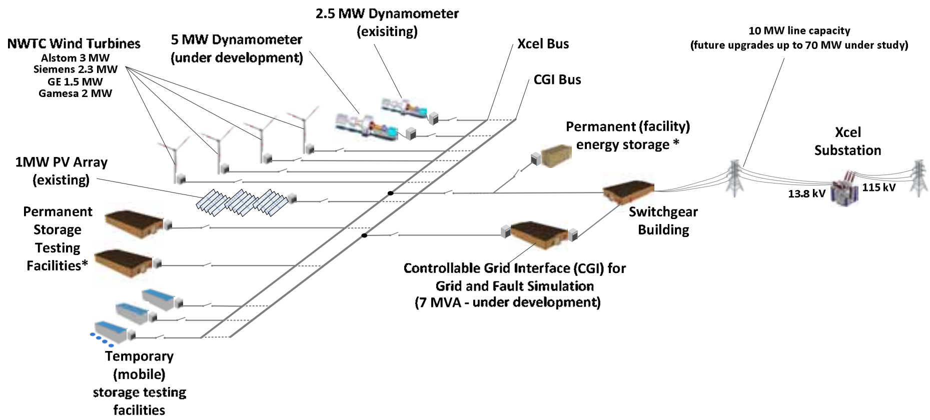
- Torque - 4.6 kNm
- Axial loads - 4 MN
- Radial and vertical loads 3.5 MN
- 7.5 MN-m bending
  - NTL system capacity can be increased
- Foundation capable of sustaining higher loads





NATIONAL RENEWABLE ENERGY LABORATORY 9

NWTC Two Bus testing Concept



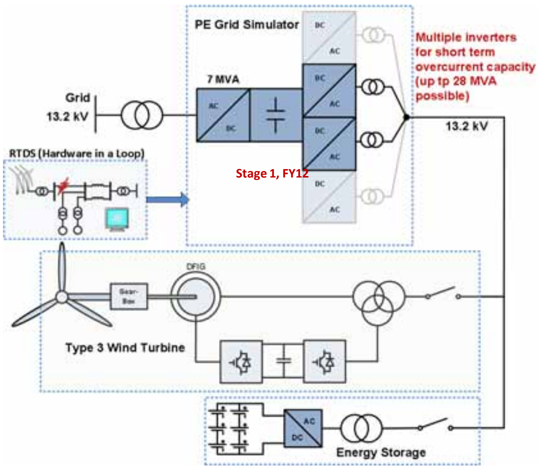
*Permanent storage facility concept is under evaluation

- Improve storage technology
- Tune up controls
- Test inverters (FRT, parallel operation with wind and PV inverters)
- Validate model

- Test different energy storage technologies:
  - Under real multi-MW renewable power variability conditions
  - With different MW-scale wind turbine topologies
  - Mix of MW-wind and MW-PV
  - Wind, PV, and elements conventional generation (dynamometers)
  - Under fully controlled grid conditions (both frequency and voltage)

NATIONAL RENEWABLE ENERGY LABORATORY 10

CGI for Wind Turbine Testing



- Low Voltage Ride Through (LVRT) testing is a certification requirement for all wind turbines (-21)
- Fully DOE funded project
  - $2.2M –hardware (being built by ABB)
  - $1M – building
- End of FY12 - commissioning with a turbine drive train on new 5MW dynamometer

NREL Contact: Vahan Gevorgian and Mark McDade

NATIONAL RENEWABLE ENERGY LABORATORY 11

CGI – Main Specifications

Power rating
- 7 MVA continuous
- 14 MVA short circuit capacity in Stage 1 (FY 12)
- 28 MVA short circuit capacity in Stage 2

Possible loads
- Types 1, 2, 3 and 4 wind turbines
- PV inverters
- Energy storage
- Conventional generators

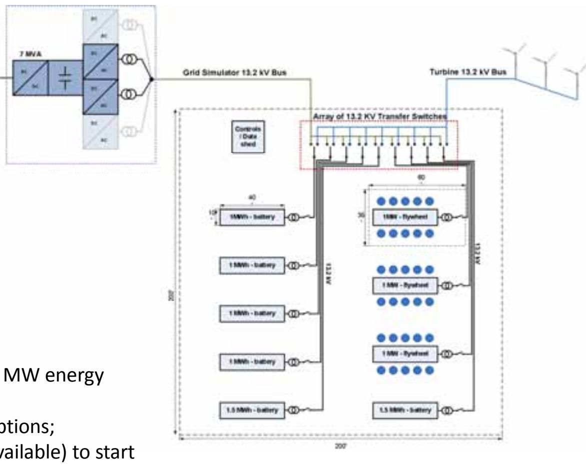
Voltage control
- Short-term balanced and un-balanced voltage fault conditions
- Long-term symmetrical voltage variations (+/- 10%)
- Voltage magnitude modulations (0-10 Hz)
- Programmable impedance
- Programmable distortions

Frequency control
- Fast output frequency control (+/- 3 Hz)
- 50/60 Hz operation
- Simulate frequency response of various power systems (RTDS / HIL)

NATIONAL RENEWABLE ENERGY LABORATORY 12

NWTC Unique Testing Site in U.S. for Energy Storage

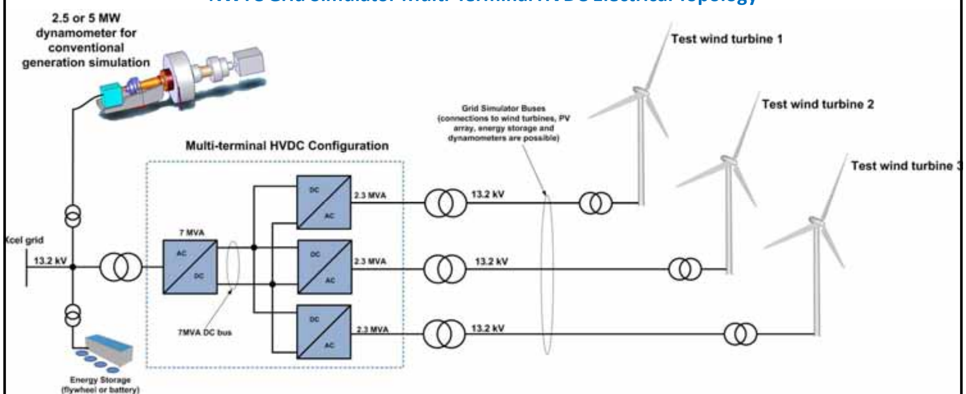
- MW-scale variable generation (wind and PV)
- Mix of modern variable speed wind turbine electrical topologies
  - o Different fault behavior
  - o Different voltage distortion spectrums
  - o Different control architectures
  - o Different mechanical inertia
- These conditions create unique opportunity for testing combinations of renewable technologies and energy storage



- Engineering study completed for 9-10 MW energy storage testing facility;
- $3.5-4.5 M is needed depending on options;
- Funding was requested (but not yet available) to start construction of the first stage (2-3 MW)

NATIONAL RENEWABLE ENERGY LABORATORY 13

Other Advanced Testing Concepts



- **Advanced coordinated control architectures for VSC-based MTDC can be tested**
- **Coordinated active power flow control to provide inertia and primary response**
- **Test variable frequency bus concept for offshore wind**
- **Demonstrate storage operation with MTDC transmission**
- **MTDC is a promising topology for offshore wind farms**

NATIONAL RENEWABLE ENERGY LABORATORY 14

Large U.S. Test Facilities

Wind Technology Testing Center (WTTC):

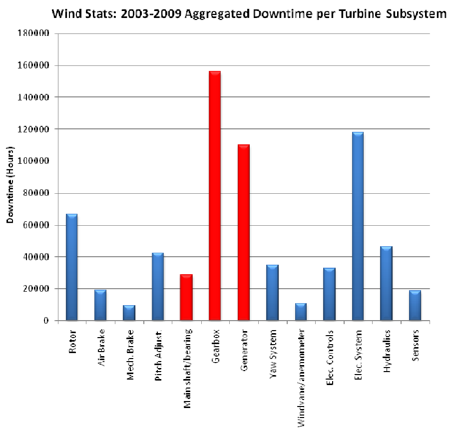
- Operated by the MassCEC (Massachusetts Clean Energy Center)
- Awarded $24-million in US DOE funding for construction under American Recovery and Reinvestment Act (ARRA)
- NREL provides 3 key staff
- NREL assists with development of loading hardware and data acquisition systems
- 3 test stands; 84 MN-m bending moment capacity
- 90-m blade testing
- Commissioning complete, active test programs in progress

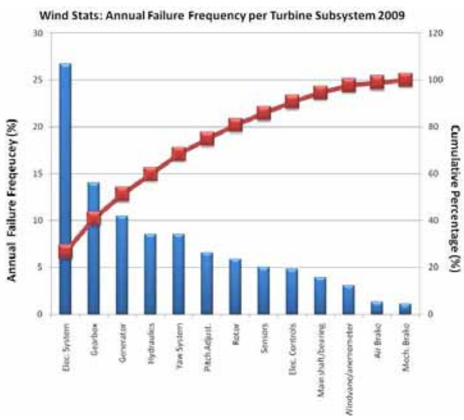
Clemson Drivetrain Test Facility

- Operated by Clemson University
- 15 MW
- DOE funding grant

NATIONAL RENEWABLE ENERGY LABORATORY 15

Continued opportunities for improvements in reliability

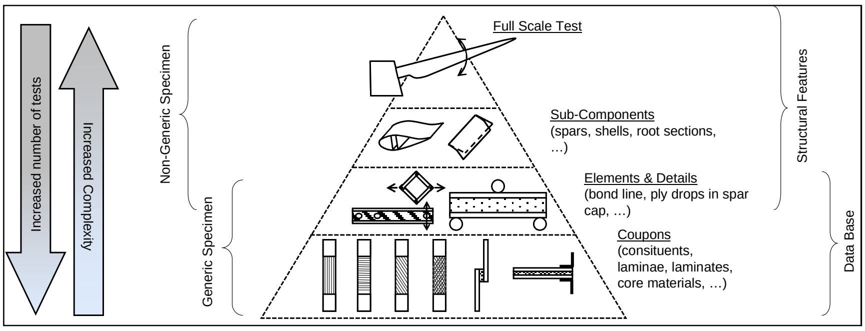




- Need for continued improvement in reliability of onshore systems
- Offshore wind deployment requires tremendous attention to demonstrating high-reliability design approaches
- Data Source: Wind Stats Newsletter, Vol. 16 Issue 1 to Vol. 22 Issue 4, covering 2003 to 2009

NATIONAL RENEWABLE ENERGY LABORATORY 16

IEC PT5: 61400-5 Rotor Blades



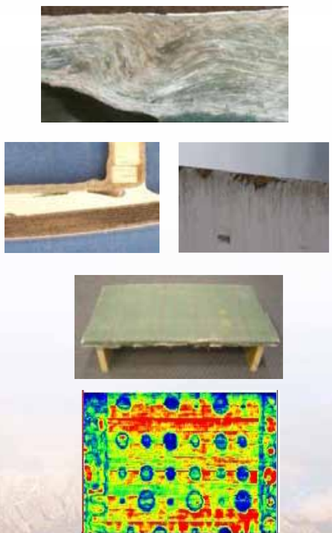
- **Design, Manufacturing, Handling, Transportation and Field O&M standard for blades**
- **Document is approximately 75% complete**
- **Trying to establish a 'building block' approach to design and testing: coupon, component, full scale (see next slide)**
- **Much of the work left includes blade structural design – including partial factors for loads and materials**
- **Expected timeline: Committee Draft (CD) by the end of calendar year 2012**

NREL Contact: Derek Berry

NATIONAL RENEWABLE ENERGY LABORATORY 17

Blade Reliability Collaborative

- **Goal:** Develop a collaborative framework to determine the causes of premature blade failure, the best inspection methods, and the adequacy of modeling tools and testing protocols
- **Methodology:**
  - Blade Defect and Damage Database – Aggregate data from blade manufacturers, service companies, and operators to determine largest sources of blade unreliability
  - Inspection Validation – Evaluate the ability of inspection techniques to accurately characterize blade defects and damage in manufacturing plants and in the field
  - Effects of Defects – Determine how common manufacturing defects affect blade strength and service life
  - Analysis Validation – Assess the ability of design analysis tools to find and characterize potential failure modes
  - Certification Testing – Evaluate the ability of certification testing to uncover potential reliability issues and find innovative ways for testing to provide better insight
  - Standards and Partnerships – Interface with international standards committees and industrial partners to identify pathways to implementing improved design, manufacture, and inspection
- **Partners:** NREL, Montana State, EPRI, U-Mass. Lowell, TPI Composites, GE, Vestas, Gamesa, Rope Partners, EDPR, Iberdrola, ~30 NDI Manufacturers



SNL Contact: Joshua Paquette

Sandia National Laboratories

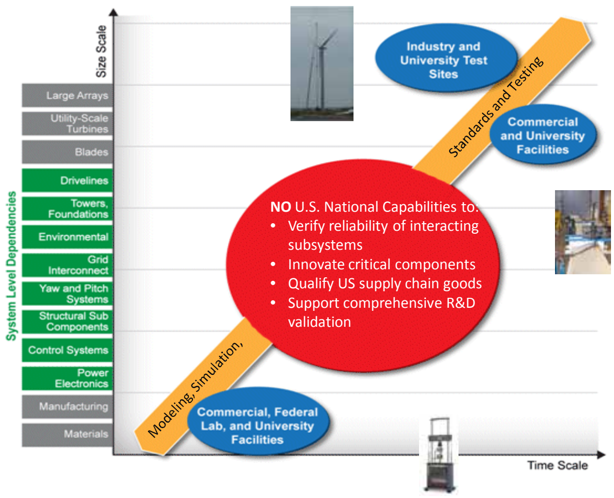
Full scale blade testing opportunities

- Even with standards and test capabilities, there continues to exist opportunities to improve reliability
- Majority of laboratory failure events are during fatigue testing
  - 95% discovered in fatigue tests
  - Laminate waves/wrinkles and debonds dominate failure modes
  - Wrinkles most structural issue
- It is not possible to test every detail
  - Evaluate expanded component testing recommendations
  - Full-scale tests are still necessary – subcomponent testing will not capture manufacturing details of as-built blades
  - Evaluate how normative NDE practices could be effectively included
- Test articles are typically from the initial lot of production blades if not the first article produced
  - Benefit of attention to detail during construction
  - Test Article can be subject to defects due to lack of production experience
- Full scale testing expensive and time consuming
  - Develop methods to decrease time and cost
    - Test duration versus characteristics
- -5 has the opportunity to bridge some gaps

NATIONAL RENEWABLE ENERGY LABORATORY 19

Capability Gaps for U.S. Supply Chain

- US Lags Europe and Asia in number of suppliers and manufacturing capacity
- Global surplus of components will necessitate emerging suppliers demonstrate reliability to be competitive with foreign supply
- Large OEM's have product development centers, but not available to emerging suppliers
- No current capability for US companies to demonstrate innovative system or component performance to OEM's
- Lack of qualification testing restricts US supplier product entrance to OEM systems
- Need to provide cost-effective component level testing for demonstrating innovative designs



NATIONAL RENEWABLE ENERGY LABORATORY 20

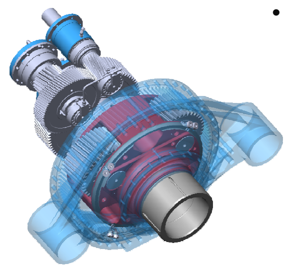
System Level and Component Test Capability gaps in U.S.

Drivetrain

- Component-based Highly-Accelerated Lifetime Testing (HALT)
  - Generator and subcomponents
  - Gearbox components
  - Main shaft bearings
  - High speed couplings
  - Brakes
- Environmental conditioning chambers
- Marine drivetrain components

Blade

- Blade / Hub / Pitch bearings
- Blade elements and details
- High-cycle fatigue
- Characteristic loading
- Thick laminate R&D and testing



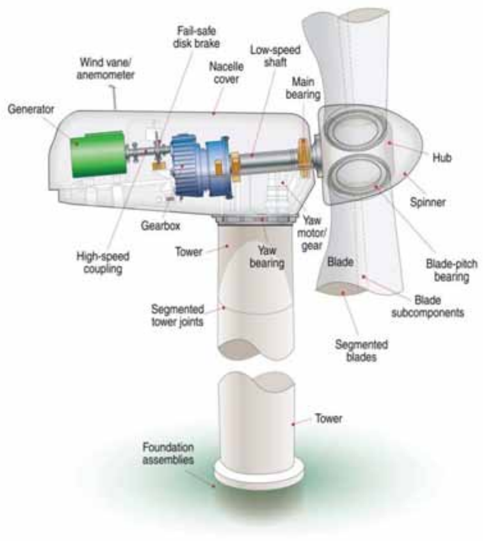
BOS and systems

- Tower and nacelle
  - Yaw bearings
  - Yaw drives
  - Segmented towers
  - Foundations
- Electronics and Instrumentation
  - SCADA systems
  - NDI system evaluation
  - Power electronics testing
- Real-time test and simulation
  - Dynamometer
  - Blade test cells
  - Grid integration and simulation laboratories

NATIONAL RENEWABLE ENERGY LABORATORY 21

Summary

- Many new capabilities at NWTC and in U.S.
- In U.S., robust small element and large-scale component test capabilities
- Many opportunities remain to improve reliability
- In U.S., gaps exist for testing components and interacting systems
  - Higher levels of reliability needed for maturing industry
  - Comprehensive, multi-disciplinary approach to system and component testing needed to match
  - Establish research basis for reliability program
  - Component Standards development
  - Foster and accelerate innovative system development
  - Industry needs for component qualification testing
- Evaluation of needs for both wind and marine hydrokinetic technologies

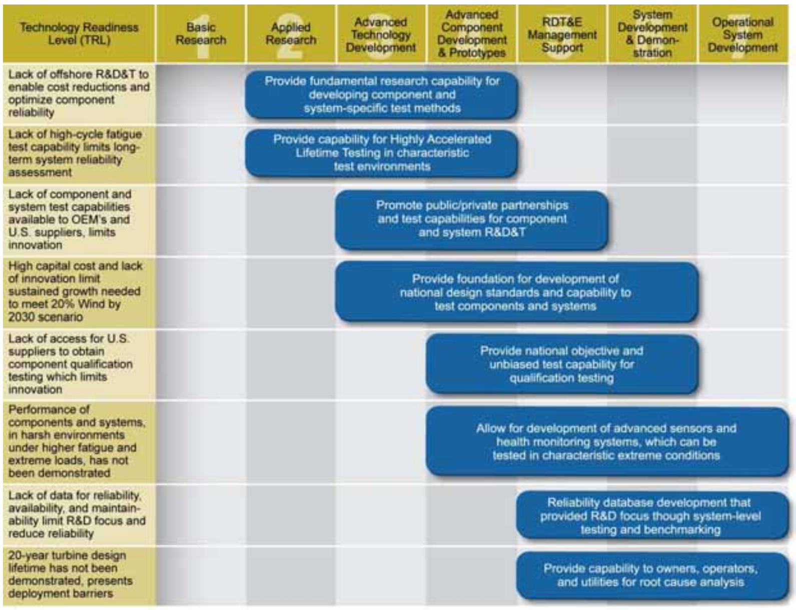


NATIONAL RENEWABLE ENERGY LABORATORY 22

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Thank You

Cross-spectrum Support of TRL's



NATIONAL RENEWABLE ENERGY LABORATORY 24

Full-scale Structural Testing of Rotor Blades - Ultimate Type Testing Design

Zheng Lei
Manager, Blade Certification Division, Wind Business Development
China General Certification Center
TEM #68, Feb 21st-22nd, 2012

1

Contents

- Introduction – CGC and NEL-WSTC
- Technical topic – Ultimate type testing design
- Future plan – Fatigue type testing

2

Introduction

CHINA GENERAL CERTIFICATION

- China General Certification Center (CGC) is a third-party certification body, which was founded in 2003. It's the first authorized wind energy certification body by Certification and Accreditation Administration of the People's Republic of China (CNCA)

Introduction

CHINA GENERAL CERTIFICATION

- Accredited by China National Accreditation Service for Conformity Assessment (CNAS) in accordance with ISO/IEC Guide 65 which is a signatory to the multilateral agreement of IAF and PAC for mutual recognition

Introduction

鉴衡认证
CHINA GENERAL CERTIFICATION

- Business:
  wind, solar and other renewables

- Service:
  standards development, certification, testing, industry study, consulting and training

5

Introduction

鉴衡认证
CHINA GENERAL CERTIFICATION

- National Energy Laboratory of Wind and Solar Simulation, Testing and Certification (NEL-WSTC) was founded in 2010

- Construction area: 17,600 m^2
- Total investment: 98,000,000 RMB

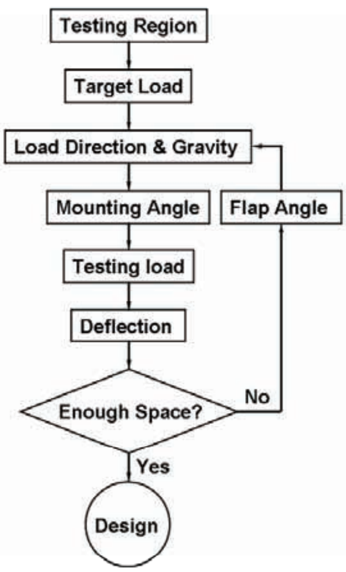
6

Introduction

- NEL-WSTC includes 3 parts in wind energy field: material testing laboratory (GB, ISO, ASTM & Guideline), full-scale testing place (3 testing beds, up to 100m) & wind tunnel testing laboratory
- Ultimate testings of blade MZ52.5

 7

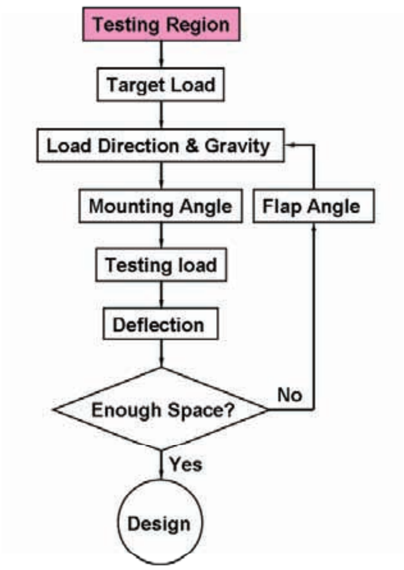
Technical topic



- Full-scale ultimate type testings of rotor blade shall be performed in flapwise and edgewise directions, both positive and negative
- Design procedure shall include 8 parts

 8

Technical topic

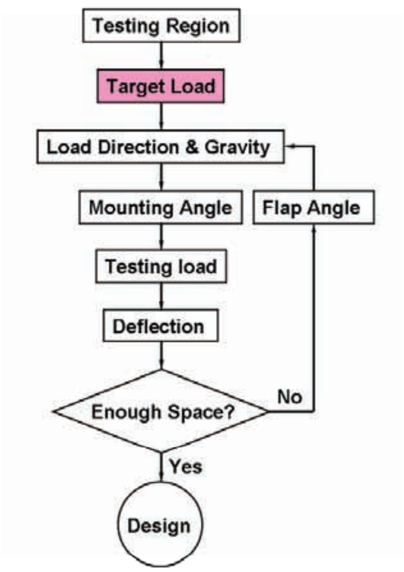


1. Testing Region

- From at least 2.5% to about 70% of blade length
- Possibly critical areas in loading course

9

Technical topic



2. Target Load

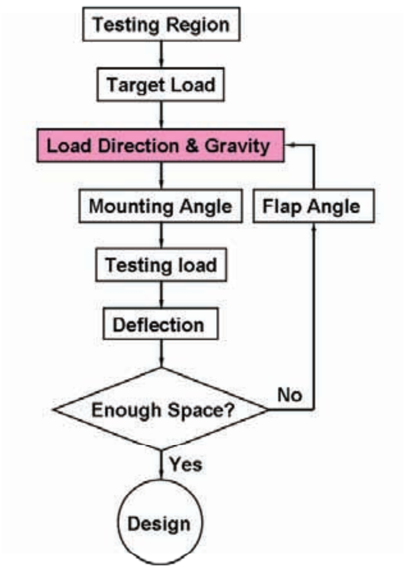
- Chord coordinate system
- Combining flapwise & edgewise moment simultaneously
- Safety factors

			Flap BM	Edge BM
		Load case	kNm	kNm
Flap BM	Max	DLC16016_016	3991	285.7
Flap BM	Min	dlc1.3j_00	-2786.5	1190.1
Edge BM	Max	dlc1.5b2+0_00	-1254.7	2386.1
Edge BM	Min	DLC15015_070	1607.9	-1911.8

10

Technical topic

CHINA GENERAL CERTIFICATION

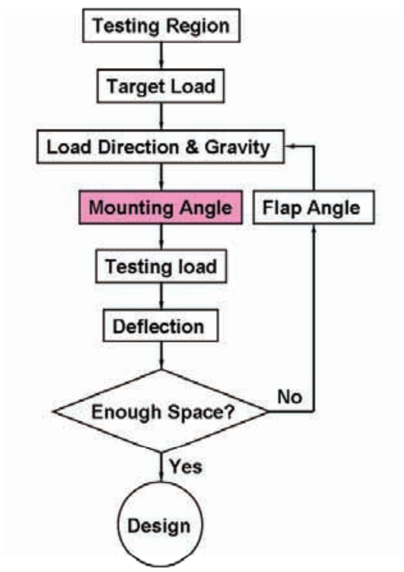


3. Load Direction & Gravity

- Along the horizontal or vertical direction
- Parallel to blade root section or normal to spanwise
- Linear density to calculate gravitational moment

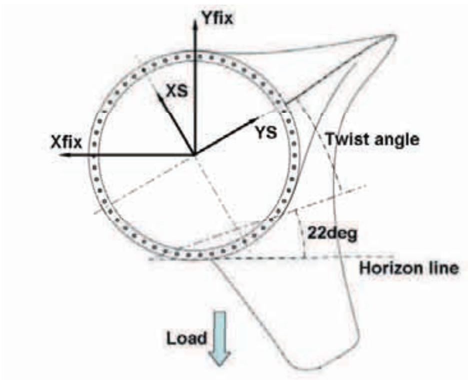
Technical topic

CHINA GENERAL CERTIFICATION

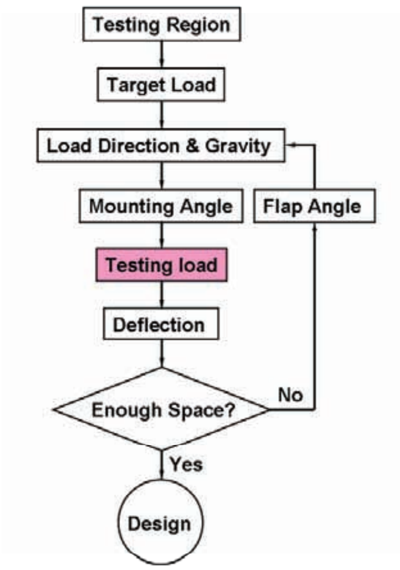


4. Mounting Angle

- Considering twist angle and target load along spanwise in testing region

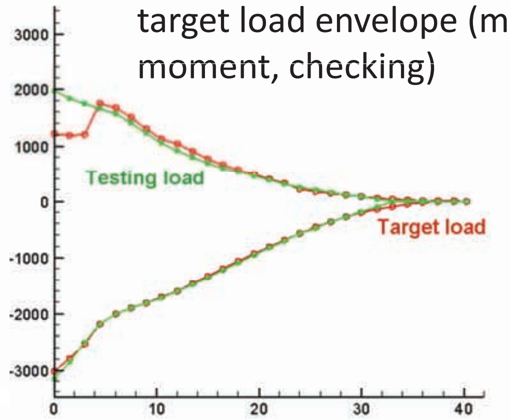


Technical topic



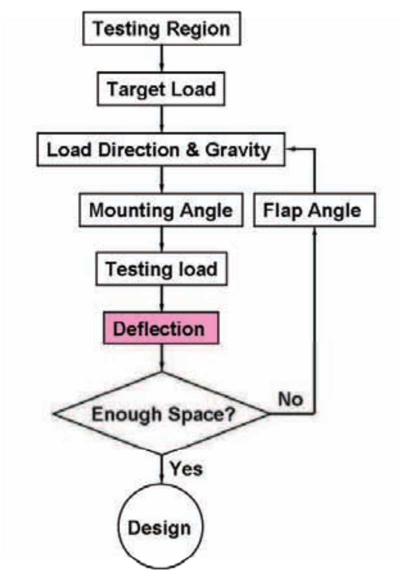
5. Testing load

- Position of load saddles
- Load value to simulate target load envelope (main moment, checking)



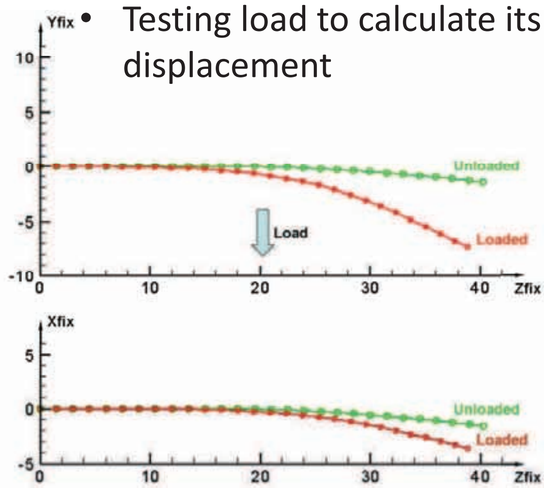
13

Technical topic



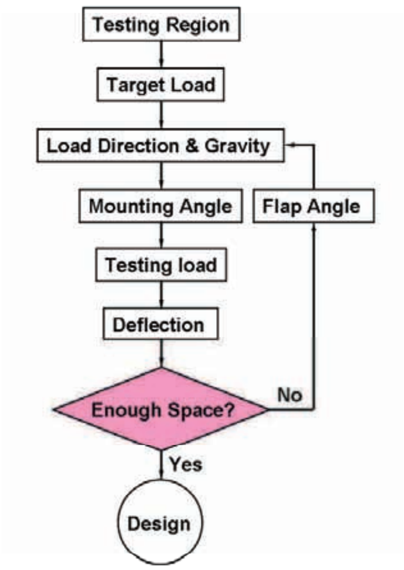
6. Deflection

- Testing load to calculate its displacement



14

Technical topic

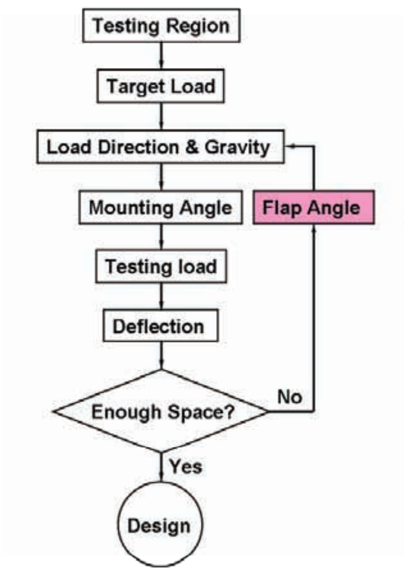


7. Enough Space?

- Checking blade tip, all load saddles & sensors have enough space to deflect
- “Yes” - finish a design, “No” – 8th part

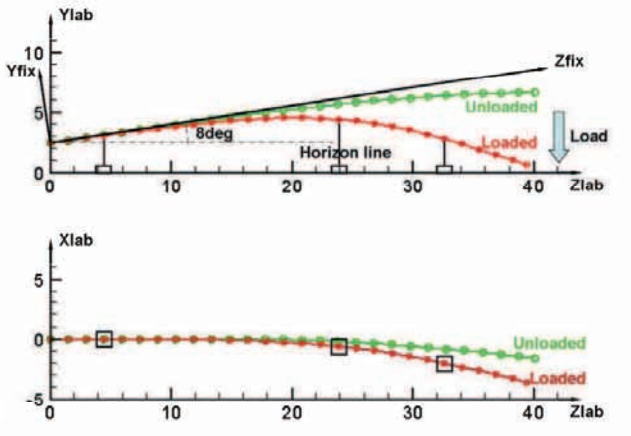
15

Technical topic



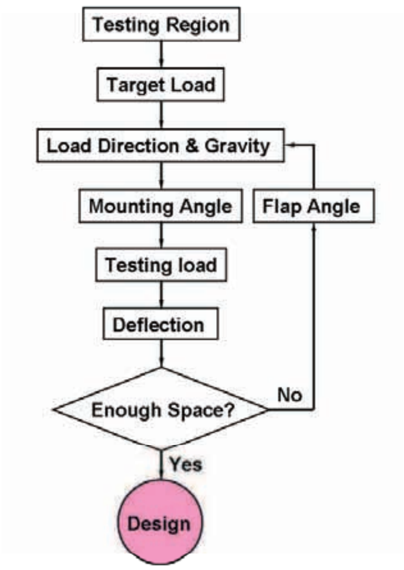
8. Flap Angle

- Load direction or adapter flange



16

Technical topic



- Repeat design cycle until getting a suitable proposal
- Decide position of device fixed points
- Considering blade deflection, load arm shall be recalculated

 17

Future plan

- Full-scale fatigue type testings of rotor blade shall be performed in flapwise and edgewise directions
- We try to find a suitable design to combine two direction moments in one testing course
- Shorter testing period, less cost, larger area to achieve target load & parts of blade with smallest calculated residual safeties against fatigue are most dangerous area among testing region during experiment

 18

Thank you for your attention!

Contact

- Add: Floor 11, 28 North 3rd Ring Road East, Beijing, P. R. China
- Tel: +86 010 59796665-3151
- Fax: +86 010 64405902
- Http: www.cgc.org.cn
- E-mail: zhenglei@cgc.org.cn
- P. C.: 100013

Fraunhofer IWES
Institute for Wind Energy and Energy System Technology

Challenges in nacelle and rotor blade testing
Hans Kyling, Eric Putnam

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Fraunhofer IWES in figures

Research spectrum:

- Wind energy from material development to grid optimization
- Energy system technology for all renewable energies

Foundation: 2009

Formerly:

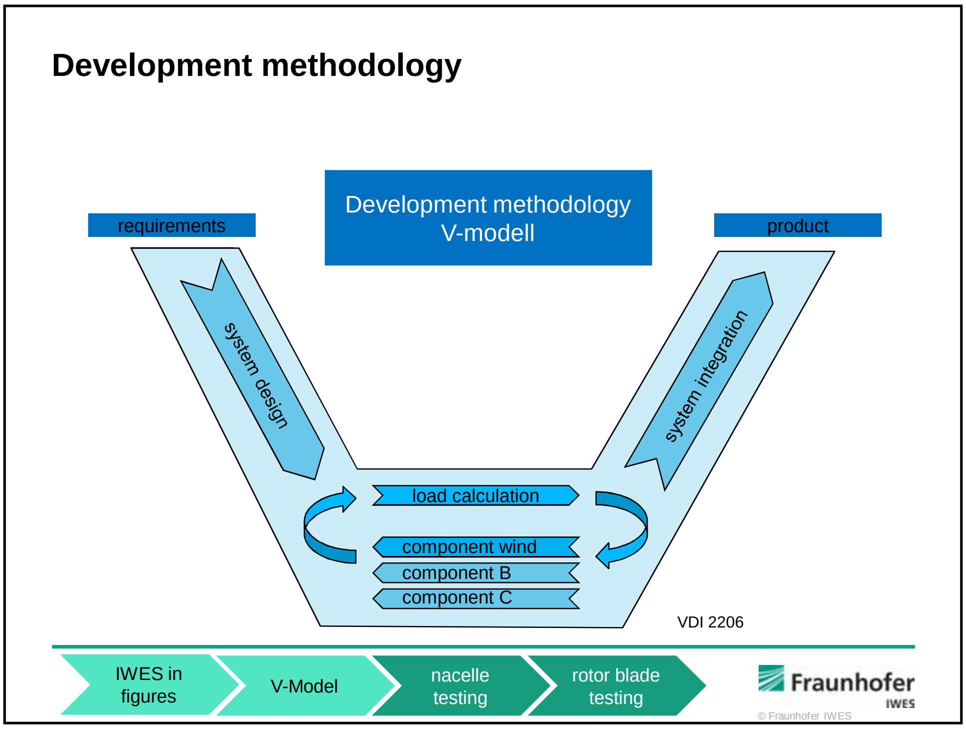
- Fraunhofer Center for Wind Energy and Maritime Technology (CWMT) in Bremer-haven
- Institute for Solar Energy Supply Technology ISET in Kassel
- **Directors:** Prof. Dr. Andreas Reuter
  Prof. Dr. Jürgen Schmid

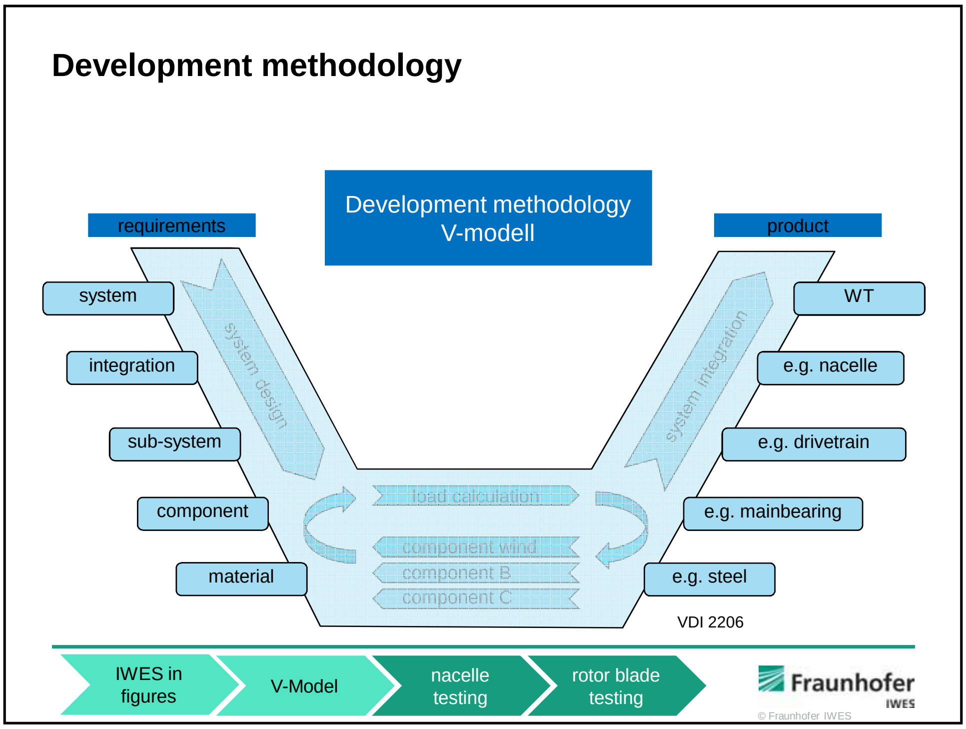
Annual budget: € 31million (2011)

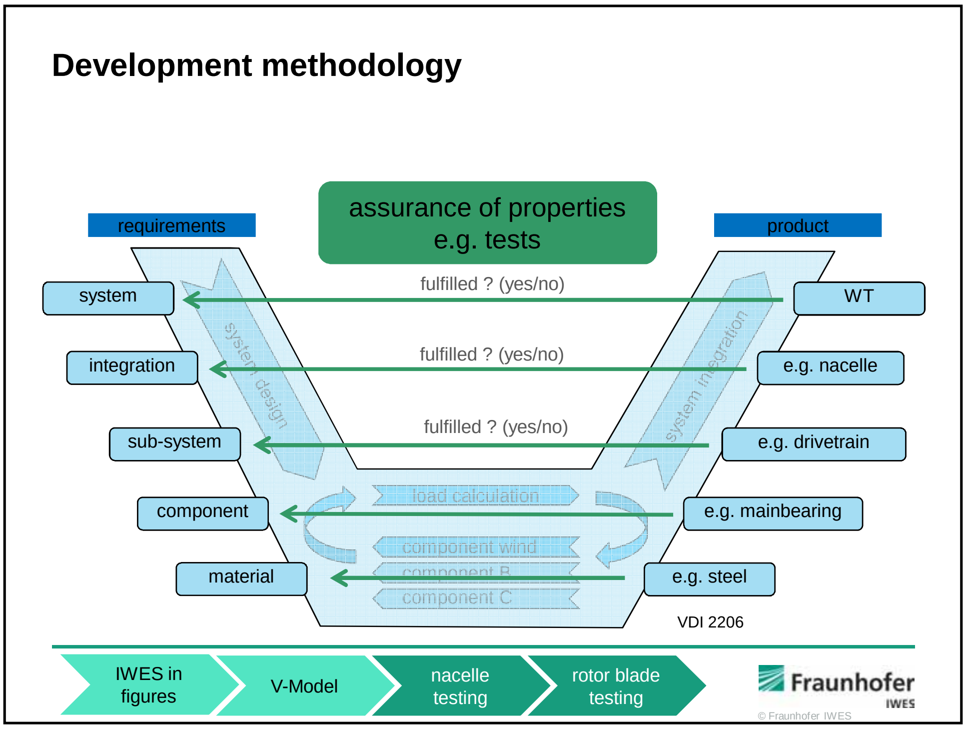
Personal: 376

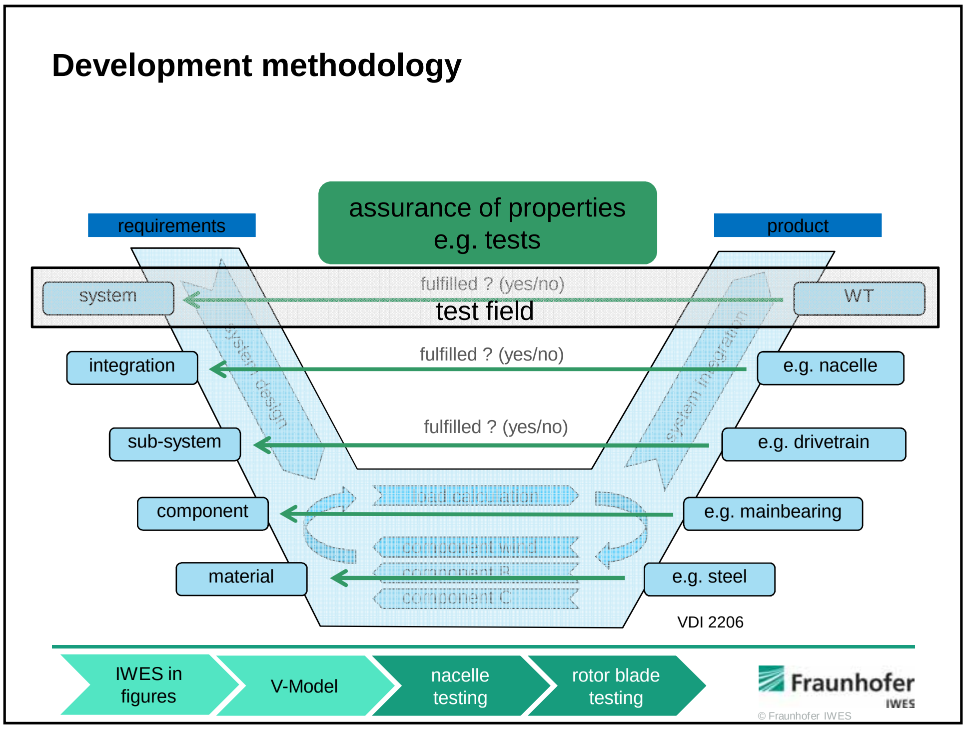
IWES in figures | V-Model | nacelle testing | rotor blade testing

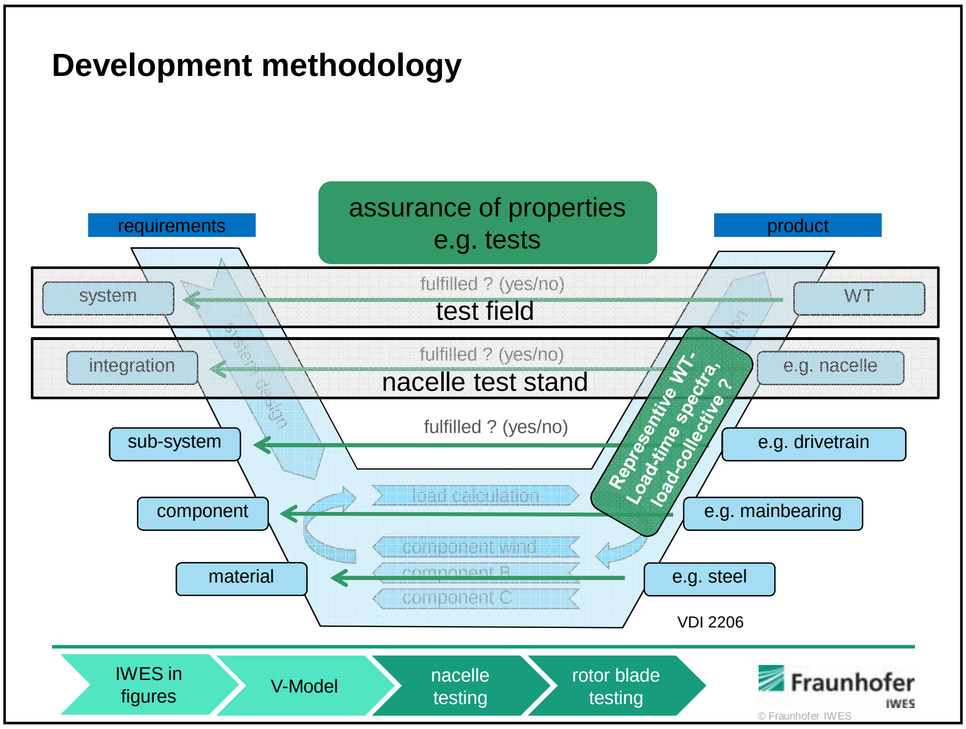
Fraunhofer IWES

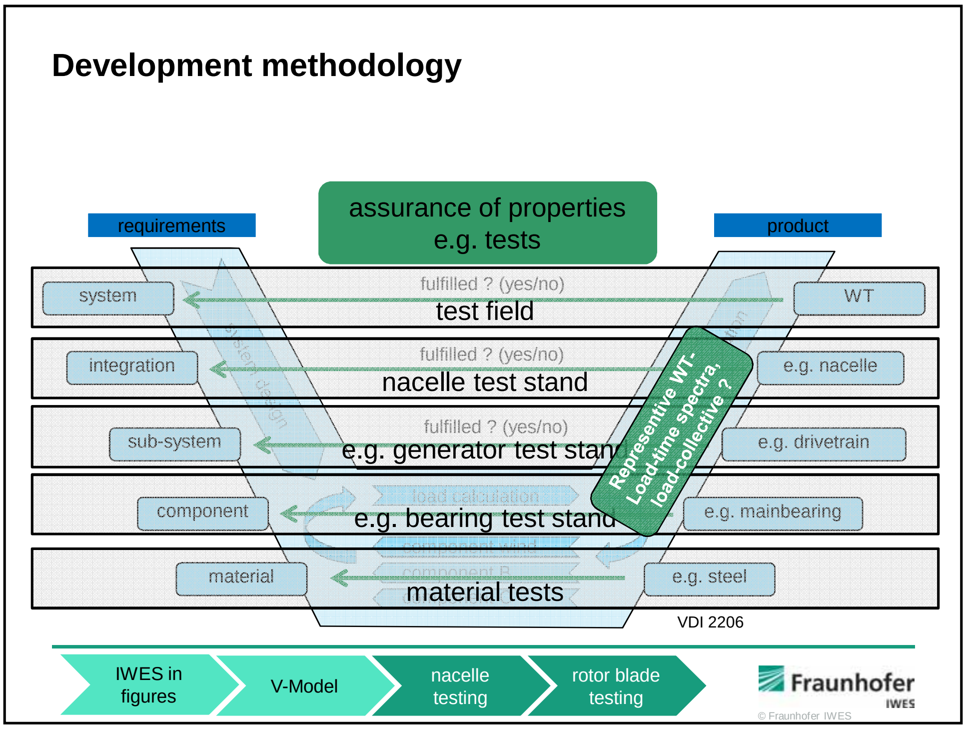

Development methodology
Development methodology
V-modell
requirements
product
system design
system integration
load calculation
component wind
component B
component C
VDI 2206
IWES in figures
V-Model
nacelle testing
rotor blade testing
Fraunhofer
IWES
© Fraunhofer IWES


Development methodology
Development methodology
V-modell
requirements
product
system
integration
sub-system
component
material
WT
e.g. nacelle
e.g. drivetrain
e.g. mainbearing
e.g. steel
system design
system integration
load calculation
component wind
component B
component C
VDI 2206
IWES in figures
V-Model
nacelle testing
rotor blade testing
Fraunhofer
IWES
© Fraunhofer IWES

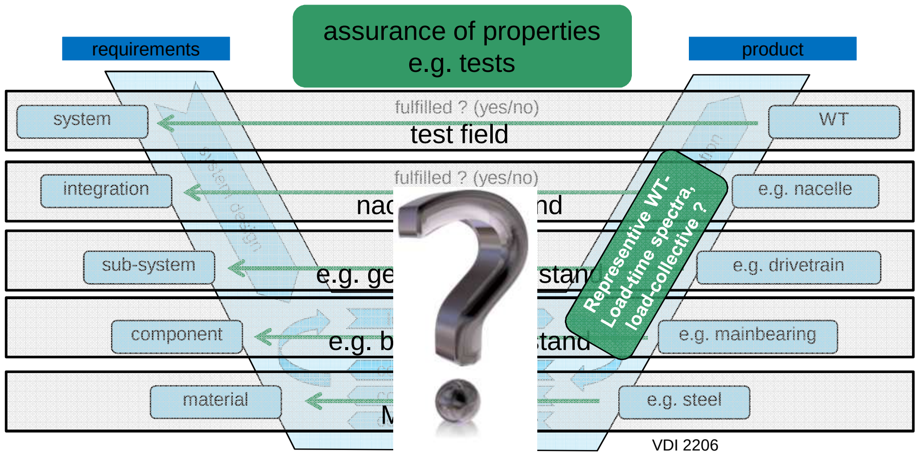

Development methodology
assurance of properties
e.g. tests
requirements
product
system
integration
sub-system
component
material
WT
e.g. nacelle
e.g. drivetrain
e.g. mainbearing
e.g. steel
fulfilled ? (yes/no)
fulfilled ? (yes/no)
fulfilled ? (yes/no)
system design
system integration
load calculation
component wind
component B
component C
VDI 2206
IWES in figures
V-Model
nacelle testing
rotor blade testing
Fraunhofer IWES
© Fraunhofer IWES


Development methodology
assurance of properties
e.g. tests
requirements
product
system
WT
fulfilled ? (yes/no)
test field
integration
sub-system
component
material
e.g. nacelle
e.g. drivetrain
e.g. mainbearing
e.g. steel
fulfilled ? (yes/no)
fulfilled ? (yes/no)
system design
system integration
load calculation
component wind
component B
component C
VDI 2206
IWES in figures
V-Model
nacelle testing
rotor blade testing
Fraunhofer IWES
© Fraunhofer IWES


Development methodology
assurance of properties
e.g. tests
requirements
product
system
fulfilled ? (yes/no)
test field
WT
integration
fulfilled ? (yes/no)
nacelle test stand
e.g. nacelle
sub-system
fulfilled ? (yes/no)
e.g. drivetrain
component
load calculation
e.g. mainbearing
material
component wind
component B
component C
e.g. steel
Representative WT-Load-time spectra, load-collective ?
system design
VDI 2206
IWES in figures
V-Model
nacelle testing
rotor blade testing
Fraunhofer IWES
© Fraunhofer IWES


Development methodology
assurance of properties
e.g. tests
requirements
product
system
fulfilled ? (yes/no)
test field
WT
integration
fulfilled ? (yes/no)
nacelle test stand
e.g. nacelle
sub-system
fulfilled ? (yes/no)
e.g. generator test stand
e.g. drivetrain
component
e.g. bearing test stand
e.g. mainbearing
material
material tests
e.g. steel
Representative WT-Load-time spectra, load-collective ?
VDI 2206
IWES in figures
V-Model
nacelle testing
rotor blade testing
Fraunhofer IWES
© Fraunhofer IWES

Development methodology



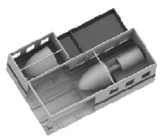
IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Test facilities at Fraunhofer IWES

Test level according to V-model

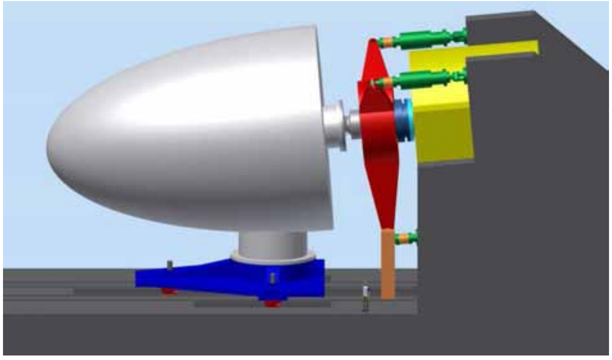
- Material
  - Climate chambers
  - Offshore test field
- Component
  - Rotor blade (full scaled, down scaled)
  - Composite part testing and development
- Sub-system and integration
  - Dynamic Nacelle Laboratory (DyNaLab) -in development-

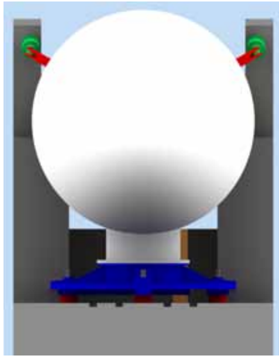


IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Wind turbine test-rig as central element of the DyNaLab





technical data

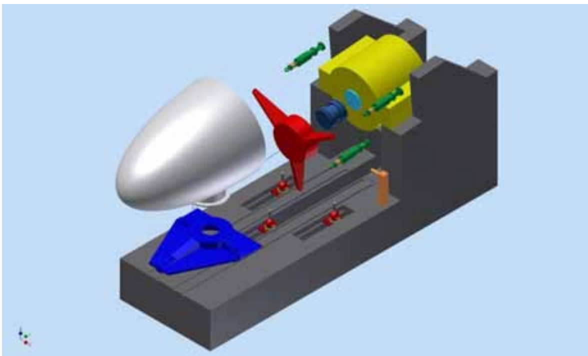
- max. nacelle weight 400 t
- max. nacelle dimensions (length=18m, width=12m, height=13 m)
- turbines of up to 6 (7,5) MW rated power
- 10 MW drive power
- 15 MVA input power
- 40 MVA 50/60Hz transient grid simulation
- 1+(3) dof el./hydr. load application

commissioning scheduled for: 2014

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Wind turbine test-rig as central element of the DyNaLab



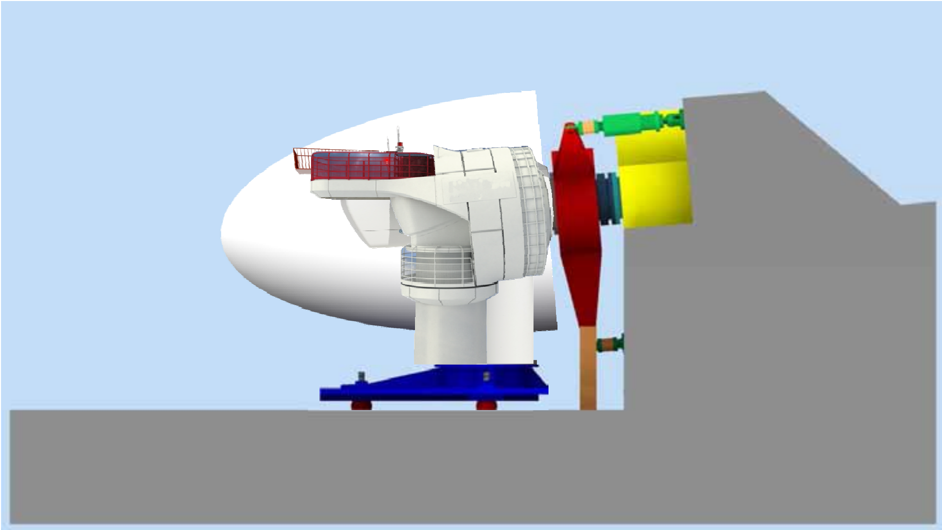
Scope of testing

- ✓ design development / optimization
- ✓ design verification / analysis
- ✓ model validation
- ✓ end of line / production conformity
- ? accelerated lifetime test
- ? turbine partial certification (reduction of field tests)
- x (complete) turbine certification
- x (complete) fatigue/endurance tests

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

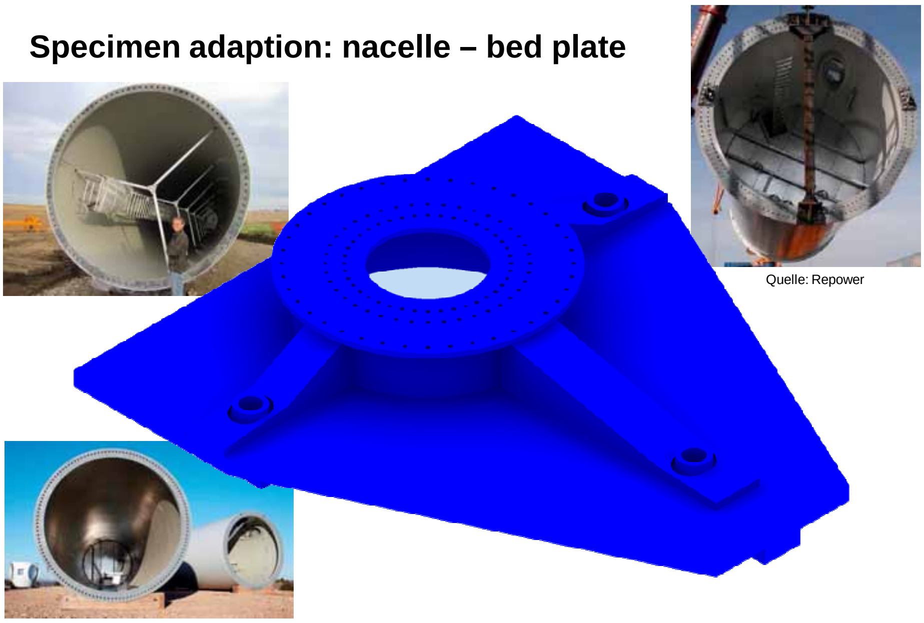
Specimen adaption



IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Specimen adaption: nacelle – bed plate

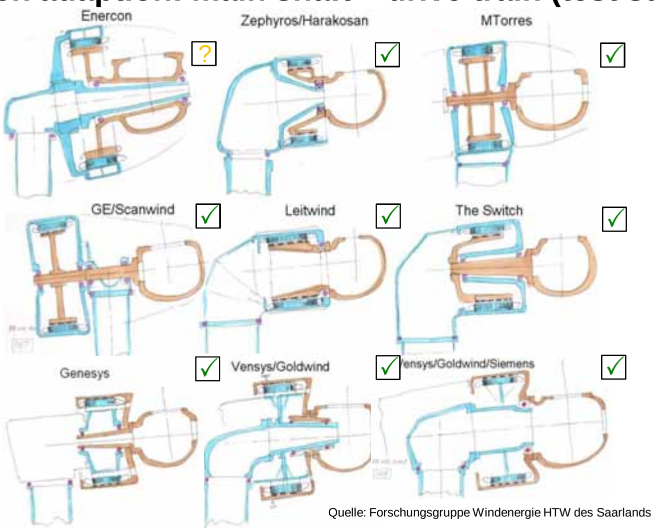


Quelle: Repower

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Specimen adaption: main shaft – drive train (test stand)



overview over some gearless wind turbine concepts

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

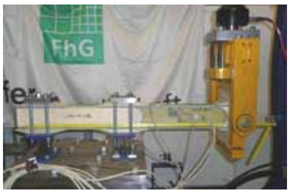
Competence Center Rotor Blade

Beam Testing:

- Sub-component tests
- Material tests
- Composite lab
- NDT-Methods
- Material development

Blade Testing:

- Static blade tests
- Cyclic blade tests (Biaxial blade tests)
- NDT-Methods
- Simulation



Supported by the rotor blade industry:

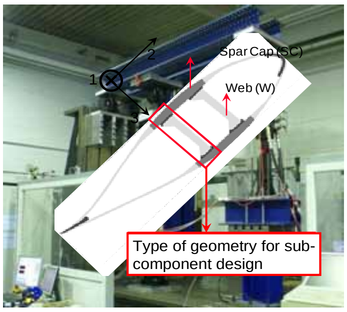
BARD, REpower Systems, GE Energy, Henkel, Sinoi, ENERCON Energie für die Welt, SGL ROTEC Wind Energy Components

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Testing Scales for the CoC

1. Material characterization/models
2. Sub – components
3. Components
4. Full-Scale Testing



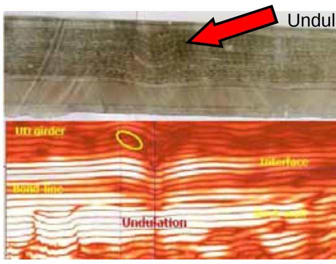
IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

NDT (Manuf./Lab)

- UT (Phase Array & P-Scan)
  - 3D images without immersion
  - Faster scan
  - Automation

Undulations

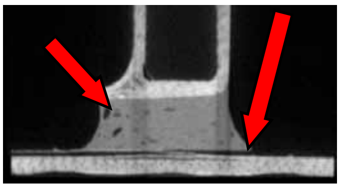


UT Photo: Force Technology

- Computer Tomography

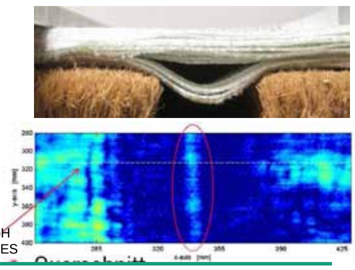
Adhesive to substrate disbond

Voids



CT Photo: Fraunhofer EZRT
Structure: Fraunhofer IWES

- Tera Hertz



TH Photo: SynView GmbH
Laminate: Fraunhofer IWES

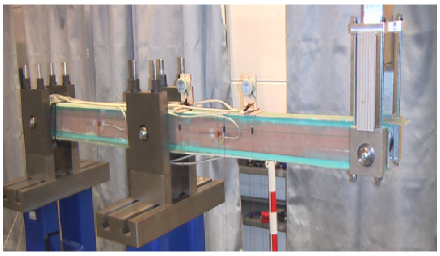
IWES in figures | V-Model | nacelle testing | rotor blade testing

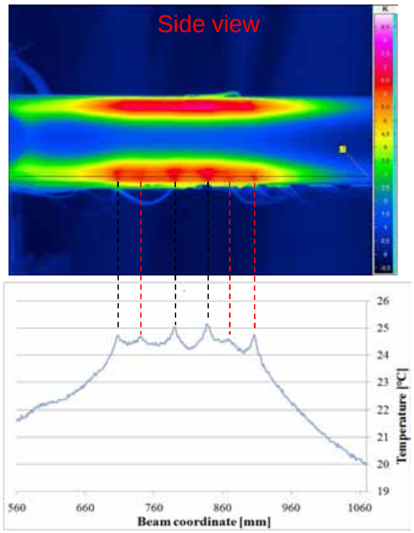
Fraunhofer IWES

Structural Health Monitoring (Lab./Field)

Thermography

- Spar-caps to shear web adh. joint
- R=-1
- Side & Top view





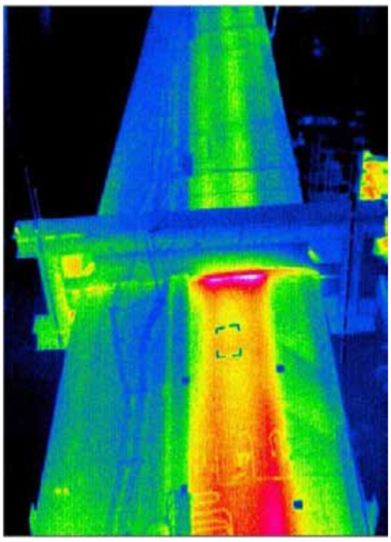
IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Structural Health Monitoring (Lab./Field)

Thermography

- Blade fatigue test
- R=-1
- Top view



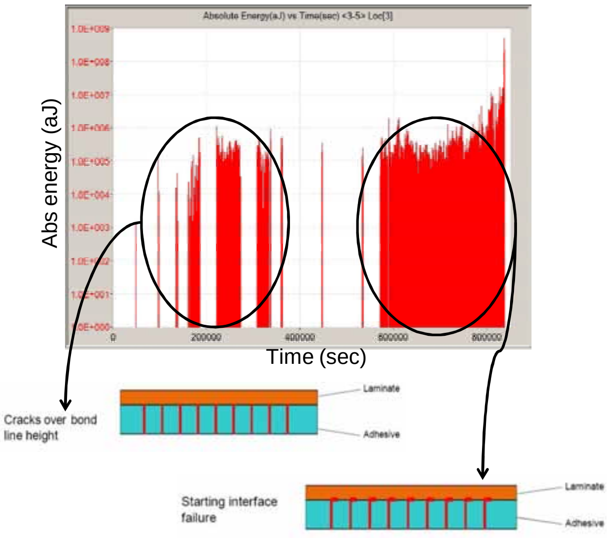
IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Structural Health Monitoring (Lab./Field)

Acoustic Emission

- Beam test



RISOE 2011 symposium on material science: *Real time monit. of composite testing with AE*

IWES in figures | V-Model | nacelle testing | rotor blade testing

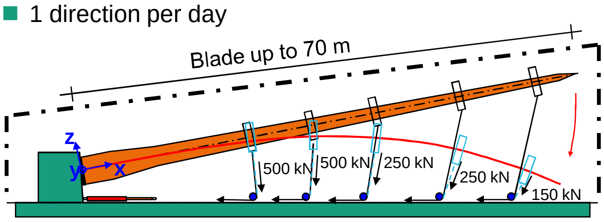
Fraunhofer IWES

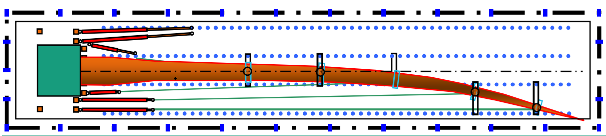
70m Rotor Blade Test Rig

Layout of static rotor blade tests

- Loading with hydraulic actuators
- Loads up to 500 kN per load frame
- Up to 8 load frames
- 1 direction per day

Units: m, t, kN	1. Hall
Max. blade length	70
Max. flange diameter	4.8
Max. static bending moment	50.000
Max. displacement at blade tip (static)	17.5
Max. dynamic bending moment	+/-30.000
Max. displacement at blade tip (dynamic)	9.5





IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

70m Rotor Blade Test Rig

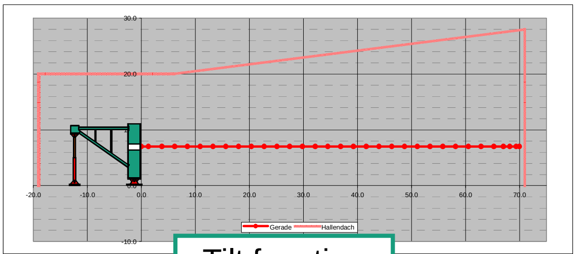
Static test of a 56m blade

IWES in figures | V-Model | nacelle testing | rotor blade testing

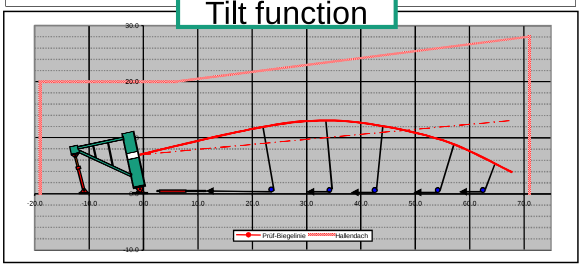
Fraunhofer IWES

90m Rotor Blade Test Rig

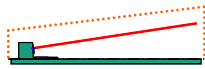
Static tests



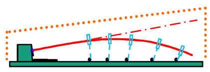
Tilt function



Units: m, t, kN	2. Hall
Max. blade length	80 (90)
Max. flange diameter	6.0
Max. static bending moment	115.000
Max. displacement at blade tip (static)	30
Max. dynamic bending moment	+/-30.000
Max. displacement at blade tip (dynamic)	9.5



Fixed angle



IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

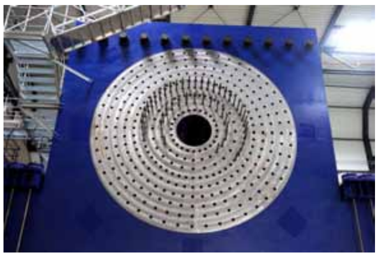
© Fraunhofer IWES

90m Rotor Blade Test Rig
Tilt-Block

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

90m Rotor Blade Test Rig
Tilt-Block

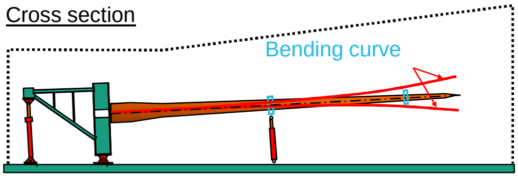


IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

70m/90m Rotor Blade Test Rigs
Layout of fatigue tests

- Loading of the blade with oscillation of the blade in our near eigenfrequency
- Flap and edge direction separately (biaxial test possible)
- Pure blade eigenfrequency test is possible
- 1 mio. to 5 mio. cycles per direction
- Time needed app. 2 to 10 month

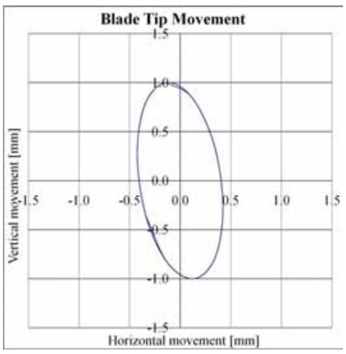


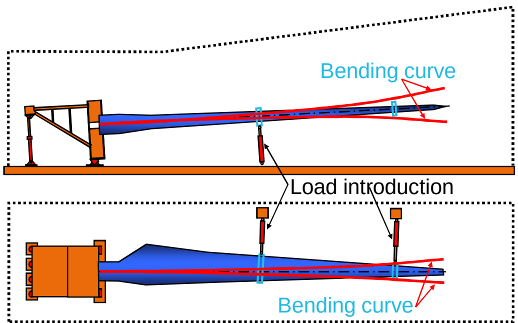
IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

70m/90m Rotor Blade Test Rigs
Bi-axial fatigue tests

- Vertical loading with hydraulic cylinder in blade eigenfrequency
- Horizontal quasi-static loading with two cylinders or edge eigenfrequency tuned to flap frequency



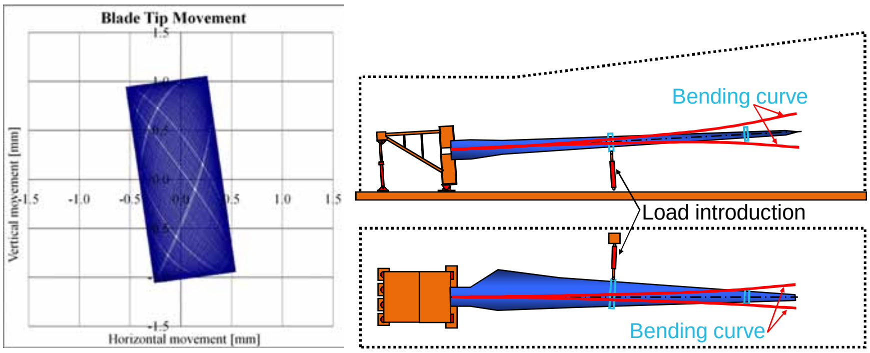


IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

70m/90m Rotor Blade Test Rigs
Bi-axial fatigue tests

- Vertical loading with hydraulic cylinder in blade eigenfrequency
- Horizontal loading with hydraulic cylinder in blade eigenfrequency

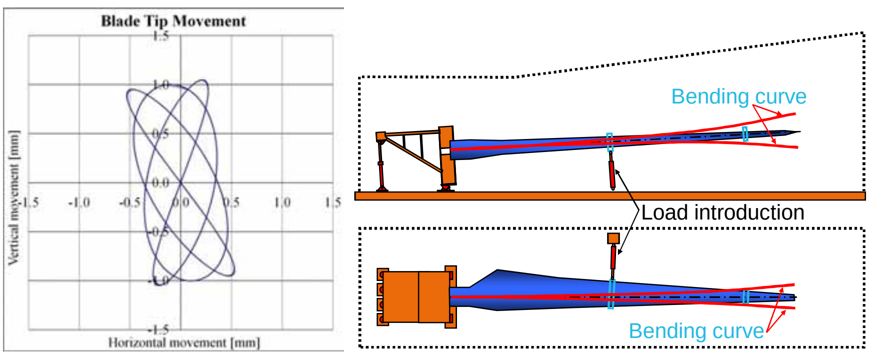


IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

70m/90m Rotor Blade Test Rigs
Bi-axial fatigue tests

- Vertical and horizontal loading with hydraulic cylinder near blade eigenfrequencies to a Lissajous Figure



IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Acknowlegdement

Fraunhofer IWES is funded by the

- Federal State of Bremen
  - Senator für Umwelt, Bau, Verkehr und Europa
  - Senator für Wirtschaft und Häfen
  - Senatorin für Bildung und Wissenschaft
  - Bremerhavener Gesellschaft für Investitions-Förderung und Stadtentwicklung GmbH
- Federal State of Hessen
- Federal State of Lower Saxony

and Federal Republic of Germany

- BMU Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
- BMBF Bundesministerium für Bildung und Forschung

with support of the

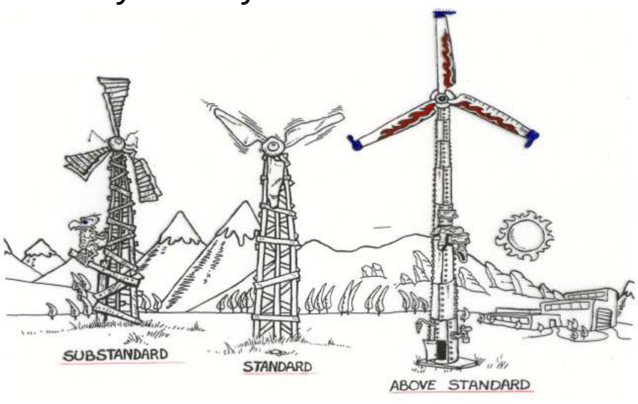
- European Regional Development Fund ERDF

Bremen Bremerhaven | HESSEN | Niedersachsen | Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit | Bundesministerium für Bildung und Forschung

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Thank you for your attention!



New standards for wind turbine testing are necessary.

IWES in figures | V-Model | nacelle testing | rotor blade testing

Fraunhofer IWES

Testing and Optimization of Support Structures for Wind Energy Turbines

Dr.-Ing Maik Wefer

TEM #68, February 21-22, 2012, Aachen, Germany

AGENDA

- **Motivation and Objectives**
- **Test Center for Support Structure in Hannover**
  - **Location and Dimensions**
  - **Planned Specifications of the Testing Equipment**
  - **Scenarios and Objectives of Testing**
- **Research**

Motivation and Objectives

- Multi-axial, Realistic, Quasi-static and Dynamic Tests with Loading according to Offshore Environment
- Testing of Large and Full Scale Specimen
- Large Scale Models of Support Structures



- Components of the Support Structure in Full Scale

Test Center for Support Structure in Hannover
Leibniz Universität Hannover and Fraunhofer IWES

ForWind — Leibniz Universität Hannover — Fraunhofer IWES

Test Site: Location

In the northern part of
Hannover, Germany

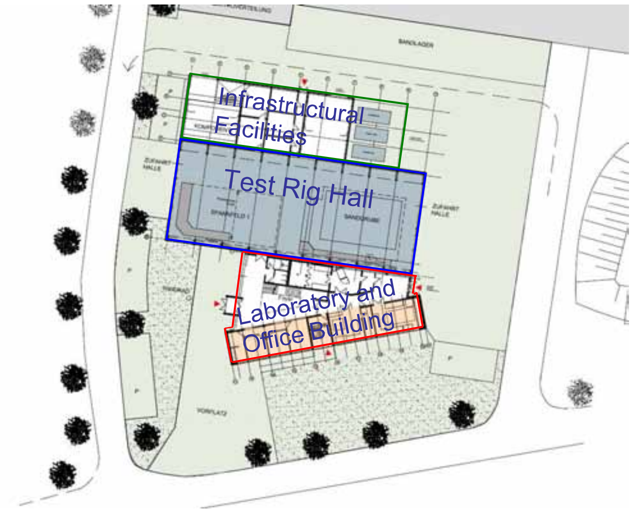
Next to the well known
Large Wave Flume (GWK)


Source: Franzius-Institute for Hydraulic, Waterways and Coastal Engineering. Arndt Hildebrandt, 2010.

ForWind — Leibniz Universität Hannover — Fraunhofer IWES

Test Site: Buildings

- Hall for Testing Rigs
- Laboratory and Office Building
- Infrastructural Facilities



ForWind · Leibniz Universität Hannover · Fraunhofer IWES

Hall with Laboratory and Office Building

Visualization

ForWind · Leibniz Universität Hannover · Fraunhofer IWES

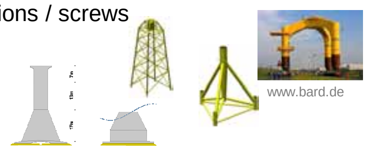
Scenarios and Objectives of Planned Testing

- **Scenarios**
  - Standard tests on large scale support structures and foundations
  - Detailed multi-axial fatigue tests on large/full scale support structure components like structural nodes, grouted joints and other welded or hybrid connections
  - Investigation of the soil structure interaction of foundations in water saturated soils
  - Large scale tests of horizontally and vertically loaded single piles
  - Testing of novel installation techniques and foundation concepts
- **Objectives**
  - Validation of numerical simulations and up scaling methods
  - Optimization of design, manufacturing and installation procedures
  - Improvement of guidelines and recommendations

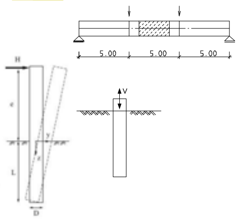
ForWind | Leibniz Universität Hannover | Fraunhofer IWES

Target Specifications of the Testing Equipment

- **Length Scales**
  - Full scale
    - for joints / grouted joint / hybrid connections / screws
  - Large scale (1:10 – 1:5)
    - jacket, tripod or tripile structures
    - concrete support structures
    - piles (up to 1:3.5) or suction buckets



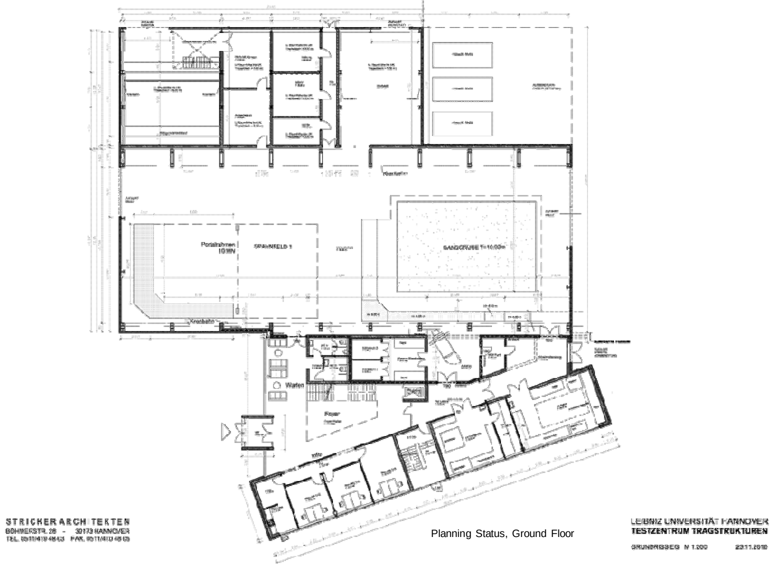
- **Hydraulic Testing Rigs**
  - Frequencies: up to 5Hz
  - Loading (multi-axial):
    - force of up to 2MN
    - bending moments up to 15MNm



- **Resonant Testing Machines**
  - Frequencies: up to 120Hz
  - Loading (axial): force of more than 1MN

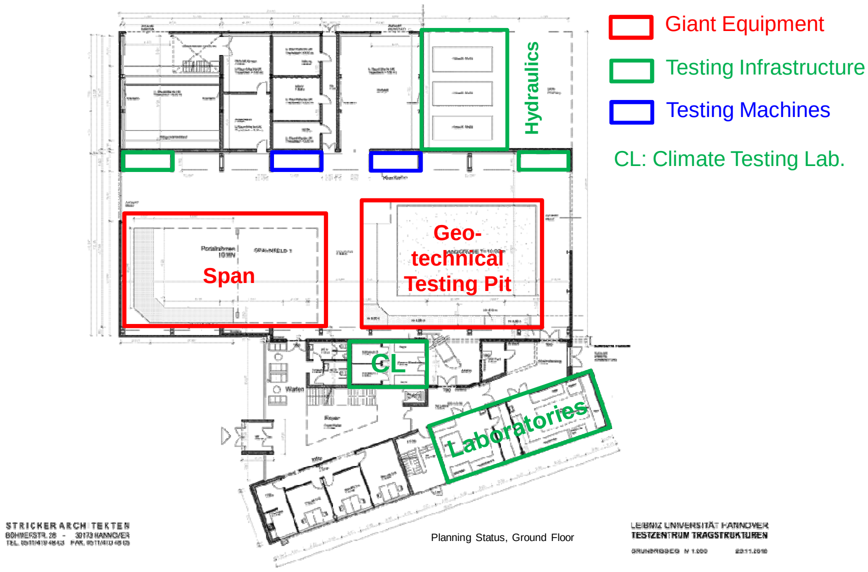
ForWind | Leibniz Universität Hannover | Fraunhofer IWES

Planning Status of Testing Facilities



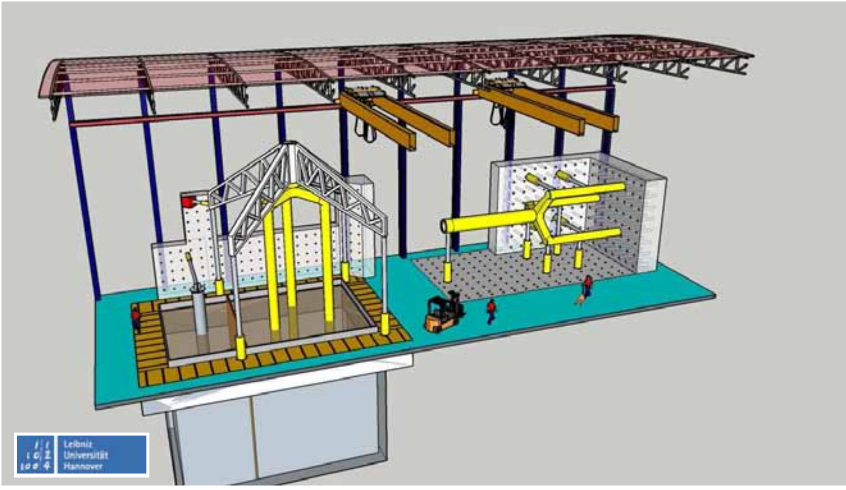
ForWind | Leibniz Universität Hannover | Fraunhofer IWES

Planning Status of Testing Facilities

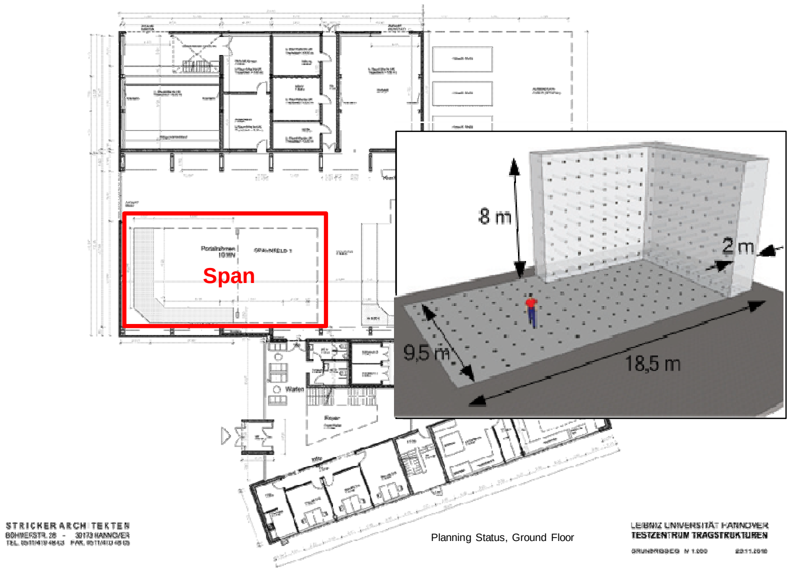


ForWind | Leibniz Universität Hannover | Fraunhofer IWES

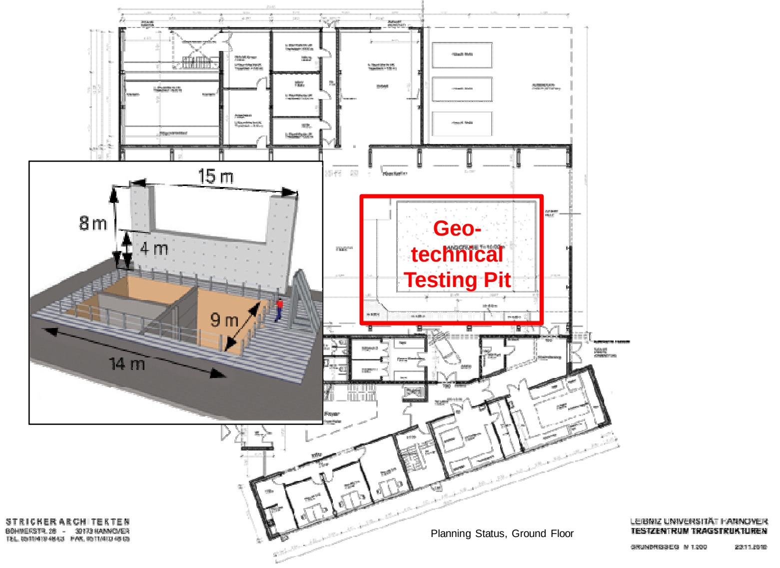
Testing Pit of 10 m Depth to be filled with Sand and Water (left) and Span (right) with Support Walls



Planning Status of Testing Facilities



Planning Status of Testing Facilities



Research

- Load Analysis
  - Wave Loading and Structural Interaction
- Numerical Simulations
  - Analysis of Measurement Data
  - Validation against Experiments
  - Validation of SHM Models
  - Extrapolation to the Full Scale
  - Analysis of Structural Joints and Hybrid Connections
  - Assessment of Different Types of Support Structures
- Material Modeling
  - Soil Structure Interaction
  - Behavior of Saturated Media in Cyclic Loading

Acknowledgements

BMU Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

European Regional Development Fund ERDF

Federal State of Lower Saxony

Leibniz Universität Hannover

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

Niedersachsen

Leibniz Universität Hannover

ForWind Zentrum für Windenergieforschung Bremen Hannover Oldenburg

Testing and Optimization of Support Structures for Wind Energy Turbines

Dr.-Ing Maik Wefer

TEM #68, February 21-22, 2012, Aachen, Germany

ForWind Zentrum für Windenergieforschung Bremen Hannover Oldenburg

Testing and Optimization of Support Structures for Wind Energy Turbines

Dr.-Ing Maik Wefer

TEM #68, February 21-22, 2012, Aachen, Germany

ForWind | Leibniz Universität Hannover | Fraunhofer IWES

Introduction of Wind Turbine LVRT Testing in China

Li Qing

China Electric Power Research Institute

Introduction of speaker

国家电网
STATE GRID

1999-2003: Study of Electrical Engineering at Hunan University

2003-2006: Study of Power System Automation at CEPRI

Studies on Measurement of Power Performance and Power Quality of Wind turbine and Wind Farm.

2006-2009: Test engineer and Quality Manager at Renewable Energy Department of CEPRI

Responsible for power performance and power quality measurement and QMS.

Since 2010: Head of Renewable Energy Lab of Renewable Energy Department of CEPRI

Responsible for type test and grid code compliance test of wind turbines and wind farm.

Li Qing

NWIC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网 STATE GRID

1. Introduction of Zhangbei test site
2. Status of wind power development
3. Wind turbine LVRT testing
4. Conclusions

NWIC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

National Wind Power Integration Research and Test Center (NWIC)

国家电网 STATE GRID

- **Zhangbei test site**
  - **Comprehensive testing section, includes R&D building, central power distribution room, SVC room;**
  - **4 35kV distributed power distribution rooms;**
  - **Fixed LVRT & Grid adaptability test facilities;**
  - **30 wind turbine testing positions;**
  - **3 wind turbines for testing & research;**
  - **640kW PV generation system;**
  - **2.5MW energy storage system.**

NWIC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网 STATE GRID

Functions

- Measurements of power performance, power quality, acoustic noise, mechanical load, and active/reactive power control of wind turbine
- LVRT and Grid adaptability measurement of wind turbine
- Key electrical component testing of wind turbines and wind farms
- Research of wind farm active/ reactive control system

NWPC

中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网 STATE GRID

Core devices in Zhangbei test site

35kV/6MVA Grid simulator

35kV/6MVA Voltage dip generator

NWPC

中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

Qualification for Wind turbine testing

国家电网 STATE GRID

CEPRI is accredited to ISO/IEC 17025:2005 General Requirements for the Competence of Testing and Calibration Laboratories, and accredited by China National Accreditation Service for Conformity Assessment (CNAS) and China Metrology Accreditation (CMA) for power performance, power quality, noise, load and LVRT measurement of wind turbines.

NWTC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

Main customers

国家电网 STATE GRID

Vestas
Gamesa
SUZLON
SINOVEL 华锐风电
GOLDWIND
DEC 东方汽轮机有限公司 DONGFANG TURBINE CO.,LTD.
联合动力 United Power
MINGYANG WIND POWER 明阳风电
NORDEX
上海电气 SHANGHAI ELECTRIC
XEMC 湘电风能
运达风电 WINDEY
CSIC 中船重工(重庆)海装风电设备有限公司 CSIC (Chongqing) Haizhuang Windpower Equipment Co., Ltd.

NWTC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

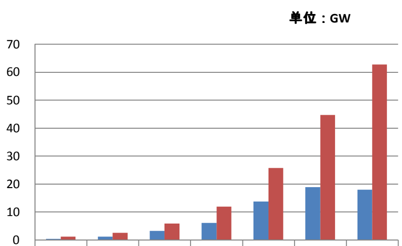
1 Introduction of Zhangbei test site

2 Status of wind power development

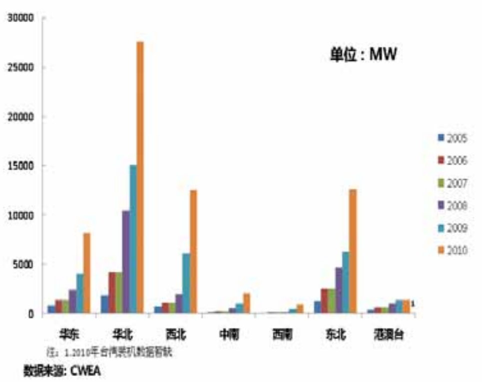
3 Wind turbine LVRT testing

4 Conclusions

Installed capacity of wind power



	2005	2006	2007	2008	2009	2010	2011
新增装机	0,5	1,3	3,3	6,2	13,8	18,9	18,0
累计装机	1,3	2,6	5,9	12,0	25,8	44,7	62,7



- **The newly added and cumulative installed capacity of wind power in China take the world's leading position in 2011.**

Wind turbine manufacturers in the world

国家电网 STATE GRID

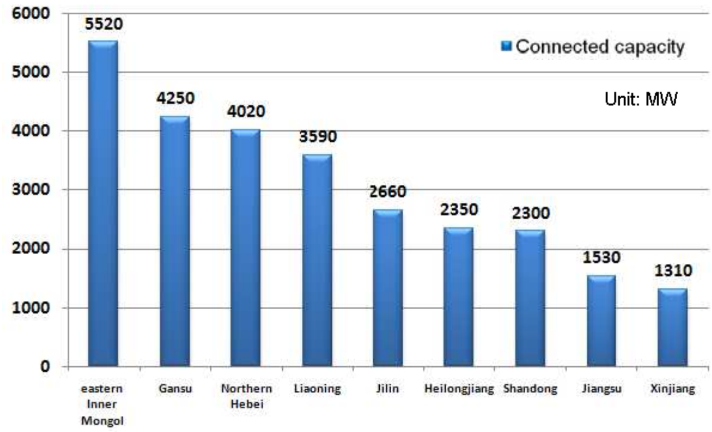
No.	Manufacturer	2010 newly increased /MW	2010 Market share	No.	Manufacturer	2010 newly increased /MW	2010 Market share
1	Vestas (Denmark)	5 842	14.8%	9	Siemens (Denmark)	2 325	5.9%
2	Sinovel (China)	4 386	11.1%	10	United Power(China)	1 643	4.2%
3	GE (USA)	3 796	9.6%	11	Mingyang (China)	1 052	2.7%
4	Goldwind (China)	3 740	9.5%	12	NORDEX (Germany)	889	2.3%
5	Enercon(Germany)	2 846	7.2%	13	Mitsubishi (Japan)	643	1.6%
6	Suzlon(India)	2 736	6.9%	14	SH Electric(China)	598	1.5%
7	DEC （China）	2 624	6.7%	15	XEMC(China)	507	1.3%
8	Gamesa (Spain)	2 587	6.6%		Total	36 214	91.9%

Data Source：BTM， World Market Update 2010

中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

Grid connected wind power in China

国家电网 STATE GRID



Source : wind power development monthly report of State Grid in Oct. 2011

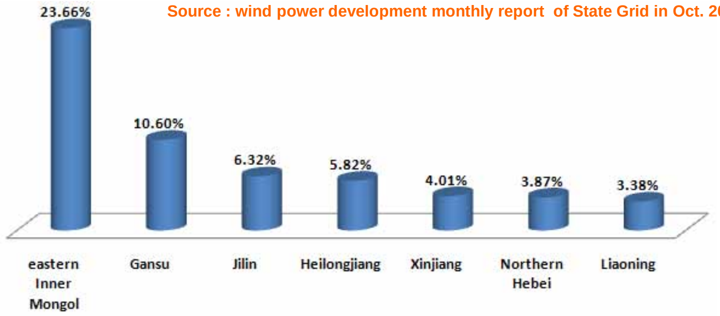
- **9 provinces with connected wind power more than 1000 MW within supplied areas of State Grid by October of 2011.**

中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网 STATE GRID

Ratio of wind power installed capacity
in the total installed capacity in some provinces

Province	eastern Inner Mongol	Northern Hebei	Gansu	Jilin	Heilongjiang	Liaoning	Xinjiang
Value	29.36%	20.1%	16.79%	12.41%	11.28%	11.08%	7.59%



Ratio of electricity sourced from wind in total electricity consumption in Sept. 2011

NWIC 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网 STATE GRID

Long distance power transmission of 10GW wind power base

Fast development

Large scale

Highly concentrated

Long distance

High voltage

NWIC 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

Electrical properties of wind power turbine

国家电网 STATE GRID

By April of 2011, there were 28 tripping accidents within supplied areas of State Grid.

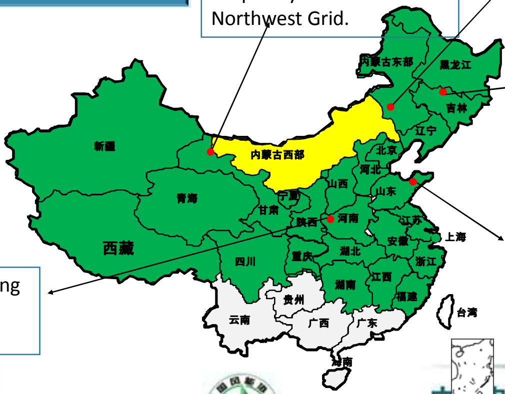
Breakdown of equipment in 35kV side, causing the frequency decrease of Northwest Grid.

Wind power turbines can't tolerate harmonics produced by wind farm, resulting to wind turbine tripping.

2-phase short circuit fault lead to tripping off of wind turbines.

The tripping usually occurs because of insufficient grid adaptability of wind turbines.

Wind turbines tripping due to the voltage unbalance of grid.



中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网 STATE GRID

1. Introduction of Zhangbei test site
2. Status of wind power development
3. Wind turbine LVRT testing
4. Conclusions

中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

Grid code for wind power integration

国家电网 STATE GRID

GB/Z 19963-2005 *Technical rule for connecting wind farm to power system* in 2005

No.779 technical documents of State Grid in 2006, *Technical Rule for connecting wind farm into power grid (the first version)*

No.327 technical documents of State Grid in 2009, *Technical Rule for connecting wind farm into power grid (the second version)*

Q/GDW 392-2009 *Technical Rule for connecting wind farm into power grid* in December of 2009

Q/GDW 630-2011 *Measurement standard of wind farm power regulation capability and power quality* in 2011

GB/T 19963-2011 *Technical rule for connecting wind farm to power system* in Dec., 2011

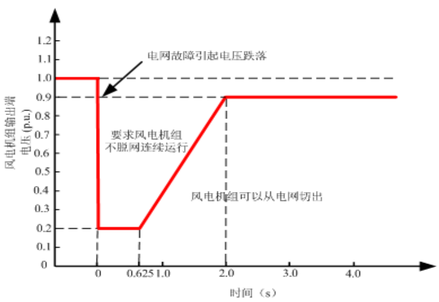
NWPC 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

GB/T 19963-2011 Technical rule for connecting wind farm to power system

国家电网 STATE GRID

General requirements

- Voltage dip to 20%Un in PCC, WTs should not tripped for 625ms.
- Voltage recovery back to 90%Un in PCC within 2s, WTs should not tripped .
- Active power recovery
  active power of WF should recover with at least 10%Pn/s to its available power.



NWPC 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

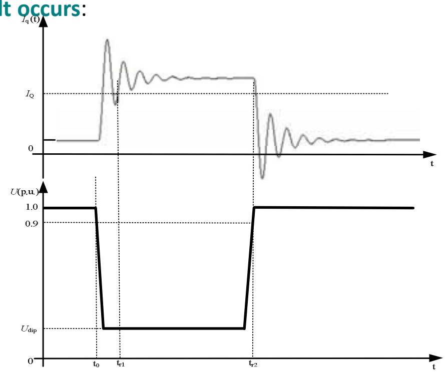
GB/T 19963-2011 Technical rule for connecting wind farm to power system

国家电网 STATE GRID

Reactive current injection requirements

For WFs larger than 1GW, each WF is required to have the ability to **inject reactive current to PCC, when three phase fault occurs**:

- Voltage range: 20%-90%Un
- $I_T \geq 1.5 \times (0.9 - U_T) I_N$ $(0.2 \leq U_T \leq 0.9)$
- $t_s \leq 75ms$; $T_{last} \geq 550ms$



NWIC — CWEA — 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

LVRT measurement

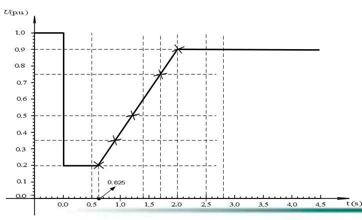
国家电网 STATE GRID

Measurement standards

- **IEC 61400-21:2008**, *Measurement and assessment of power quality characteristics of grid connected wind turbines*
- **NB/T**, *Measurement standard of wind turbine LVRT (Draft)*

Measurement contents

- **Three-phase voltage dip(20%~90% *U*n)**
- **Two-phase voltage dip(20%~90% *U*n)**



NWIC — CWEA — 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

LVRT measurement

国家电网 STATE GRID

Measurement methods

- two-phase and three-phase voltage drop
- Repeat every condition twice

Operating conditions	The Amplitude of Voltage dip (pu)	The duration of Voltage dip(ms)
0.1Pn≤P ≤0.3Pn	0.90±0.05	2000±20
	0.75±0.05	1705±20
	0.50±0.05	1214±20
	0.35±0.05	920±20
	0.20±0.05	625±20
$P>0.9P_n$	0.90±0.05	2000±20
	0.75±0.05	1705±20
	0.50±0.05	1214±20
	0.35±0.05	920±20
	0.20±0.05	625±20

LVRT measurement

国家电网 STATE GRID

Wind turbine LVRT type test

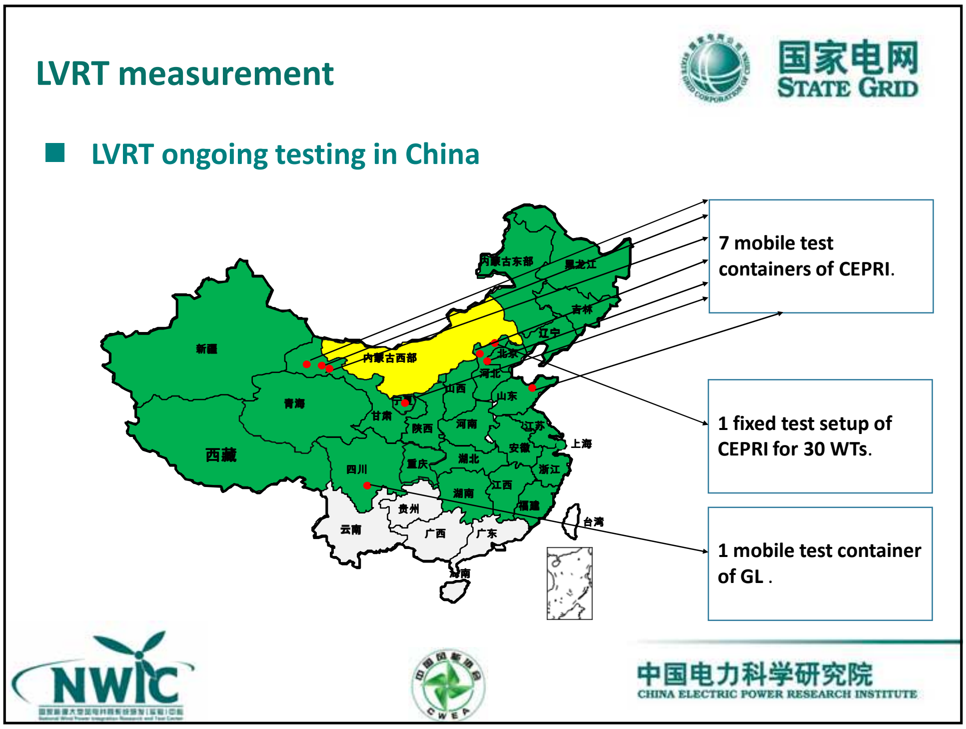
- Started on 21 February, 2010.
- We now have 7 mobile test containers and 1 fixed setup in Zhangbei test site.
- 39 WT type finished, and 15 WTs ongoing.

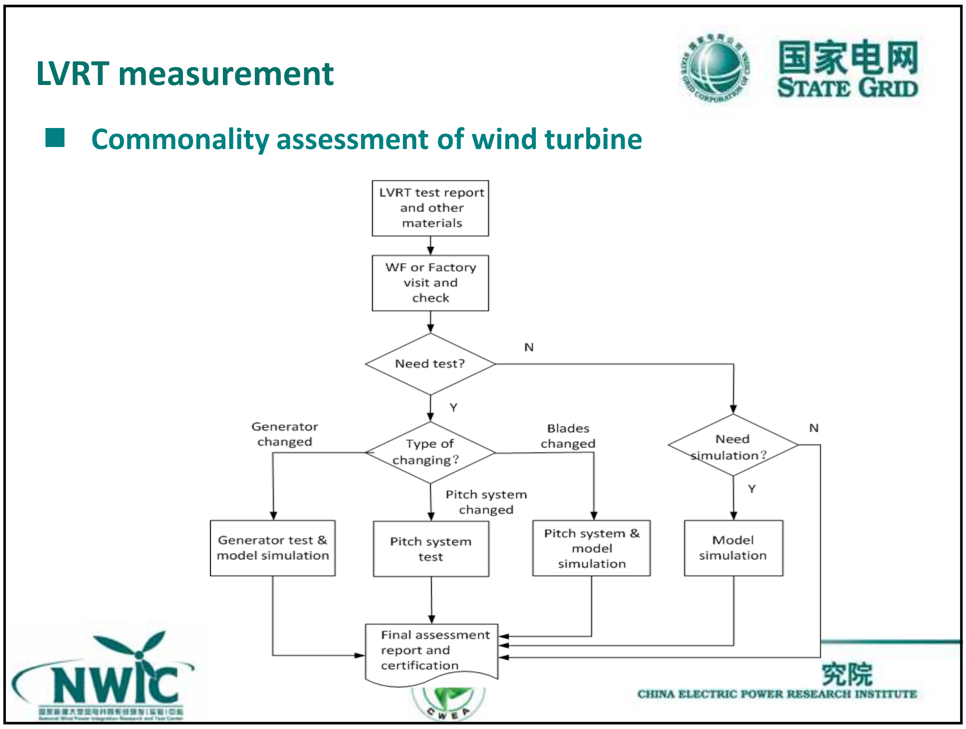
Wind turbine LVRT sample test

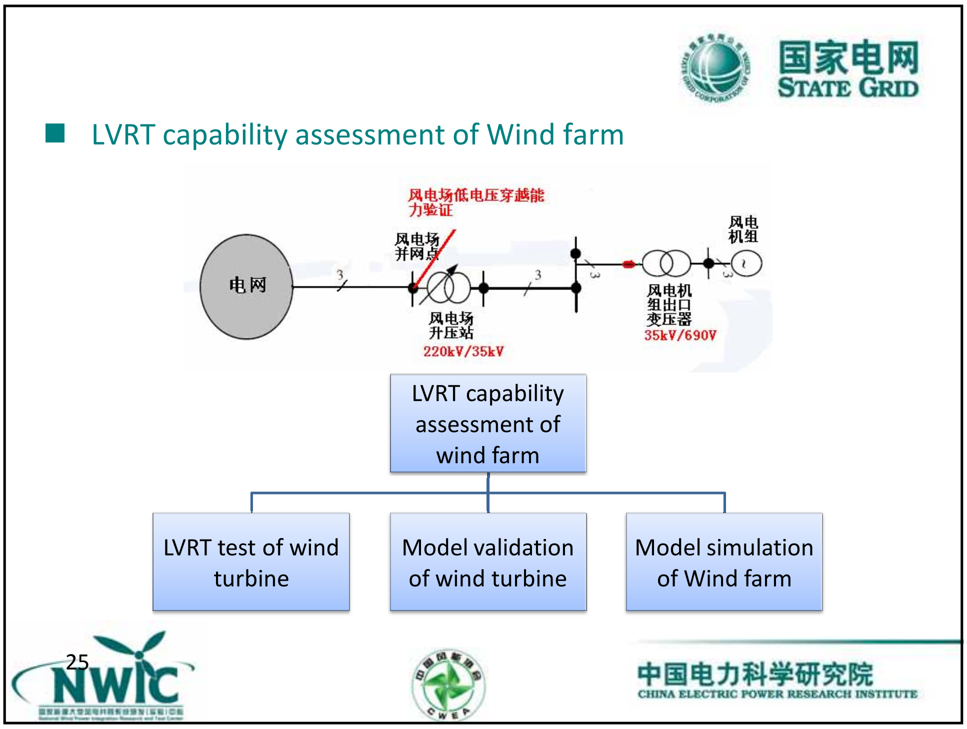
- The test institute drafts a wind farm test plan
- The grid dispatch center determines the tested WT randomly
- The test is only of 20%Un, 3phase and 2phase voltage dip, in power range from 0.1-0.3 Pn to above 0.9Pn and repeat for every condition twice

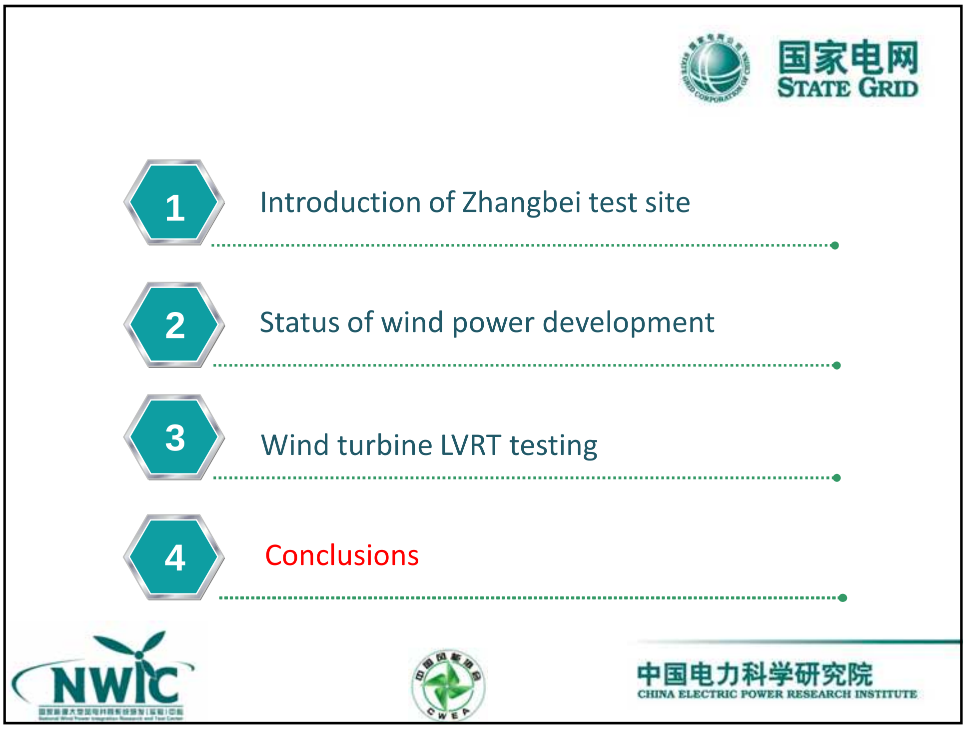
NWIC

中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE


LVRT measurement
国家电网
STATE GRID
LVRT ongoing testing in China
新疆
西藏
青海
甘肃
四川
云南
贵州
广西
广东
湖南
湖北
江西
福建
浙江
上海
江苏
安徽
河南
山东
山西
陕西
重庆
河北
北京
辽宁
吉林
黑龙江
内蒙古西部
内蒙古东部
台湾
海南
7 mobile test containers of CEPRI.
1 fixed test setup of CEPRI for 30 WTs.
1 mobile test container of GL .
NWIC
中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE


LVRT measurement
国家电网
STATE GRID
Commonality assessment of wind turbine
LVRT test report and other materials
WF or Factory visit and check
Need test?
N
Y
Type of changing?
Generator changed
Blades changed
Pitch system changed
Need simulation?
N
Y
Generator test & model simulation
Pitch system test
Pitch system & model simulation
Model simulation
Final assessment report and certification
NWIC
究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE


国家电网
STATE GRID
LVRT capability assessment of Wind farm
风电场低电压穿越能力验证
风电场并网点
电网
风电场升压站
220kV/35kV
风电机组出口变压器
35kV/690V
风电机组
LVRT capability assessment of wind farm
LVRT test of wind turbine
Model validation of wind turbine
Model simulation of Wind farm
25
NWIC
中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE


国家电网
STATE GRID
1 Introduction of Zhangbei test site
2 Status of wind power development
3 Wind turbine LVRT testing
4 Conclusions
NWIC
中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

Conclusions

国家电网
STATE GRID

- Wind power increased very fast in last 5 years , and cause more than 80 manufacturers in China. There are 7 Chinese manufacturers in top 15 globally.
- It is high efficient to test electrical behavior of wind turbine in Zhangbei test site due to Universal Foundation and Electric Switching System.
- It is important to support grid during the fault if the wind turbine had LVRT function.
- Wind turbine LVRT sample test is useful to check the grid code compliance because old wind farms need to be retrofitted.
- Electrical behavior certification system for wind farm is necessary and will be set up in China.

NWIC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

国家电网
STATE GRID

Thanks for your attention!

NWIC

中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

Thoughts on Design Verification of a WTG Drivetrain

Brian McNiff
McNiff Light Industry
brian@mcnifflight.com
&
Bill LaCava
Hal Link
Jon Keller
NREL
nrel.gov/wind/grc/

NREL

1

McNiff Light Industry
Wind Turbine Testing and Analysis

Outline

- Common dynamometer testing
- NREL Gearbox Reliability Collaborative
  - survey design process
- How to improve dyno testing
- Validating design assumptions
- Some questions

NREL

2

McNiff Light Industry
Wind Turbine Testing and Analysis

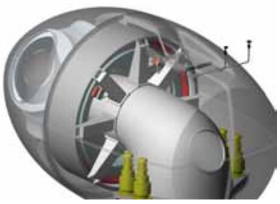
NREL 2.5 MW Dynamometer

NREL Drivetrain Testing since 1999

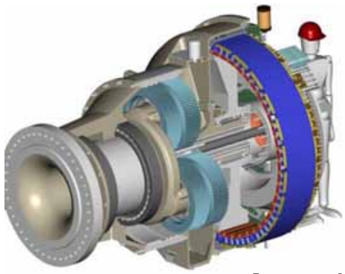
Zond Z-750 Integrated

Enron/GE 1.5 MW

Clipper Multi- generator



NPS Direct Drive-
Permanent Magnet



GEC Medium Speed

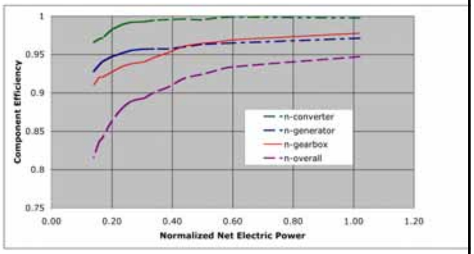
NREL

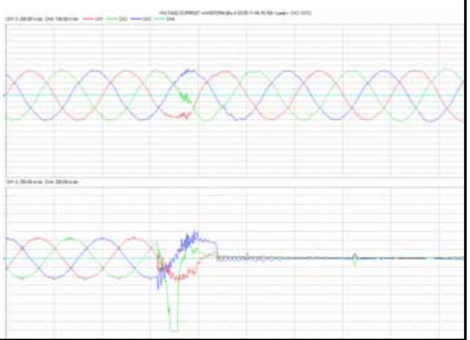
Wind Turbine Testing and Analysis

4

Original Testing Approach

- Contact tests
- Endurance tests
  - Elevated fixed torque
- Load distribution/ load sharing tests
- Transient events
- Measure Efficiency
- Control system tests

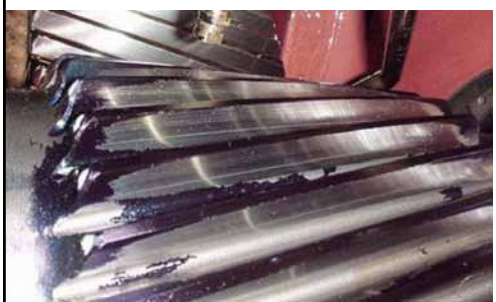


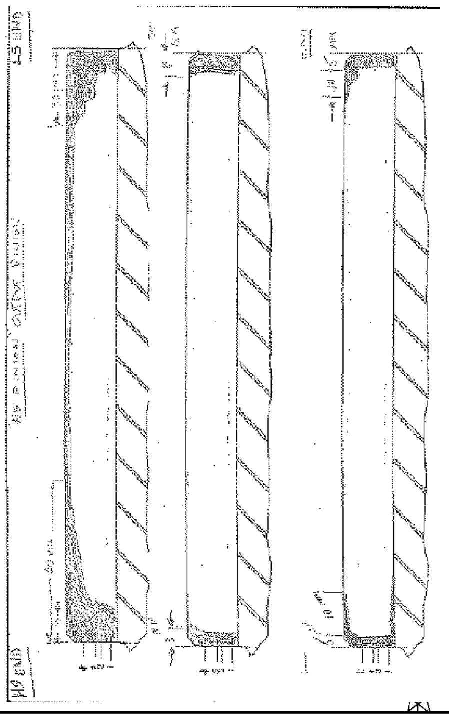


5

Contact Pattern Progression

Output Pinion
33% - 66% -100%

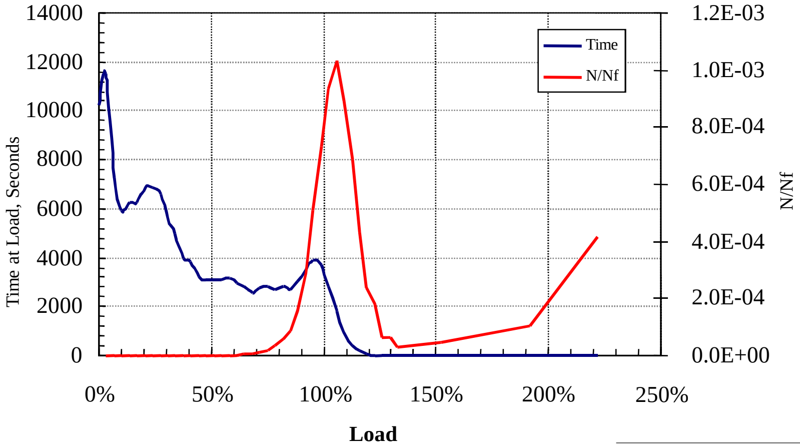




6

Apply Fatigue Damage Equivalent Load

based on torque histogram, 1.3 -1.7x rated



McNiff Light Industry
Wind Turbine Testing and Analysis

7

Modify Approach to Dyno Testing

- Is accelerated load test useful?
  - Doesn't reproduce ALL observed problems
  - Tests only one mesh or element
  - What about bearings?
- Should validate design assumptions
  - Focus tests/ measurements to reduce uncertainty
  - Validation - does unit meet the specification?
  - Verification - is unit appropriate for application?
- Reproduce design load cases
  - Identify other DLC nasty to gears/ bearings
  - difficult to get with field testing

McNiff Light Industry
Wind Turbine Testing and Analysis

8

Validating Design Assumptions

from Test clause IEC/ ISO 61400-4 CDV

- design & rating factors for gears
  - Khβ, Ka, K- gamma
- selection, sizing and life rating of bearings
  - Load distribution – axial and radial, load zone
- details of lubricant and lubricant system
  - Cleanliness de-rating on bearings?
- structural analysis integrated into WTG
  - Elastic deflections, motion at interfaces,
  - System dynamics

NREL

9

McNiff Light Industry
Wind Turbine Testing and Analysis

Design Uncertainties from Critical Design Review

Priority or RIsk	Item	Dependency	How to evaluate	-
	HS locating bearing	Lube, mount stiffness	Temp?	
	Planet bearings	Carrier + pin stiffness	Load distribution	
Limit could be destructive	Carrier bearings axial tolerance range	Motion, initial position of shaft and bearing fits		
	Planet gear microgeometry	Bearing compliance, housing motion, carrier defelction	Measure load distrib on sun or ring	

NREL

10

McNiff Light Industry
Wind Turbine Testing and Analysis

Design Validation

- Improved design analysis tools
  - increase drivetrain DOFs in WTG aeroelastic models
  - Integrated FEA/ multibody models
- Dynamometer testing to validate as-built
  - What situations / DLC to simulate
  - What does accelerated fatigue test verify/ validate
  - Should be verifying design assumptions, to reduce uncertainty and increase confidence

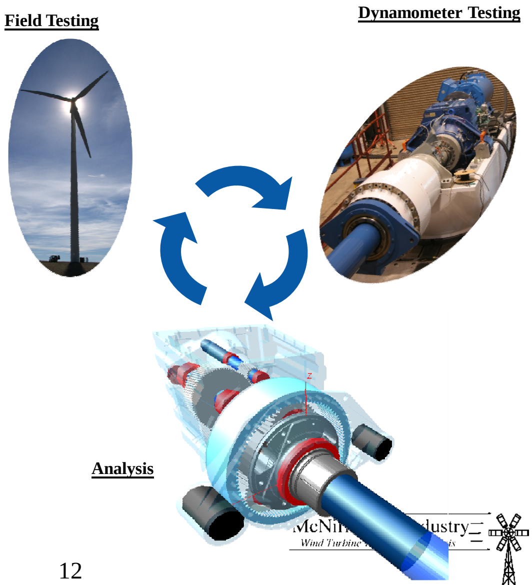
McNiff Light Industry
Wind Turbine Testing and Analysis

11

NREL Gearbox Reliability Collaborative Overview

GRC Goals

- Understand internal and external gearbox response to specific loading
- Explore gaps in design process
- Develop dynamometer test to validate design assumptions
- Exercise current state of the art design tools from rotor to tribological surfaces
- Suggest improvements in design practices, validation testing and analytical tools



12

Test Approach & Objectives

- Redesigned, rebuilt 2 identical 750 kW gearboxes
- Modified to MW state of the art
- Instrumented with over 125 signals to sense motions, deflections, load distributions, strains and temp
- Objective: Collect data to characterize gear, bearing and structural response in all operating situations
- Field Test – capture normal operation and transients
- Dyno Test – static torque, add rotor forces and moments, add dynamics to reproduce field response
- Developed data post processing and visualization tools
- Validate data to provide to analysis partners

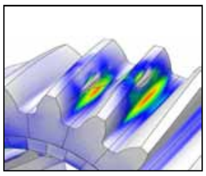
NREL McNiff Light Industry Wind Turbine Testing and Analysis

13

Gearbox Modeling

Gearing Analysis

- Gear tooth loading
- Gear mesh stiffness
- Gear tooth contact stress



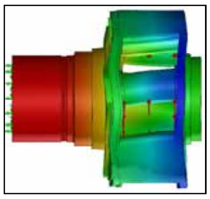
Source: Ansol (Calyx)

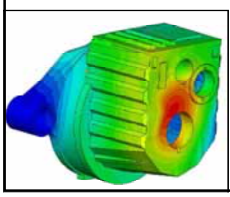
Shaft Analysis

- Torsional deflections
- Bending defection and misalignment

Planet Carrier Analysis

- Torsional deformation of the planet carrier
- Misalignment the planet pin
- Planet carrier and pin interaction



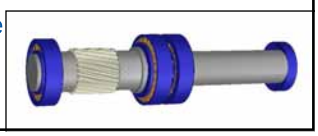


Housing Analysis

- Deflections
- Misalignment
- Tolerance stack up
- Virtual modal testing

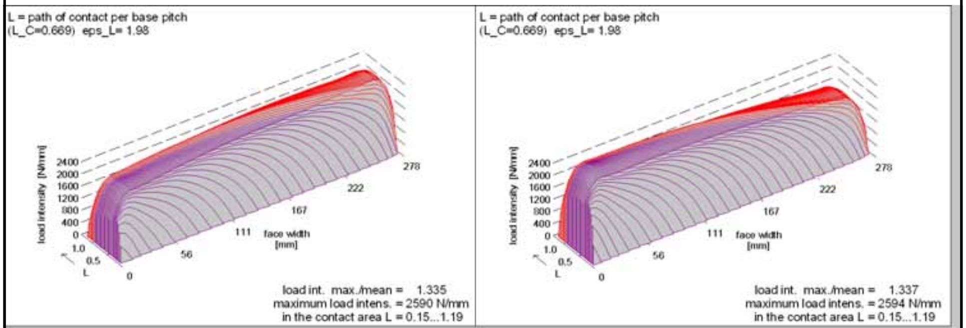
Bearing Analysis

- Bearing stiffness
- Roller contact stress
- Roller load distribution
- Bearing life

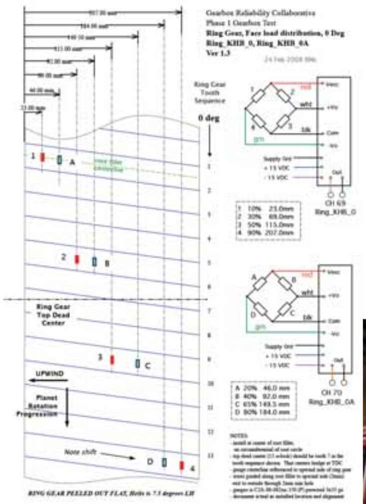


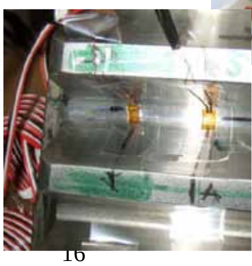
14

RESULTS OF MESH ANALYSIS, $K_{H\beta}$



Instrumentation – Ring Gear Tooth Load Distribution





16

McNiff Light Industry
Wind Turbine Testing and Analysis

Gear Tooth Geometry

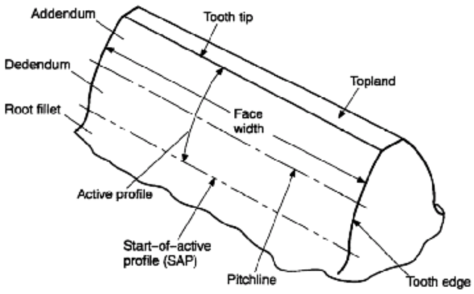
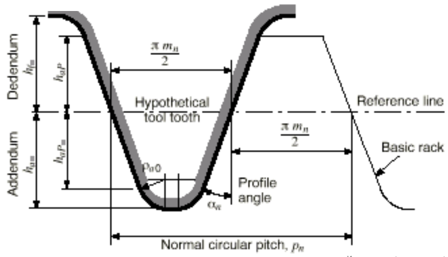
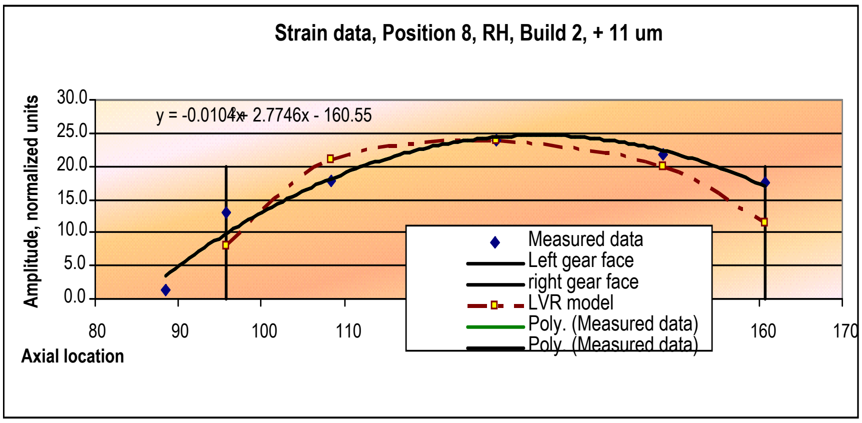


Figure 1 – Gear tooth nomenclature



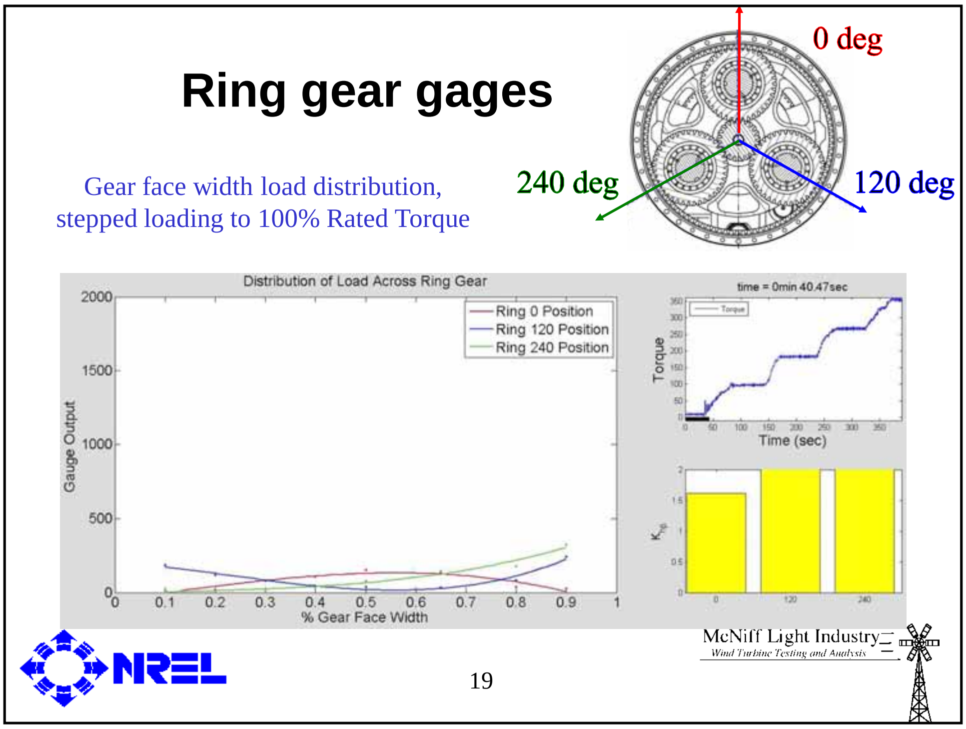
17

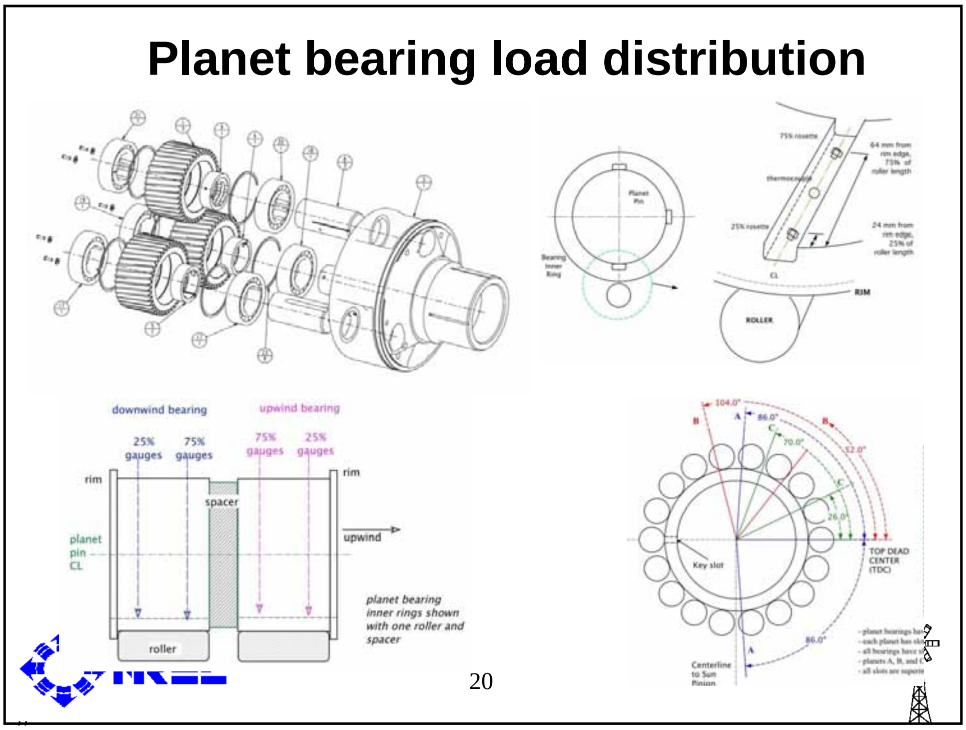
COMPARE TO MODEL



McNiff Light Industry
Wind Turbine Testing and Analysis

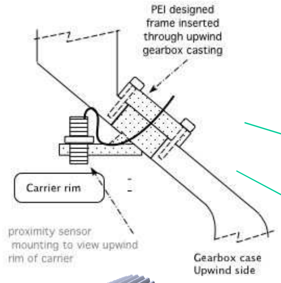
18

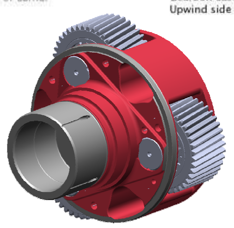

Ring gear gages
Gear face width load distribution,
stepped loading to 100% Rated Torque
0 deg
240 deg
120 deg
Distribution of Load Across Ring Gear
Ring 0 Position
Ring 120 Position
Ring 240 Position
Gauge Output
% Gear Face Width
time = 0min 40.47sec
Torque
Time (sec)
McNiff Light Industry
Wind Turbine Testing and Analysis
19


Planet bearing load distribution
downwind bearing
upwind bearing
25% gauges
75% gauges
75% gauges
25% gauges
rim
spacer
rim
planet pin CL
upwind
roller
planet bearing inner rings shown with one roller and spacer
ROLLER
RIM
Key slot
TOP DEAD CENTER (TDC)
20

Carrier Rim Deflection

CARRIER RADIAL

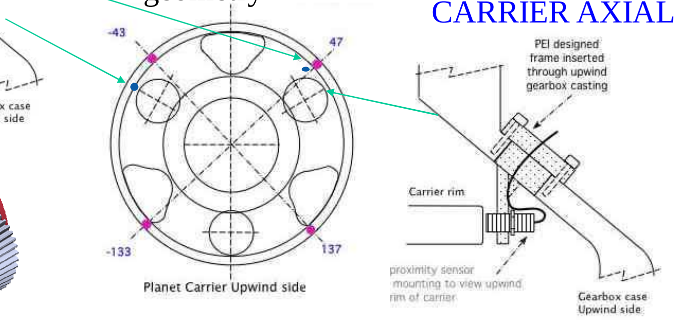




-Can models accurately reproduce carrier deflection and motion?

- Key to evaluating loading on bearings, planet load share and proper gear micro-geometry

CARRIER AXIAL



NREL

21

McNiff Light Industry
Wind Turbine Testing and Analysis

Non-torque loading requirements

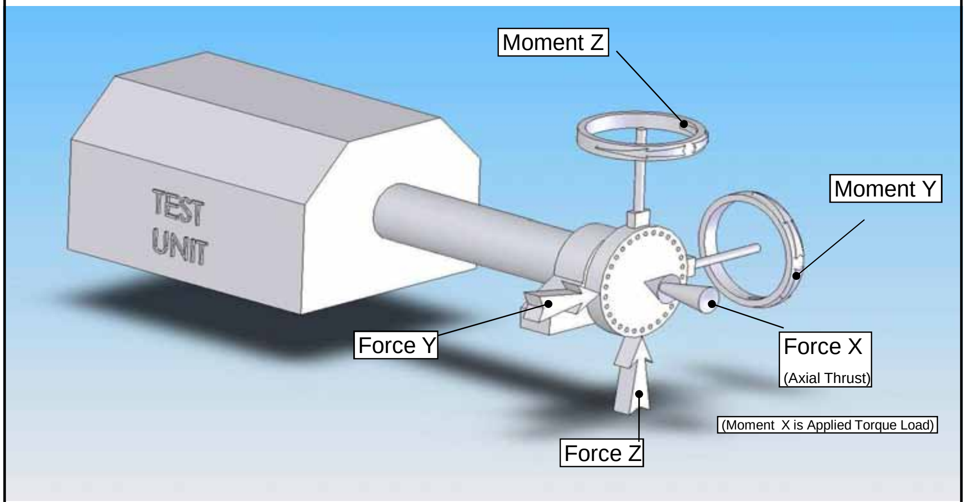
- what forces and moments? All?
- what load level to size system?
  - Max operating or extreme?
  - Fatigue eqivalent?
  - Phasing
- inertia simulation
- dynamic application of torque and NTL
  - load and speed sweeps?

NREL

22

McNiff Light Industry
Wind Turbine Testing and Analysis

Non-torque Loads and Coordinates on LSS

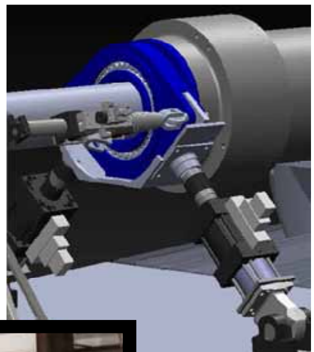


NREL

McNiff Light Industry
Wind Turbine Testing and Analysis

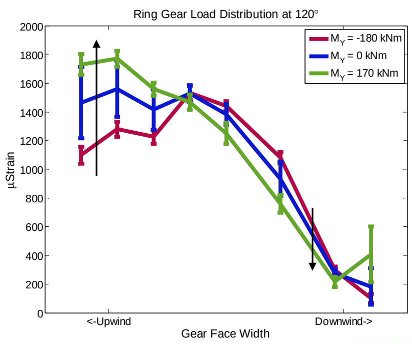
23

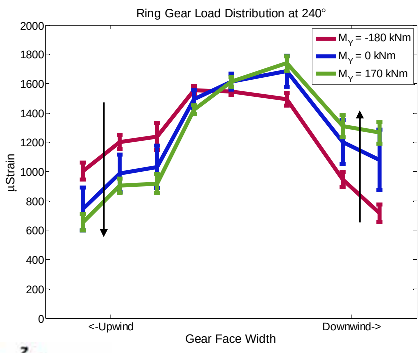
Non Torque Loading Mechanism

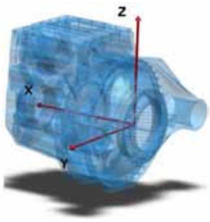


NREL

Shaft Bending Effect on Ring Gear







+My

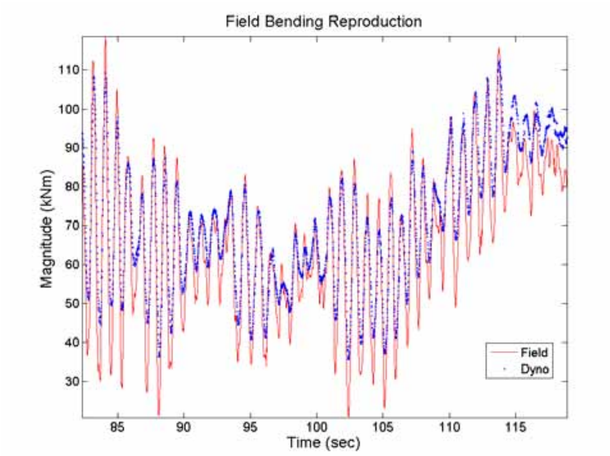
NREL

25

McNiff Light Industry
Wind Turbine Testing and Analysis

Dynamic Non-Torque

- LSS Bending data from the field test was fed into NTL system for a proof of concept
- Magnitude error due to calibration of the system
- Field data was low pass filtered to 2 Hz.
- Other sources or error need to be tracked down and accounted for (actuator response, limited degrees of freedom, etc)

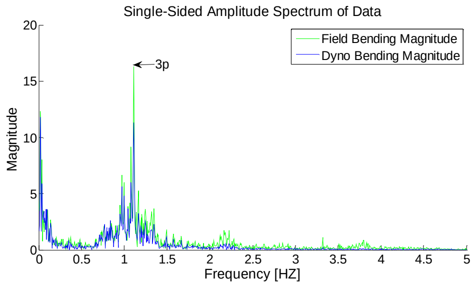


NREL

26

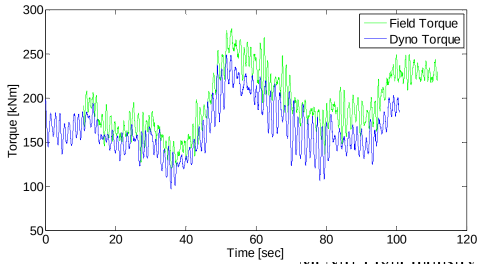
McNiff Light Industry
Wind Turbine Testing and Analysis

Dynamically Simulating Field Data



- Able to operate NREL dynamometer to dynamically match shaft bending from actual field data

- Same with torque



McNiff Light Industry
Wind Turbine Testing and Analysis

27

McNiff Light Industry
Wind Turbine Testing and Analysis

28

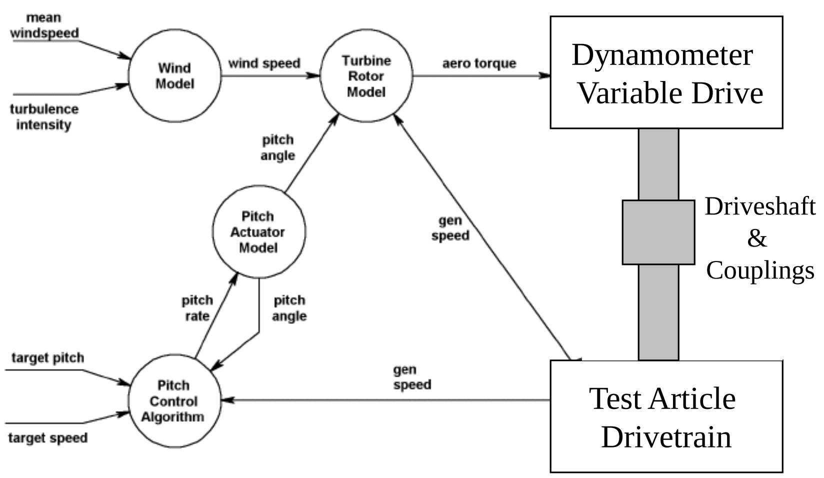
Improving capabilities

- Need good transfer functions/ models between field and dyno response
- Requires more degrees of freedom in drivetrain part of WTG models
- Apply dynamically changing loads
- Requires controlling Dyno like a rotor
  - Using aero models, FAST, HAWC, FLEX
- Requires applying non-torque loads

NREL

McNiff Light Industry
Wind Turbine Testing and Analysis

Dyno-as-Rotor Feedback Control



NREL

McNiff Light Industry
Wind Turbine Testing and Analysis

Testing Cases (e.g., IEC 61400-13 MLC)

- HALT – what, how, GETS:
  - 2X load applied short duration at start
  - 1600 hrs at 1.X load endurance
  - Periodic application of highest load in histogram
- Test to observed failures
  - Low Q, high NTL + scuffing, skidding, WEC
- Torque, Speed, NTL Sweeps and Steps
- Speed ramps at different rates
- Torque oscillations – slow and fast
- Actual DLCs (eg, faults, large yaw error)

NREL 31 McNiff Light Industry Wind Turbine Testing and Analysis

Dyno test difficulties

- Rotor inertia
- Difference in drive train stiffness
- Non-torque loads
- Fluctuating loads
- High ramp rates and accelerations
- Transient event dynamics

NREL 32 McNiff Light Industry Wind Turbine Testing and Analysis

Questions?

NREL

McNiff Light Industry
Wind Turbine Testing and Analysis

33

WIND TURBINE GEARBOX TEST

IEA Wind, TEM #68, Feb 21-22 2012,
Aachen, Germany

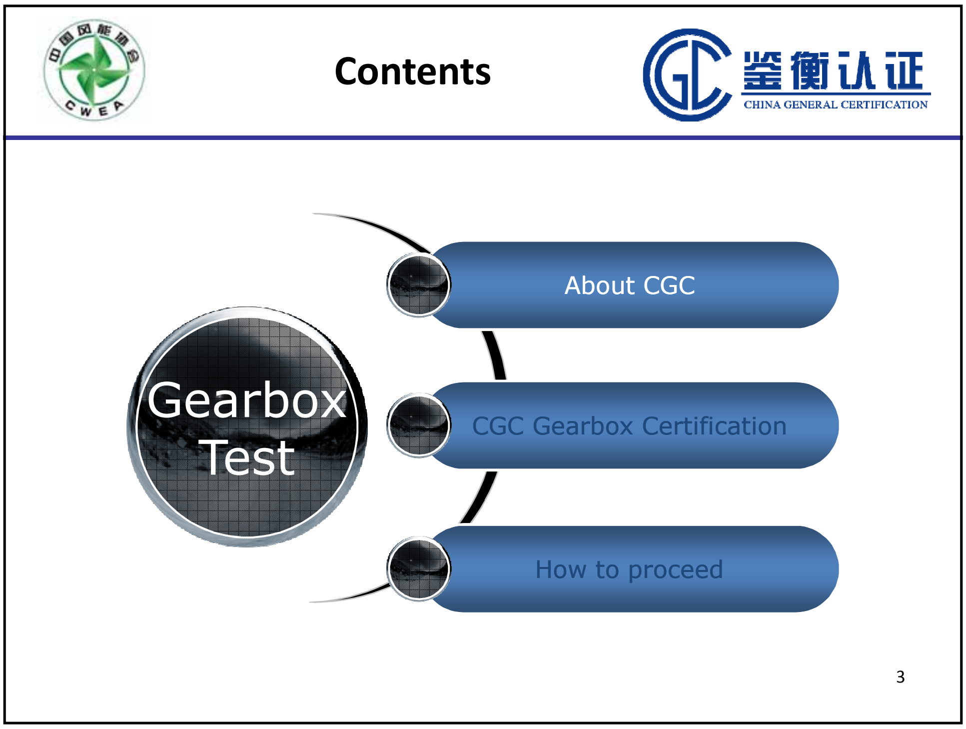
Ximei Li, Engineer
E-mail: lixm@cgc.org.cn
China General Certification Center

1

Contents

Gearbox Test

2


Contents
鉴衡认证
CHINA GENERAL CERTIFICATION
Gearbox Test
About CGC
CGC Gearbox Certification
How to proceed
3


About CGC
鉴衡认证
CHINA GENERAL CERTIFICATION
4

About CGC

鉴衡认证 CHINA GENERAL CERTIFICATION

Main references for wind turbines

IEC 61400-22 : 2010	Wind Turbines- Part 22: Conformity testing and certification
IEC 61400-1 Second Edition 1999-02	Wind Turbine Generator System-Part 1: Safety Requirements
IEC 61400-1 Third Edition 2005-08	Wind Turbines-Part 1: Design Requirements
IEC 61400-2 Second Edition 2006-03	Wind Turbines-Part 2: Design Requirements for Small Wind Turbines
IEC 61400-3 First Edition 2009-02	Wind Turbines-Part 3: Design Requirements for Offshore Wind Turbines
IEC 61400-11 Consolidated	Wind Turbine Generator Systems-Part 11: Acoustic

5

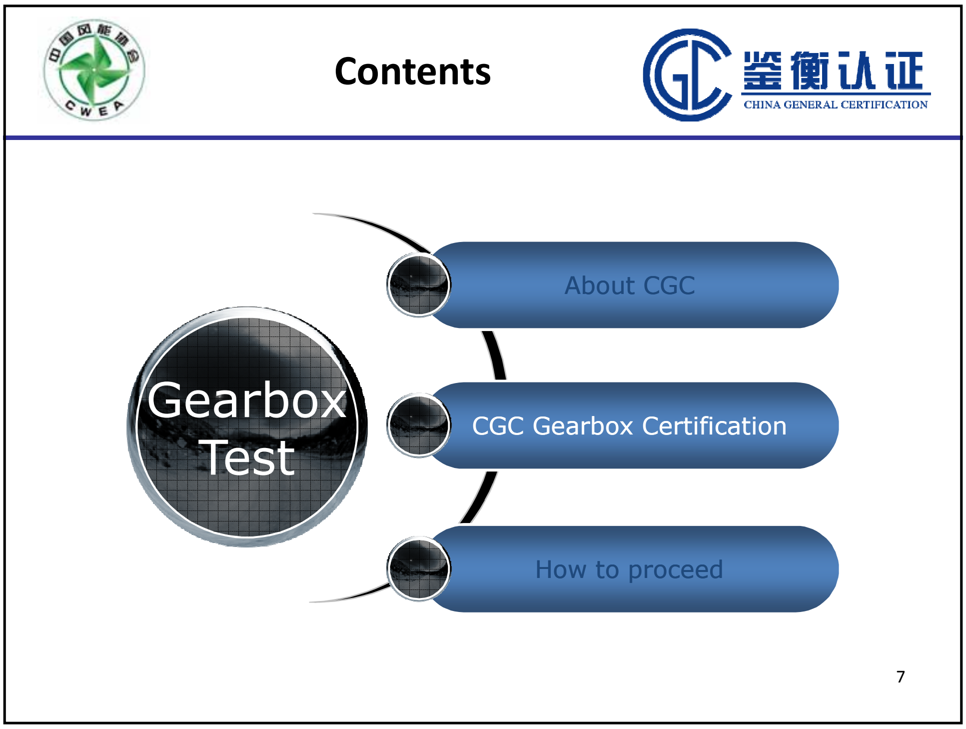
About CGC

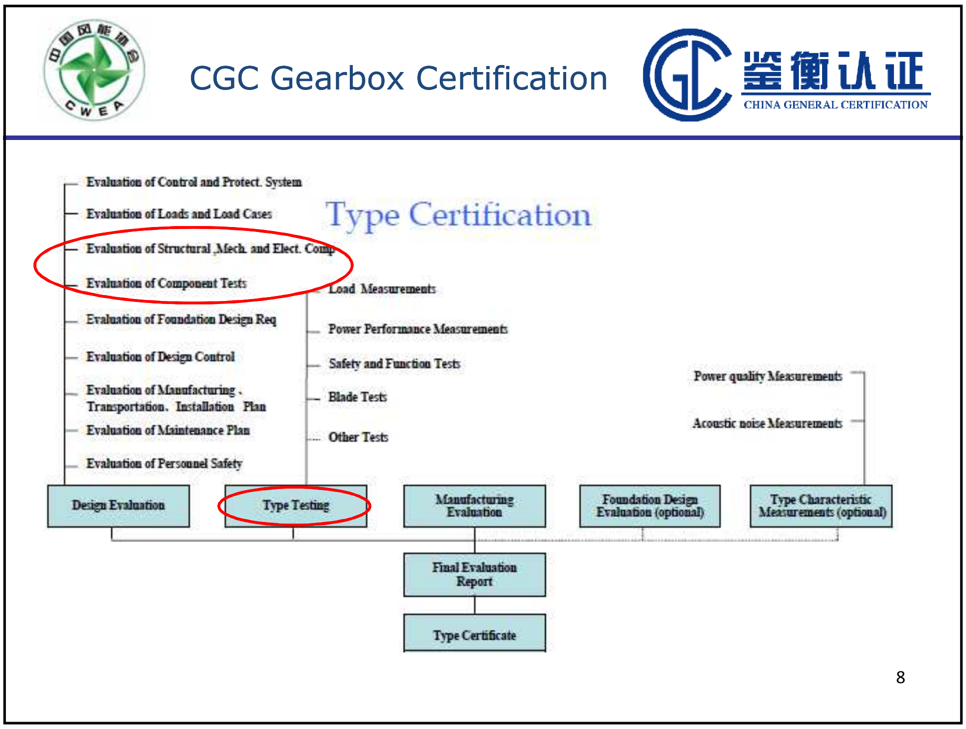
鉴衡认证 CHINA GENERAL CERTIFICATION

Main references for wind turbines

IEC 61400-12-1 First Edition 2005-12	Wind Turbines-Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines
IEC 61400-13 First Edition 2001-06	Wind Turbine Generator System-Part 13: Measurements of Mechanical Loads
IEC 61400-21 Third Edition 2008-08	Wind Turbines-Part 21: Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines
IEC 61400-23 First Edition 2001-04	Wind Turbines Generator Systems-Part 23: Full-scale Structural Testing of Rotor Blades
IEC 61400-24 First Edition 2002-07	Wind Turbines Generator System-Part24: Lighting Protection

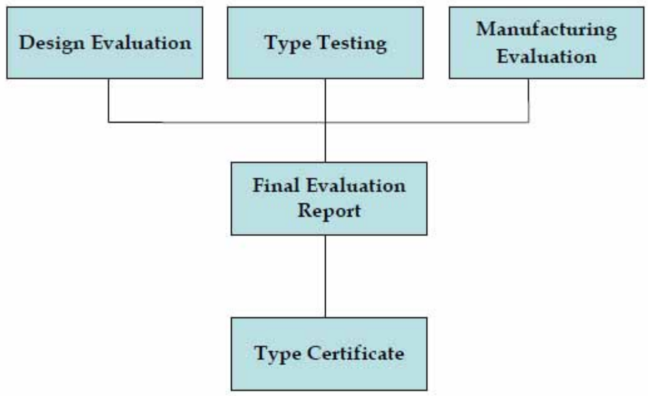
6


Contents
鉴衡认证
CHINA GENERAL CERTIFICATION
Gearbox Test
About CGC
CGC Gearbox Certification
How to proceed
7


CGC Gearbox Certification
鉴衡认证
CHINA GENERAL CERTIFICATION
Type Certification
Evaluation of Control and Protect. System
Evaluation of Loads and Load Cases
Evaluation of Structural ,Mech. and Elect. Comp
Evaluation of Component Tests
Evaluation of Foundation Design Req
Evaluation of Design Control
Evaluation of Manufacturing、Transportation、Installation Plan
Evaluation of Maintenance Plan
Evaluation of Personnel Safety
Load Measurements
Power Performance Measurements
Safety and Function Tests
Blade Tests
Other Tests
Power quality Measurements
Acoustic noise Measurements
Design Evaluation
Type Testing
Manufacturing Evaluation
Foundation Design Evaluation (optional)
Type Characteristic Measurements (optional)
Final Evaluation Report
Type Certificate
8

CGC Gearbox Certification

Component Certification



9

CGC Gearbox Certification

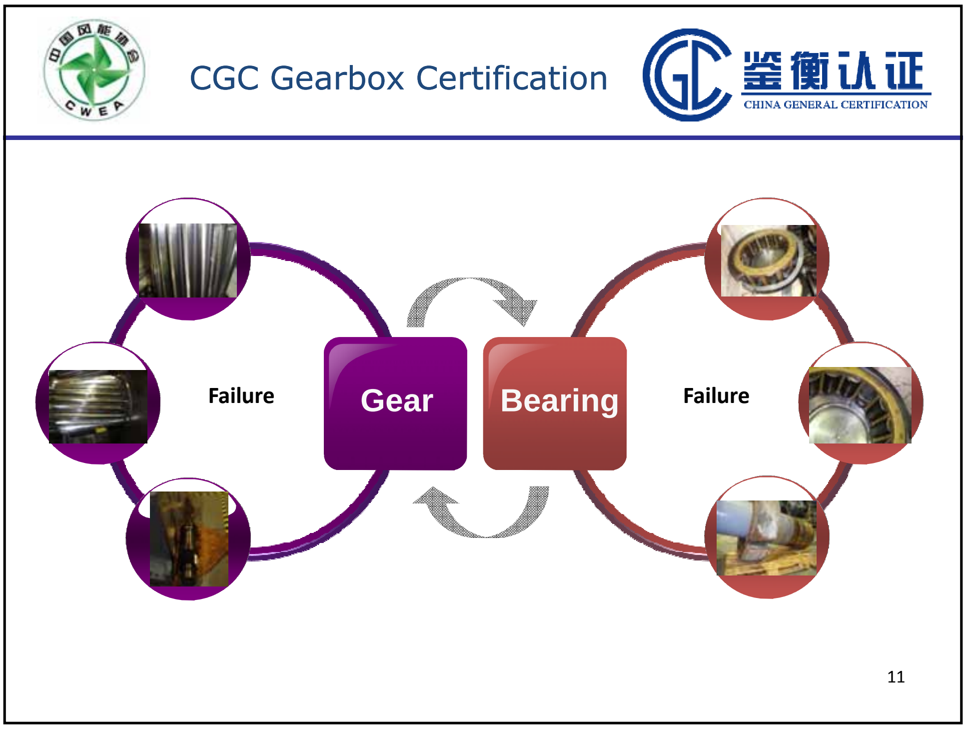
Certification & Witness

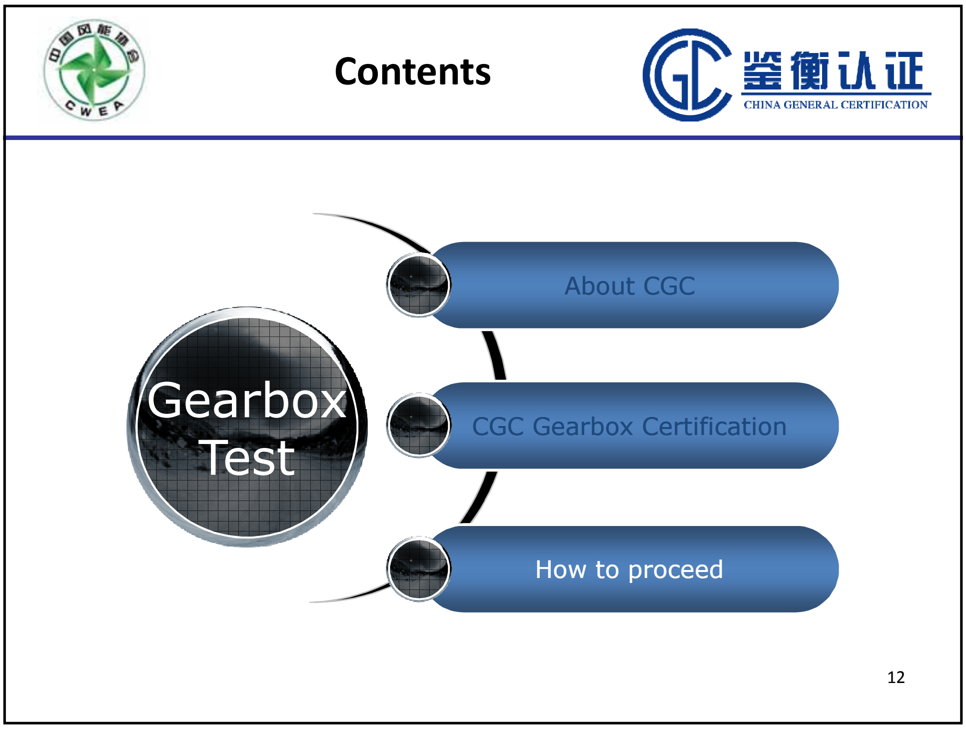
Still up to 19.4% Failures from gearbox

Problems

Source: Downtime due to failures(WindStats)

10


CGC Gearbox Certification
鉴衡认证
CHINA GENERAL CERTIFICATION
Failure
Gear
Bearing
Failure
11


Contents
鉴衡认证
CHINA GENERAL CERTIFICATION
Gearbox Test
About CGC
CGC Gearbox Certification
How to proceed
12

How to Improve

CHINA GENERAL CERTIFICATION

Approach 1 | Approach 2 | Approach 3

Test requirements(IEC 61400-4)
e.g.Strain gauges test

IEC/TC or SC: 88	Project number: IEC 61400-4 Ed.1	
Title of TC/SC: Wind turbines	Date of circulation: 2009-10-16	Closing date for comments: 2010-01-22

IEC 61400-4 Ed.1: Wind Turbines – Part 4: Design requirements for wind turbine gearboxes

– 76 – 61400-4/CD © IEC 20XX

- Test duration at the nominal torque until sump and bearing temperatures are stable with normal cooling, or 6 hours minimum.
- For visual contact pattern evaluation, the torque steps shall be applied at the same rotational speed (preferably at nominal) or along the power-speed curve of the turbine. For inaccessible meshes other methods shall be applied to evaluate the related face load distribution factor, such as tooth root strain gauges.
- For planet and other split path gear meshes, measurement of actual face load distribution at each load step using tooth root strain gauges. The results shall be used to evaluate the design performance in relation to the resulting contact pattern and applied load factors (K-factors in clause 7.2.3) for the gear rating. Annex G.2 provides proposals and literature references to applied methods in order to make such assessments.

13

How to Improve

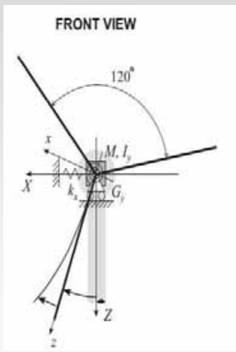
CHINA GENERAL CERTIFICATION

Approach 1 | Approach 2 | Approach 3

reasons | simulation | Result& Test

Possible reasons

- Wind turbine is extremely prone to vibration
- Drivetrain size is more larger while their structures and materials are almost same as before
- The single DOF mathematical model of load calculation do not agree with multi-MW wind turbine

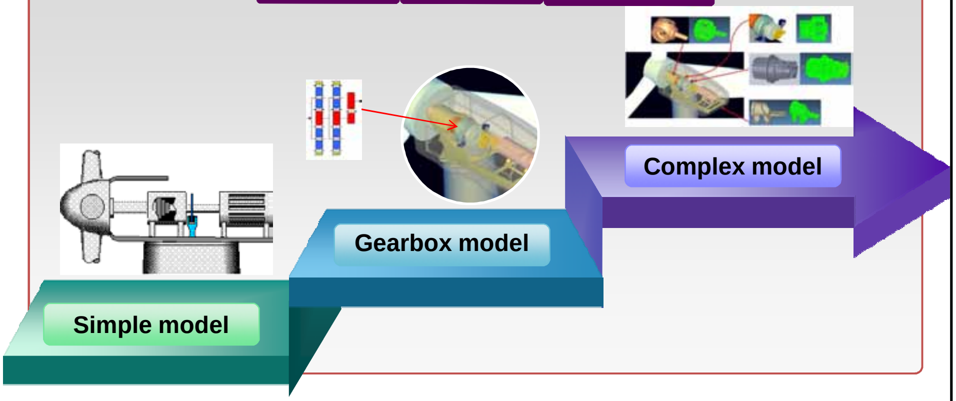


14

How to Improve

Approach 1 | Approach 2 | Approach 3

reasons | simulation | Result& Test



15

How to Improve

Approach 1 | Approach 2 | Approach 3

reasons | simulation | Result& Test 1

Load Compare

No.	A	B
1	Load calculated by Bladed	Load calculated by SAMCEF(simple model)
2	load of simple model	Load data measured
3	Load of complex model	Load data measured
4	Load of simple model, gearbox model	

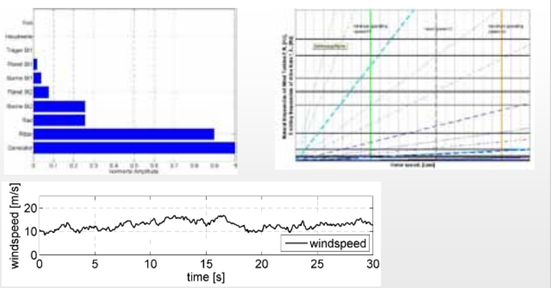
16

How to Improve

Approach 1 | Approach 2 | Approach 3

reasons | simulation | Result& Test 2

analysis



17

How to Improve

Approach 1 | Approach 2 | Approach 3

State key Laboratory

No.	Test center
1	WT Semi-physical Simulation Center
2	Key Components of WT Test Center
3	WT Field Test Center
4	WT Remote Monitoring Center

18

How to Improve

Approach 1 | Approach 2 | Approach 3

Multi-DOFs Gearbox Test Rig

Plan : introduce realistic loading condition on the test gearbox

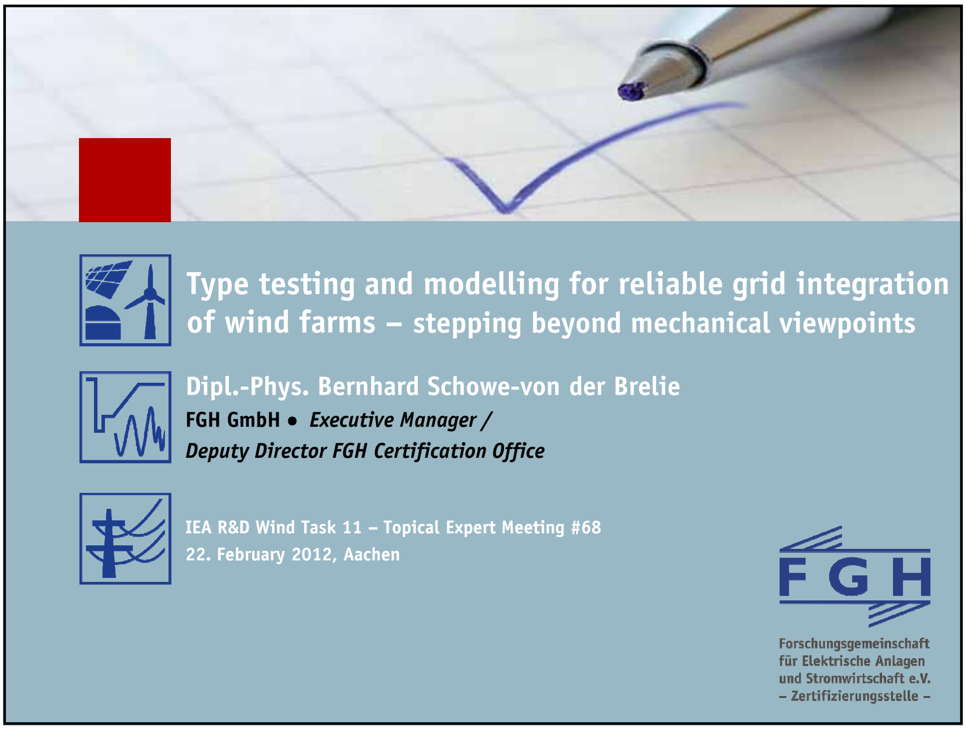
Challenge: maybe need to consider many aspects of bench, like size, capacity, accuary, control etc.

Suggestions for gearbox test rig?

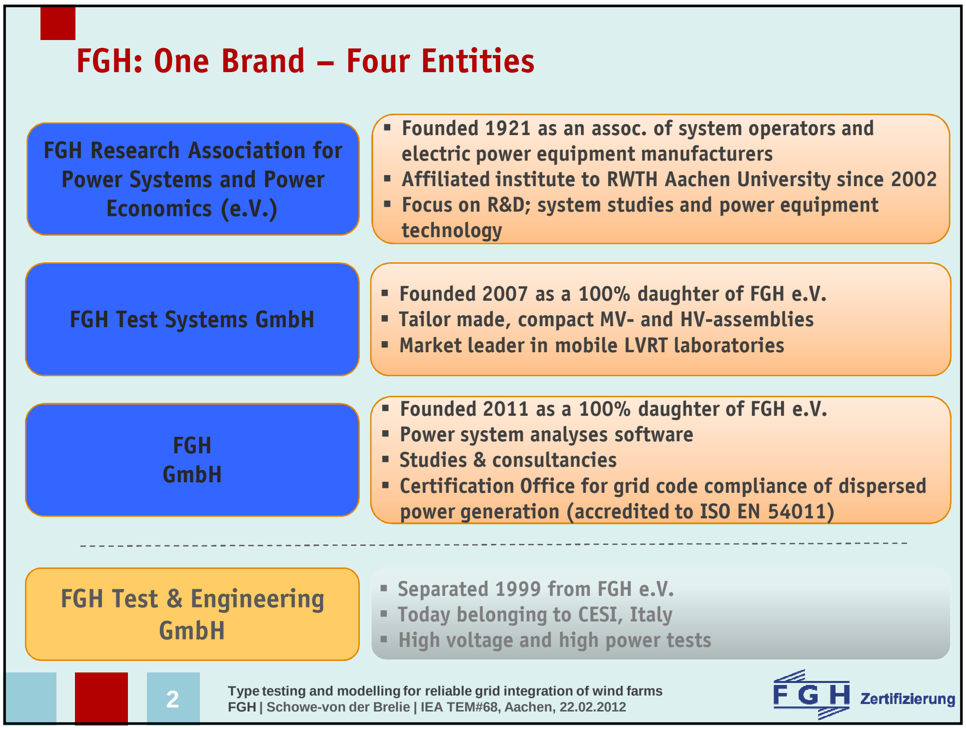
19

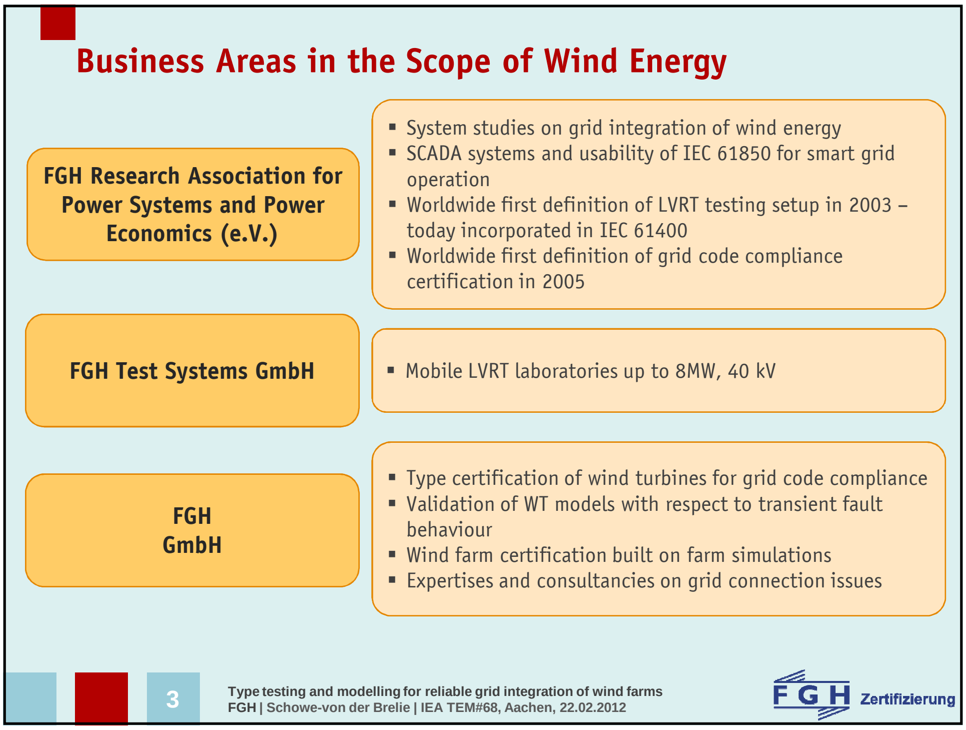
Thank you for your attention!

20

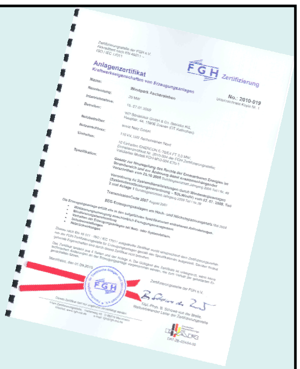

Type testing and modelling for reliable grid integration of wind farms – stepping beyond mechanical viewpoints
Dipl.-Phys. Bernhard Schowe-von der Brelie
FGH GmbH • Executive Manager /
Deputy Director FGH Certification Office
IEA R&D Wind Task 11 – Topical Expert Meeting #68
22. February 2012, Aachen
F G H
Forschungsgemeinschaft
für Elektrische Anlagen
und Stromwirtschaft e.V.
– Zertifizierungsstelle –


Agenda
FGH at a glance
FGH Entities
Business Areas in the Scope of Wind Energy
Type Testing & Certification
Motivation and Regulatory Framework
Type Testing
Fault Performance / LVRT
Modelling
Certification
Type / Product
Wind Farm
Conclusion & Outlook
Trends & Requirements
R&D at FGH
1
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
F G H Zertifizierung


FGH: One Brand – Four Entities
FGH Research Association for Power Systems and Power Economics (e.V.)
Founded 1921 as an assoc. of system operators and electric power equipment manufacturers
Affiliated institute to RWTH Aachen University since 2002
Focus on R&D; system studies and power equipment technology
FGH Test Systems GmbH
Founded 2007 as a 100% daughter of FGH e.V.
Tailor made, compact MV- and HV-assemblies
Market leader in mobile LVRT laboratories
FGH GmbH
Founded 2011 as a 100% daughter of FGH e.V.
Power system analyses software
Studies & consultancies
Certification Office for grid code compliance of dispersed power generation (accredited to ISO EN 54011)
FGH Test & Engineering GmbH
Separated 1999 from FGH e.V.
Today belonging to CESI, Italy
High voltage and high power tests
2
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Business Areas in the Scope of Wind Energy
FGH Research Association for Power Systems and Power Economics (e.V.)
System studies on grid integration of wind energy
SCADA systems and usability of IEC 61850 for smart grid operation
Worldwide first definition of LVRT testing setup in 2003 – today incorporated in IEC 61400
Worldwide first definition of grid code compliance certification in 2005
FGH Test Systems GmbH
Mobile LVRT laboratories up to 8MW, 40 kV
FGH GmbH
Type certification of wind turbines for grid code compliance
Validation of WT models with respect to transient fault behaviour
Wind farm certification built on farm simulations
Expertises and consultancies on grid connection issues
3
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

References



- Definition of **LVRT testing procedure** in 2003
- Provision of **first mobile LVRT laboratory** in 2004; today: world market leader
- First **certification on WT grid code compliance** world wide in 2005
- First **model validation** acc. to enhanced German TR4 scheme in 2009
- First **wind farm certificate** acc. to enhanced German grid code requirements based on validated WT models in 2010 (more than 200 certificates in 2011)
- Certification of the **major WT suppliers** acc. to German grid code requirements – **80 type** certificates in 2010/2011
- Long-term **co-operation with TÜV Rheinland** on IEC 61400 type certification and grid integration consultancies in 2012
- Member of: **IEC** TCs (partl. Chairman); **DKE** (partl. Chairman); EWEA (Working Group Grid Connection Requirements); **FGW** (partl. Chairman)

4 Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012 FGH Zertifizierung

Agenda

FGH at a glance

- FGH Entities
- Business Areas in the Scope of Wind Energy

Type Testing & Certification

- Motivation and Regulatory Framework
- Type Testing
  - Fault Performance / LVRT
  - Modelling
- Certification
  - Type / Product
  - Wind Farm

Conclusion & Outlook

- Trends & Requirements
- R&D at FGH

5 Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012 FGH Zertifizierung

Need for System Operators to involve DER / RES – A paragigm shift in WT performance requirements !

Status Quo in power supply with high penetration of renewables

Increasing penetration of DER / RES

Problems of the system operator

Frequency stability	Voltage regulation	Dynamic operation
Lacking involvement of RES in balancing power oscillations	Substitution of conventional power plants with reactive power supply	Danger of deficit in power supply after fault clearance in case of disconnection

Replacement of conventional power plants enforces mandatory system services of DER / RES

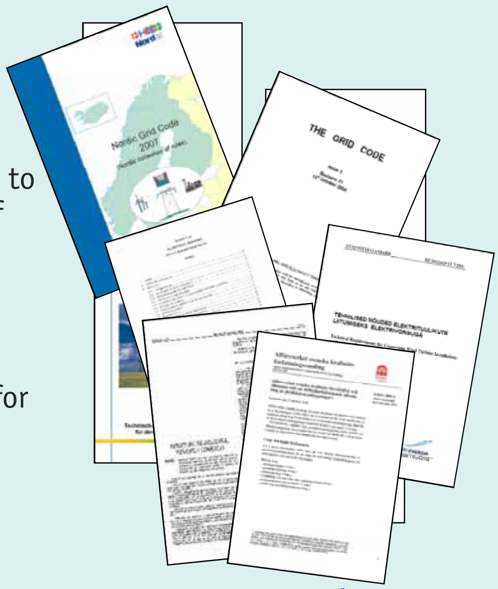
6

Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012

FGH Zertifizierung

Grid Code – History

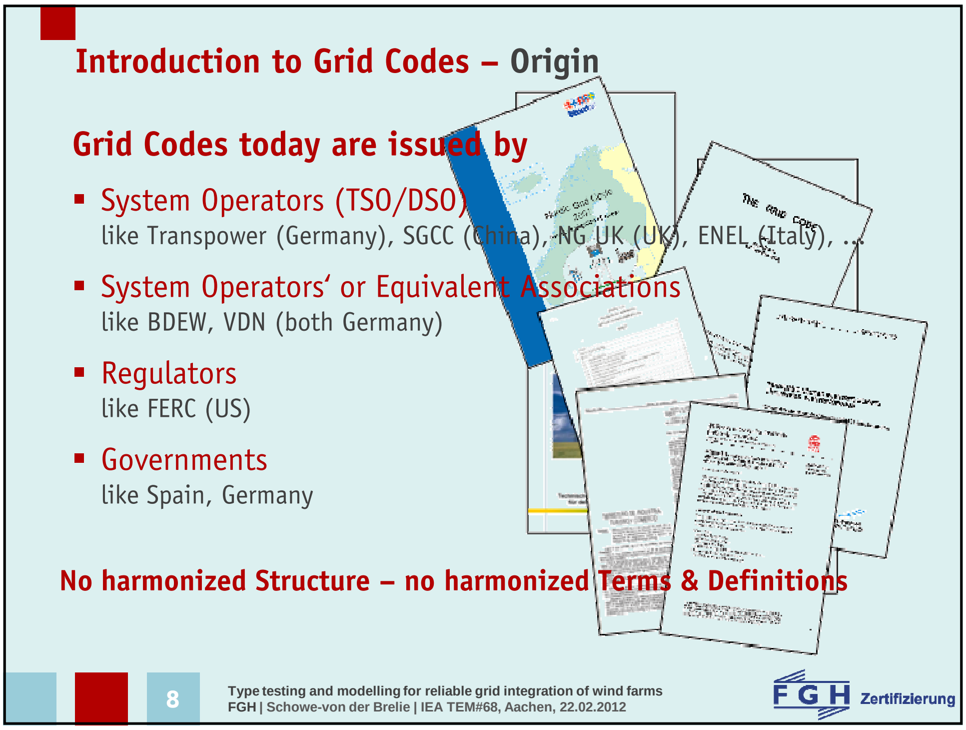
- a regulatory framework on grid connection requirements to ensure security and quality of supply
- definition of permissible electrical characteristics
- RES specific or general valid for all kinds of generators
- may give requirements on compliance proof

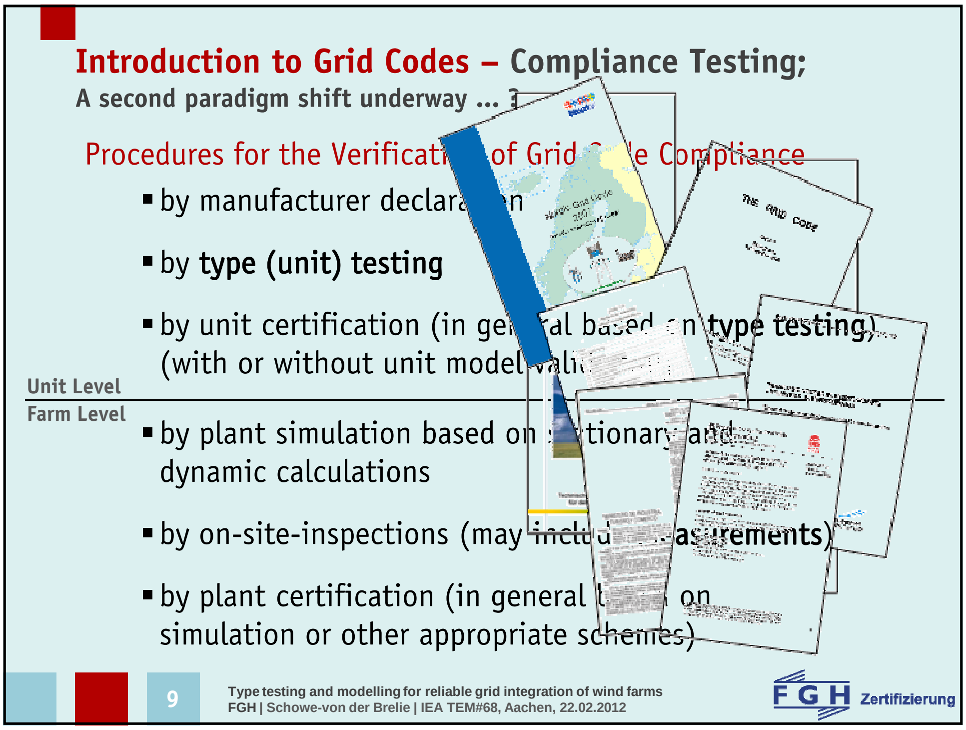


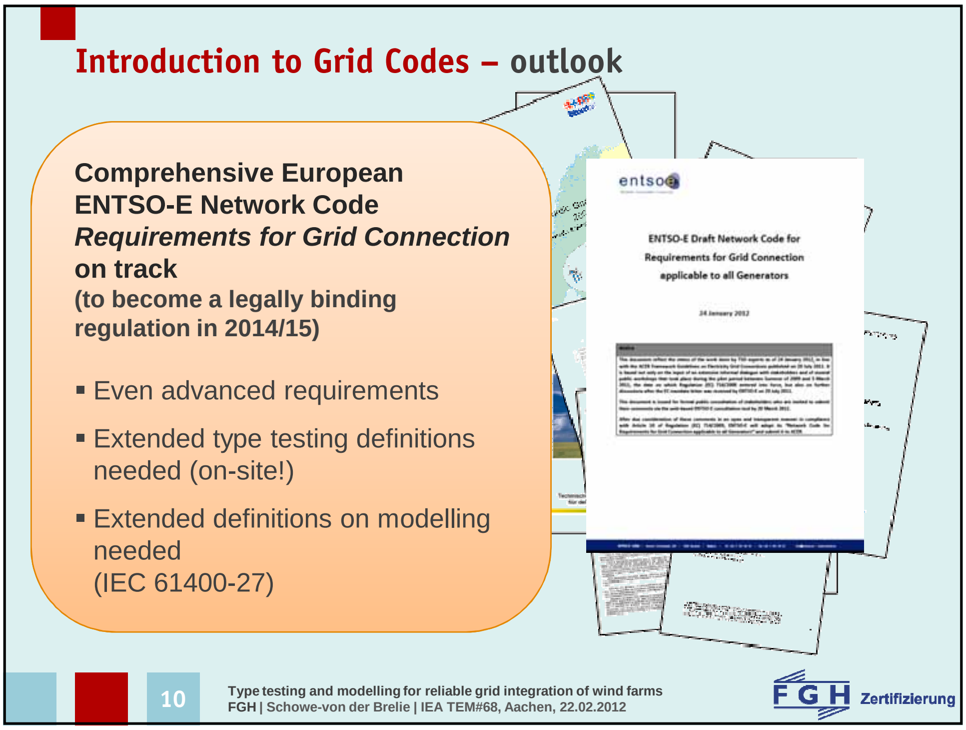
7

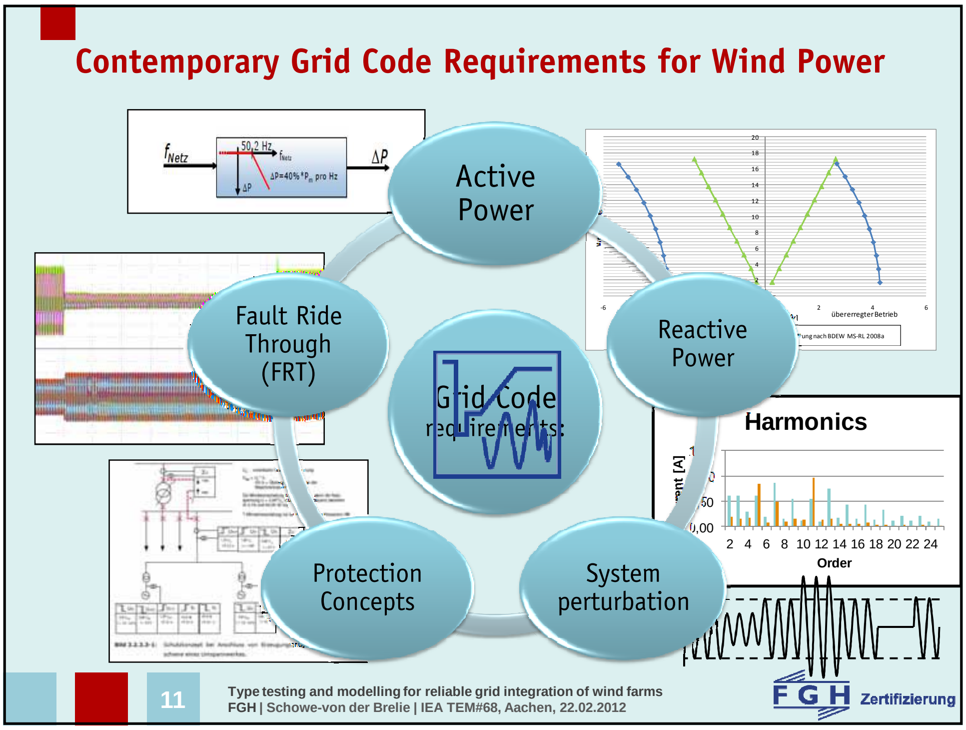
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012

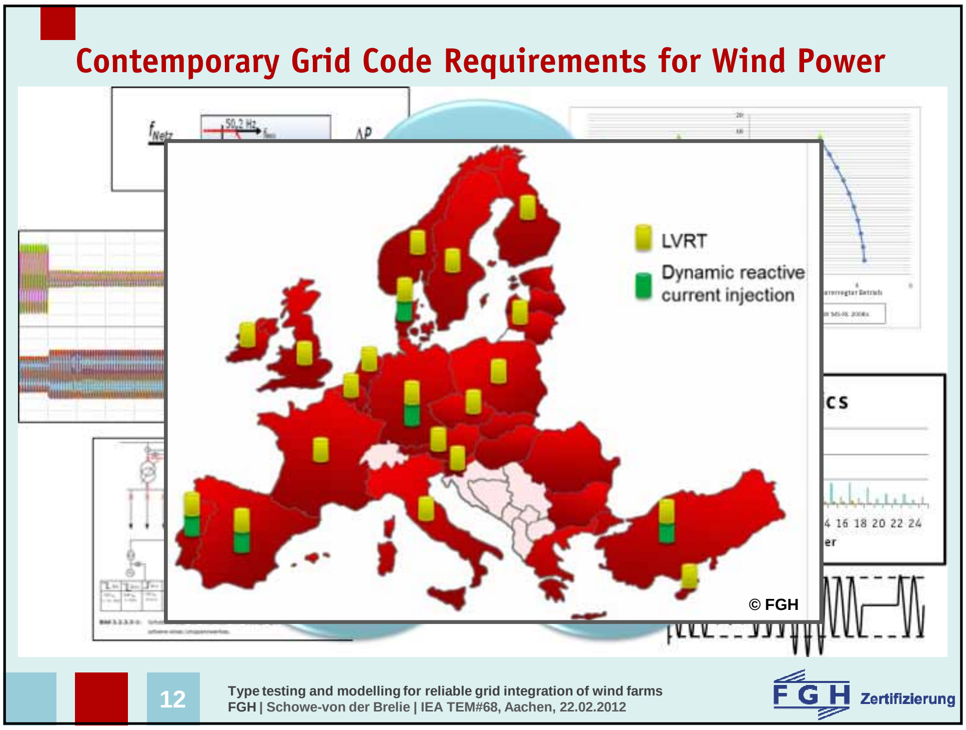
FGH Zertifizierung

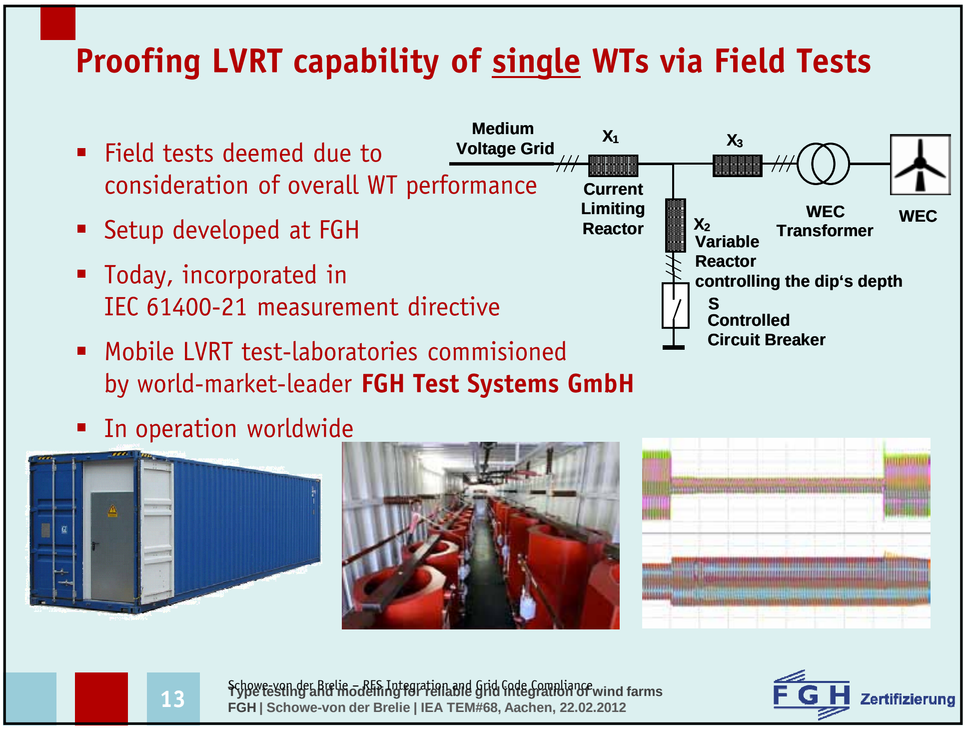

Introduction to Grid Codes – Origin
Grid Codes today are issued by
System Operators (TSO/DSO)
like Transpower (Germany), SGCC (China), NG UK (UK), ENEL (Italy), ...
System Operators' or Equivalent Associations
like BDEW, VDN (both Germany)
Regulators
like FERC (US)
Governments
like Spain, Germany
No harmonized Structure – no harmonized Terms & Definitions
8
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

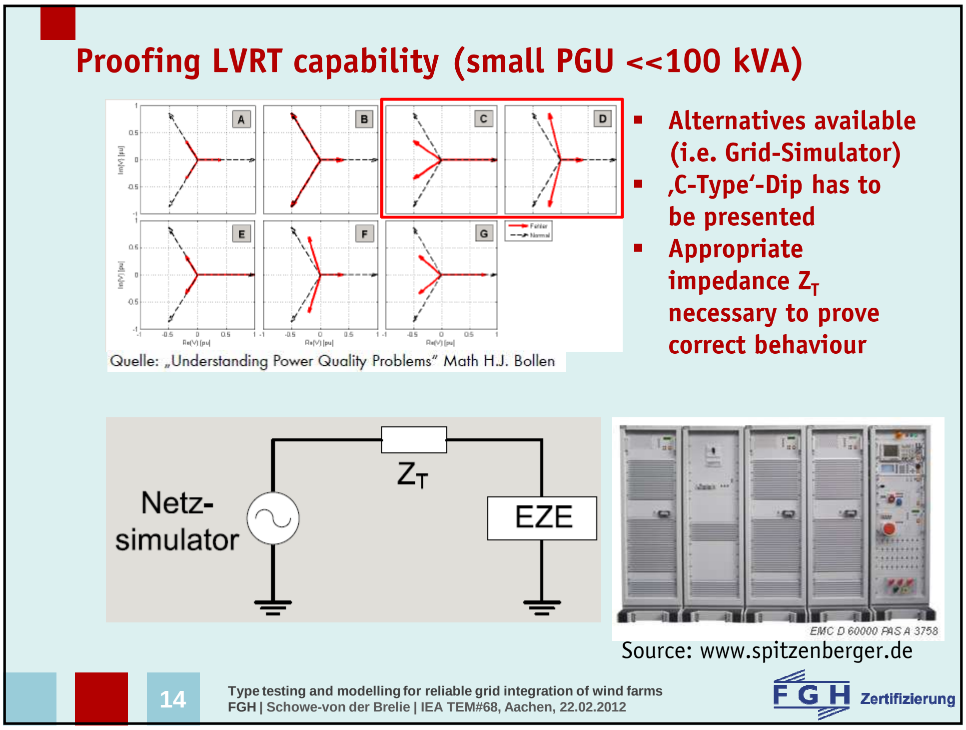

Introduction to Grid Codes – Compliance Testing;
A second paradigm shift underway ... ?
Procedures for the Verification of Grid Code Compliance
by manufacturer declaration
by type (unit) testing
by unit certification (in general based on type testing)
(with or without unit model validation)
Unit Level
Farm Level
by plant simulation based on stationary and dynamic calculations
by on-site-inspections (may include measurements)
by plant certification (in general based on simulation or other appropriate schemes)
9
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

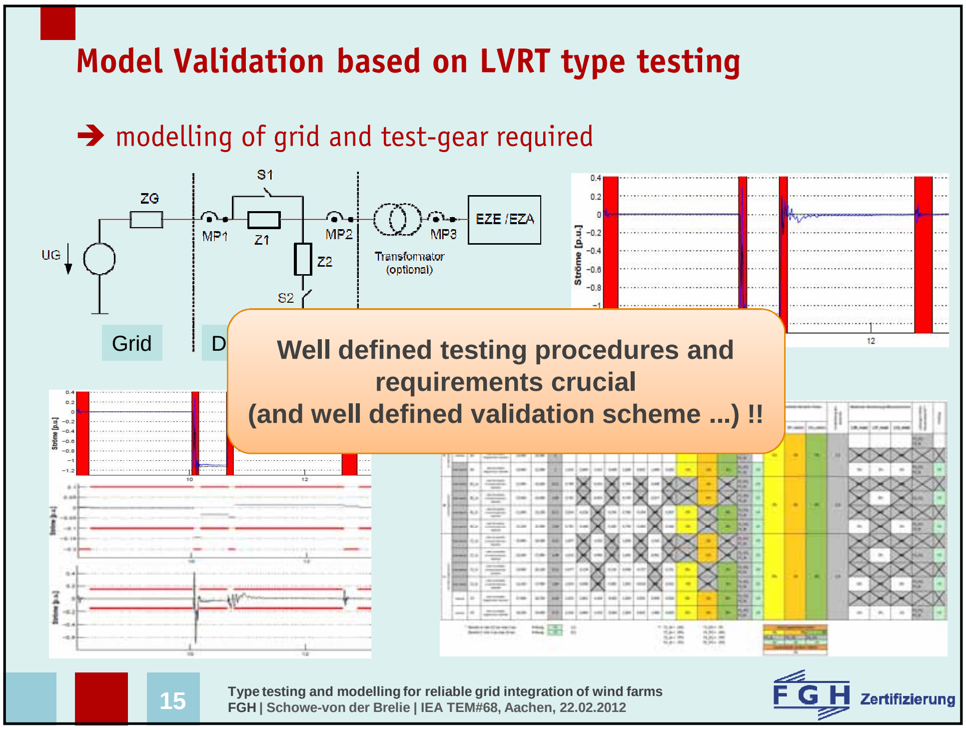

Introduction to Grid Codes – outlook
Comprehensive European ENTSO-E Network Code
Requirements for Grid Connection
on track
(to become a legally binding regulation in 2014/15)
Even advanced requirements
Extended type testing definitions needed (on-site!)
Extended definitions on modelling needed
(IEC 61400-27)
entsoe
ENTSO-E Draft Network Code for
Requirements for Grid Connection
applicable to all Generators
24 January 2012
10
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

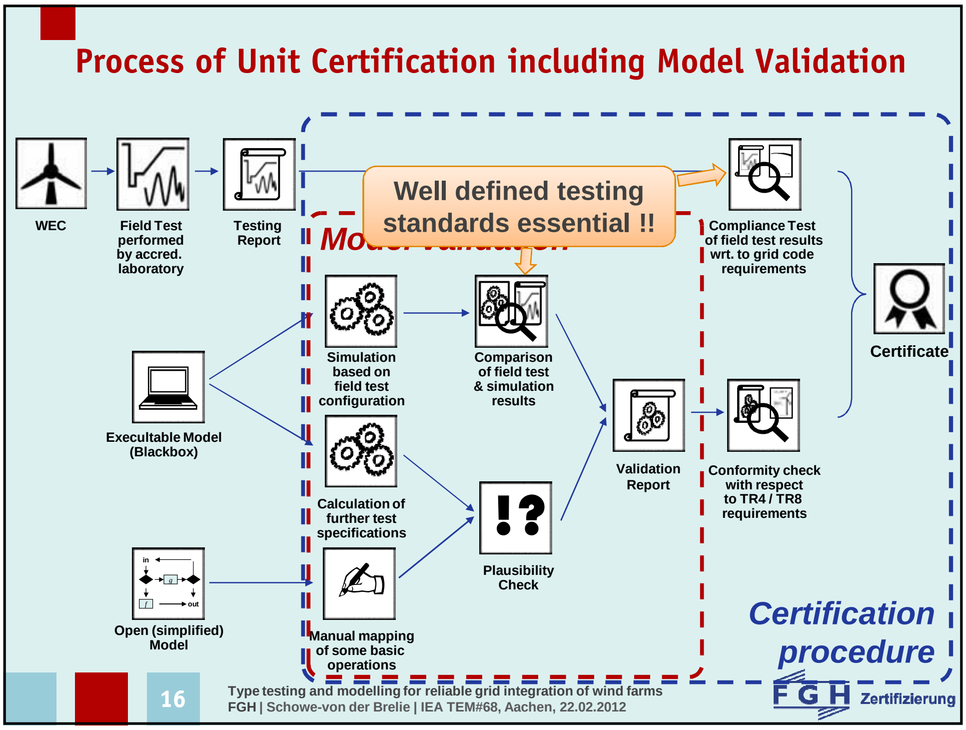

Contemporary Grid Code Requirements for Wind Power
Active Power
Reactive Power
Fault Ride Through (FRT)
Grid Code requirements
Protection Concepts
System perturbation
Harmonics
Order
11
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

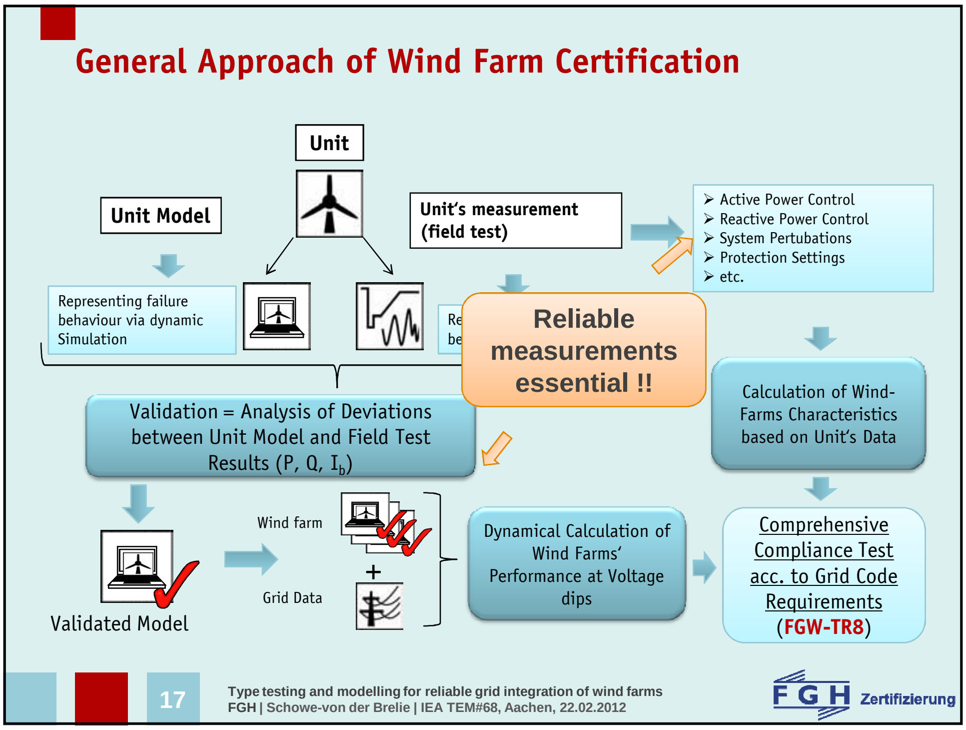

Contemporary Grid Code Requirements for Wind Power
LVRT
Dynamic reactive current injection
© FGH
12
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Proofing LVRT capability of single WTs via Field Tests
Field tests deemed due to consideration of overall WT performance
Setup developed at FGH
Today, incorporated in IEC 61400-21 measurement directive
Mobile LVRT test-laboratories commisioned by world-market-leader FGH Test Systems GmbH
In operation worldwide
Medium Voltage Grid
X1
Current Limiting Reactor
X3
WEC Transformer
WEC
X2
Variable Reactor
controlling the dip's depth
S
Controlled Circuit Breaker
13
Schowe-von der Brelie – RES Integration and Grid Code Compliance
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Proofing LVRT capability (small PGU <<100 kVA)
A
B
C
D
E
F
G
Quelle: „Understanding Power Quality Problems“ Math H.J. Bollen
Alternatives available (i.e. Grid-Simulator)
‚C-Type‘-Dip has to be presented
Appropriate impedance Z_T necessary to prove correct behaviour
Netz-simulator
Z_T
EZE
EMC D 60000 PAS A 3758
Source: www.spitzenberger.de
14
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Model Validation based on LVRT type testing
➔ modelling of grid and test-gear required
UG
ZG
S1
MP1
Z1
MP2
Z2
S2
Transformator (optional)
MP3
EZE /EZA
Grid
D
Well defined testing procedures and requirements crucial
(and well defined validation scheme ...) !!
15
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Process of Unit Certification including Model Validation
WEC
Field Test performed by accred. laboratory
Testing Report
Well defined testing standards essential !!
Model Validation
Compliance Test of field test results wrt. to grid code requirements
Certificate
Simulation based on field test configuration
Comparison of field test & simulation results
Executable Model (Blackbox)
Validation Report
Conformity check with respect to TR4 / TR8 requirements
Calculation of further test specifications
Plausibility Check
Open (simplified) Model
Manual mapping of some basic operations
Certification procedure
16
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


General Approach of Wind Farm Certification
Unit
Unit Model
Unit's measurement (field test)
Active Power Control
Reactive Power Control
System Pertubations
Protection Settings
etc.
Representing failure behaviour via dynamic Simulation
Reliable measurements essential !!
Calculation of Wind-Farms Characteristics based on Unit's Data
Validation = Analysis of Deviations between Unit Model and Field Test Results (P, Q, I_b)
Wind farm
+
Grid Data
Validated Model
Dynamical Calculation of Wind Farms' Performance at Voltage dips
Comprehensive Compliance Test acc. to Grid Code Requirements (FGW-TR8)
17
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

Components test-bench vs. full-scale field test – some notes from the certifier's view

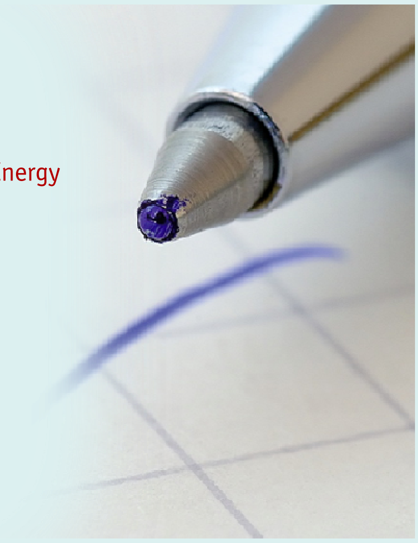
- Grid Code compliance certificates imply the correct WT behavior to support the power grid – any misbehaviour **may induce system collapse**!
- Hence, measurements for grid code compliance certification must
  - ⇨ provide a reliable basis to testify certified product characteristics connected to the power grid
  - ⇨ consider the full system & interactions

Primary Energy /Loads ⇨ **WT** (with all main & subsidary mechanical and electrical systems!) ⇔ **Power Grid**

- Test bench measurements have to be validated for use in certification – validation schemes and conditions for transfer of results not yet developed
- However, component testing may significantly contribute to R&D testing and reduce certification testing

18 Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012 FGH Zertifizierung

Agenda

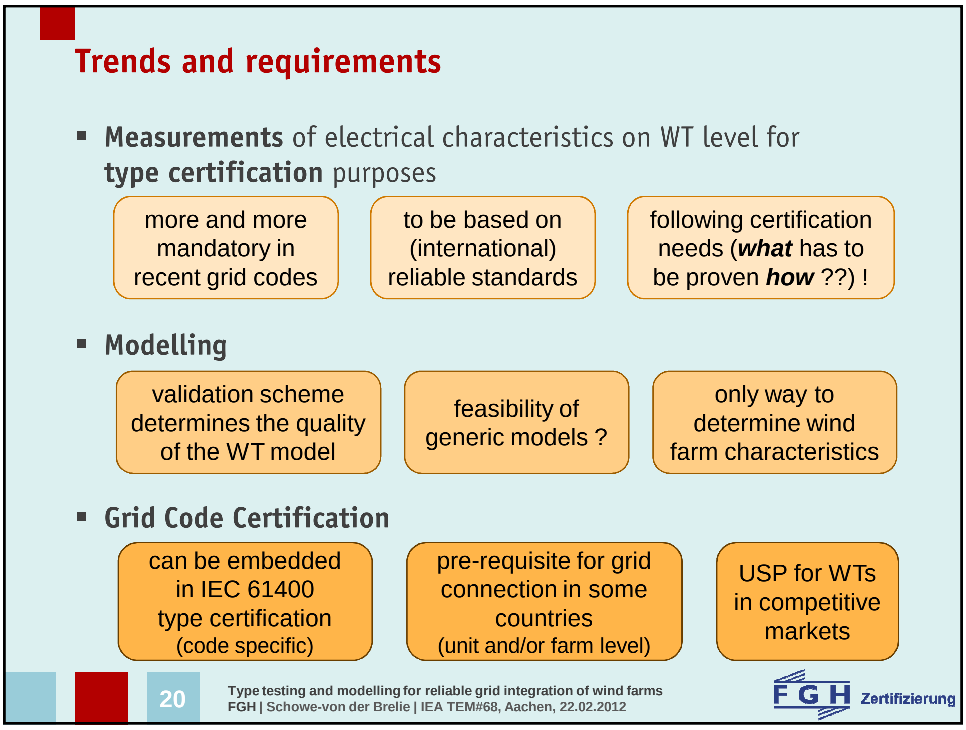


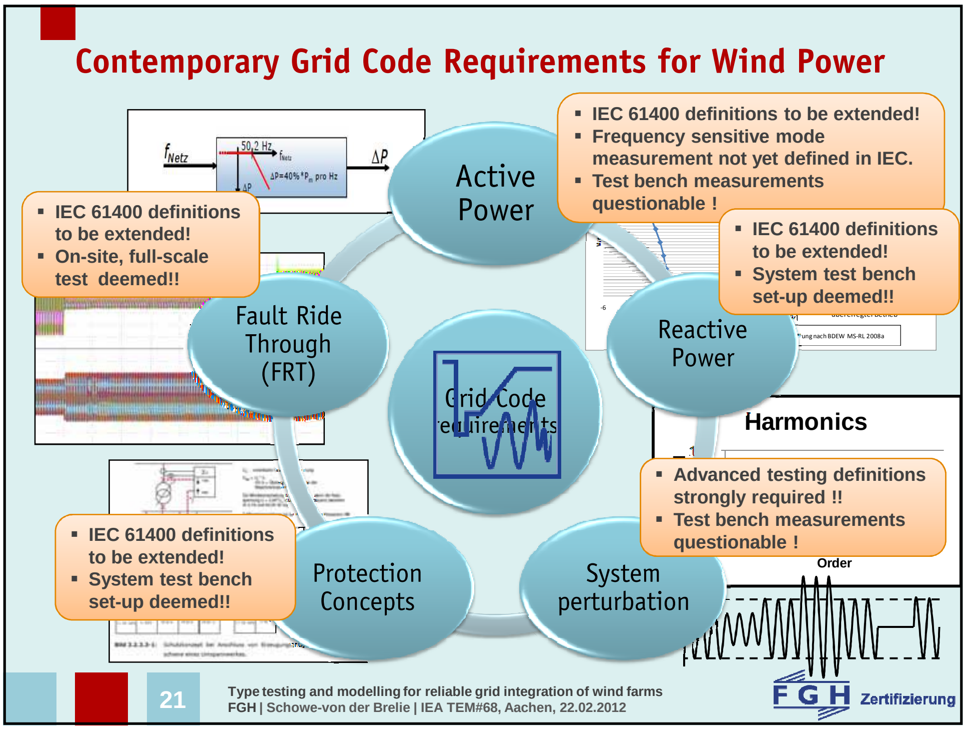
FGH at a glance
- FGH Entities
- Business Areas in the Scope of Wind Energy

Type Testing & Certification
- Motivation and Regulatory Framework
- Type Testing
  - Fault Performance / LVRT
  - Modelling
- Certification
  - Type / Product
  - Wind Farm

Conclusion & Outlook
- Trends & Requirements
- R&D at FGH

19 Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012 FGH Zertifizierung


Trends and requirements
Measurements of electrical characteristics on WT level for type certification purposes
more and more mandatory in recent grid codes
to be based on (international) reliable standards
following certification needs (what has to be proven how ??) !
Modelling
validation scheme determines the quality of the WT model
feasibility of generic models ?
only way to determine wind farm characteristics
Grid Code Certification
can be embedded in IEC 61400 type certification (code specific)
pre-requisite for grid connection in some countries (unit and/or farm level)
USP for WTs in competitive markets
20
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Contemporary Grid Code Requirements for Wind Power
Active Power
IEC 61400 definitions to be extended!
Frequency sensitive mode measurement not yet defined in IEC.
Test bench measurements questionable !
Reactive Power
IEC 61400 definitions to be extended!
System test bench set-up deemed!!
Harmonics
Advanced testing definitions strongly required !!
Test bench measurements questionable !
Order
System perturbation
Protection Concepts
IEC 61400 definitions to be extended!
System test bench set-up deemed!!
Fault Ride Through (FRT)
IEC 61400 definitions to be extended!
On-site, full-scale test deemed!!
Grid Code requirements
21
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

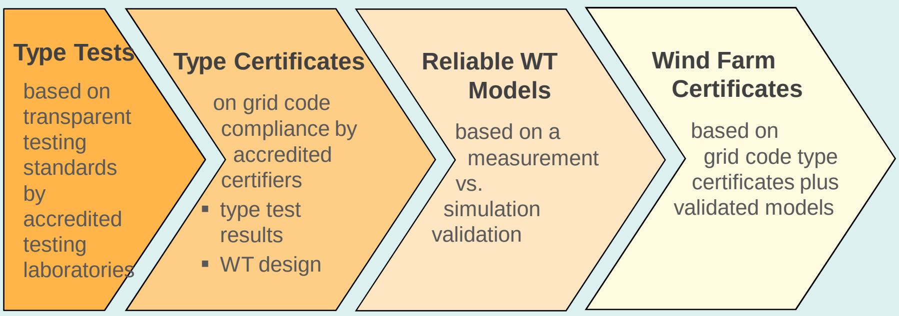
Ongoing and recent R&D at FGH

- System Study on Wind Power Integration in Germany
  (German government, 2008)
- Analysis of European grid codes, compliance schemes and regulatory requirements
  (European Commission, 2012)
- On-site LVRT testing labs > 10MVA (farm level) and OVRT testing set-up
- Model requirements for fault performance simulation
  - Feasibility of generic models vs. detailed (physical) manufacturers' models
  - Scalability of WT models to describe wind farm characteristics
  - Assessment of fault type characteristics in farm simulations
- Offshore wind farm grid integration (esp. HVDC): requirements, testing, modelling

22 Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

Conclusion – working hypotheses for the paradigm shift

In order to ensure a reliable replacement of conventional power plants by DER / RES these generators must provide grid code compliance based on



23 Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung


Thank you for your attention !
Bernhard Schowe von der Brelie
FGH GmbH
www.fgh-ma.de / www.fgh-certification.com
24
Type testing and modelling for reliable grid integration of wind farms
FGH | Schowe-von der Brelie | IEA TEM#68, Aachen, 22.02.2012
FGH Zertifizierung

Validation Requirements for WTGs

Utility´s point of view

IEA R&D Wind Task 11 – Topical Expert Meeting
"Advances in Wind Turbine and components testing"
Jan-Bernd Franke (Jan-Bernd.Franke@rwe.com), RWE Innogy

The energy to lead

Content

> **Introduction**
> RWE Innogy
> Portfolio of Wind Turbine Generators
> Project Pipeline

> **WTG Engineering @ RWE Innogy**

> **Validation requirements for WTGs**

Introduction, RWE Innogy, Facts

> Established in February 2008, 100% RWE AG

> Bunding renewables activities and competencies across RWE Group

> European focus

> Focus on capacity growth in commercially mature renewable technologies, i.e. wind, biomass and hydro

> Asset portfolio of 2,4GW* in operation and 1,1GW* under construction mainly located in United Kingdom, Germany, Spain, Netherlands, Italy, France and Poland

* Q4 2010

Introduction, RWE Innogy, footprint

In MW_{el}	Onshore Wind	Offshore Wind	Biomass	Hydro	Biogas	Solar	Total
RWE Innogy[1] operational capacities: Accounting view[2] + power purchase agreements, Q4 2010							
Germany	445[1]		107	376	1[6]	1	930
UK	316[4]	150[4]		69			535
Spain	400			12			412
Netherlands	201[1]						201
France	36			45			81
Poland	108						108
Italy	50						50
Switzerland				23			23
Czech Republic			19				19
Portugal				16			16
Total RWE Innogy	**1,556**	**150**	**126[5]**	**541**	**1**	**1**	**2,375**
RWE Innogy[1] operational capacities: Pro rata view[3] + power purchase agreements, Q4 2010							
Germany	447[1]		105	357	2[6]	1	912
UK	361[4]	150[4]		69			580
Spain	396			10			406
Netherlands	201[1]						201
France	36			45			81
Poland	92						92
Italy	26						26
Switzerland				23			23
Czech Republic			20				20
Portugal	3			15			18
Belgium		8					8
Total RWE Innogy	**1,562**	**158**	**125[5]**	**519**	**2**	**1[7]**	**2,367**

[1] Essent contributed 232 MW onshore wind assets in the Netherlands and 405 MW in Germany as of September 30, 2009. The total operational capacity has decreased due to the decommissioning of WP Eemsmond (Kenetech) (32MW), a condition associated with the development of another onshore site.
[2] Capacity with <50% RWEI ownership is consolidated to 0 MW, capacity with 50% is consolidated to 50% of capacity, and capacity with >50% RWEI ownership is consolidated to 100% of capacity.
[3] Capacity equal to share of ownership.
[4] 316 (361 pro rata view) MW onshore = 101 MW Innogy wholly owned assets + 196 (241 pro rata view) MW of Zephyr assets + 19 MW of Green GECCO assets. RWE Innogy operates 601 MW, of which 391 MW (331 MW onshore/60 MW offshore) is owned by Zephyr Investments Ltd which is 1/3 owned by RWE Innogy. Of the 331 MW onshore, 196 MW is 100% contracted to RWE npower through PPAs (power purchase agreements). An additional capacity of 135 MW is contracted to the NFPA (Non-Fossil Fuel Purchasing Agency). Of the offshore capacity of 150 MW, 90 MW is wholly owned by RWE Innogy. 60 MW offshore capacity is owned by Zephyr and is 100% contracted to RWE npower through a PPA. Of the onshore capacity, 19MW is owned by Green GECCO GmbH & Co KG (51% owned by RWE Innogy) and is contracted to RWE Npower Renewables Ltd through a PPA.
[5] Including 32 MW of biomass/fossil mix, 14 MW of fossil capacity.
[6] Includes only Biogas used directly in power generation.
[7] RWE Innogy owns solar capacity in both Germany and Spain (of which only the former is visible above due to rounding).

RWE The energy to lead — RWE Innogy | Factbook Renewable Energy 15/03/2011 PAGE 9

Source: http://www.rwe.com/web/cms/mediablob/de/86206/data/87200/30/rwe-innogy/unternehmen/fact-book/dl-factbook-new.pdf

Portfolio of WTGs, Locations and Types

> Onshore
  Locations: Germany, Spain, UK, Netherlands, Poland, Italy, France
  WTG Types: up to 5MW, Geared Drive and Direct Drive

> Offshore
  Locations: UK, Belgium
  WTG Types: Vestas V80-2MW, Siemens SWT3.6-107, REpower 5M

> All WTGs are commercially operated

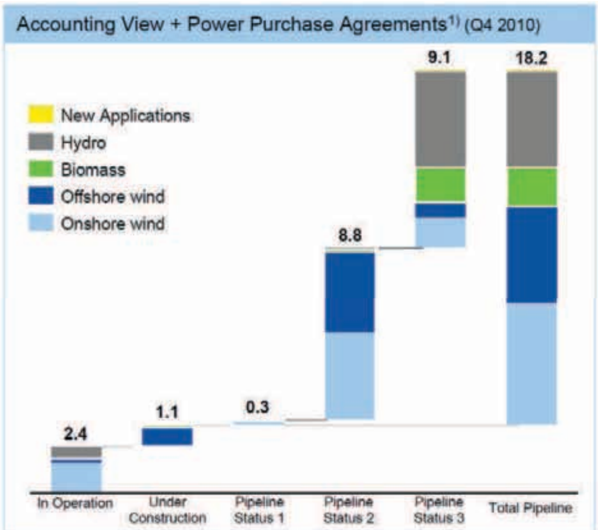
WPP North Hoyle,
30x V80-2MW

WPP Rhyl Flats,
25x SWT3.6-107

WPP Thornton Bank,
6x RE5M

RWE Innogy 2/21/2012 PAGE 5

Project pipeline in GW, Renewables



Note:
Pipeline status 1 – Permitted projects: all permits (including grid) in place, but not yet under construction
Pipeline status 2 – Unconsented projects: RWEI has rights to the project, e.g. land agreements
Pipeline status 3 – Prospects: identified sites with a known MW capacity, initial discussion on agreements

> Wind plays a significant role!

> Investment appr. 1 bn per year

> Offshore Wind:
  WTGs are 40-60% of investment

Source: http://www.rwe.com/web/cms/mediablob/de/86206/data/87200/30/rwe-innogy/unternehmen/fact-book/dl-factbook-new.pdf

RWE Innogy 2/21/2012 PAGE 6

Projects under construction

Examples of offshore wind projects

Nr.	Wind Farm	Size	Distance to shore	Water depth	First generation
1	Gwynt y Môr	160 x 3.6 MW Siemens turbines (576 MW), 124 km²	13 km off the coast of North Wales	12 – 28 m depth	First generation in 2013, full generation in 2014
2	Greater Gabbard[1]	140 x 3.6 MW Siemens turbines (504 MW[1]), 147 km²	25 – 47 km offshore	24 – 34 m depth	First generation in December 2010, full generation in late 2011
3	Nordsee Ost	48 x 6 MW REpower turbines (288 MW), 34 km²	32 – 45 km offshore	22 – 26 m depth	First generation in 2012, full generation in 2013

[1] 50% owned by RWE Innogy.

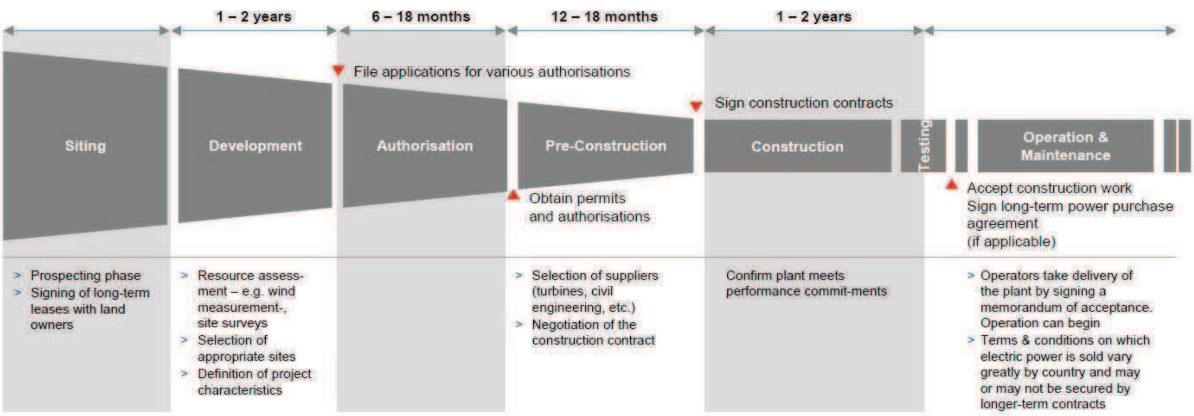
> Number of validated WTG types is limited!

Source: http://www.rwe.com/web/cms/mediablob/de/86206/data/87200/30/rwe-innogy/unternehmen/fact-book/dl-factbook-new.pdf

RWE The energy to lead

RWE Innogy 2/21/2012 PAGE 7

WTG Engineering @ RWE Innogy



Source: http://www.rwe.com/web/cms/mediablob/de/86206/data/87200/30/rwe-innogy/unternehmen/fact-book/dl-factbook-new.pdf

> WTG Engineering is involved from the beginning of the WPP projects:
WTG Assessment,
Technical contract negotiations,
Support of Quality Assurance,
Support of Operation & Maintenance.

RWE The energy to lead

RWE Innogy 2/21/2012 PAGE 8

Validation requirements for WTGs

> Health and Safety: HSE Review

> Functionality: e.g. grid compliance, SCADA operation

> Energy Yield: availability, power curve

> Durability: design life, teething troubles solved on prototype WTGs

> Validation tests can be performed in the field, on test stands and by simulations

> Validation strategies need to be improved: e.g. component tests

> Validation scope should be harmonised: standardisation, certification

RWE
The energy to lead

RWE Innogy 2/21/2012 PAGE 9

REOLTEC.NET I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

Coordinated by aee Spanish Wind Energy Association

WIND ENERGY TESTING FACILITIES IN SPAIN

22 – 02 – 2012

Aachen

IAE Task 11 TEM#67

Emilien Simonot
stecnica@reoltec.net

Subsidized by
FONDO EUROPEO DE DESARROLLO REGIONAL "Una manera de hacer Europa"
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN
Plan Nacional de I+D+i 2008-2011
Subprograma INNFLUYE - convocatoria 2011
Expediente nº: INF-2011-0098-120000

REOLTEC.NET I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

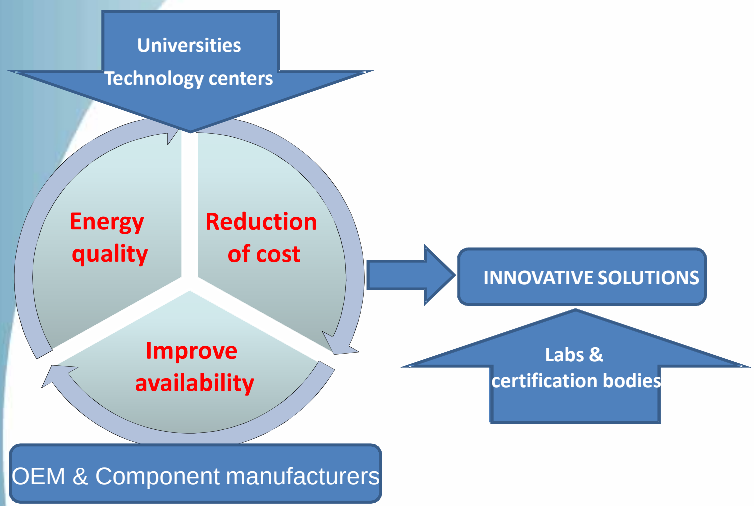
REOLTEC AT A GLANCE

REOLTEC: SPANISH WIND ENERGY TECHNOLOGY PLATFORM

- Vertebrate Spanish wind energy R&D system.
- Ensure a convenient framework for wind R&D – follow R&D support mechanism.
- Impulse transversal projects with benefits at sector level.
- Promote inter-sectorial approach.
- Point out future threats for the sector, rise important debate themes.

3

STRATEGIC OBJECTIVES

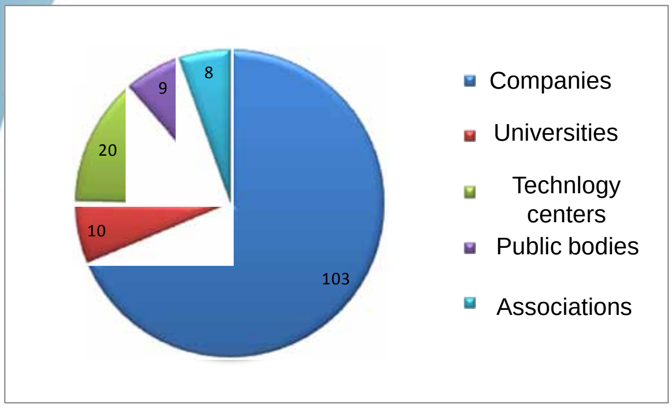


CONTEXT OF STRONG INTERNATIONAL COMPETITON.

4

REOLTEC.NET
I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

PARTICIPANTS IN REOLTEC



150 ENTITIES PARTICIPATE IN REOLTEC
WORKING IN 7 THEMATIC WORKING GROUPS

5

REOLTEC.NET
I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

TECHNOLOGY CENTER IN SPAIN

6

Source: CENER

CENER - LEA (LABORATORIO DE ENSAYOS DE AEROGENERADORES)

7

LEA Blade Test Laboratory

8

Source: CENER

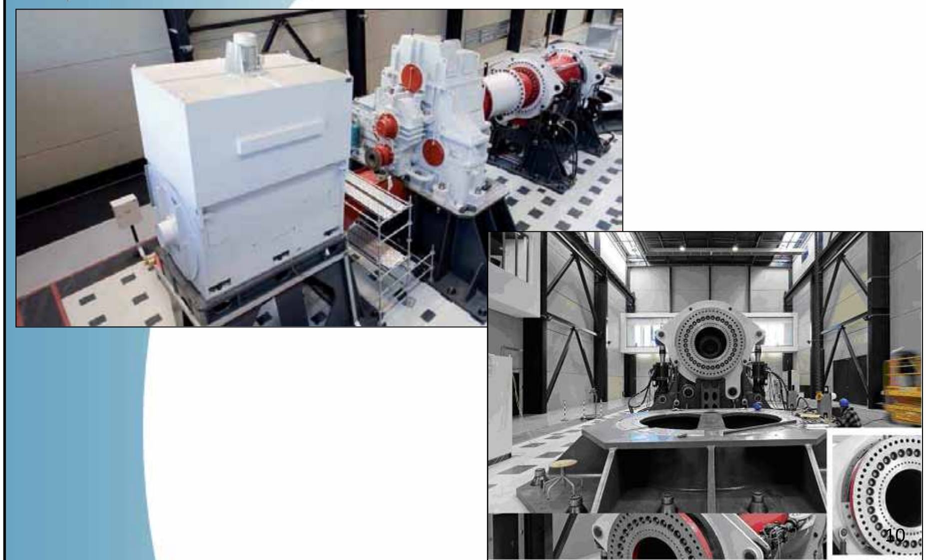
LEA Blade Test Laboratory

- Performs structural tests on WTG blades
  - In accordance to IEC TS-61400-23 standard
  - 2 test position for static and fatigue test
  - Effective blade lengths of up to 75 m
  - Static tests on sections of blades of 100m nominal length
- Static Tests
  - Basic properties: mass, COG, moments of inertia
  - Stiffness on bending and torsion
  - Ultimate load resistance
- Fatigue Tests
  - Modal analysis
  - Endurance test with fatigue loads

9

Source: CENER

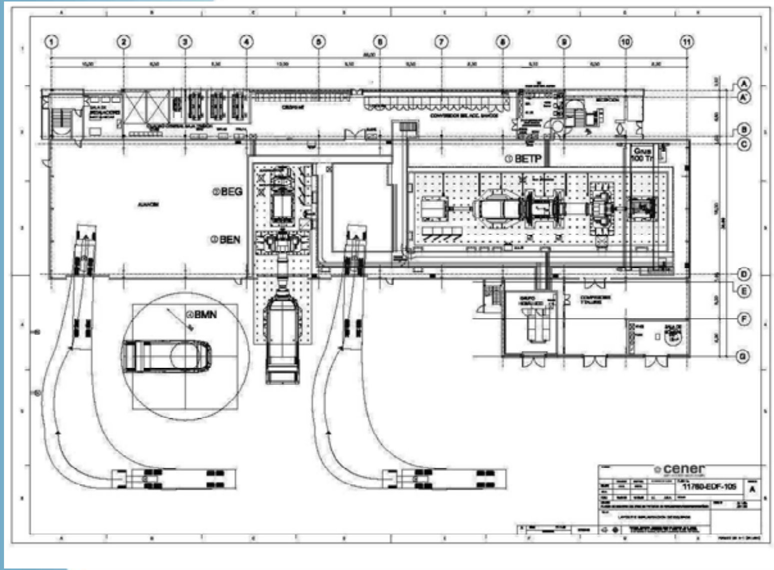
LEA Power Train Test Laboratory



10

Source: CENER

LEA Power Train Test Laboratory



11

Source: CENER

LEA Power Train Test Laboratory

- Power Train test bench
  - ❑ Designed and built to test power train in WTG up to 5MW
  - ❑ Functional/accelerated lifespan test of WTG drivetrain
  - ❑ Functional tests on mechanical parts
    - ➢ Accelerated life test for bearings in the main shaft (LSS)
    - ➢ Accelerated life test for gears and bearings in the gearbox
    - ➢ Functional/load test for the brakes in the high speed shaft (HSS)
- Generator test bench
  - ❑ Designed and built to test generators and converters
    - ➢ Functional/accelerated lifespan test of WTG on the generator and power electronics
    - ➢ Electrical transient simulation (voltaje dips)
    - ➢ Functional tests, vibration, acoustic noise, heating, etc.
    - ➢ Overspeed tests and transients surges

12

Source: CENER

REOLTEC.NET I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

LEA Power Train Test Laboratory

- Nacelle test bench
  - Designed and built to perform
    - functional tests on complete nacelle
    - electrical transient simulation "Voltage dips"

- Nacelle assembly bank
  - Designed and built to test nacelle assembly
    - WTG erecting and nacelle setup procedures
    - Use of auxiliary assembly cranes
    - Simulation of maintenance exercises, including major corrections
    - Staff training in the assembly and maintenance of WTG
    - Training in evacuation and security operations in WTG

13

Source: CENER

REOLTEC.NET I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

CIEMAT - CEDER (CENTRO DE ENSAYO DE ENERGIAS RENOVABLES

GOBIERNO DE ESPAÑA · MINISTERIO DE CIENCIA E INNOVACIÓN · Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

14

WIND POWER UNIT

Capacities and Projects developed at CEDER-CIEMAT:

Small wind turbine test plants

Flywheels energy storage

Small wind blade test

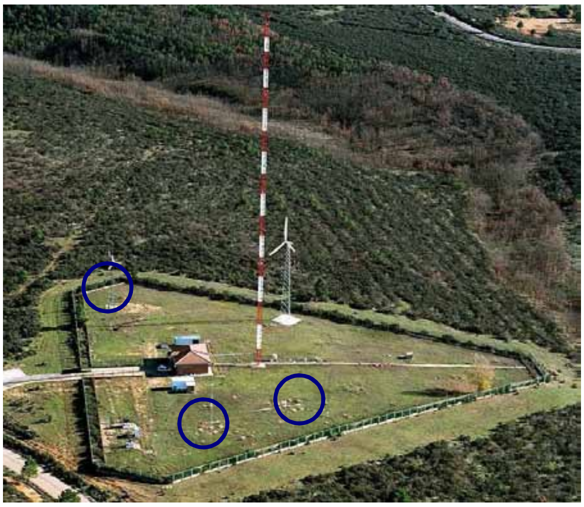
15

Source: CEDER - CIEMAT

Plant diagram (I)

PEPA I (Small Wind Turbines Test Facility. 1st stage)

Places A, B and C



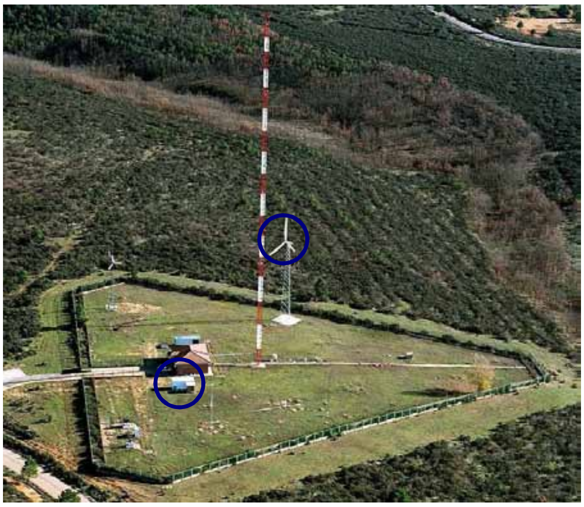
16

Source: CEDER - CIEMAT

Plant diagram (I)

PEPA I (Small Wind Turbines Test Facility. 1st stage)

Wind-diesel system



17

Source: CEDER - CIEMAT

Plant diagram (*I)*

PEPA I (Small Wind Turbines Test Facility. 1st stage)

Wind pumping

18

Source: CEDER - CIEMAT

Plant diagram (I)

PEPA I (Small Wind Turbines Test Facility. 1st stage)

- Batteries bank up to 300 V (40 kW).
- Li-Ion battery bank (60 kW)
- Charges: simulation of consumptions.
- Inverters/chargers: versatility in the tests with batteries.

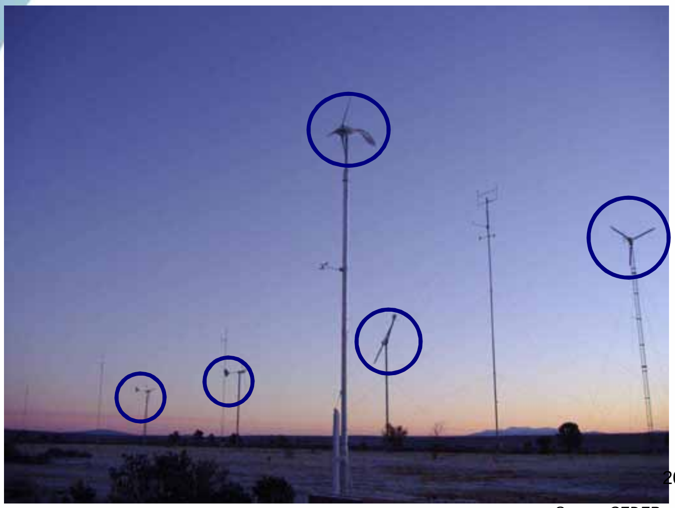
19

Source: CEDER - CIEMAT

Plant diagram (II)

PEPA II (Small Wind Turbines Test Facility. 2nd stage)

5 test places



20

Source: CEDER - CIEMAT

REOLTEC.NET
I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

Plant diagram (III)

PEPA III (Small Wind Turbines Test Facility. 3rd stage)

8 test places:

21

Source: CEDER - CIEMAT

REOLTEC.NET
I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

Plant diagram (IV)

PEPA IV (Small Wind Turbines Test Facility. 4rd stage)

1 test place:

Wind class 2 (Vref = 42.5 m/s = 153 Km/h)

22

Source: CEDER - CIEMAT

CAPACITIES

✓ Characterization and development of small wind turbines (maximum of 6 kW) (ISO 17025 Accreditation on going)

- ➢ Power performance curve
- ➢ Acoustic noise emissions
- ➢ Duration certification.
- ➢ Safety and operation.
- ➢ Test of components (generator, gear box, blades, etc.)

✓ Collaboration with manufacturers, government, etc.

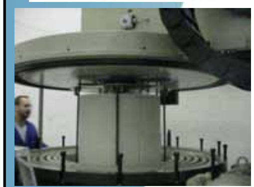
✓ Collaboration in the validation of normative for small wind turbines.

✓ Wind pumping.

23

Source: CEDER - CIEMAT

FLYWHEELS



✓ Development of kinetic storage with high rotational speed.

- ➢ Development of design and manufacture capacity of flywheels with high rotational speed with compound materials.
- ➢ Development of test procedures with flywheels and other components at high velocity.
- ➢ Carrying out centrifugal tests at high rotational velocity (up to 60,000 rpm and 120ºC):
  - ✓ Mechanical fatigue cycles.
  - ✓ Thermal fatigue.
  - ✓ Breakage.

24

Source: CEDER - CIEMAT

SMALL WIND TURBINE BLADE TEST FACILITY CEDER-CIEMAT

Location: Soria (Spain)

Wind turbine power range : 1 to 100 kW
Length blade range: 1 to 11 m.

Type of tests available:
a) blade property tests: structural damping, natural frecuencies, center of gravity...
b) static load tests
c) fatigue load tests


Automated control and data adquisition system.


Indoor test rig.
Multiple posibilities for tests configuration

25

STATIC LOAD TESTS:

- Pulling down system up to 3 points
- Capabilities of analysis:
• strains (extensometry)
• displacements of airfoil sections
• accelerations
• termography


Static test


Strain gauges on blade root

FATIGUE LOAD TESTS:

- 2 system blade exciting options:
• forced actuator (small blades)
• resonance actuator (large blades)

- Fatigue test length: up to 1-2 months


Fatigue forced actuator


Fatigue resonance actuator

26

REOLTEC.NET

I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

CASTILLA LA MANCHA UNIVERSITY WIND ENERGY TESTING LABORATORY

ier

Instituto de Investigación de Energías Renovables

PARQUE CIENTÍFICO Y TECNOLÓGICO DE ALBACETE

UCLM

UNIVERSIDAD DE CASTILLA-LA MANCHA

27

REOLTEC.NET

Building of 2 test rigs: 2 MW (DFIG) y 30 kW (DFIG y PMSG)

Planned activities:

- WTG tests
- Motor tests
- Gearboz tests
- Converter tests
- Control schemes validation

30 kW test rig already operative

2 MW test rig to be operative in June 2012

REOLTEC.NET
I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

TEST RIGS OVERVIEW

REOLTEC.NET
I+D+i PLATAFORMA EÓLICA TECNOLÓGICA

FIELD TEST INSTALATIONS

30

AUTHORIZED EXPERIMENTAL WIND FARMS ONSHORE (133,8 MW)

Name	Region	Province	Capacity (MW)
Parque Eólico Experimental Las Balsas-Sierra de Alaiz	NAVARRA	NAVARRA	30
Parque Eólico I+D El Boyal I	ARAGÓN	ZARAGOZA	4,5
Parque Eólico I+D El Boyal II	ARAGÓN	ZARAGOZA	4,5
Parque Eólico I+D El Boyal III	ARAGÓN	ZARAGOZA	4,5
Área Experimental de Barásoain	NAVARRA	NAVARRA	15
Área Experimental de Vedadillo	NAVARRA	NAVARRA	9
Parque Eólico el Valle I + D Fase I, aerogenerador 1	NAVARRA	NAVARRA	4,5
Parque Eólico el Valle I + D Fase I, aerogenerador 2	NAVARRA	NAVARRA	4,5
Parque Eólico el Valle I + D Fase I, aerogenerador 5	NAVARRA	NAVARRA	4,5
Parque Eólico el Valle I + D Fase I, aerogenerador 6	NAVARRA	NAVARRA	4,5
Parque Eólico el Valle I + D Fase I, aerogenerador 7	NAVARRA	NAVARRA	4,5
Parque Eólico Experimental Vestas Cantabria	CANTABRIA	CANTABRIA	3
Parque Eólico La Cámara	ANDALUCÍA	MÁLAGA	18
Parque Eólico Experimental El Llano	ANDALUCÍA	GRANADA	3
Parque Eólico Experimental San José	ANDALUCÍA	GRANADA	1,5
Primer Prototipo experimental NED100	GALICIA	LUGO	0,1
Prototipo experimental NED100 con generador de diseño propio	GALICIA	LUGO	0,1
Parque Eólico de Investigación Villanueva	ASTURIAS	ASTURIAS	6
Parque Eólico Experimental Cerros Pelaos	ANDALUCÍA	GRANADA	3
Prototipo experimental NED100 con generador comercial	GALICIA	LUGO	0,1
Parque Eólico I+D Monte Genaro I	CASTILLA-LA MANCHA	TOLEDO	4,5
Parque Eólico I+D Monte Genaro II	CASTILLA-LA MANCHA	TOLEDO	4,5

31

•Experimental Wind Farm

32

Source: CENER

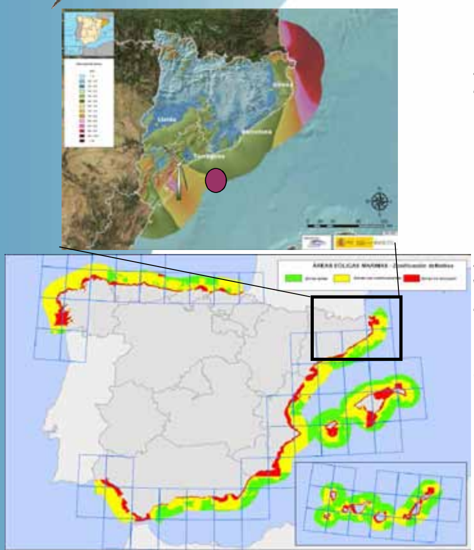
Experimental Wind Farm

- 6 calibrated positions used to
  - install WTG prototypes of machines up to 5 MW
  - perform complex field test on prototypes
  - certify wind turbines
- Equipment
  - 6 meteorological towers 120 m high
  - 6 sites up to 5 MW
  - electrical network connection 20KV/66KV
- Technological services
  - Certification IEC tests (Power Curve, Noise, PQ, Mechanical Loads)
  - Verification of response to voltage dips
  - Others (design, optimization, validation, etc.)

33

Source: CENER

OFFSHORE ZÈFIR Test Station



Two phases:

Phase 1: A total of 4 bottom-fixed turbines will be installed with a maximum total capacity of 20MW, 3 km off the coast and at 40 meters water depth. Construction is planned for Q4 2012.

Phase 2: A total of 8 wind turbines will be installed using floating technology with a maximum total capacity of 50MW, 30 km off the coast and at 110 meters water depth. Construction is planned for Q4 2012.

34

Source: CIEMAT


REOLTEC.NET
Coordinated by
aee
MUCHAS GRACIAS
LA EXCELENCIA TECNOLÓGICA ES LA CLAVE DEL ÉXITO
TECHNOLOGY EXCELLENCE IS THE KEY TO SUCCESS
Emilien Simonot
REOTLEC Technical Secretary
stecnica@reoltec.net
Subsidized by
FONDO EUROPEO DE DESARROLLO REGIONAL
Plan Nacional de I+D+i 2008-2011
Subprograma INNFLUYE - convocatoria 2011
Expediente nº: INF-2011-0098-120000

SUMMARY

a) Participants

28 participants from 7 countries (Denmark, China, Germany, Norway, Spain, Sweden, and USA), attended the meeting. A total of 18 presentations were given.

Participants List

- "Advances in Wind Turbine and Components Testing" .

	Last Name	Name	Job Center	Country	E-mail
1	Li	Quing	China Electric Power Research Institute	China	liqing@epri.sgcc.com.cn
2	Li	Ximei	China Genera Certification	China	lixm@cgc.org.cn
3	Zheng	Lei	China Genera Certification	China	zhenglei@cgc.org.cn
4	Zuohui	Liu	Sinovel Wind Group Co.Ltd.	China	dlliuzuohui@yahoo.com.cn
5	Berggreen	Christian	Technical Univ. of Denmark, Department of Wind	Denmark	cber@dtu.dk
6	Brennecke	Martin	FGH Certification	Germany	martin.brennecke@fgh-ma.de
7	Schowe	Bernhard	FGH Certification	Germany	bernhard.schowe@fgh-ma.de
8	Kutscher	Joachim	Forschungszentrum Jülich Gmbh	Germany	j.kutscher@fz-juelich.de
9	Kyling	Hans	Fraunhofer IWES	Germany	hans.kyling@iwes.fraunhofer.de
10	Pilas	Martin	Fraunhofer IWES	Germany	martin.pilas@iwes. fraunhofer.de
11	Putnam	Eric	Fraunhofer IWES	Germany	eric.putnam@iwes.fraunhofer.de
12	Bosse	Dennis	Institute of Machine Elements & Machine Design	Germany	bosse@ime.rwth-aachen.de
13	Jacobs	Georg	Institute of Machine Elements & Machine Design	Germany	jacobs@ime.rwth-aachen.de
14	Radner	Dominik	Institute of Machine Elements & Machine Design	Germany	radner@ime.rwth-aachen.de
15	Schelenz	Ralph	Institute of Machine Elements & Machine Design	Germany	schelenz@ime.rwth-aachen.de
16	Schwarf	Hans	GE	Germany	
17	Wefer	Maik	Leibniz Universität Hannover	Germany	maik.wefer@forwind.uni-hannover.d
18	Resing-Wörmer	Helmut	Nordex Energy GmbH	Germany	
19	Armin	Diller	Renk Test System Gmbh	Germany	armin.diller@renk.biz
20	Sagner	Sven	RETC Gmbh	Germany	sven.sagner@retc.de
21	Jan-Bernd	Franke	RWE Innogy Gmbh	Germany	jan-berno.franke@rwe.com
22	Yuri	Petryna	Technical University Berlin	Germany	statol@tu-berlin.de
23	Capellaro	Mark	Universität Stuttgart	Germany	capellaro@ifb.uni-stuttgart.de
24	Hagstrom	Espen	Statkraft Development	Norway	espen.hagstrom@statkfraft.com
25	Simonot	Emilien	AEE	Spain	esimonot@aeeolica.org
26	Stalin	Thomas	Vattenfall	Sweeden	thomas.stalin@vattenfall.com
27	Niff	Brian	Mc Niff Industry	USA	brian@mcnifflight.com
28	Scott	Hughes	NREL	USA	scott.hughes@nrel.gov


ADITEC
25

b) Discussion

The presentations covered different areas going from capabilities and requirements of testing facilities, testing procedures and new developments in this sector, and covering testing of materials, components, subsystems, full wind turbines and wind farms.

More than half of the presentations were focused on component testing: blade testing (6, 7, 8, 9 and 10), gearbox testing (1, 14 and 16), support structures (11), and nacelle (10). Test rig capabilities were covered also in several presentations.

Following the presentations the floor was opened and a general discussion took place. A number of different topics were handled.

Test in wind turbines and components are required for several necessities, but mainly for designs validation, certification, tools validation, and R&D projects. Consequently depending of the target of the test, there are different procedures and methodologies.

Testing facilities are high cost installations and require high experienced technicians involving also high cost of operation and maintenance. The realisation of fatigue test of full wind turbine components is very expensive and takes long time.

Testing facilities have a broad scope of users and clients, form manufacturers of wind turbines and components, wind farm operators, grid operators, and researchers and developers.

Due to the requirements of confidentiality of the main users (manufacturers), usually it is very complicated to have access to the procedures and results of the test performed.

Test procedures of components, sub-systems, full wind turbines and wind farms already exist in standardized form. The following IEC standards exist for testing and measurement techniques:

- IEC 61400-11 Ed. 3.0 Wind turbines - Part 11: Acoustic noise measurement techniques
- IEC 61400-12-1 Ed. 2.0 Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2 Ed. 1.0 Wind turbines - Part 12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- IEC 61400-12-3 Ed. 1.0 Wind turbines - Part 12 - 3: Wind farm power performance testing
- IEC 61400-13 Ed. 1.0 Wind turbines - Part 13: Measurement of mechanical loads
- IEC 61400-21 Ed. 3.0 Wind turbines - Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines
- IEC 61400-23 Ed. 1.0 Wind turbines - Part 23: Full-scale structural testing of rotor blades

However, there was a general consensus between the participants that still it is required to develop new standards and testing procedures. For instance, test procedures to determine acceptable strain of machine elements and groups of components, apparently do not deliver sufficient results in their existing, often standardized form.

Main conclusions of the discussion were:

- ✓ There are different positions between wind farm operators and manufacturers about the certification required for the wind turbines. Even there are different opinions about component certification between manufacturers, depending that the component is manufactured in house of supplied by an external company.
- ✓ For commercial test (design validation, type certification, project certification …) more harmonization of the procedures it is required, as well as the elaboration of new international reliable accepted standards. It was a general consensus that it is necessary to continue updating and improving the already existing IEC standards.
- ✓ It was discussed the necessity and usefulness of performing fatigue test of full scale large wind turbine components (blades, gear boxes and towers). It was expressed the difficulty to made scale test of components and wind turbines that could be useful.
- ✓ It was identified the necessity to develop new testing procedures, mainly in the sector of components fatigue testing, in order to reduce time and cost. The new methods developed to perform accelerated load test was questioned.
- ✓ It was detected the necessity of main collaboration between manufactures, wind farm operators and researchers form test centres, to define testing necessities and testing requirements that will help the new developments of the sector.
- ✓ Wind turbine manufactures should be more clear defining the test that they need (Are really need it?). Wind turbine manufacturers should give more information about the test performed. Was commented that some manufacturers give information about the test facility were test were performed, but reduced information about the methodologies used and results obtained.
- ✓ Wind turbine user should be the drivers to push test facilities, defining the type of test need it.
- ✓ For R&D test will be very useful to use uniform test specimens that will allow making comparative studies and analysis using data from different test performed. This action will also help the tools validation activity.

c) Future actions under the umbrella of IEA Wind

After the discussion it was decided to launch a new Task Force under the umbrella of the IEA Wind Implement Agreement on **"New test methods for full scale wind turbine components"**. The following organizations showed interest in participating in this task group:

- RWTH (D)
- University of Stuttgart (D)
- Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) (D)
- Technical University of Berlin (D)
- DTU – RISO (DK)
- NREL (USA)
- McNiff Light Industry (USA)
- CENER (SP)

Christian Berggreen, Vice-leader of the Danish Centre for Composites Structures and Materials (DCCSM) from the DTU Wind Energy, and Simon Serowy, from the Institut für Maschinenelemente und Maschinengestaltung of the RWTH University of Aachen will coordinate the working group that will prepare the proposal for the new task.

The task proposal will be presented at the IEAWind Executive Committee for approval.