INTERNATIONAL ENERGY AGENCY

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

67nd IEA Topical Expert Meeting

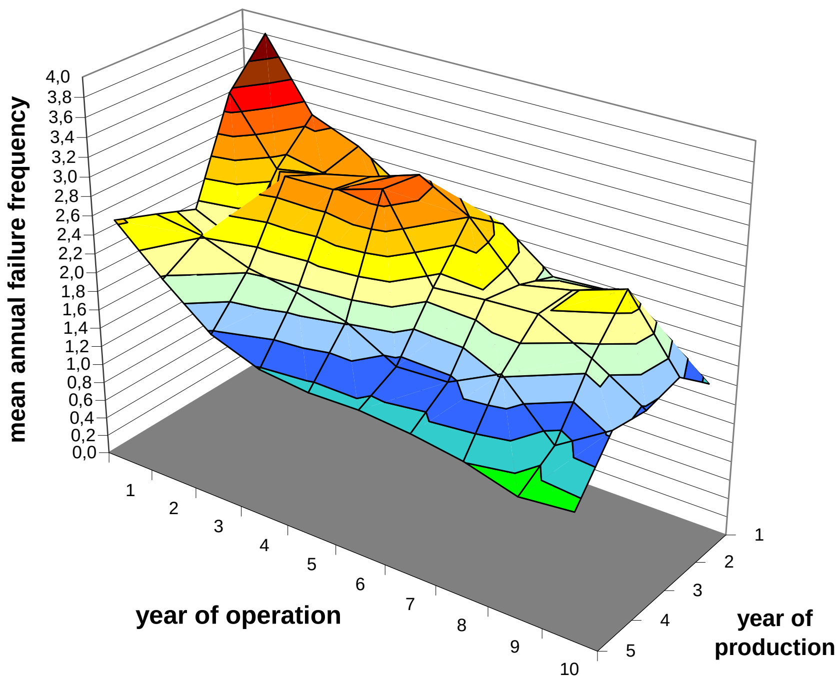
INTERNATIONAL STATISTICAL ANALYSIS ON WIND TURBINE FAILURES

March 30-31, 2011

Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

Königstor 59, 34119 Kassel - Germany

Organized by: CENER



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Please note that these proceedings may only be redistributed to persons in countries participating in the IEA RD&D Task 11.

The reason is that the participating countries are paying for this work and are expecting that the results of their efforts stay within this group of countries.

The documentation can be distributed to the following countries: Canada, Denmark, European Commission, Finland, Germany, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, United States.

After one year the proceedings can be distributed to all countries, that is March 2012

Copies of this document can be obtained from:

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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, the United Kingdom, and the United States are now members.

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

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

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

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

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

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

Two Subtasks

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry". A document dealing with Sodar measurements are presently under development.

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 60 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

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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	CESI S.p.A. and ENEA Casaccia
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

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INTRODUCTORY NOTE

Prepared by Dipl.-Ing. M.Sc. Stefan Faulstich, Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), R&D Division Energy Economy and Grid Operation, Group Reliability and Maintenance Strategies

a) Background

High reliability guarantees a high degree of operating and personal safety, high system availability, low maintenance necessity, and low production downtime. Therefore, it is one of the overriding aims of development work in the area of wind energy technology.

Modern onshore wind turbines attain high technical availability of up to 98%. Evaluation of maintenance work in previous projects shows, however, that high wind turbine availability requires additional maintenance work. Additionally, the upcoming commissioning of several offshore wind farms stimulates the demand for improved reliability and maintenance. Tough environmental factors resulting in higher requirements with regard to reliability, maintenance, and service management have to be adapted to the restricted accessibility and offshore conditions.

There is a considerable scope for optimizing the reliability and maintenance procedures. A possibility therefore is to systematically make use of past experience. Statistical analyses of operation and maintenance data of turbines and their components can be used to define maintenance services at an early stage.

The best known database of wind turbine failure statistics has been established in the scientific measurement and evaluation programme “WMEP” (“Wissenschaftliches Mess- und Evaluierungsprogramm”), included in the German subsidy measure „250 MW Wind“. The WMEP database contains a large quantity of operational and maintenance data and detailed information about both the reliability and availability of wind turbines. It provides the most comprehensive worldwide study of the long-term reliability behaviour of wind turbines and the most trustworthy characteristic reliability parameters -Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR)- published to date.

Besides the WMEP other publicly available sources of experiences do exist. However, these data bases differ from each other in monitoring period, number, size and type of turbines, in the definition of subassemblies and failures, in the level of detail, and in the overall structure. Nevertheless, other surveys have been compared with WMEP, including Windstats Germany and Denmark, Landwirtschaftskammer Schleswig-Holstein (LWK) Germany, Ekofisk Sweden & VTT Finland and it has been found out that, despite their differences, there is considerable agreement between these surveys. However, the loads on wind turbine components differ due to the technical concepts and site conditions. This results in a dispersion of results. Therefore, a wide statistical base is necessary to equalize varying values and to attain reliable results for all cases.

By using detailed, systematically recorded operation and maintenance data that has been processed with standardized and electronically aided protocols, validity can be achieved. For this reason, a joint data base of several wind farm operators, who add data and use the results, is indispensable. For realizing such a common data base it has to be investigated whether it is possible to collaborate between the different initiatives with respect to sharing or grouping data. How could a more open sharing of reliability data in the wind industry be encouraged, particularly for older data, which has less commercial significance but is very important for establishing trends as well as providing the background of allowing new turbine configurations against a sound reliability basis?

In order to get a large statistical data base for evaluations and therefore results with strong validity, a common issue will be standardized designation systems of components and subassemblies as well as common descriptions of failures and causes. Only through standardization, particularly of Turbine and SCADA I/O

Structure, Failure Modes, Root Causes, and Reliability Methods to be used for wind turbines, a common data base can be generated and helping to reduce maintenance efforts while reliability and availability improves.

b) Topics to be addressed

The main objective is to hold a meeting to discuss and gather information on:

- Databases of wind turbine failure statistics
- Standardised designation systems of components and subassemblies
- Descriptions of failures and causes.
- Statistical analyses of operation and maintenance data of turbines and their components
- Systematically recorded operation and maintenance data
- Data processed with standardized and electronically aided protocols
- Etc

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

Proceedings from the meeting will be distributed soon after the symposium. To assist in this the participants are urged to bring along one copy (preferably in digital format) of the material they want to have included in the documentation. A summary of the meeting will be written by the host or persons involved in preparing the Introductory Note.

d) Agenda

Wednesday, March 30th

9:00 **Registration**. Collection of presentations and final Agenda

9:30 **Introduction by Host**
Prof. Jürgen Schmid. Director IWES

10:00 **Introduction by AIE Task 11 Operating Agent. Recognition of Participants**
Mr. Felix Avia, Operating Agent Task 11 IEAWind R&D

10:20 Introduction of Attendees.

10:30 Presentation of Introductory Note
Dipl.-Ing. M.Sc. Stefan Faulstich
Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

1st Session Individual Presentations:

11:00 Definition of a database of offshore wind farm
Philipp Lyding, Fraunhofer IWES, Germany

11:30 Definition of a database of offshore wind farm operational and failure data (EERA)
Jorn Heggset, SINTEF, Norway

12:00 What can the offshore wind industry learn from the OREDA project run for 25 years in the offshore oil and gas industry?
Jorn Vatn, NTNU Norwegian Univ. Of Science & Technology, Norway

12:30 Towards cost-effective maintenance of wind power systems
Katharina Fischer, Chalmers University of Technology, Sweden

- *13:00 Lunch*

2nd Session Individual Presentations

14:30 Turbine blade reliability and failure assessment through accelerated testing
Nathan Post, NREL, USA

15:00 RAMS Database for Wind Turbines
Lassse Petterson, Vattenfall Power Consultant AB, Sweden

15:30 Influence of uncertainty in failure data on modeling O&M aspects
R. P. van de Pieterman, ECN, The Netherlands

16:00 Serious Incident to Vestas Products
Jens A B Lauesen, Vestas Wind System A/S, Denmark

16:30 Coffe Break

17:00 Wind energy statistics in Finland
Andes Stenberg, VTT Technical Research Centre of Finland, Finland

r

17:30 Tailwind for the wind industry
Michael Schrempp, Munich Re, Germany

18:00 End of the meeting

19:00 Dinner

Thursday, March 31st

3rd Session Individual Presentations

09:00 Life cycle cost analysis for offshore wind farm
Francois Besnard, Chalmers University (seating Vattenfall Wind), Sweden

09:30 Operator's requirements for maintenance and inspection
Axel Ringhandt, Enertrag – Windstrom, Germany

10:00 Approach to systematically record O&M Data for Offshore Wind Farms
Burcu Özdirik, RWE Innogy, Germany

10:30 SKF a driving force in wind energy
Matthias Hofmann, SKF, Germany

11:00 Coffe Break

11:30 Blade failures and the lack of control
Knut Austreng, Statoil, Norway

12:00 Discussion

13:00 Lunch

14:30 Summary of Meeting

15:00 End of the meeting

PRESENTATIONS

Topical Expert Meeting – Failures Database

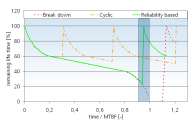
INTERNATIONAL STATISTICAL ANALYSIS ON WIND TURBINE FAILURES

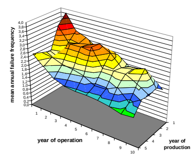
Dipl.-Ing. M.Sc. Stefan Faulstich
Dipl.-Wi.-Ing. P. Lyding, M.Sc. Paul Kühn
Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

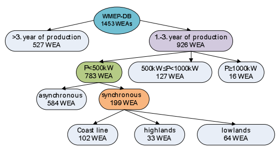
Fraunhofer IWES

Topical Expert Meeting – Failures Database

- Introduction
  - Motivation
  - Maintenance strategies
- Failures Database
  - Reliability of Wind Turbines
  - Parameter Diversity
  - Existing Sources of Experience
  - Comparability
- Conclusions & Outlook







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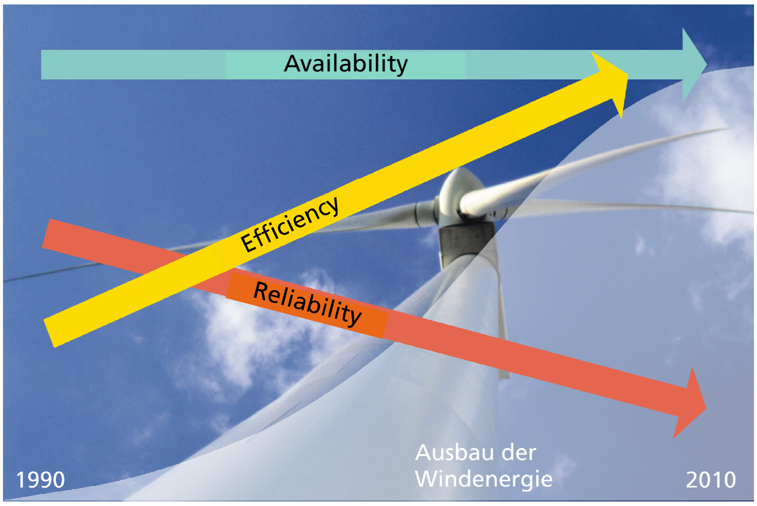
Motivation



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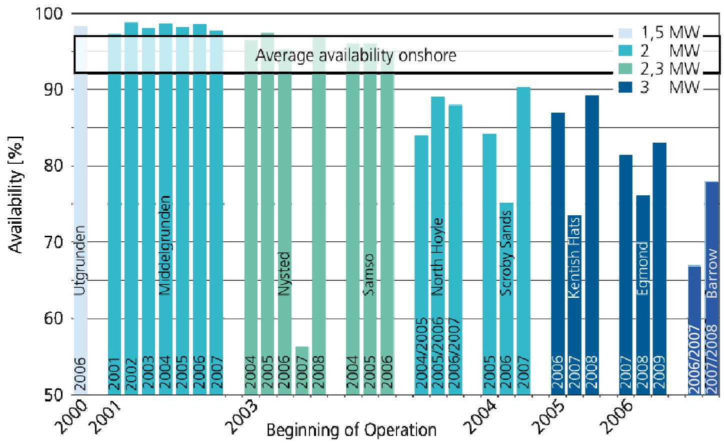
Motivation

Starting Point: Modern wind turbines achieve high availability

Number of faults cause unplanned downtimes→ high maintenance efforts and costs

Offshore: drop of availability expected



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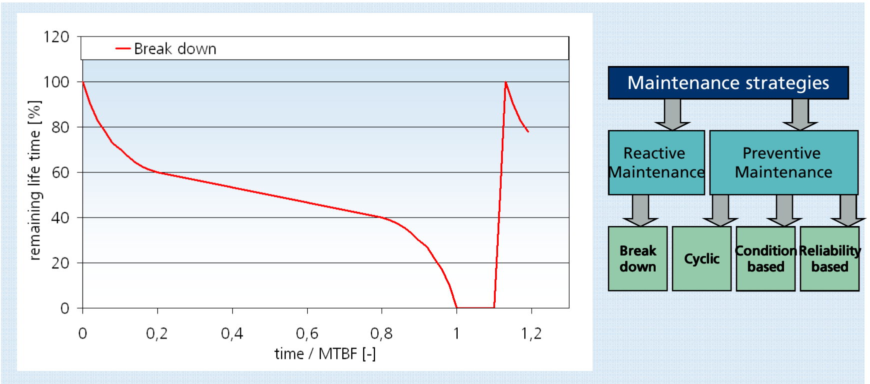
Maintenance strategies

It can be distinguished between reactive and preventive maintenance strategiesWithin the break down maintenance strategy the system will be operated until a major failure of a component will result in a shut down



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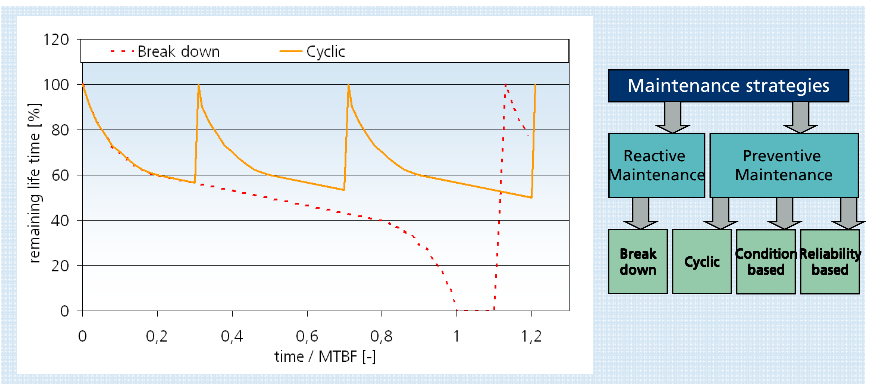
Maintenance strategies

Preventive maintenance strategies try to react before a failure occurs

With the cyclic maintenance strategy components of the wind turbine will be inspected and maintained cyclically, e. g. on semi annual intervals



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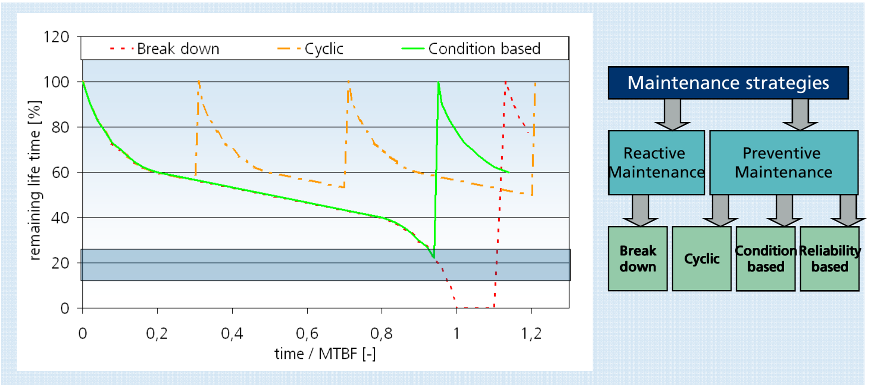
Maintenance strategies

The condition based maintenance strategy tries to find the optimum point in time for carrying out the required maintenance actions by monitoring the current state of a specific component



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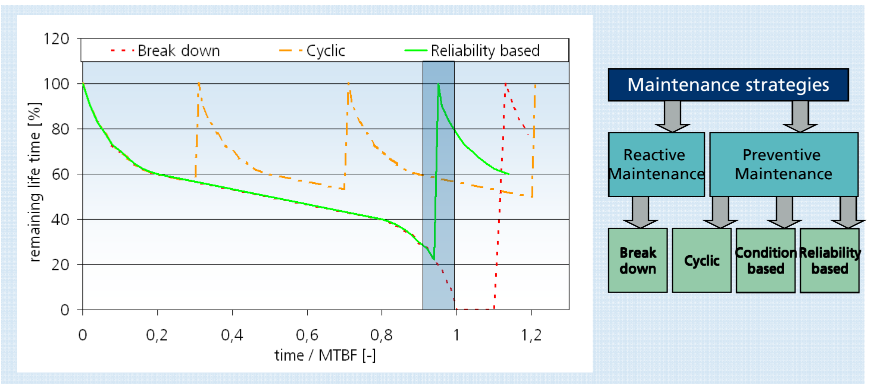
Maintenance strategies

The reliability based maintenance tries to find the right time for maintenance measures through analysing a broad data base filled with experiences from the past



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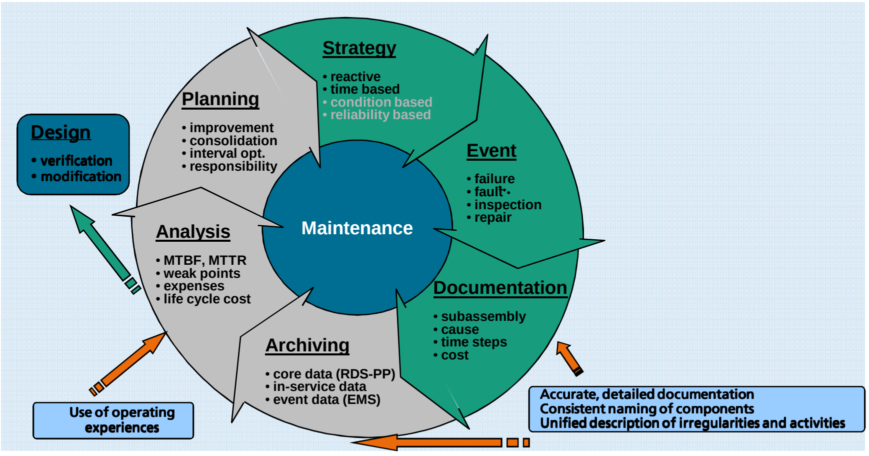
Maintenance organisation

- Lacking of a closed maintenance loop



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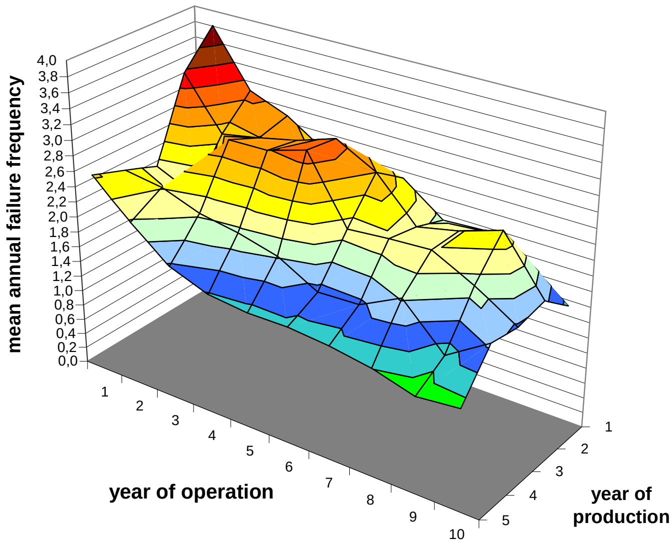
Value of Experience



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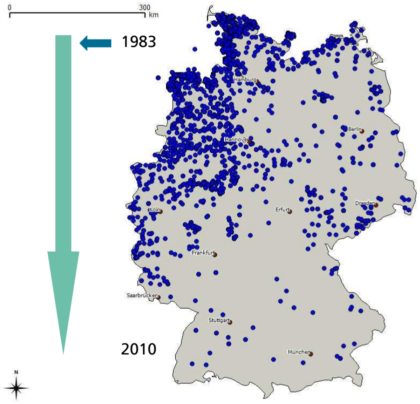
Failure Database: WMEP

Scientific **M**easurement and **E**valuation **P**rogram („250 MW Wind“ (1989-2006))



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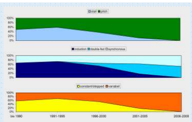
Failure Database: WMEP

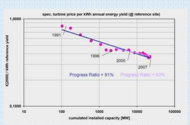
Scientific **M**easurement and **E**valuation **P**rogram („250 MW Wind“ (1989-2006))

193.000 monthly operation reports
and 64.000 Incident reports
from 1.500 wind turbines

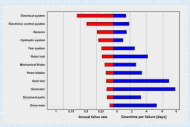
Technology development

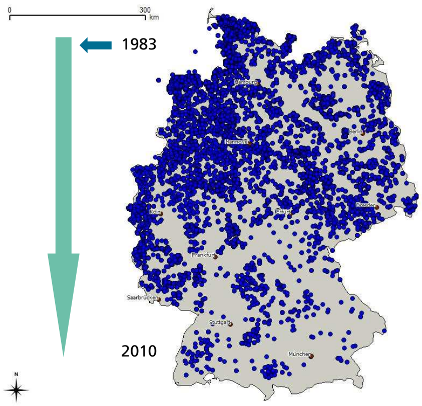


Learning curves



Reliability





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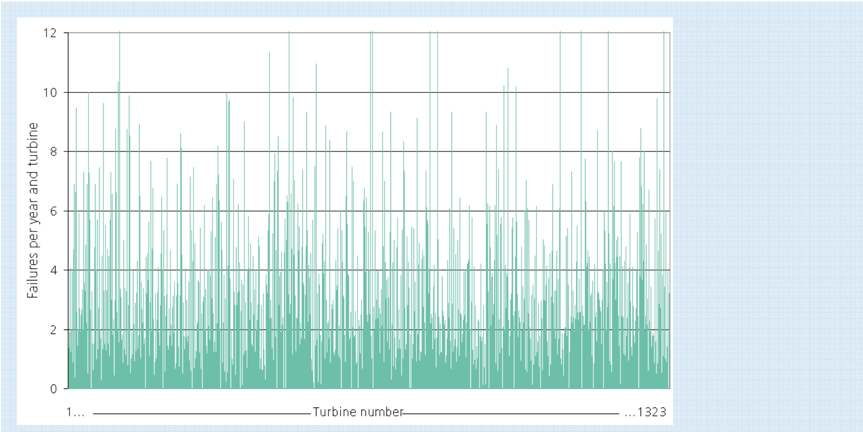

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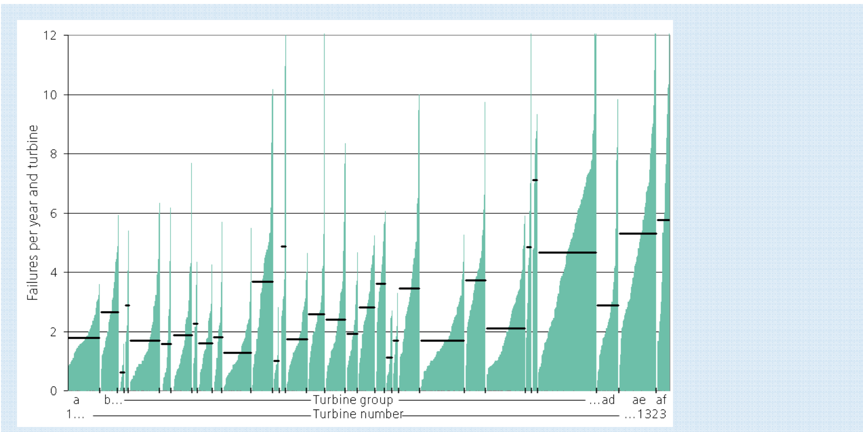

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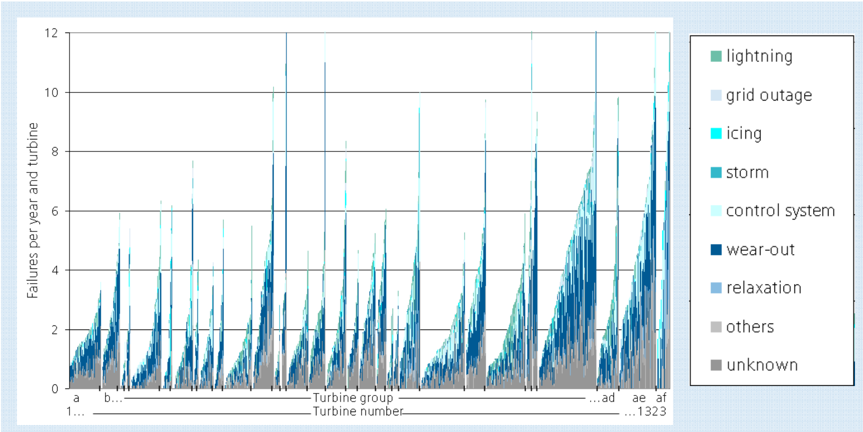

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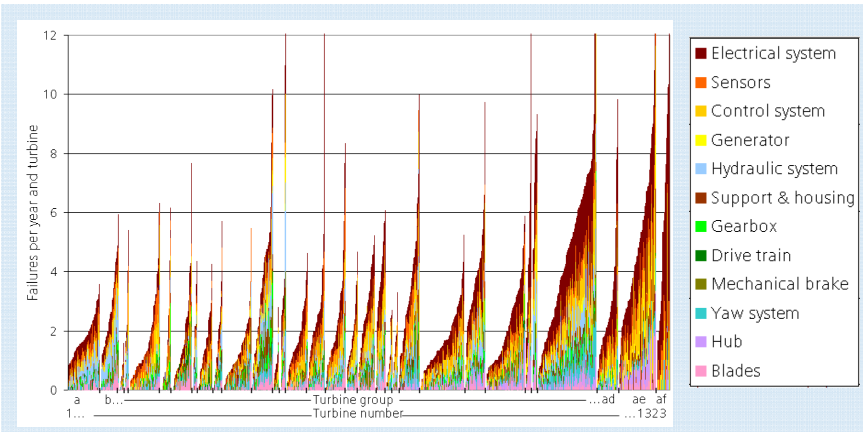

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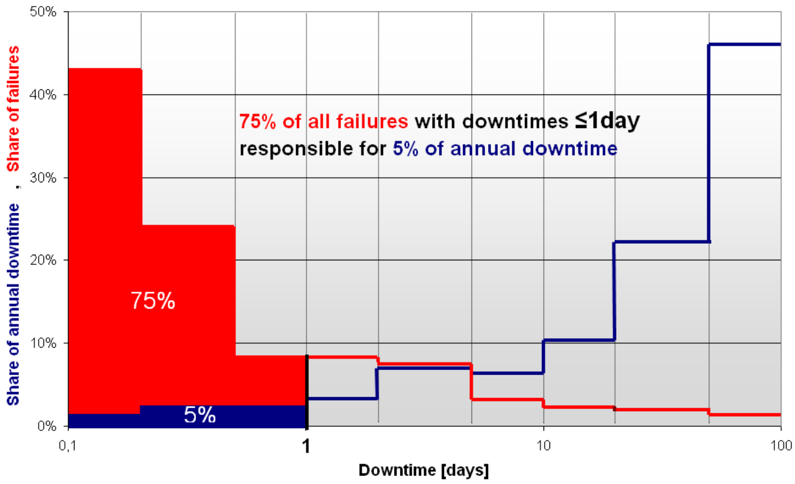
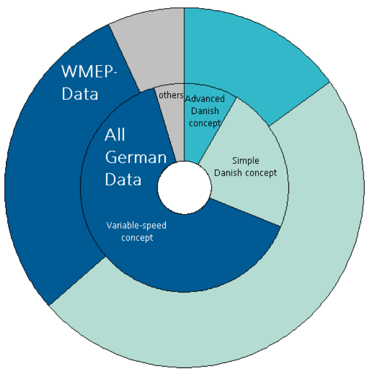


Failure Database: WMEP

	I	II	III
	Simple Danish concept	Advanced Danish concept	Variable-speed concept
Exemplary turbine groups	AN Bonus 100/150 Vestas V 17/20	Vestas V 25/27/29 Ventis 20-100	Vestas V 63/66 Enercon E 66
Control	Stall	Pitch	
Speed characteristic	constant		variable



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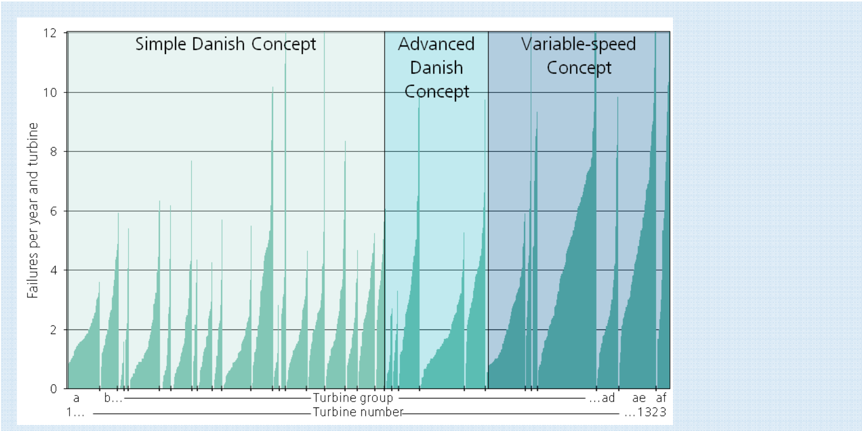

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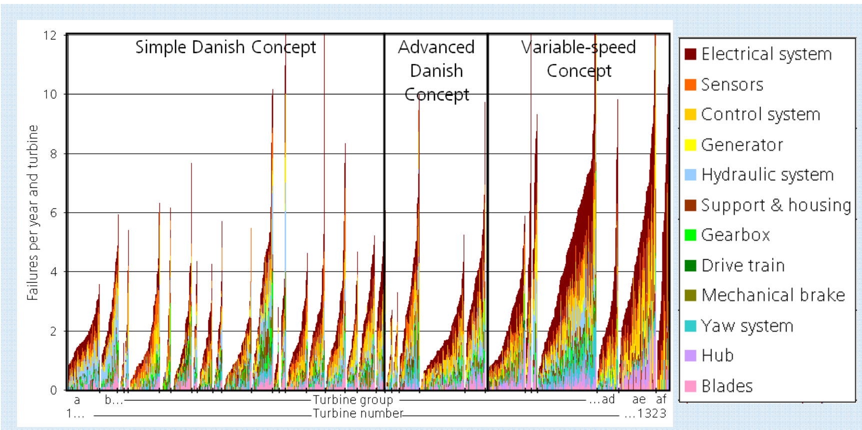

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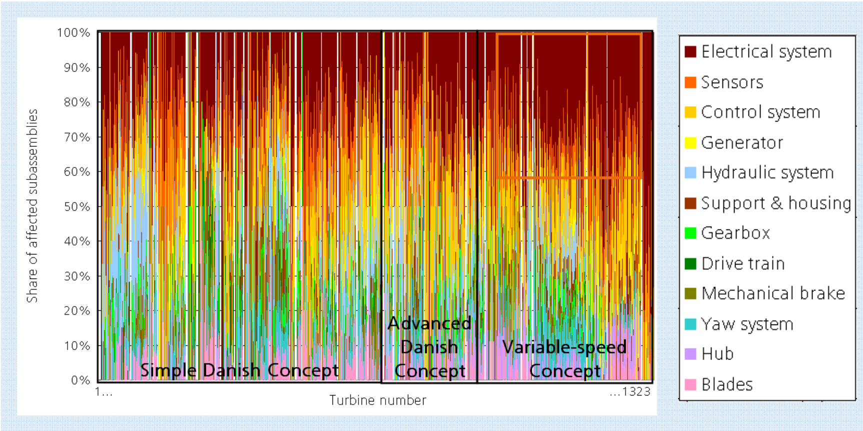

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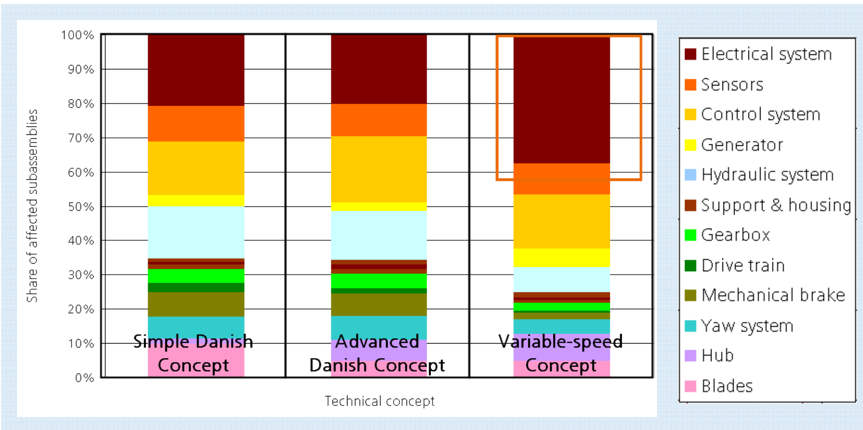

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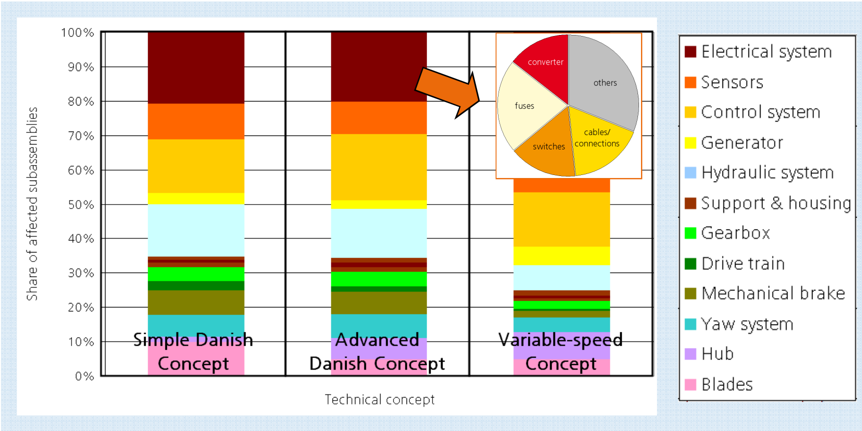

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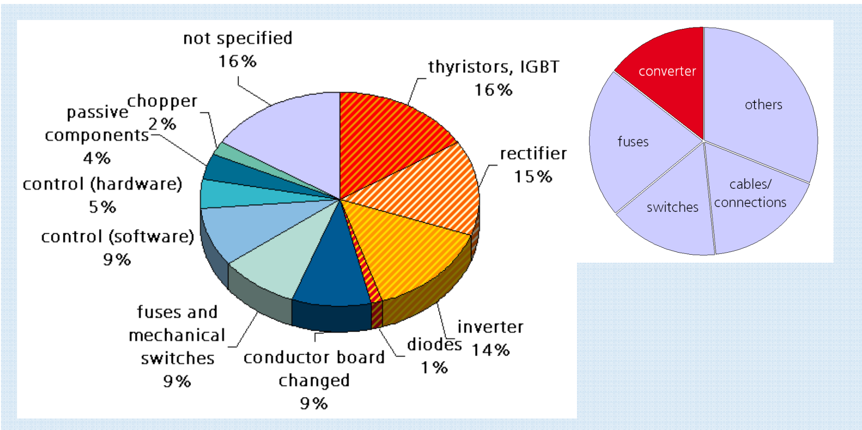

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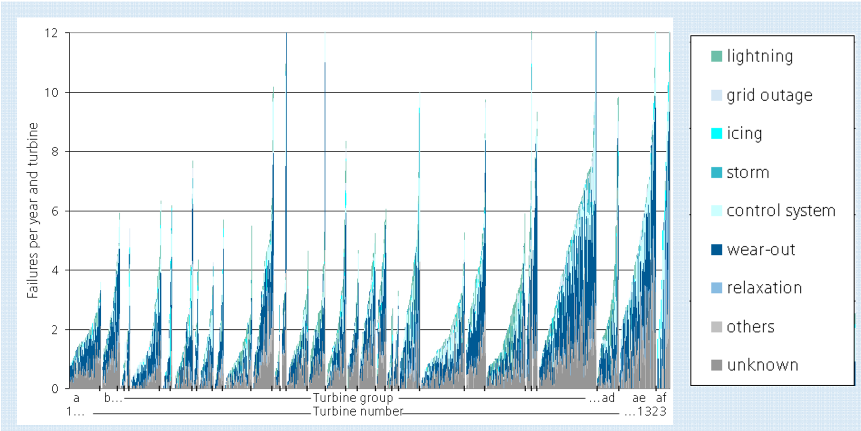

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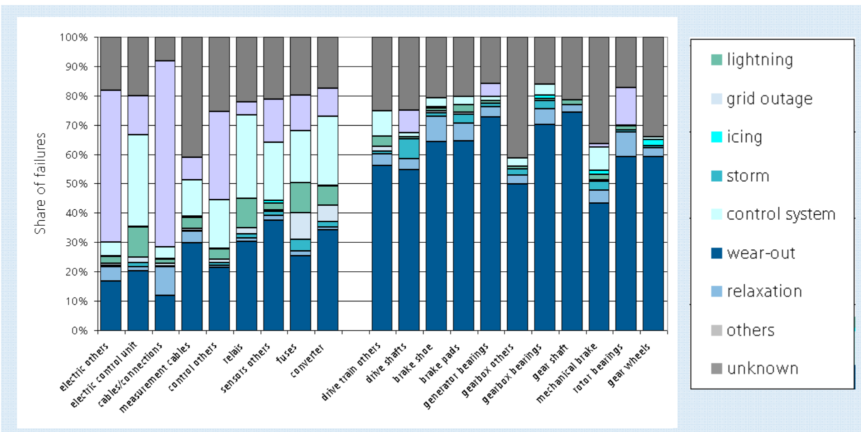

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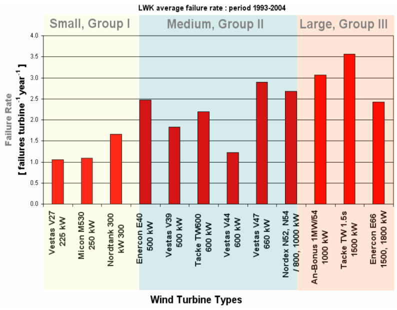
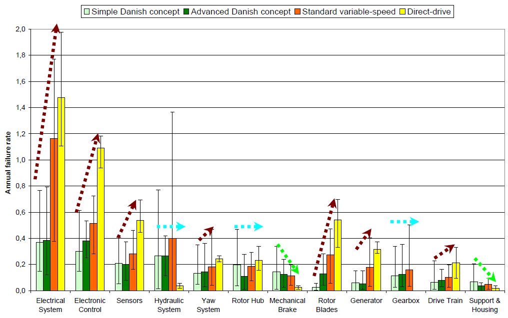
Reliability of wind turbines – Trends



Failure rate vs. turbine size (Durham University, LWK)

Failure rate vs. technical concept (IWES, WMEP)



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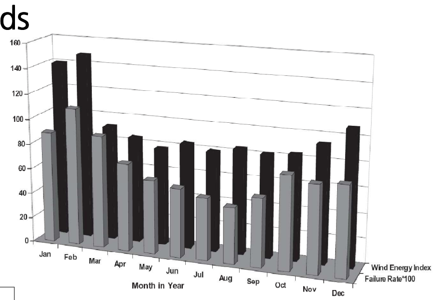
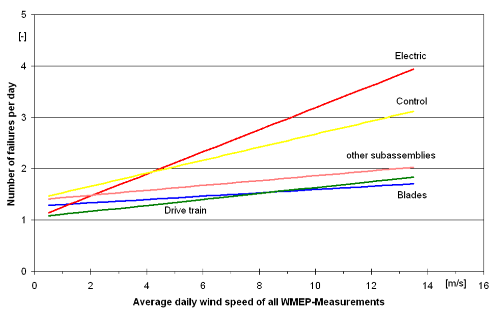
Reliability of wind turbines – Trends

Correlation between Wind energy index and failure rate (Durham University, LWK)





Wind speed dependancy of failure rate (IWES, WMEP)

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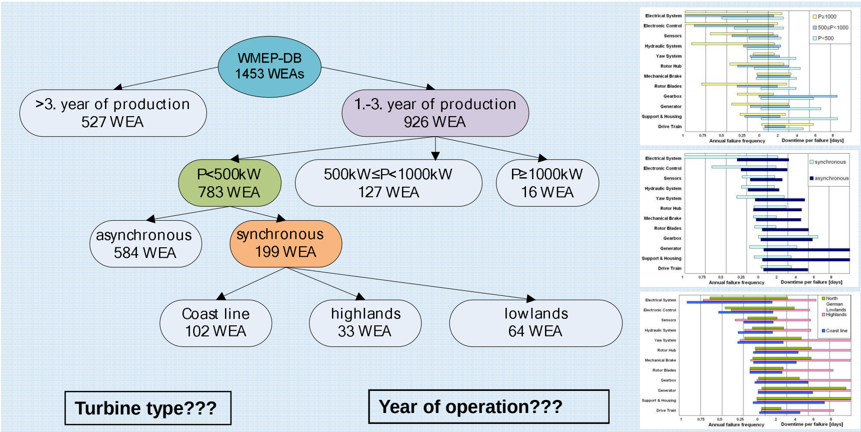
Appropriate Failure Statistics

- For differential analysis distinctions regarding size, technical concepts, site conditions, etc. must be made



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Failure Database: other sources of experience

	Country	*Time span*	*Number of turbines*	*Turbine-Years of experience*
WMEP	Germany	1989 – 2006	1468	~15.000
LWK	Germany	1993 – 2006	241	5.719
Windstats	Germany	1995 – 2004	4285	27.700
Windstats	Denmark	1994 – 2003	904	18.700
VTT	Finnland	2000 – 2004	92	356
Elforsk	Sweden	1997 – 2004	723	4.378

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Failure Database: other sources of experience

	Average failure rate [failures/turbine/year] over whole survey period	*Annual downtime [hours/turbine/year] over whole survey period*
WMEP	**2,4**	**156**
LWK	**1,9**	**27**
Windstats	**1,8**	**93**
Windstats	**0,7**	**-**
VTT	**1,5**	**237**
Elforsk	**0,9**	**58**

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Failure Database: other sources of experience

	Highest failure rate	*Longest downtime per failure*
WMEP	**Electric** **Control** **Sensors**	**Gearbox** **Drive train** **Generator**
LWK	**Electric** **Blades** **Control**	**Gearbox** **Blades** **Electric**
Windstats	**Blades** **Electric** **Sensors**	**Gearbox** **Blades** **Drive Train**
Windstats	**Control** **Blades** **Yaw-System**	-
VTT	**Hydraulic** **Blades** **Gearbox**	**Gearbox** **Blades** **Support & Housing**
Elforsk	**Electric** **Hydraulic** **Sensors**	**Drive train** **Yaw-System** **Gearbox**

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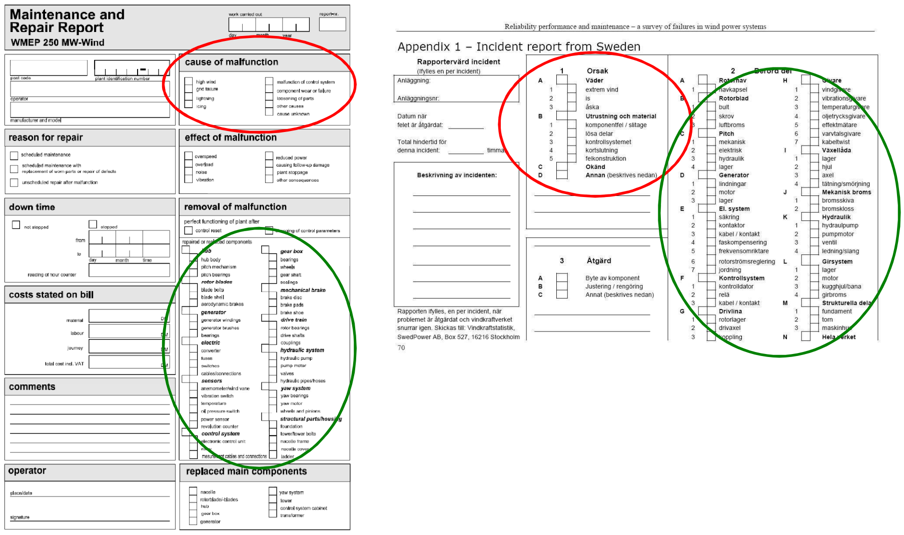
Failure Database: comparability



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Failure Database: comparability

Kompenent	WMEP	LWK	Elforsk	VTT	Windstats Denmark: Denmark	Windstats Denmark: Germany	WTGS Japan
Rotor	Rotorblätter	Blade	Blades/Pitch	Blade/Pitch	Blades	Rotor	Rotor
	Rotornabe	Rotor brake	Hub	Hub	Hub	Air Brake	Air brake
		Pitch mechanism			Air brakes	Pitch Control	Pitch control system
Mechanische Bremse	Mechanische Bremse	Brake	Mech. Brakes	Mech. Brakes	Mechanical Brake	Mechanical Brake	Mech. Brakes
Elektrik	Elektrik	Elektric	Elec. System	Elec. System	Grid	Electrical System	Elec. System
		Invertor					
Generator	Generator	Generator	Generator	Generator	Generator	Generator	Generator
Getriebe	Getriebe	Gear box	Gear	Gears	Gearbox	Gearbox	Gear box
Hydraulikanlage	Hydraulikanlage	Hydraulics	Hydraulic	Hydraulics	Hydraulic System	Hydraulics	Hydraulic
Regelung	Regelung	Electronics	Control System	Control System	Electrical Control	Electrical Controls	Control system
					Mechanical Control		
Sensoren	Sensoren	Sensors	Sensors	Sensors		Sensors	Sensors
		Windvane/anemometer				Measurement System	Windvane
Tragende Teile	Tragende Teile		Structure	Structure	Tower		
					Foundation		
Antriebstrang	Antriebstrang	Shaft & Bearing	Drive train	Drive Train	Main Shaft	Main Shaft	Shaft & bearing
Windrichtungsnachführung	Windrichtungsnachführung	Yaw System	Yaw System	Yaw system	Yaw System	Yaw System	Yaw system
Sonstiges		Other		Entire Unit	Coupling	Other	Entire unit
				Other	Entire nacelle		others
				Entire turbine			
				Other			

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Conclusions

- Potential for availability improvement and for reducing maintenance effort exists
- Common database needed due to parameter diversity
- Different concepts necessary
  - Overall data structure
  - Standards and definitions
  - Accessibility of information

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iea wind

Thank you for your attention

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Reliability & Maintenance strategies
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Definition of a Data Base of Offshore Wind Farm

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Reliability & Maintenance strategies
R&D Division Energy Economy and Grid Operation

Fraunhofer Institute for Wind Energy and Energy System Technology IWES
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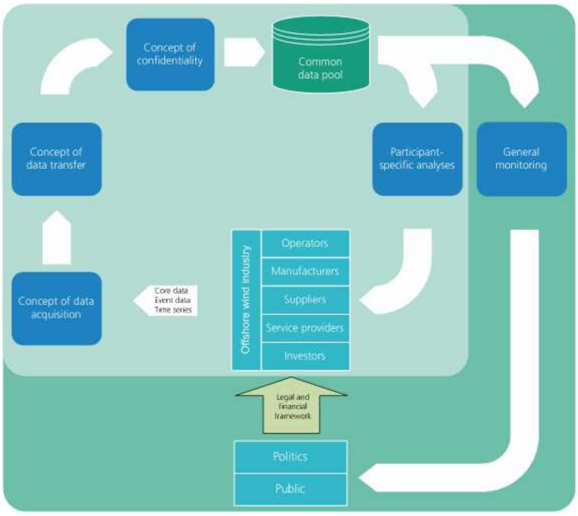
Introduction

- Potential for availability improvement and for reducing maintenance effort exists
- Common database needed due to parameter diversity
- Different concepts necessary
  - Overall data structure → Core data, In-Service data, Event data
  - Standards and definitions → RDS-PP, EMS (adopted), GSP, Time steps
  - Accessibility of information → Offshore~WMEP, concept of confidentiality

Offshore~WMEP

- The project is a follow-up project to the onshore wind energy monitoring program 'Scientific Measurement and Evaluation Program' (WMEP) and accompanies the offshore wind energy deployment in Germany

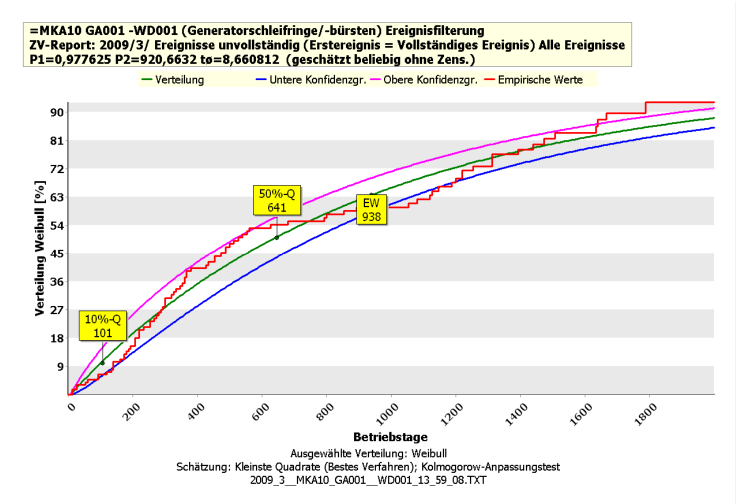
- Funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety



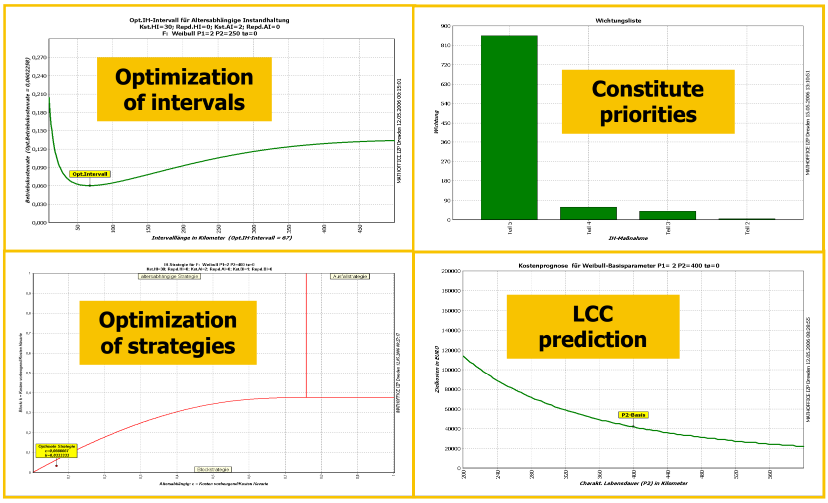
Offshore~WMEP – General monitoring

- Core issues
  - Site-specific offshore conditions
  - Installation
  - Energy output
  - Reliability
  - Availability
  - Facility concepts
  - Operation and maintenance concepts
  - Investment and operating costs

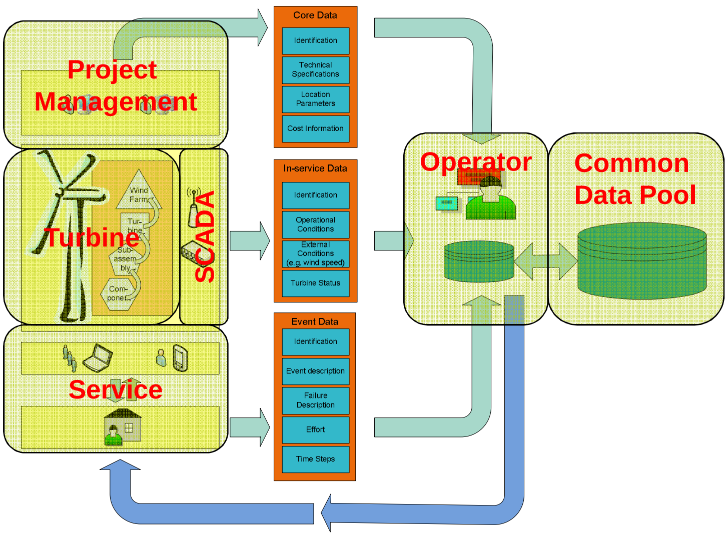
Offshore~WMEP – Participant-specific analyses



Offshore~WMEP – Participant- specific analyses



Concept of data aquisition



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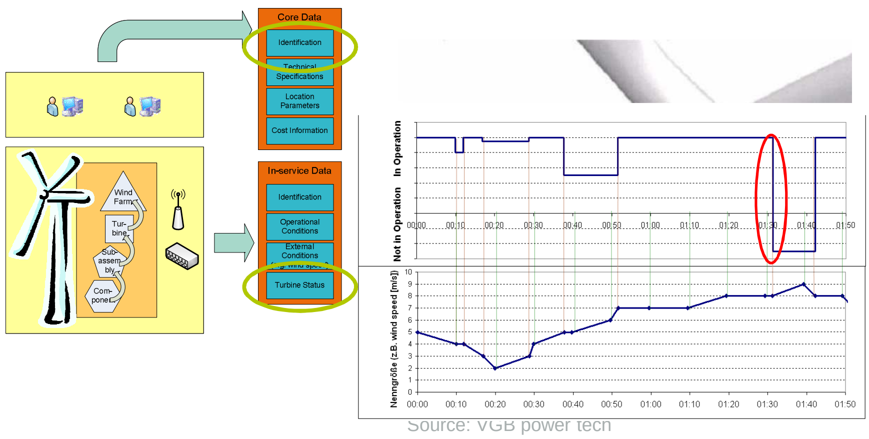
Concept of data aquisition



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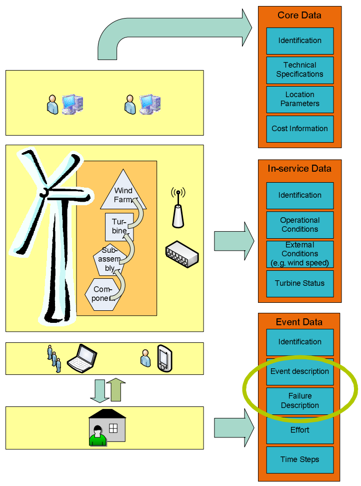
Concept of data aquisition



type of event EMS1+10	failure mechanism EMS07
failure	wearout
preventive maintenance	fatigue
retrofit	corrosion
non-application	deterioration
test	force use
compliance test	fouling
operation	pre-existing damage
other	no damage
	not investigated
	other

cause EMS06	failure mode EMS08
planning	fouling
construction	material weakening
installation	plastic yielding
startup	dislocation
operation	material change
retrofit	material separation
transport	electric material change
external cause	accumulation
internal cause	other deviation from normal conditions
unknown	other change of material
not investigated	no damage
other	failure mode unclear
	not investigated
	other

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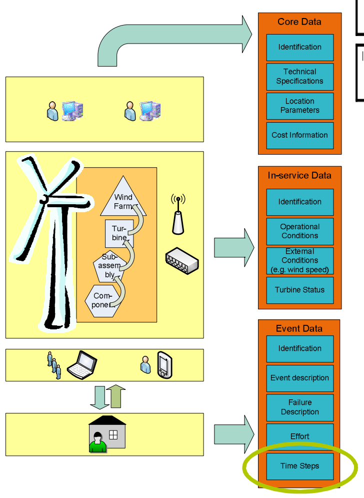
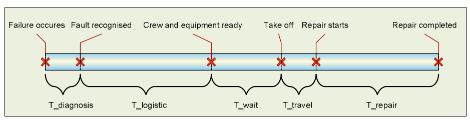
Concept of data aquisition

Identification	Event-ID	Type of Event EMS 01+10	Travelling expenses	Beginning	Reason for delay	Repair starts	End

Identification	Event-ID	Failure Cause EMS06	Damage mechanism EMS07	Damage pattern EMS08	Labour cost	Material cost	Costs for support	Repair time





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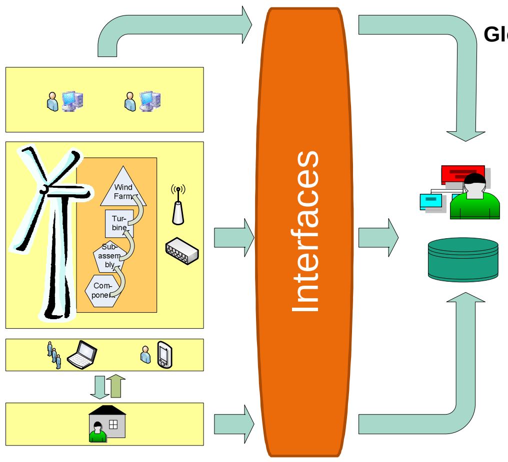
Concept of data transfer



Global Service Protocol „GSP“

Uniform, data-technical protocol between clients and contractors for the purpose of automated acquisition and storage of information,

1. Turbine data
2. Protocol data
3. Order information (client / contractor)
4. Service information
5. …

(lifetime file of the system)

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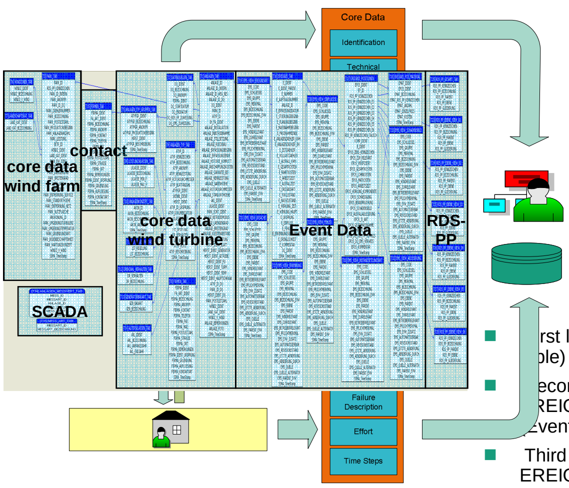
Data structure



- rst level = EREIGNIS_TAB (Event ble)
- econd level = REIGNIS_POSITIONEN vent_position table)
- Third level = EREIGNIS_POS_MATERIAL (Event_position_material table)

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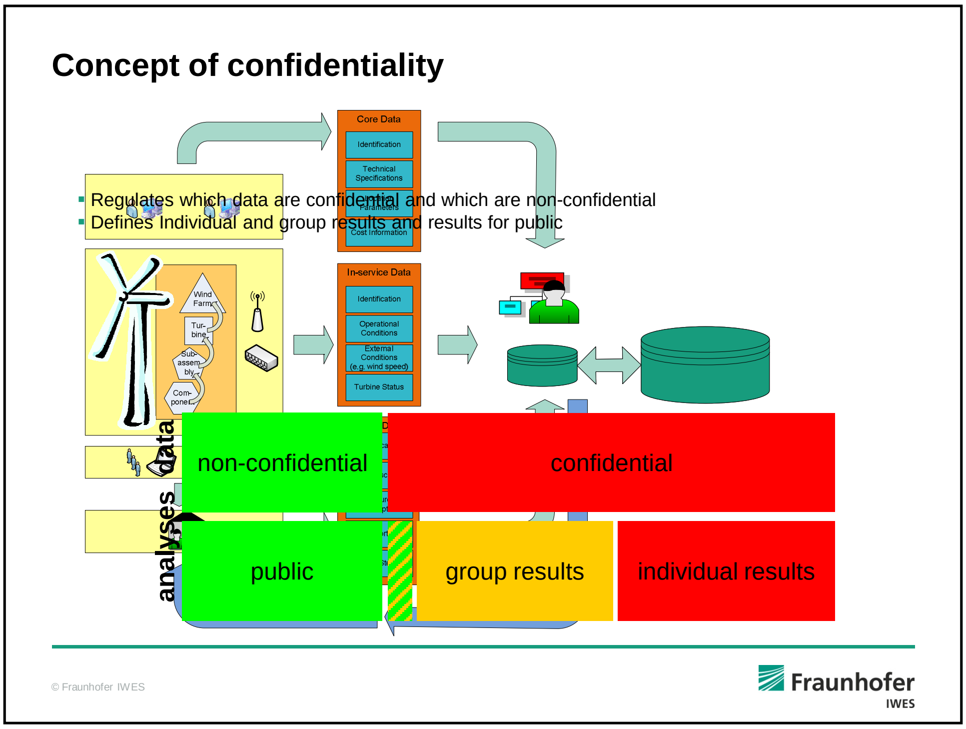
Concept of confidentiality
Regulates which data are confidential and which are non-confidential
Defines Individual and group results and results for public
Core Data
Identification
Technical Specifications
Cost Information
In-service Data
Identification
Operational Conditions
External Conditions (e.g. wind speed)
Turbine Status
Wind Farm
Tur-bine
Sub-assem-bly
Com-ponent
data
non-confidential
confidential
analyses
public
group results
individual results
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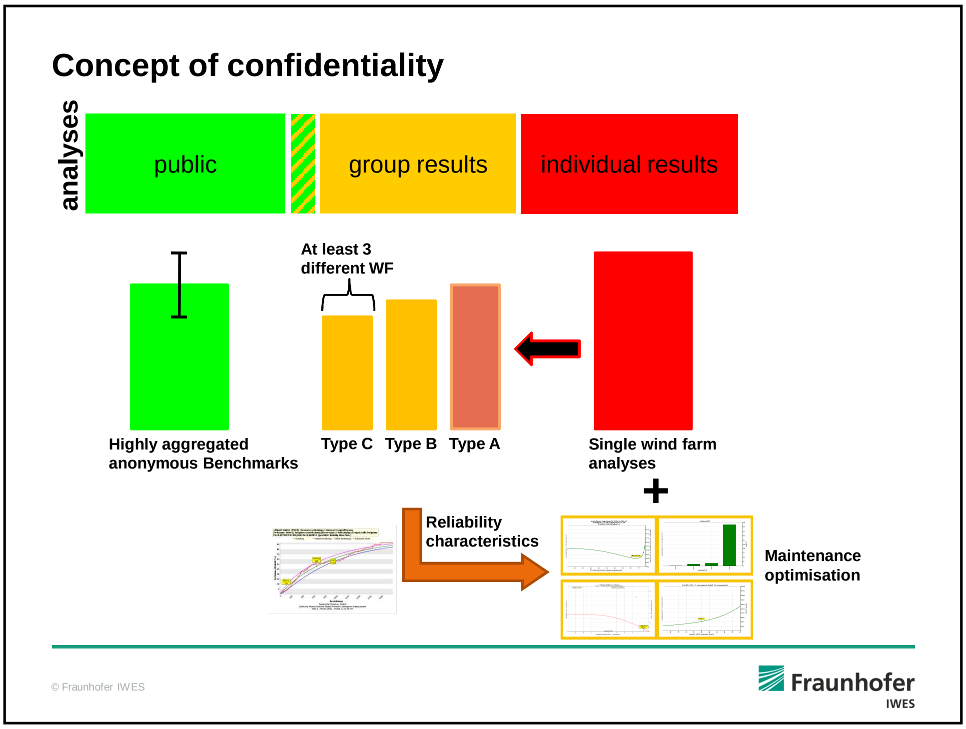
Concept of confidentiality
analyses
public
group results
individual results
At least 3 different WF
Highly aggregated anonymous Benchmarks
Type C
Type B
Type A
Single wind farm analyses
+
Reliability characteristics
Maintenance optimisation
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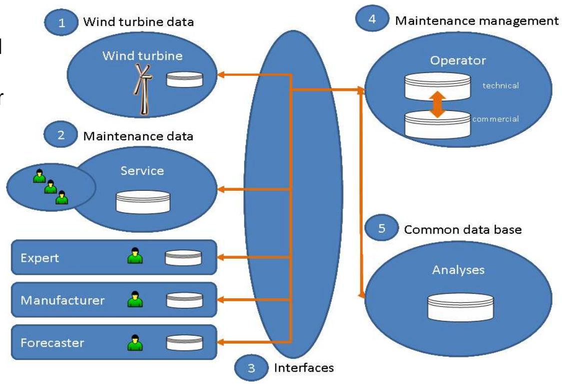
EVW

Increasing availability of wind turbines

- Funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
- Task: Knowledge management and maintenance optimization as methodical base for increasing the availability of wind power plants



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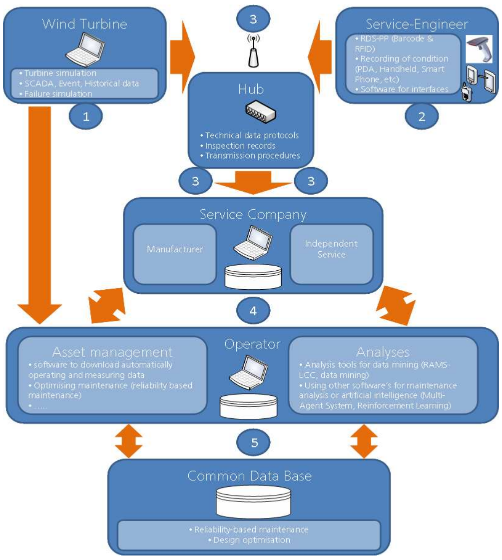
Outlook

- Developing a test and demonstration system
- Preparing recommended practices for reliability based maintenance
- Technical guidelines / standards (Federation of German Windpower)
- **Expand common database (onshore and offshore)**



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Thank you for your attention

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Reliability & Maintenance strategies
R&D Division Energy Economy and Grid Operation

Fraunhofer Institute for Wind Energy and Energy System Technology IWES
Königstor 59, 34119 Kassel

IIEA TEM, 30-31 March 2011 in Kassel

Definition of a database of offshore wind farm operational and failure data

Proposed activity in the EERA Joint programme Wind Energy

- Sub-programme 3: Offshore Wind Energy

Jørn Heggset
Senior Research Scientist
SINTEF Energy Research

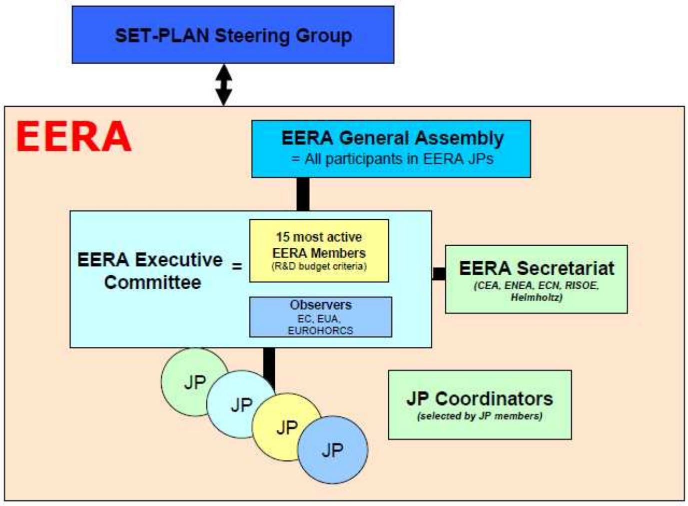
European Energy Research Alliance (EERA)

- Participants in JP Wind Energy
  - CWMT
  - CENER
  - CIEMAT
  - CRES
  - ECN
  - FhG-ISET
  - HGF-DLR
  - IWES
  - LNEG
  - Risø DTU
  - SINTEF
  - UoS
  - VTT

EERA European Energy Research Alliance

http://www.eera-set.eu/

Governance structure



SINTEF — Technology for a better society 3

Sub-programme 3: Offshore Wind Energy

RT 4: Numerical tools for reducing O&M costs

- The aim of this research theme (RT) is to develop numerical tools for reducing O&M costs. Particular emphasis is put on the following three topics all being critical for offshore wind farms:
  - tools for selecting more robust design of components and need for redundancy
  - tools for doing predictive maintenance, hereunder models of component degradation
  - **establish a database with operational and failure data**

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From the work description of sub-programme 3:

- The most important data to be used as input for the quantification of corrective maintenance with the O&M costs models are failure rates and reliability data of wind turbine (and balance of plant) components. Such data, especially reliability data, are hard to obtain. **Databases with operational and failure data should become available and the industry should exchange such data**. Parties involved should collect in a similar and structured way. Next, information about local weather conditions, capabilities of vessels, and logistic aspects are needed as input and should be collected centrally and exchanged.

- This RT could focus on **structuring the format for data collection, setting up procedures for analysis and reporting, and developing a central database** that can be accessed by industrial parties, keeping in mind the confidentiality aspects.

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Data structure in ISO 14224 (modified with information about technical condition)

<u>Alternatives</u>:

- Should EERA take the initiative to a joint project with the aim of developing a standard for wind energy reliability data collection and exchange? (similar to ISO 14224)

- Or should EERA take the initiative to develop such a European database?

- Or should EERA....?

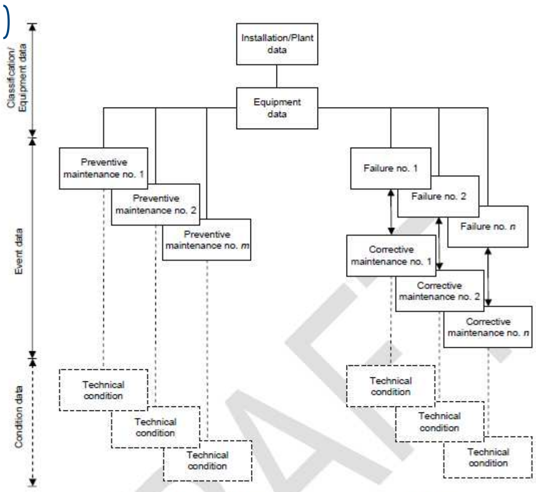

Figure 2.3 Logical data structure (based on ISO 14224:2006 [13])

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Possible outcomes of an EERA joint project

- Common guidelines and recommendations for data collection and exchange
  - Terminology
  - Taxonomy
  - Coding/definition of various data types
  - Format(s) for data exchange
  - Definition of standard reports/statistics
  - Etc.
- Long-term goal:
  A standard for collection and exchange of RAMS data for wind turbines
- Both onshore and offshore data, or focus only on offshore?

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Technology for a better society

What can offshore wind learn from OREDA: 30 years of experience with data collection and analysis in the offshore oil and gas industry?

Jørn Vatn

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History

- In the early 80s a number of oil companies operating in the North Sea and the Adriatic started a collaborative project
- The idea was to survey the reliability of important equipment under 'real life' operational conditions
- The project, which was given the acronym OREDA® (Offshore REliability DAta), has been carried out in 10 phases up to now

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Achievements in the OREDA include

- Standard for reliability data collection: **ISO 14 224**: “Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment”
- Guidelines and software for data collection and data analysis
- Publication of 5 public editions of a **Reliability Data Handbook** (1984, -92, -97, -02, -09) sold in more than 50 countries world-wide
- **Exchange of reliability knowledge between the participating companies, and co-operation with miscellaneous parties such as manufacturers, research institutes etc**
- Formalised co-operation with the subsea system **suppliers** Cameron, FMC Kongsberg Subsea, Aker Solutions and Vetco Gray
- Promotion of the OREDA concept and OREDA data application by > 40 papers at various international conferences
- **Data used in various research projects and student thesis**
- **OREDA Data Analysis Guideline**

Participants

- BP Exploration Operating Company Ltd
- ConocoPhillips Skandinavia AS
- Eni S.p.A Exploration & Production Division
- ExxonMobil Production Company
- Gassco (associated member)
- Shell Global Solutions UK
- Statoil ASA
- TOTAL S.A.

EXAMPLE PAGE OREDA HANDBOOK (5th EDITION)

Taxonomy no		Item								
1.3.1.9		Machinery Pumps Centrifugal Oil export								
Population	Installations	Aggregated time in service (10^6 hours)					No of demands			
		Calendar time *		Operational time †						
4	2	0.1018		0.0792			480			

Failure mode	No of failures	Failure rate (per 10^6 hours). Lower	Mean	Upper	SD	n/τ	Active rep. hrs Mean	Max	Manhours Mean	Max
Critical	**19*** **19†**	**121.72** **144.86**	**186.12** **238.62**	**261.64** **351.32**	**42.80** **63.30**	**186.58** **240.00**	**14**	**45**	**23**	**90**
Breakdown	1* 1†	0.04 0.06	9.67 12.21	36.47 44.87	13.45 16.57	9.82 12.63	18	18+	35	35+
External leakage - Process medium	6* 6†	0.35 0.44	60.58 81.27	214.15 291.26	79.09 107.62	58.92 75.79	8.6	16+	11	16+
External leakage - Utility medium	10* 10†	0.50 0.66	95.46 118.26	344.12 421.59	127.16 155.76	98.20 126.32	16	45+	29	90+
Noise	1* 1†	0.54 0.79	9.93 12.99	29.48 38.07	9.82 12.63	9.82 12.63	-	-	-	-
Spurious stop	1* 1†	0.04 0.06	9.67 12.21	36.47 44.87	13.45 16.57	9.82 12.63	8.0	8.0+	8.0	8.0+
Degraded	**12*** **12†**	**2.61** **4.47**	**115.19** **143.92**	**354.81** **437.00**	**124.67** **150.66**	**117.84** **151.58**	**5.5**	**15**	**8.6**	**30**
External leakage - Utility medium	7* 7†	7.90 13.04	67.69 85.56	176.19 211.15	55.26 64.53	68.74 88.42	4.7	15+	7.1	30+
Vibration	5* 5†	0.37 0.54	47.89 59.66	162.25 198.12	59.66 72.54	49.10 63.16	6.6	8.5+	11	17+
Incipient	**32*** **32†**	**100.04** **152.50**	**310.91** **395.56**	**616.58** **731.12**	**162.23** **180.34**	**314.24** **404.21**	**3.4**	**12**	**3.7**	**12**
Abnormal instrument reading	25* 25†	54.80 83.90	242.28 307.08	539.20 644.45	154.61 177.34	245.50 315.79	2.9	10.0	3.0	10.0
External leakage - Utility medium	2* 2†	3.49 4.52	19.65 25.31	46.60 59.98	13.89 17.86	19.64 25.26	7.0	12+	7.0	12+
Minor in-service problems	1* 1†	0.54 0.79	9.93 12.99	29.48 38.07	9.82 12.63	9.82 12.63	1.0	1.0+	1.0	1.0+
Vibration	1* 1†	0.04 0.06	9.67 12.21	36.47 44.87	13.45 16.57	9.82 12.63	5.0	5.0+	10.0	10.0+
Other	3* 3†	7.98 10.18	29.36 37.64	61.73 79.28	17.01 21.88	29.46 37.89	7.0	8.0+	7.0	8.0+
Unknown	**1*** **1†**	**0.04** **0.06**	**9.67** **12.21**	**36.47** **44.87**	**13.45** **16.57**	**9.82** **12.63**	-	-	-	-
Unknown	1* 1†	0.04 0.06	9.67 12.21	36.47 44.87	13.45 16.57	9.82 12.63	-	-	-	-
All modes	**64*** **64†**	**158.90** **238.75**	**620.35** **786.19**	**1330.15** **1592.22**	**372.09** **426.23**	**628.49** **808.42**	**6.6**	**45**	**10**	**90**

Comments

On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0

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OREDA EQUIPMENT COVERAGE

Rotating machinery	Mechanical equipment	Control & Safety	Subsea equipment
Combustion engines Compressors Electric generators Electric motors Gas turbines Pumps Steam turbines Turboexpanders	Cranes Heat exchangers Heaters and Boilers Loading arms Swivels Turrets Vessels Winches	Control Logic Units Fire & Gas detectors HVAC Input devices Nozzles Power transformers UPS Valves Frequency converters Switchgear	Control systems Dry tree riser El. power distribution Flowlines Manifolds Pipelines Production risers Running tools Subsea pumps Subsea vessels Templates Wellhead & X-mas trees

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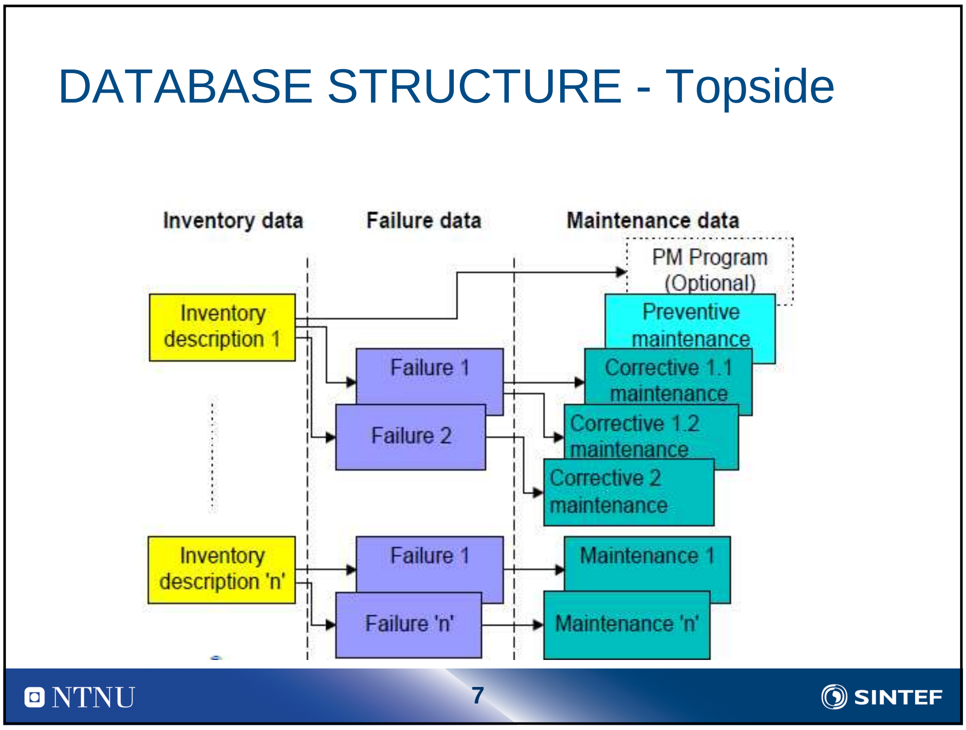
DATABASE STRUCTURE - Topside
Inventory data
Failure data
Maintenance data
PM Program (Optional)
Inventory description 1
Preventive maintenance
Failure 1
Corrective 1.1 maintenance
Failure 2
Corrective 1.2 maintenance
Corrective 2 maintenance
Inventory description 'n'
Failure 1
Maintenance 1
Failure 'n'
Maintenance 'n'
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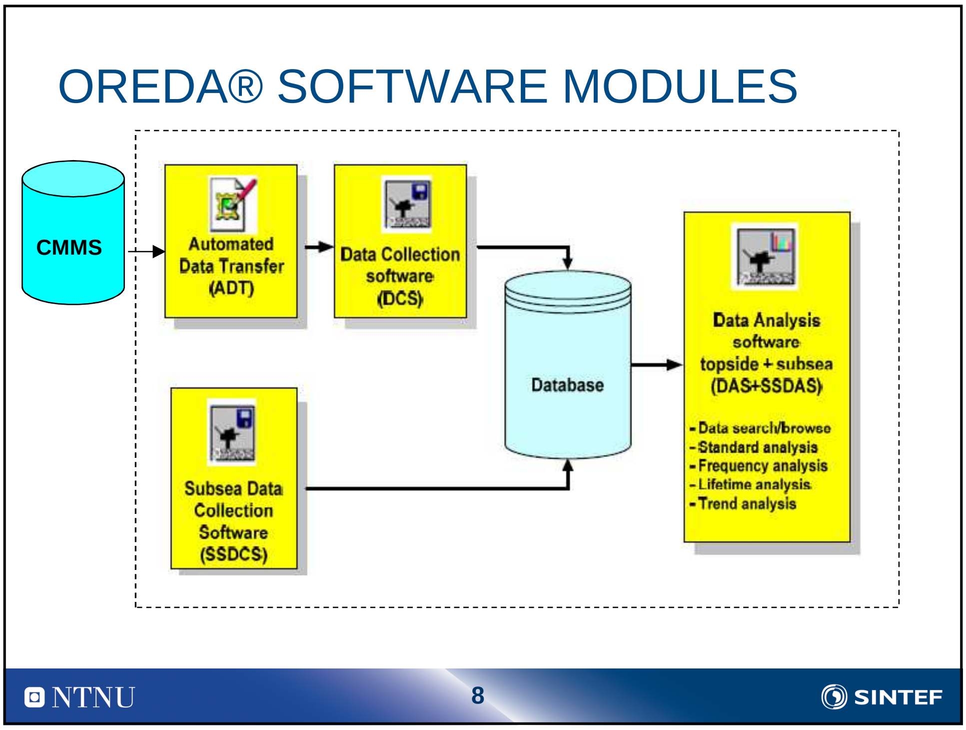
OREDA® SOFTWARE MODULES
CMMS
Automated Data Transfer (ADT)
Data Collection software (DCS)
Database
Data Analysis software topside + subsea (DAS+SSDAS)
- Data search/browse
- Standard analysis
- Frequency analysis
- Lifetime analysis
- Trend analysis
Subsea Data Collection Software (SSDCS)
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SUMMARY - OREDA

- OREDA has become the forum for the collection and exchange of reliability data within the offshore industry, and used as model for data collection within other industries
- OREDA has been widely accepted as the source for reliability data in the offshore industry
- OREDA data and results have been used as input in many RAMS analyses to give more confidence in results
- OREDA experience have generated a more standardized approach to defining, specifying and utilizing reliability knowhow in the offshore industry
- OREDA knowhow has been widely used in development of the international standards ISO 14 224 and ISO 20815
- 30 years of joint industry co-operation has shown that is it possible to work for a common goal across differences in company philosophy, language, culture, distance etc.

Success factors, OREDA

- The operators see the **benefit of sharing** data, and that data exchange can be made without any distortion of competition
- This is achieved both by implementing **anonymization** of data
  - in the common database each operator can only see his own data unanonymizied, and the remaining data is shown with dummy values for e.g., “Installation”
- Publishing of the OREDA Data Handbook
- OREDA is run as **a project** with resources to organize the required work
- The participants contributes with a small **fee**
- The participants are responsible to **provide data** on an agreed format

Success factors, future offshore wind RAMS data

- Commitment from main operators of the wind farms
- Clarification of the roles of operators, maintenance contractors, and manufacturer of equipments
- Clear strategies for anonymizatoin of data
- Funding to run a RAMS data as a long term project activity
  - One option might be to cooperate with OREDA; i.e.,
  - Share their knowledge
  - Take advantage of OREDA project manager experience and effort in OREDA also for Offshore Wind RAMS data
  - Cooperation on the software, and issuing of data handbooks

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Objectives data collection and analysis

- Collection and analysis of safety and reliability data is an important element of RAMS management and continuous improvement
- There are several aspects of utilizing experience data

1. Learning from experience
2. Identification of common problems
   - "Top ten"-lists (visualized by Pareto diagrams)
3. A basis for estimation of reliability parameters
   - MTTF, MDT, aging parameters

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Collection of data

- We differentiate between
  - Accident and incident reporting systems
    - These data is event-based, i.e. we report into the system only when critical events occur
    - Examples of such system is Synergy, and Tripod Delta
  - Databases with the aim of estimating reliability parameters
    - These databases contains system description, failure events, and maintenance activities
    - The Offshore Reliability Data (OREDA) is one such database
    - Such databases will be denoted ***RAMS databases*** in the following

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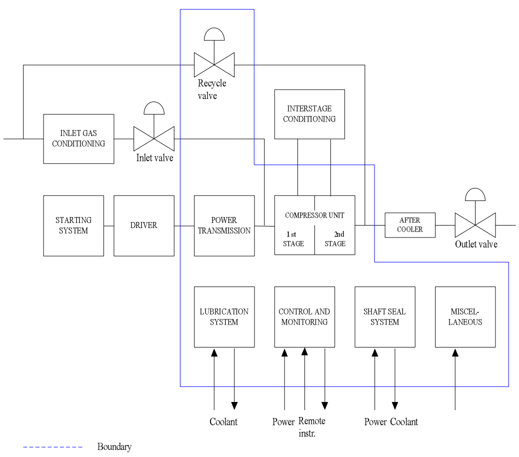
RAMS data: Boundary description

- A clear boundary description is imperative for collecting, merging and analyzing RAMS data from different industries, plants or sources
  - The merging and analysis will otherwise be based on incompatible data.
- For each equipment class a boundary must be defined. The boundary defines what RAMS data are to be collected



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Data categories

- Equipment data
- Failure data
- Maintenance data
- State information

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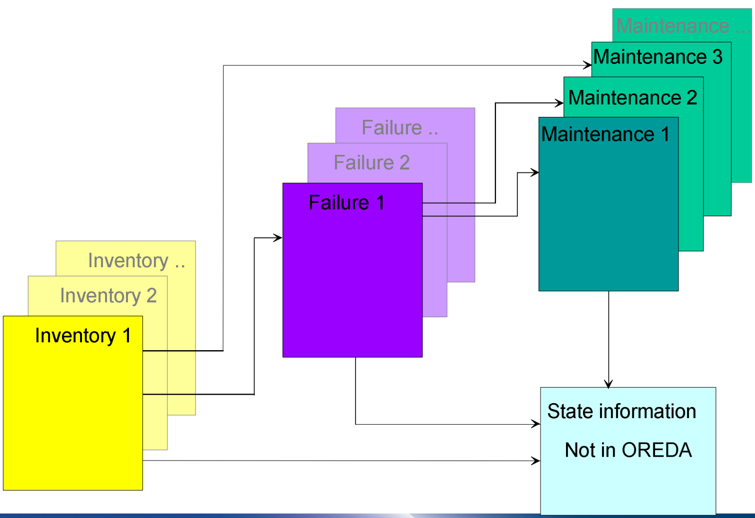
RAMS database structure



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Equipment data - Inventory

- Identification data; e.g.
  - equipment location
  - classification
  - installation data
  - equipment unit data;
- Design data; e.g.
  - manufacturer's data
  - design characteristics;
- Application data; e.g.
  - operation, environment

Failure data

- identification data, failure record and equipment location;
- failure data for characterizing a failure, e.g. failure date, maintainable items failed, severity class, failure mode, failure cause, method of observation

Failure data (From ISO 14224)

Category	Data	Description
Identification	Failure record (*)	Unique failure identification
	Equipment location (*)	Tag number
Failure data	Failure date (*)	Date the failure was detected (year/month/day)
	Failure mode (*)	At equipment unit level as well as at maintainable item level)
	Impact of failure on operation	Detailed list exist
	Severity class (*)	Effect on equipment unit function: critical failure, non-critical failure
	Failure descriptor	The descriptor of the failure (see Table 18)
	Failure cause	The cause of the failure (see Table 19)
	Subunit failed	Name of subunit that failed (see examples in Annex A)
	Maintainable Item(s) failed	Specify the failed maintainable item(s) (see examples in Annex A)
	Method of observation	How the failure was detected (see Table 20)

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Failure causes (From ISO 14224)

No	Notation	Description
1.0	Mechanical failure-general	A failure related to some mechanical defect, but where no further details are known
1.1	Leakage	External and internal leakages, either liquids or gases. If the failure mode at equipment unit level is leakage, a more causal oriented failure descriptor should be used wherever possible
1.2	Vibration	Abnormal vibration. If the failure mode at equipment level is vibration, a more causal oriented failure descriptor should be used wherever possible
1.3	Clearance/ alignment failure	Failure caused by faulty clearance or alignment
1.4	Deformation	Distortion, bending, buckling, denting, yielding, shrinking, etc.
1.5	Looseness	Disconnection, loose items
1.6	Sticking	Sticking, seizure, jamming due to reasons other than deformation or clearance/alignment failures

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Failure causes, cont

No	Notation	Description
2.0	Material failure-general	A failure related to a material defect, but no further details known
2.1	Cavitation	Relevant for equipment such as pumps and valves
2.2	Corrosion	All types of corrosion, both wet (electrochemical) and dry (chemical)
2.3	Erosion	Erosive wear
2.4	Wear	Abrasive and adhesive wear, e.g. scoring, galling, scuffing, fretting, etc.
2.5	Breakage	Fracture, breach, crack
2.6	Fatigue	If the cause of breakage can be traced to fatigue, this code should be used
2.7	Overheating	Material damage due to overheating/burning
2.8	Burst	Item burst, blown, exploded, imploded, etc.

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Failure causes, cont

No.	Notation	Description
3.0	Instrument failure – general	Failure related to instrumentation, but no details known
3.1	Control failure	
3.2	No signal/ indication/-alarm	No signal/indication/alarm when expected
3.3	Faulty signal-/indication/-alarm	Signal/indication/alarm is wrong in relation to actual process. Could be spurious, intermittent, oscillating, arbitrary
3.4	Out of adjustment	Calibration error, parameter drift
3.5	Software failure	Faulty or no control/monitoring/operation due to software failure
3.6	Common mode failure	Several instrument items failed simultaneously, e.g. redundant fire and gas detectors

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Failure causes, cont

No.	Notation	Description
4.0	Electrical failure-general	Failures related to the supply and transmission of electrical power, but where no further details are known
4.1	Short circuiting	Short circuit
4.2	Open circuit	Disconnection, interruption, broken wire/cable
4.3	No power/ voltage	Missing or insufficient electrical power supply
4.4	Faulty power/voltage	Faulty electrical power supply, e.g. over voltage
4.5	Earth/isolation fault	Earth fault, low electrical resistance

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Failure causes, cont

No.	Notation	Description
5.0	External influence – general	The failure where caused by some external events or substances outside boundary, but no further details are known
5.1	Blockage/plugged	Flow restricted/blocked due to fouling, contamination, icing, etc.
5.2	Contamination	Contaminated fluid/gas/surface e.g. lubrication oil contaminated, gas detector head contaminated
5.3	Miscellaneous external influences	Foreign objects, impacts, environmental, influence from neighbouring systems
6.0	Miscellaneous – general[a]	Descriptors that do not fall into one of the categories listed above.
6.1	Unknown	No information available related to the failure descriptor.

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Maintenance data

- Maintenance is carried out
  - To correct a failure (corrective maintenance);
  - As a planned and normally periodic action to prevent failure from occurring (preventive maintenance).

Maintenance data (From ISO 14224)

Category	Data	Description
Identifi- cation	Maintenance record	Unique maintenance identification
	Equipment location	Tag number
	Failure record (*)	Corresponding failure identification
Mainten- ance data	Date of maintenance	Date when maintenance action was undertaken
	Maintenance category	Corrective maintenance or preventive maintenance
	Maintenance activity	Description of maintenance activity (see Table 21)
	Impact of maintenance on operation	Zero, partial or total, (safety consequences may also be included)
	Subunit maintained	Name of subunit maintained
	Maint. item(s) maintained	Specify the maintainable item(s) that were maintained
	Spare parts	Spare parts required to restore the item
	Maintenance man-hours, per discipline	Maintenance man-hours per discipline (mechanical, electrical, instrument, others)
	Maintenance man-hoursl	Total maintenance man-hours.
	Active maintenance time	Time duration for active maintenance work on the equipment
	Down time	The time interval during which an item is in a down state

State information

- State information (condition monitoring information) may be collected in the following manners:
  - Readings and measurements during maintenance
  - Observations during normal operation
  - Continuous measurements by use of sensor technology

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Data analysis

- Graphical techniques
  - Histogram
  - Bar charts
  - Pareto diagrams
  - Visualization of trends
- Parametric models
  - Estimation of constant failure rate
  - Estimation of increasing hazard rate
  - Estimation of global trends (over the system lifecycle)

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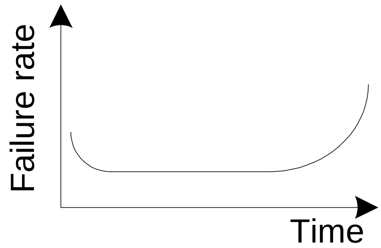
Parameter estimation /bath tub curve

- The bath tub curve is a basis for reliability modelling, but



- There are two such curves
  - The *hazard rate* for ”local time”
  - The *failure intensity* for ”global time”
- Combining the two:

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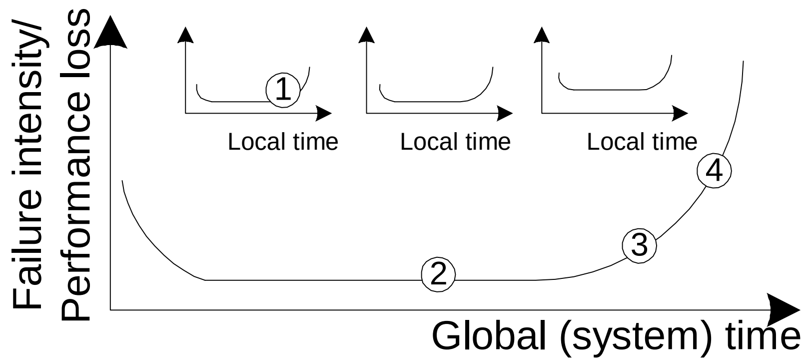
Performance loss



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Use of the bath tub curve

- Local bath tub curve (RCM=Reliability Centred Maint'nce)
  - Used to determine time of optimal maintenance
  - Crucial parameters: MTTF and α = aging parameter
- Global bath tub curve (Prioritization of renewal)
  - Used to determine when it is optimal to renew a system
  - Crucial parameters: λ = Intensity parameter, and α = trend parameter

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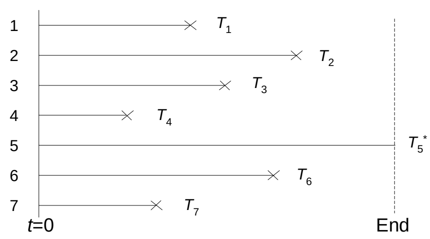
Plotting techniques, lifetime data (local bath tub curve)

- Several plots exists to visualize characteristics of lifetime data
  - TTT-plot
  - Kaplan-Meier plot
  - Hazard plot
- All these plots assume
  - Failure times are identical, and independent distributes
  - I.e. no change over ***system*** lifetime
- Examples of how life times are generated are shown to the right



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TTT- Total Time on Test plot

- Let $T_1, T_2, T_3, .., T_7$ be the recorded lifetimes
- Let $T_{(1)}, T_{(2)}, T_{(3)}, ..$ be *ordered* lifetimes, i.e. $T_{(1)} \leq T_{(2)} \leq T_{(3)} \leq ..$
- Define the total test on time at time *t* by

$$TTT(t) = \sum_{j=1}^{i} T_{(j)} + (n - i)t$$

- s
- where *i* is such that $T_{(i)} \leq t < T_{(i+1)}$
- The TTT-plot is obtained by plotting for $i = 1,..,n$:

$$\left(\frac{i}{n}, \frac{TTT(T_{(i)})}{TTT(T_{(n)})} \right)$$

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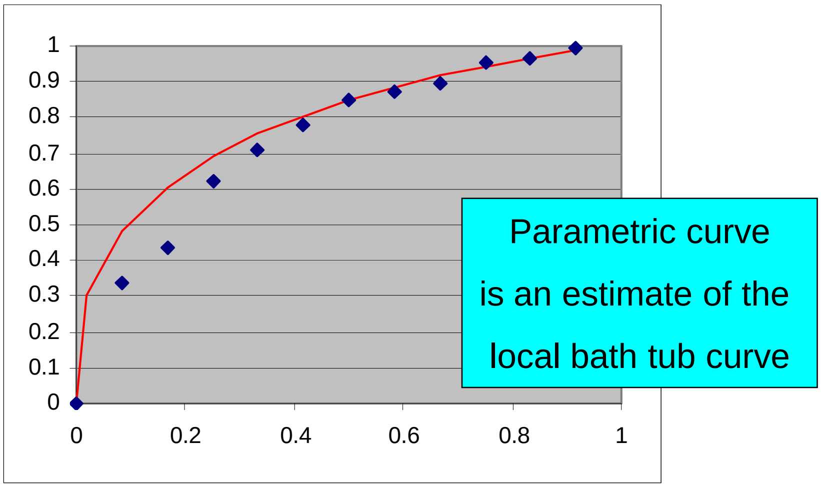
Example TTT-plot



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Assumptions, limitations & implications

- TTT plot requires life time data to be ***identical, independent distributed***
- This requires that failures are reported on unique components/parts, and
- The corrective (CM) and preventive (PM) maintenance conducted is recorded
- ➔ Strong requirements regarding both the ***structure*** and the ***quality*** of data
- Often too demanding in many organisations

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The Nelson Aalen plot for global trend over the system lifetime

- The Nelson-Aalen plot shows the cumulative number of failures on the *Y*-axis, and the *X*-axis represents the time
- A convex plot indicates a deteriorating system, whereas a concave plot indicates an improving system
- The idea behind the Nelson-Aalen plot is to plot the cumulative number of failures against time
- Actually we plot $W(t)$ which is the expected cumulative *numbers* of failures in a time interval

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Nelson Aalen procedure

- When estimating $W(t)$ we need failure data from one or more processes (systems)
- Each process (system) is observed in a time interval $(a_i,b_i]$ and t_{ij} denotes failure time j in process i (global or calendar time)
- To construct Nelson Aalen plot the following algorithm could be used
  - Group all the t_{ij}'s and sort them, and denote the result t_k, k = 1,2,…..
  - For each k, let O_k denote the number of processes that are under observation just before time t_k
  - Let $\hat{W}_0 = 0$
  - Let, $\hat{W}_k = \hat{W}_{k-1} + 1/O_k$ $\quad k$ = 1,2,…
  - Plot $(t_k, \hat{W}_k)$

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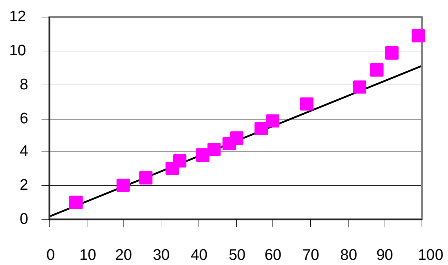
Example of Nelson Aalen plot

a_i	b_i	t_{ij}
0	50	7, 20, 35, 44
20	60	26, 33, 41, 48, 57
40	100	50, 60, 69, 83, 88, 92, 99



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Models for degradation

- Classical maintenance focuses on preventive time based replace actions
- Classical methods do not take advantage of condition of the item to be maintained
- Condition monitoring techniques (CMT) aim at:
  - Reveal the condition of the item
  - Determine if it is appropriate to replace the item
  - Determine if it is appropriate to improve the condition by an intervention
  - Determine when to do the next inspection/investigation
- We need ***parameters*** in the maintenance models

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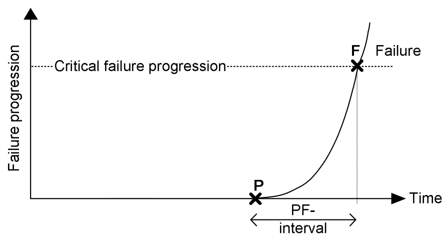
The PF-model



- The PF model is a basic model for degradation of a unit
- A potential failure (P) might be a crack, whereas a failure (F) might be a breakage
- The PF interval is crucial wrt how often to inspect in order to reveal potential failures
- A challenge is thus to estimate the PF interval, both with respect to ***expected value*** and ***standard deviation***
- ***Estimation*** requires that sate information is collected and systemized such that we "follow the failure progression" for some time

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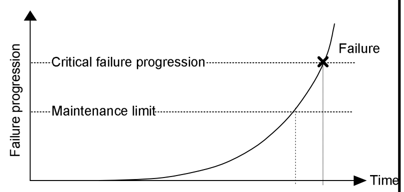
Gradual degradation models

- Degradation is slower
- Degradation starts early in the life of the item
- Various probabilistic models are used to describe degradation:
  - Gamma process
  - Markov state models
- Degradation is often only indirectly known via analysis of sensor information (e.g., vibration analysis)



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Estimation challenges

- We need condition information
  - I.e. the data from sensors need to be available as part of the RAMS database
- Often, only indirect measures are available, e.g., result from vibration analysis
- We need to link e.g., FFT data or wavelet data to the physical understanding of the underlying degradation
- Which models are relevant for modelling the probabilistic nature of failure progression
- What is the failure limit, not necessary fixed

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Parameter estimation

- Constant hazard rate, homogeneous sample
- Constant hazard rate, non-homogeneous sample
- Increasing hazard rate

Constant failure rate homogeneous sample

- In this situation we only need the following information
  - t = aggregated time in service
  - n = the total number of observed failures in the period
- An estimate for the failure rate is given by

$$\hat{\lambda} = \frac{\text{Number of failures}}{\text{Aggregated time in service}} = \frac{n}{t}$$

Multi-Sample Problems

- In many cases we do not have a homogeneous sample of data
- The aggregated data for an item may come from different installations with different operational and environmental conditions, or we may wish to present an "average" failure rate estimate for slightly different items
- In these situations we may decide to merge several more or less homogeneous samples, into what we call a multi-sample
- The various samples may have different failure rates, and different amounts of data

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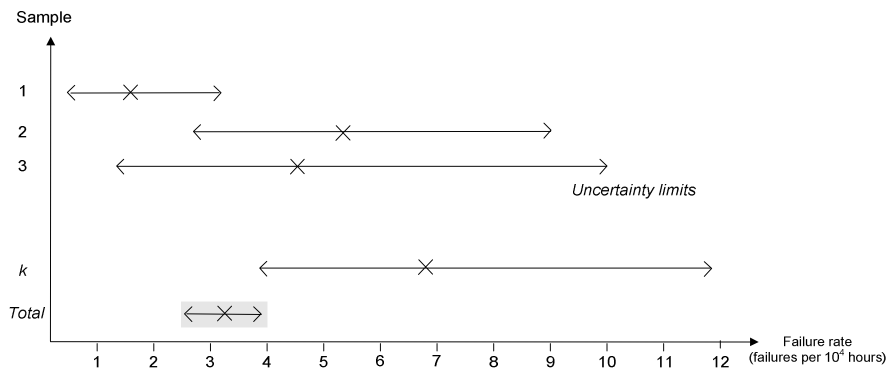
Illustration, multi-sample data



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Estimation principles, multi-sample

- The OREDA-estimator used in the OREDA data handbook is based on the following assumptions:
  - We have k different samples. A sample may e.g., correspond to a platform, and we may have data from similar items used on k different platforms.
  - In sample no. i we have observed n_i failures during a total time in service ti, for i =1,2,…, k.
  - Sample no. i has a constant failure rate λ_i, for i =1,2,…, k.
  - Due to different operational and environmental conditions, the failure rate λ_i may vary between the samples.
  - This variation is described by a probability density function, say $\pi(\lambda)$
- The OREDA handbook presents expectation and standard deviation in the estimated distribution of $\pi(\lambda)$

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Increasing hazard rate

- The estimation of parameters e.g., the Weibull distribution requires Maximum Likelihood procedures.
- Let $\boldsymbol{\theta}$ be the parameter vector of interest, for example $\boldsymbol{\theta} = [\alpha,\lambda]$ if the Weibull distribution is considered
- Let t_j denote the observed life times, both censored and real life times
- The likelihood function is now given by

$$L(\boldsymbol{\theta};\mathbf{t}) = \prod_{j\in C_L} F(t_j;\boldsymbol{\theta}) \prod_{j\in U} f(t_j;\boldsymbol{\theta}) \prod_{j\in C_R} R(t_j;\boldsymbol{\theta})$$

- where C_L, U and C_R are the set of left-censored (start of observation not known, uncensored (real lifetimes) and right-censored life times (failure time not known)
- The estimator is the value of $\boldsymbol{\theta}$ that maximizes $L(\boldsymbol{\theta};\mathbf{t})$

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Towards cost-effective maintenance of wind power systems

Wind turbine reliability and O&M related research at Chalmers

Katharina Fischer, PhD
Francois Besnard, PhD student
Lina Bertling, Professor

IEA Topical Expert Meeting
International Statistical Analysis on Wind Turbine Failures

Kassel, 30-31 March 2011

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Outline

- Background and motiviation
- Approach
- Recent work:
  - Statistical analysis of Swedish failure data
  - Reliability-Centred Maintenance (RCM) study
  - Reliability and maintenance model for quantitative assessment of maintenance strategies
- Conclusions

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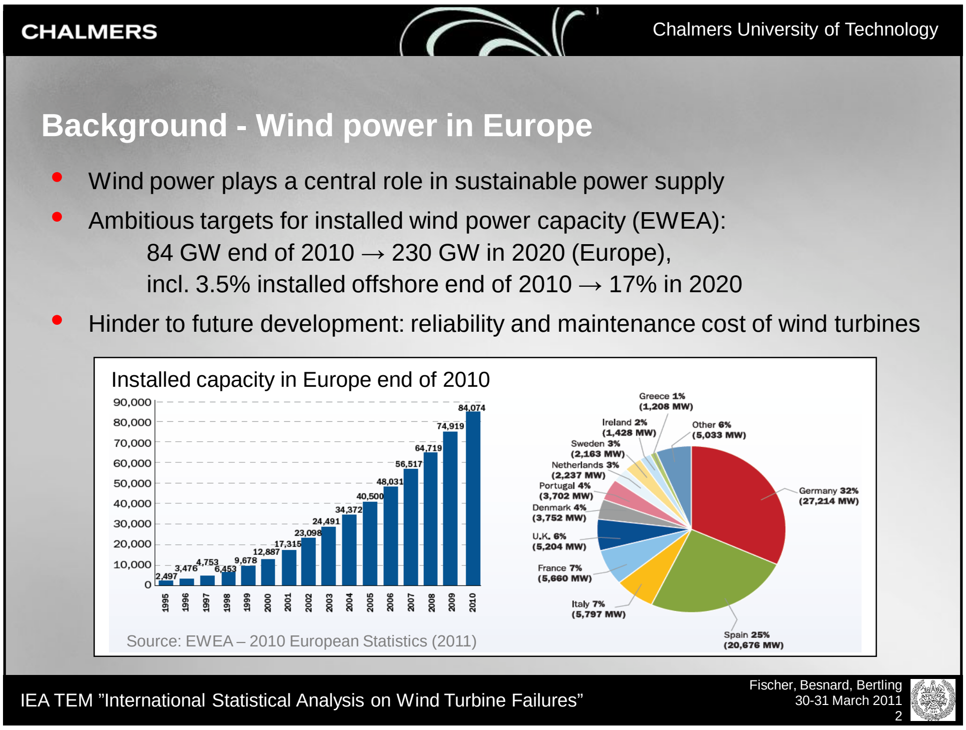
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Background - Wind power in Europe
Wind power plays a central role in sustainable power supply
Ambitious targets for installed wind power capacity (EWEA):
84 GW end of 2010 → 230 GW in 2020 (Europe),
incl. 3.5% installed offshore end of 2010 → 17% in 2020
Hinder to future development: reliability and maintenance cost of wind turbines
Installed capacity in Europe end of 2010
Germany 32% (27,214 MW)
Spain 25% (20,676 MW)
Italy 7% (5,797 MW)
France 7% (5,660 MW)
U.K. 6% (5,204 MW)
Denmark 4% (3,752 MW)
Portugal 4% (3,702 MW)
Netherlands 3% (2,237 MW)
Sweden 3% (2,163 MW)
Ireland 2% (1,428 MW)
Greece 1% (1,208 MW)
Other 6% (5,033 MW)
Source: EWEA – 2010 European Statistics (2011)
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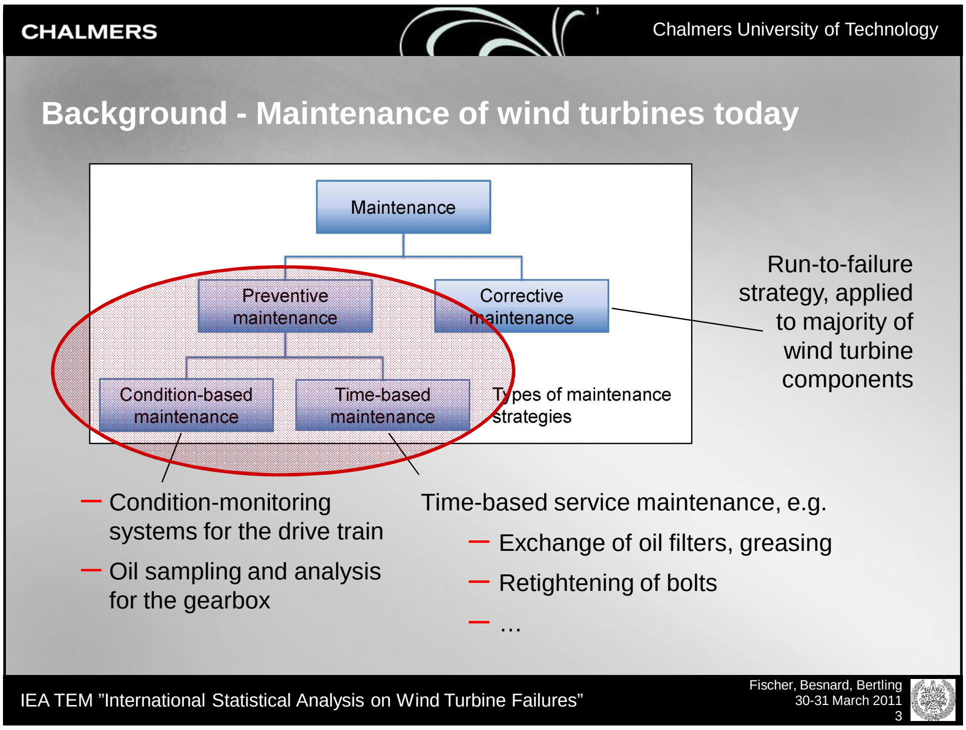
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Background - Maintenance of wind turbines today
Maintenance
Preventive maintenance
Corrective maintenance
Condition-based maintenance
Time-based maintenance
Types of maintenance strategies
Run-to-failure strategy, applied to majority of wind turbine components
Condition-monitoring systems for the drive train
Oil sampling and analysis for the gearbox
Time-based service maintenance, e.g.
Exchange of oil filters, greasing
Retightening of bolts
…
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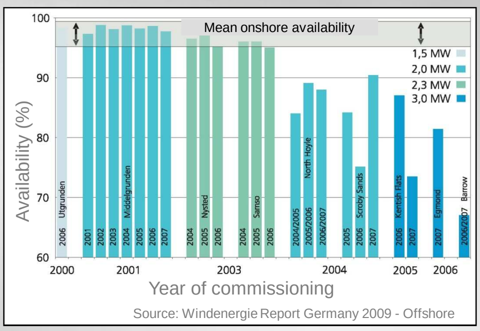
Background – Asset management for wind power plants

- Problem: high maintenance cost to ensure availability (onshore 20-30% of LCC)
- Maintenance not optimized: large potential savings by optimizing the total cost for
  - maintenance activities and component failure
  - production losses

  over turbine lifetime, especially for offshore wind parks



➢ Systematic methods for asset management of wind power plants required

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Wind Power Asset Management group (WindAM) at Chalmers

WindAM research group at Chalmers

Lina Bertling
(Project leader and research supervisor)

Ola Carlson
(Research supervisor)

Francois Besnard
(PhD student)

Katharina Fischer
(postdoctoral researcher)

Present projects:
"Maintenance Management of Wind Power Systems by means of RCM and CMS"
"Reliability modeling and optimal maintenance management for wind power systems"

Industry partners
supporting with expertise and data

Göteborg Energi, Triventus, VATTENFALL, SKF

Reference group

EBL, Elforsk, Energimyndigheten, Fortum, Göteborg Energi, Sintef / NTNU, SKF, Vattenfall

➢ Quantitative methods for cost-effective maintenance

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Methods: Reliability-Centred Maintenance (RCM)

- Systematic risk-based *qualitative* approach for developing a preventive maintenance program
- Main features characterizing RCM:
  1. preservation of system function
  2. identification of failure modes
  3. prioritization of function needs
  4. selection of applicable and effective maintenance tasks
- Origin in the civil aircraft industry (Boeing) in the 1960s
- Approach since then broadly and successfully applied in various industries, e.g. in the railway, offshore oil & gas, manufacturing sector

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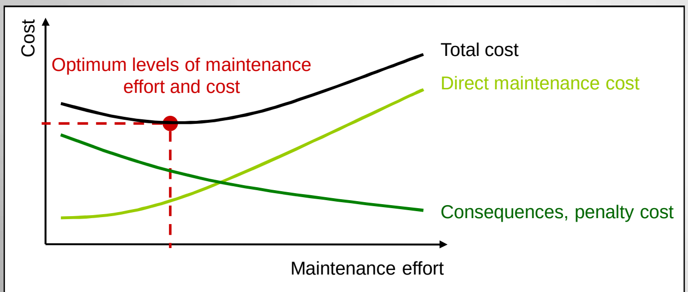
Methods: Quantitative Maintenance Optimization (QMO)

- Basic concept: use mathematical models to determine the minimum of
  - direct maintenance costs: labour, materials, administration,… and
  - consequences of not performing maintenance as required: i.e. production loss, labour, materials, …



- Decision support
- Replace reliance on subjective judgement by data-based methods

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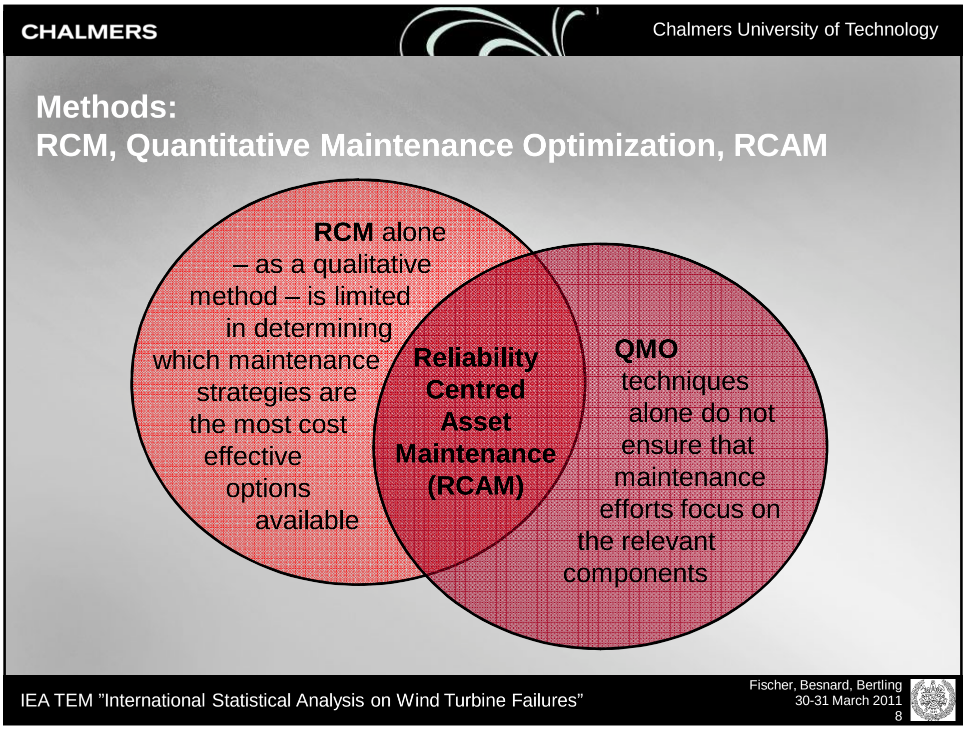
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Methods:
RCM, Quantitative Maintenance Optimization, RCAM
RCM alone – as a qualitative method – is limited in determining which maintenance strategies are the most cost effective options available
Reliability Centred Asset Maintenance (RCAM)
QMO techniques alone do not ensure that maintenance efforts focus on the relevant components
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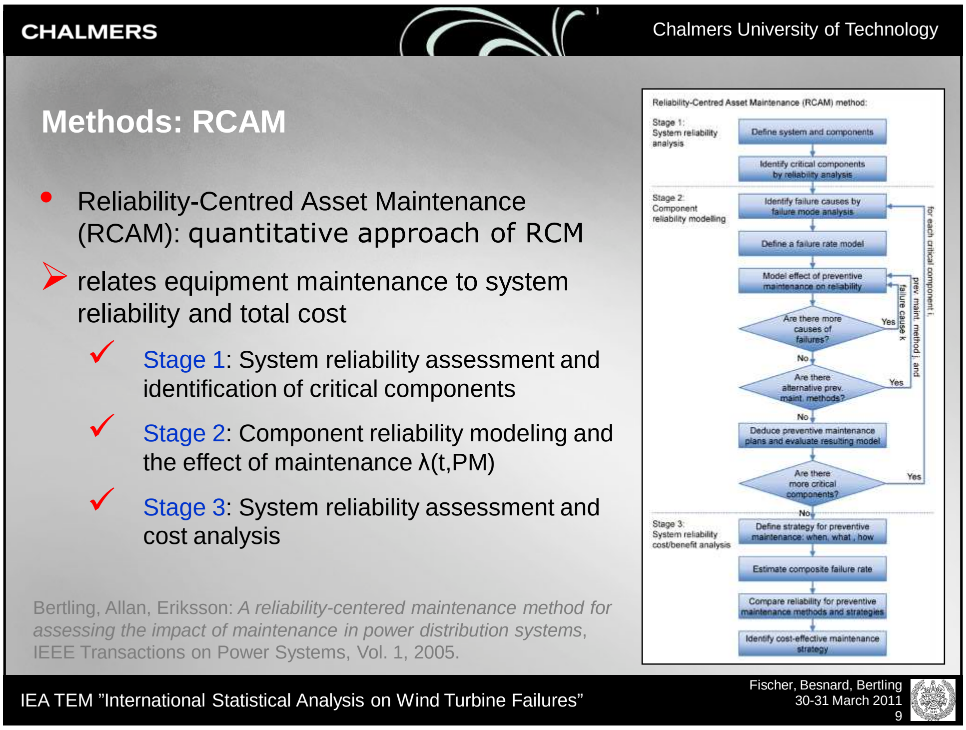
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Methods: RCAM
• Reliability-Centred Asset Maintenance (RCAM): quantitative approach of RCM
➢ relates equipment maintenance to system reliability and total cost
✓ Stage 1: System reliability assessment and identification of critical components
✓ Stage 2: Component reliability modeling and the effect of maintenance λ(t,PM)
✓ Stage 3: System reliability assessment and cost analysis
Bertling, Allan, Eriksson: A reliability-centered maintenance method for assessing the impact of maintenance in power distribution systems, IEEE Transactions on Power Systems, Vol. 1, 2005.
Reliability-Centred Asset Maintenance (RCAM) method:
Stage 1: System reliability analysis
Define system and components
Identify critical components by reliability analysis
Stage 2: Component reliability modelling
Identify failure causes by failure mode analysis
Define a failure rate model
Model effect of preventive maintenance on reliability
Are there more causes of failures?
Yes
No
Are there alternative prev. maint. methods?
Yes
No
Deduce preventive maintenance plans and evaluate resulting model
Are there more critical components?
Yes
No
for each critical component i,
prev. maint. method j, and
failure cause k
Stage 3: System reliability cost/benefit analysis
Define strategy for preventive maintenance: when, what, how
Estimate composite failure rate
Compare reliability for preventive maintenance methods and strategies
Identify cost-effective maintenance strategy
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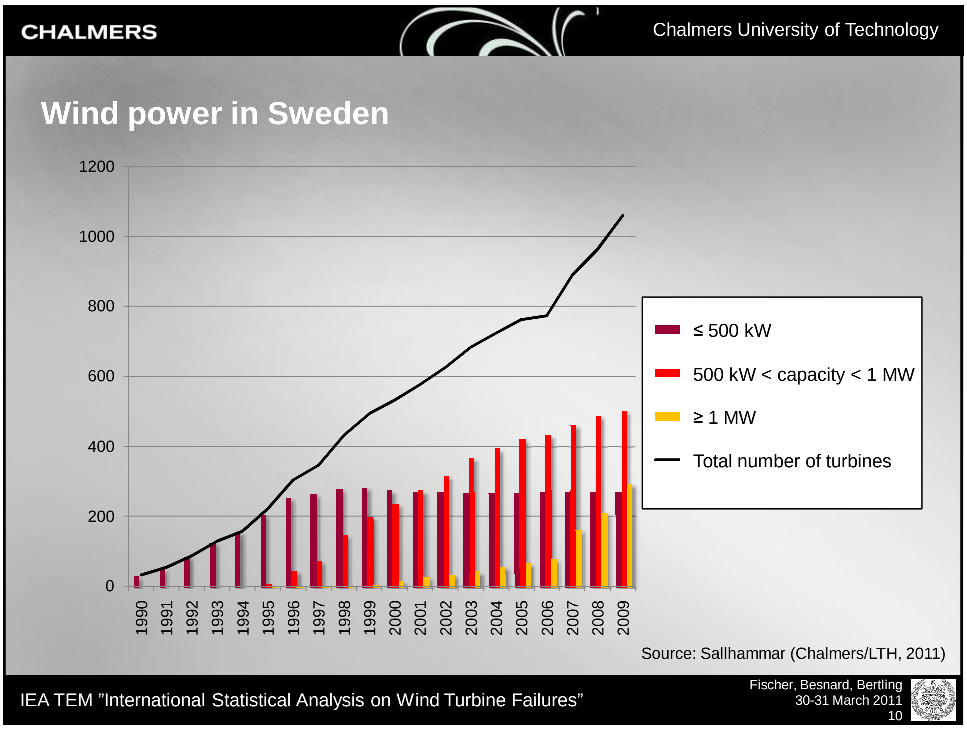
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Wind power in Sweden
1200
1000
800
600
400
200
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
≤ 500 kW
500 kW < capacity < 1 MW
≥ 1 MW
Total number of turbines
Source: Sallhammar (Chalmers/LTH, 2011)
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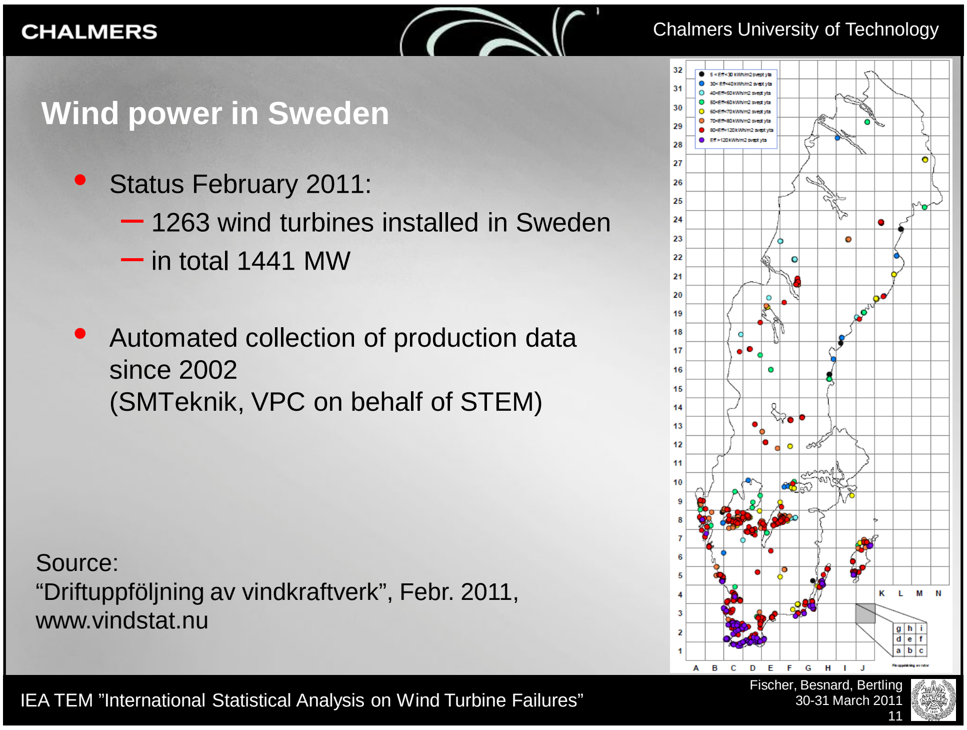
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Wind power in Sweden
Status February 2011:
1263 wind turbines installed in Sweden
in total 1441 MW
Automated collection of production data since 2002
(SMTeknik, VPC on behalf of STEM)
Source:
"Driftuppföljning av vindkraftverk", Febr. 2011,
www.vindstat.nu
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Failure data from wind turbines in Sweden

- Database compiled by SwedPower AB on behalf of Statens Energimyndighet STEM and ELFORSK
  - covers 1989-2005, most detailed failure data from 2000-2004
  - 786 wind turbines in the database
  - 2028 reported failures (downtime ≥ 1h)
  - covers technical failures; excluded: failures due to external reasons (i.e. grid failure)
  - turbine-specific failure histories (type, location, installation date, operational period, dates of failure events and related downtime, failure codes)
  - since 2005, voluntary failure reporting only, failure data too sparse for statistical analysis

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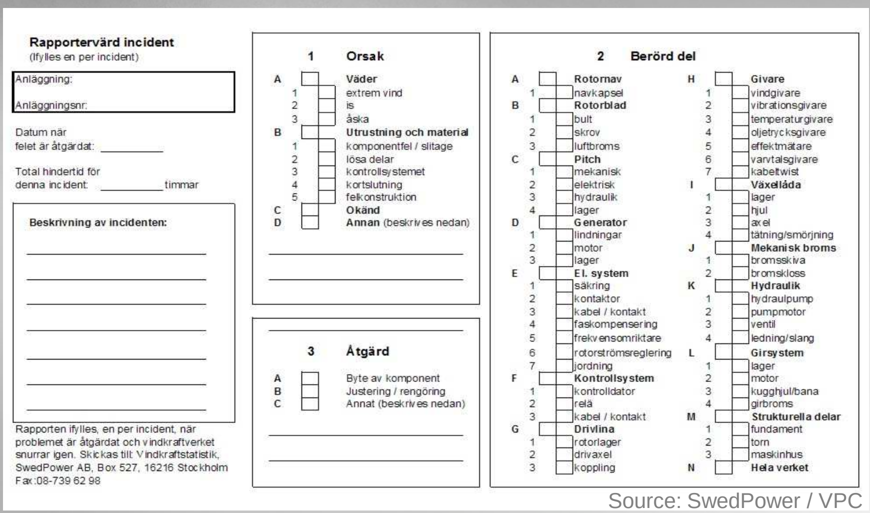
Incident report



Rapportervärd incident
(Ifylles en per incident)

Anläggning:
Anläggningsnr:

Datum när felet är åtgärdat: ________

Total hindertid för denna incident: ________ timmar

Beskrivning av incidenten:

Rapporten ifylles, en per incident, när problemet är åtgärdat och vindkraftverket snurrar igen. Skickas till: Vindkraftstatistik, SwedPower AB, Box 527, 16216 Stockholm Fax:08-739 62 98

1 Orsak

- A **Väder**
  - 1 extrem vind
  - 2 is
  - 3 åska
- B **Utrustning och material**
  - 1 komponentfel / slitage
  - 2 lösa delar
  - 3 kontrollsystemet
  - 4 kortslutning
  - 5 felkonstruktion
- C **Okänd**
- D **Annan** (beskrives nedan)

3 Åtgärd

- A Byte av komponent
- B Justering / rengöring
- C Annat (beskrives nedan)

2 Berörd del

- A **Rotornav**
  - 1 navkapsel
- B **Rotorblad**
  - 1 bult
  - 2 skrov
  - 3 luftbroms
- C **Pitch**
  - 1 mekanisk
  - 2 elektrisk
  - 3 hydraulik
  - 4 lager
- D **Generator**
  - 1 lindningar
  - 2 motor
  - 3 lager
- E **El. system**
  - 1 säkring
  - 2 kontaktor
  - 3 kabel / kontakt
  - 4 faskompensering
  - 5 frekvensomriktare
  - 6 rotorströmsreglering
  - 7 jordning
- F **Kontrollsystem**
  - 1 kontrolldator
  - 2 relä
  - 3 kabel / kontakt
- G **Drivlina**
  - 1 rotorlager
  - 2 drivaxel
  - 3 koppling
- H **Givare**
  - 1 vindgivare
  - 2 vibrationsgivare
  - 3 temperaturgivare
  - 4 oljetrycksgivare
  - 5 effektmätare
  - 6 varvtalsgivare
  - 7 kabeltwist
- I **Växellåda**
  - 1 lager
  - 2 hjul
  - 3 axel
  - 4 tätning/smörjning
- J **Mekanisk broms**
  - 1 bromsskiva
  - 2 bromskloss
- K **Hydraulik**
  - 1 hydraulpump
  - 2 pumpmotor
  - 3 ventil
  - 4 ledning/slang
- L **Girsystem**
  - 1 lager
  - 2 motor
  - 3 kugghjul/bana
  - 4 girbroms
- M **Strukturella delar**
  - 1 fundament
  - 2 torn
  - 3 maskinhus
- N **Hela verket**

Source: SwedPower / VPC

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Statistical analysis of wind turbine failure data from the SwedPower database

- Master's theses:
  - Ribrant, J.: Reliability performance and maintenance – A survey of failures in wind power systems. Master's thesis, supervisor L. Bertling, XR-EE-EEK 2006:009, KTH, Stockholm, April 2006
  - Sallhammar, M.: Reliability analysis of wind power systems - A statistical analysis of wind turbine failures in Sweden. Master's thesis, supervisor K. Fischer, Chalmers / LTH, Gothenburg/Lund, February 2011
- Postdoc project:
  - Fischer, K.: Maintenance management by means of Reliability-Centred Maintenance and Condition-Monitoring Systems (2009-2012)

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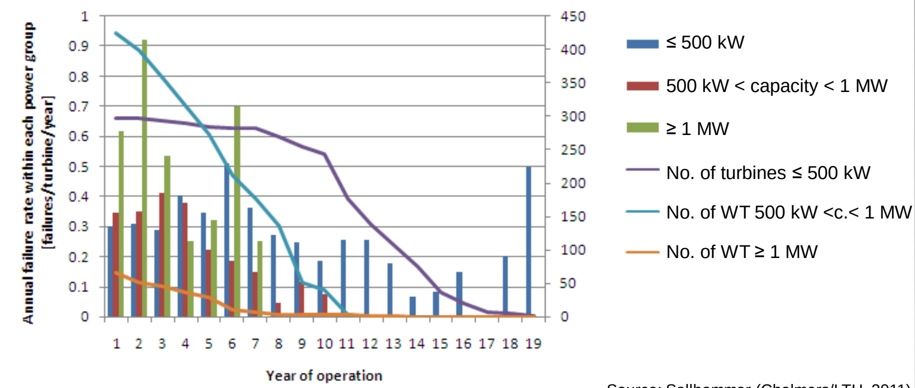
Statistical analysis of wind turbine failures in Sweden



Source: Sallhammar (Chalmers/LTH, 2011)

- WT with a rated capacity ≥ 1MW have higher failure rates than smaller WT (Ribrant 2006, Sallhammar 2011)

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Role of wind turbine capacity (data 2000-2004)

Capacity group	Subsystems with highest failure rate	Subsystems with longest downtime/failure	Subsystems causing longest downtime/year/WT
≤ 500kW	1) Sensors 2) Electrical system 3) Control system	1) Control system 2) Yaw system 3) Generator	1) Control system 2) Yaw system 3) Electrical system
500 kW < … < 1000 kW	1) Hydraulic system 2) Electrical system 3) Control system	1) Drive train 2) Gearbox 3) Generator	1) Gearbox 2) Electrical system 3) Blades
≥ 1000kW	1) Yaw system 2) Gearbox 3) Electrical system	1) Gearbox 2) Blades 3) Control system	1) Gearbox 2) Yaw system 3) Electrical system

Source: Sallhammar (Chalmers/LTH, 2011)

- Subsystem ”Gearbox” less critical in wind turbines ≤ 500kW
- Subsystem ”Electrical system” major source of downtime in turbines of all capacities (here onshore, more severe impact expected offshore)

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Subsystem-specific analysis (all turbines, 2000-2004)

- Dominant subsystem component with respect to average downtime per year and wind turbine:
  - Blades incl. pitch system: hydraulic system
  - Electrical system: rotor current control
  - Gearbox: bearings
  - Generator: windings
  - Sensors: anemometer, temperature sensors
  - Yaw system: yaw gears

Source: Sallhammar (Chalmers/LTH, 2011)

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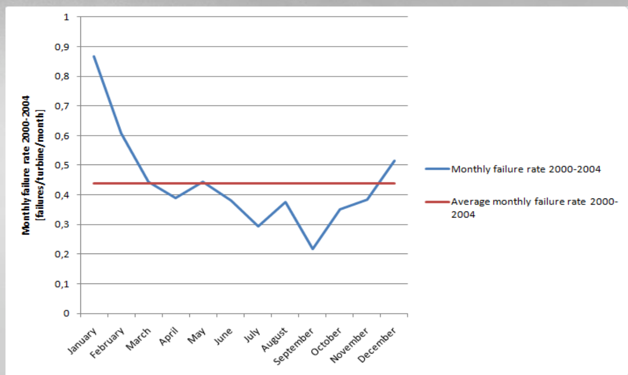
Seasonal variation of the failure rate

- Statistical analysis:



- Confirmed by experience of maintenance service provider: significant increase in failure rates *after* periods of strong wind

Source: Sallhammar (Chalmers/LTH, 2011)

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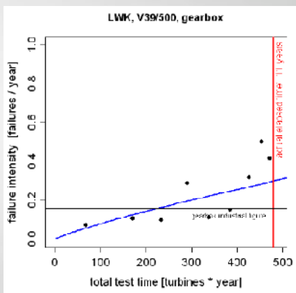
Reliability Growth Analysis (RGA)

- Reliability Growth Analysis applied to field data: determine if and in which way a product's reliability changes over time
- Underlying assumption: repairable systems
- Koutoulakos, Spinato: RGA for grouped data from LWK, WindStats and WMEP (time axis: Total Time on Test, TTT = product of the number of monitored wind turbines in one interval times the length of this interval; time-axis modulated by no. of reporting turbines)



Source: F. Spinato (2008)

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Reliability Growth Analysis (RGA)

- Strength of SwedPower database: data not aggregated
  - model-specific analysis
  - turbine age at failure known (in months)
- Failure intensity function $\hat{u}(t) = \hat{\lambda}\hat{\beta}t^{\hat{\beta}-1}$ with $\hat{\beta} = \frac{\sum_{q=1}^{K} N_q}{\sum_{q=1}^{K}\sum_{i=1}^{N_q} \log\left(\frac{T}{X_{iq}}\right)}$, $\hat{\lambda} = \frac{\sum_{q=1}^{K} N_q}{KT^{\hat{\beta}}}$ Source: Crow (1975)
  - β=1: constant intensity function (HPP)
  - β≠1: intensity function increasing (β>1) or decreasing (β<1) (NHPP)
- Cramér-von Mises goodness-of-fit test

- Implemented for Vestas V42/V44
- ➢ Provides reliability models directly applicable in the quantitative RCAM model: subcomponent failure intensity over time

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Weibull Analysis

- Underlying assumption: non-repairable system
- Lifetime follows a Weibull distribution
  - Probability density function: $f(t) = \rho\,\beta\,t^{\beta-1}e^{-\rho\,t^{\beta}}$
  - Hazard rate: $\lambda(t) = \rho\,\beta\,t^{\beta-1}$
- Applied to analyse the time to first subsystem failure
- Censoring taken into account
- Estimation of Weibull parameters using MLE

- Implemented for Vestas V42/V44: (data from 60 turbines and ca. 6-10 years of operation)

Subsystem	Shape parameter
Gearbox	β>1
Generator	β<1
Control system	β<1
Hydraulic system	β>1
Electrical system	β<1

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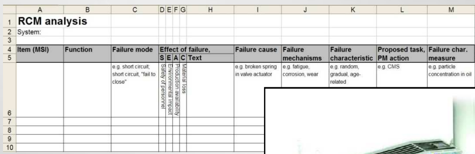
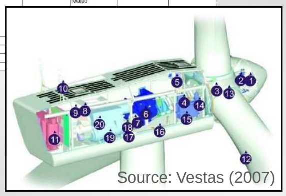
Limited-scope RCM study of two wind turbine models

- RCM workgroup:
  Göteborg Energi, SKF, Triventus, WindAM group at Chalmers
  - in total, 8 members with different wind-turbine specific areas of experience and expertise
- Objectives of the study:
  - identify the most relevant components, their *functions*, dominant *failure modes*, *failure causes* and mechanisms and *preventive maintenance measures*
  - lay basis for implementation of mathematical models for maintenance strategy selection and optimization





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Subsystem selection

- based on expert opinion and statistical analysis of failure data

	V44-600kW			V90-2MW		
	Expert judgment		*Data analysis*	*Expert judgment*		*Data analysis*
	Failure frequency	*Downtime per failure*	*Downtime per year and turbine*	*Failure frequency*	*Downtime per failure*	*Downtime per year and turbine*
1.	Gearbox	Gearbox	Electrical system	Gearbox	Gearbox	Generator incl. converter
2.	Generator	Generator	Generator	Generator	Generator	Rotor
3.	Hydraulic system	Yaw system	Control system	Converter	Converter	Drivetrain incl. gearbox
4.	Rotor	Rotor	Gearbox	Hydraulic system	Rotor	Control and protection system

- Subsystems chosen for detailed analysis:
  - Gearbox
  - Generator
  - Generator rotor current control / converter
  - Hydraulic system
  - Yaw system

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RCM results – Subsystem: Gearbox (exempl.)

Item	Function	Failure mode	Failure consequ. S	E	A	C
all gearbox components	transmission of torque from the rotor to the generator shaft, providing the desired conversion ratio for speed and torque	loss of torque transmission capability	Y	Y	Y	Y

Failure cause	Failure mechanisms	Failure characteristic	Proposed task, PM action
manufacturing or installation deficiencies	increased friction or inappropriate high cyclic loading which leads to damage	damage accumulating	training of technicians for improved quality in manufacturing, installation, and repair; alignment check; temperature and vibration monitoring (for enhanced planning, secondary damage prev.)

- Analysed gearbox components:
  - bearings ⟵ dominating
  - gearwheels
  - lubrication system

S – Safety of personnel
E – Environmental impact
A – Production availability
C – Material loss, sec. damage

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RCM results – Subsystem: Gearbox, Component: Bearings

Item	Function	Failure mode	Failure consequ. S	E	A	C
bearings	keep shafts in position while allowing rotary motion at minimal friction	high friction	N	N	Y	Y

Failure cause	Failure mechanisms	Failure characteristic	Proposed task, PM action
overloading, often due to design or installation deficiencies	increased friction due to plastic deformations, high temperature → material fatigue	damage accumulating	endoscopy, temperature and vibration monitoring for early damage detection (not preventing bearing damage)
inappropriate lubrication (insufficient lubrication, over-lubrication, wrong lubricant)	increased friction → high temperature → surface damages	damage accumulating	oil analysis; measurement of oil pressure and temperature; online particle counting; follow lubrication scheme
moisture in oil	corrosion by oxidation; reduction of steel strength possibly due to H2 ingression → surface failure	damage accumulating	filter dryer in gearbox casing to dehumidify air inflow; oil analysis; online moisture detection

➢ See article by Fischer, Besnard and Bertling in the EWEA 2011 scientific proceedings for further results

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Further results from the RCM study

- Comprehensive background information about the current maintenance practices and experiences
  - How are the analysed subsystems & components serviced today?
  - Waiting time and cost for components
  - Working time for repair / replacement
- Challenges identified by the RCM workgroup, considered to impede the achievement of cost-effective operation and maintenance of wind turbines:
  - new personnel in wind turbine maintenance with limited experience in this field
  - lack of in-depth failure and maintenance data
  - maintenance decisions aim at short-time cost savings, not at long-term minimization of life cycle cost → justification of additional equipment or preventive measures difficult

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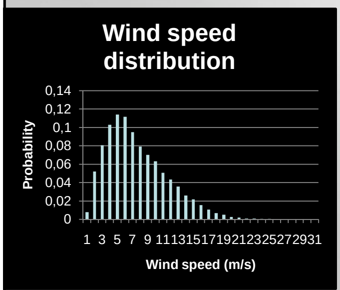
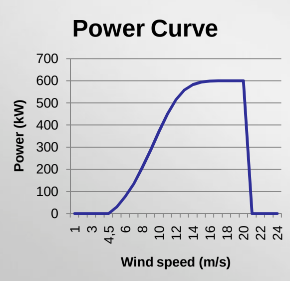
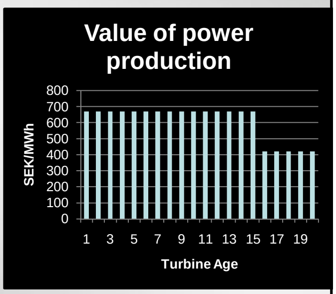
Model for maintenance strategy assessment

- B. Kerres: A comparison of wind turbine life-cycle costs and profits resulting from different maintenance strategies (Chalmers / RWTH Aachen, February 2011)
- Wind turbine revenue dependent on availability, wind speeds, power curve, power prices







Source: Kerres (Chalmers/RWTH Aachen 2011)

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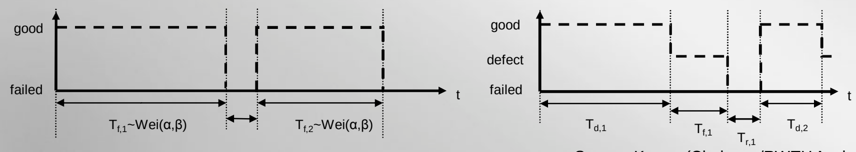
Model for maintenance strategy assessment

- Wind turbine as series connection of important components
- Components:
  - independent of each other
  - non-repairable
  - defined by deterioration process
- Two deterioration processes:

Binary deterioration process — Delay-Time deterioration process



Source: Kerres (Chalmers/RWTH Aachen 2011)

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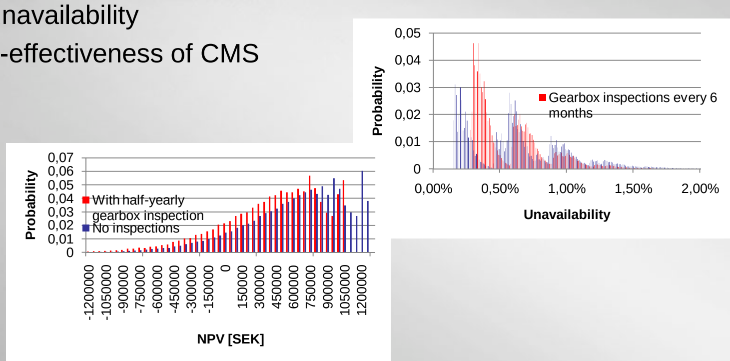
Model for maintenance strategy assessment

- Case study for the Vestas V44-600kW
- For different maintenance scenarios, comparison of distributions of
  - Net Present Value (NPV) and
  - unavailability
- Cost-effectiveness of CMS



Source: Kerres (Chalmers/RWTH Aachen 2011)

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Summary / Conclusions

- RCM is a beneficial basis for quantitative maintenance optimization
- Central role of vibration as a failure cause for a variety of components
  - measures for prevention or early detection of bearing damage particularly effective
  - independent modelling of component failure systematically underestimates e.g. the benefit of vibration CMS
- Enhanced training of maintenance personnel
- Utilization of quantitative methods for decision support in wind turbine maintenance promising, BUT relevance of results strongly dependent on access to comprehensive, in-depth failure and maintenance data also of modern turbines
  - standardized and automated data collection required

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Turbine Blade Reliability and Failure Assessment through Accelerated Testing

IEA R&D Wind Task XI – Topical Expert Meeting on International Statistical Analysis on Wind Turbine Failure

Nathan Post
Paul Veers
Scott Hughes
Jeroen van Dam

March 30-31, 2011

Outline

- U.S. Data collection activity and goals
  - Overview:
    - Department of Energy (DOE)
    - Sandia National Laboratories (SNL)
    - National Renewable Energy Laboratory (NREL)
  - Gearbox Reliability Collaborative
  - Blade Reliability Collaborative
- Full-scale testing of wind turbine blades
  - Aggregate test results
- Recommendations for interface between field data collection and laboratory testing

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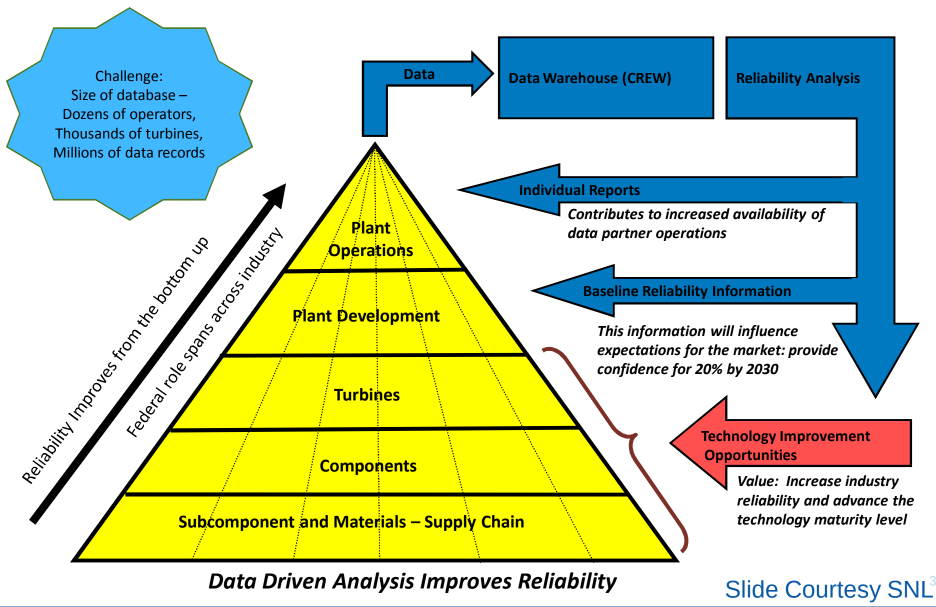
A Comprehensive Data Model for Reliability



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Key Issues

- Establishing partnerships with key owner/operators to provide sites for pilots
- Providing continuous access to operating data that is accurate, auditable, verifiable, and consistent
- Collecting sufficiently large amounts of data
  - Statistically significant
  - Ability to protect proprietary industry data through data aggregation
- Maintaining proprietary data protection (primarily through data aggregation)
- Aligning with and influencing development of standards for wind performance measurement

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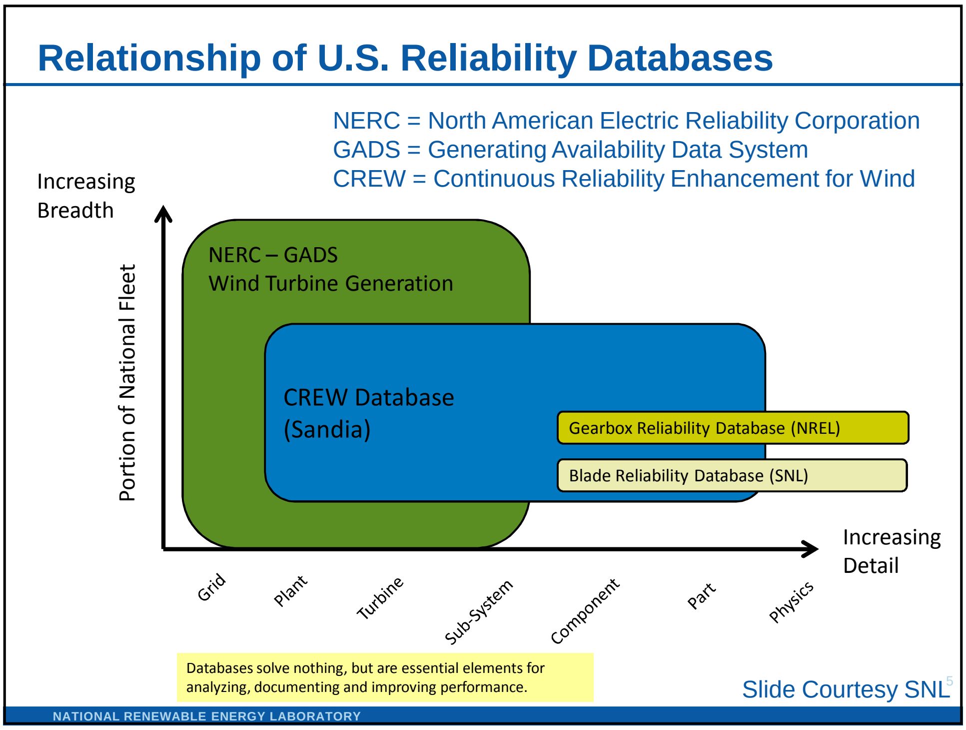
Relationship of U.S. Reliability Databases
NERC = North American Electric Reliability Corporation
GADS = Generating Availability Data System
CREW = Continuous Reliability Enhancement for Wind
Increasing Breadth
Portion of National Fleet
NERC – GADS
Wind Turbine Generation
CREW Database
(Sandia)
Gearbox Reliability Database (NREL)
Blade Reliability Database (SNL)
Increasing Detail
Grid
Plant
Turbine
Sub-System
Component
Part
Physics
Databases solve nothing, but are essential elements for analyzing, documenting and improving performance.
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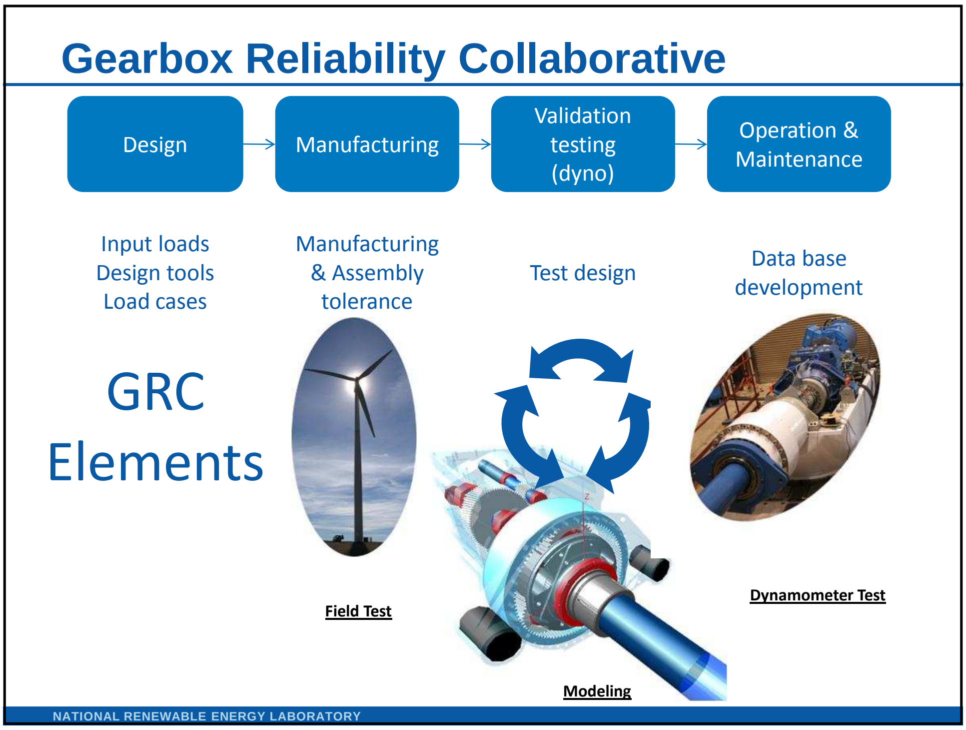
Gearbox Reliability Collaborative
Design
Manufacturing
Validation testing (dyno)
Operation & Maintenance
Input loads
Design tools
Load cases
Manufacturing & Assembly tolerance
Test design
Data base development
GRC Elements
Field Test
Modeling
Dynamometer Test
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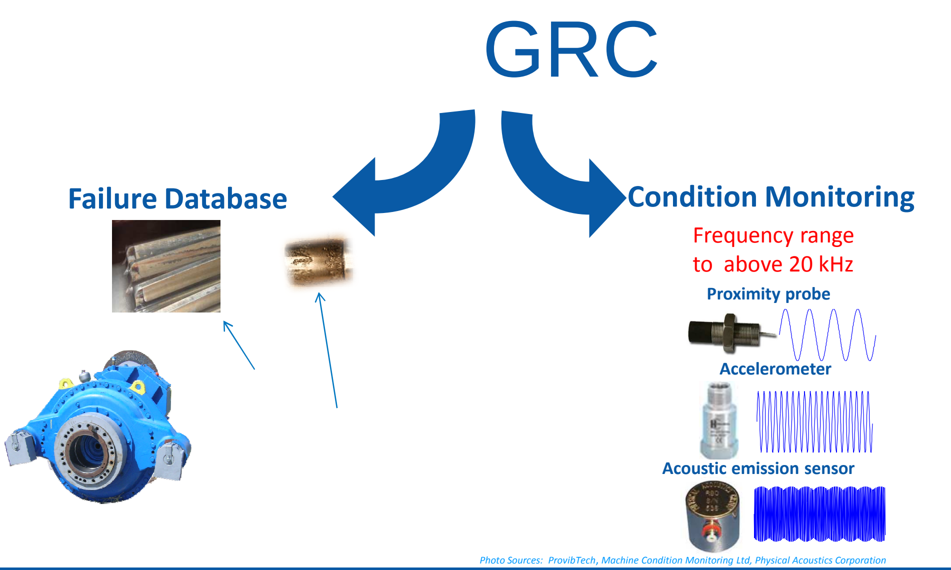
GRC – New Initiatives



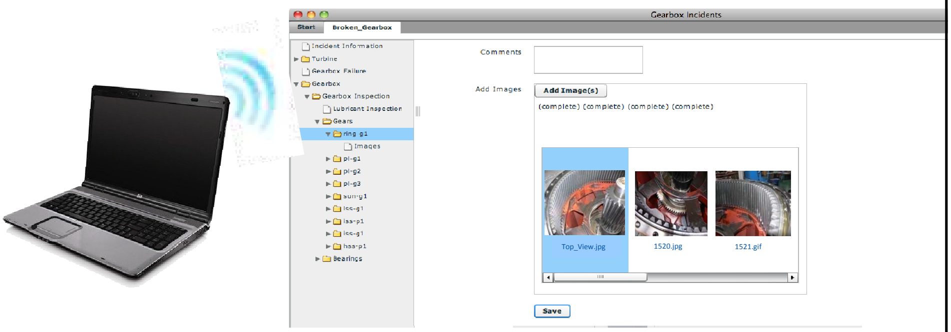
The gearbox failure database

- Collect information from gearbox rebuilds
  - In shop
  - On tower
  - Existing data from paper, Excel, etc.
- Share ‘sanitized’ data within Collaborative
- Analyze and close loop when solutions are identify

Data Collection Software

Design

- Structured data collection
- Navigation tree
- Visually oriented with wireless image transfer from camera to correct fields in software



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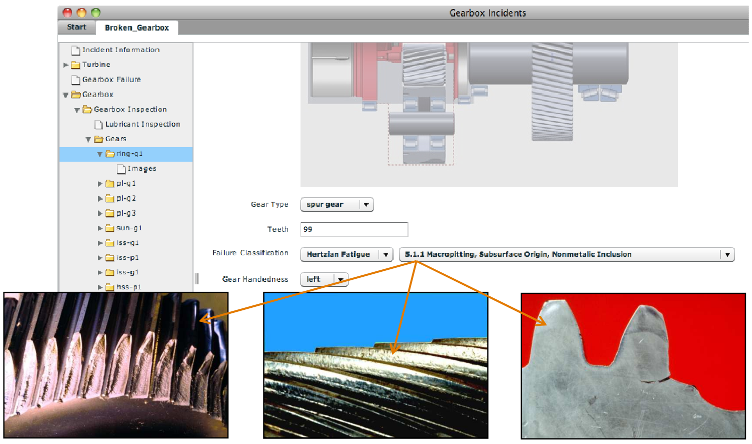
Data Collection Software

User Interface

- Embedded failure codes
- Interactive help



Source: GEARTECH

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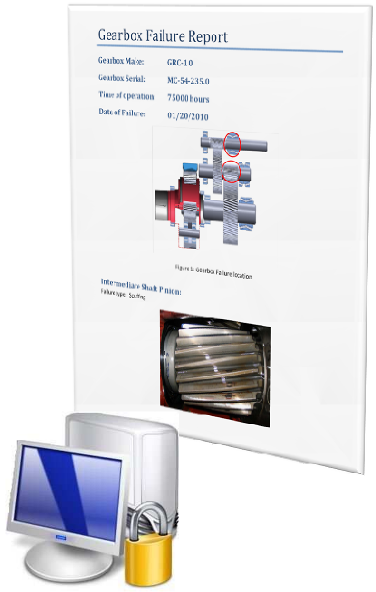
Gearbox Data Collection Software

Report Generation

- Automatically generated failure report
- Failure images and comments by inspector
- Failure mode definition and description
- Failure location at a glance

Security and Data Sharing

- GRC partners have non-disclosure agreements with NREL
- Initially, email encrypted data
- Later, a web-based application will include statistical analysis and reporting
- Aggregation for public use



GRC Accomplishments

- Database rolled out; 17% of U.S. wind generating capacity signed up
- Round robin modeling activities completed for gearbox analysis tools
- Phase 2 testing completed
- Continuing interest of new parties wanting to join the project

Goals in the Blade Reliability Collaborative

Blade Survey

Define the kinds and severity of flaws and damage that have been found in the field both, before and during operation, and document the root causes

Effects of Defects

Determine the criticality of defect types and sizes by testing coupons that mimic defects to determine damage growth and failure under typical blade loading levels

Inspection Validation

Validate inspection methods for wind turbine blades so that manufacturers can be ensured that their methods are capable of finding the defects that are critical to blade reliability

Design Analysis

Validate design analysis capability to ensure that the analysis tools are capable of modeling design details and potential flaws and their effect on failure

Certification Testing

Evaluate certification testing approaches that have potential to better evaluate blade capacity to withstand design conditions

Slide Courtesy SNL

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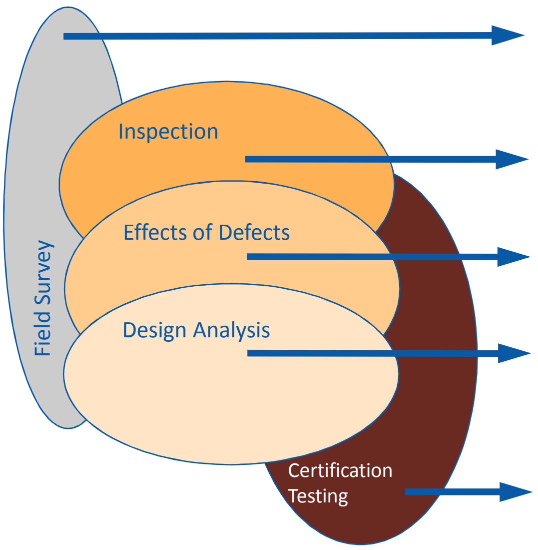
BRC Critical Topics and Strategic Partnerships



- **NREL, K&C, reliability database, materials research**
- **EPRI, TPI, Dantec, other industry…)**
- **MSU, (GE-GRC, TPI, other industry…)**
- **Start collaboration building toward analysis round-robin**
- **NREL (full-scale testing)**

Slide Courtesy SNL

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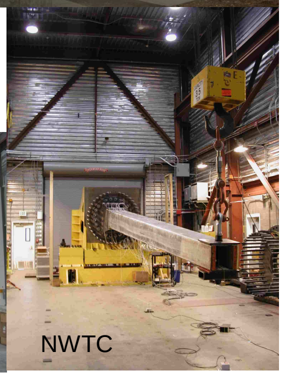
NREL Testing Capability and Roles

- Blade and subcomponent laboratories
  - WTTC / CEC - Boston
    - 90-m blade test capability, 3 test stands
  - NWTC – Boulder
    - 3 test halls
    - 50-m blades
- Full-scale and subcomponent testing of wind turbine blades
  - Research and prototype testing under DOE sponsored programs
  - Certification and R&D testing for industry clients
    - CRADA's
    - Work-for-other agreements



Necessity for Blade Testing

- Testing is a certification requirement
  - Demonstrate blade can withstand the design/test loads
- Validate Blade Design
  - As-built blade properties consistent with design
  - Stress and strain
  - Natural frequencies
  - Stiffness
  - Deflection
  - Ultimate strength
  - buckling margins
  - Design-life validation
- Testing Limitations
  - Critical loads can only be applied approximately
  - Time available for test is typically less than 1 year
  - Only a few blades can be tested
  - Certain failures are difficult to detect

Static Testing

Tests the ability of the blade to withstand design load cases or ultimate strength as required

Typically applied in 4 to 6 load vectors

Load application through quasi-static methods
- Cranes
- Ballast
- Winches
- Hydraulic actuators

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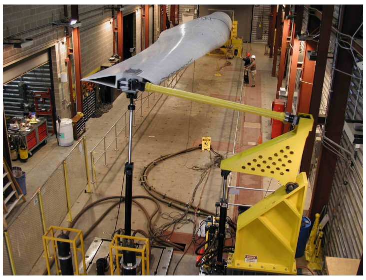
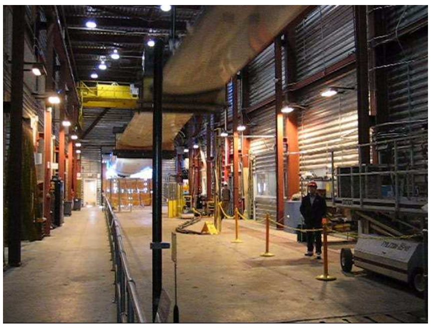
Fatigue Testing



Tests the ability of the blade to withstand operating-life loads
- 20-year blade life on the order of $1 x 10^9$ cycles
- Laboratory testing accelerates loading through increasing load magnitude

Methods
- Single-axis
- Two-axis
- Forced displacement
- Resonant



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Aggregation of Blade Failures during Structural Testing

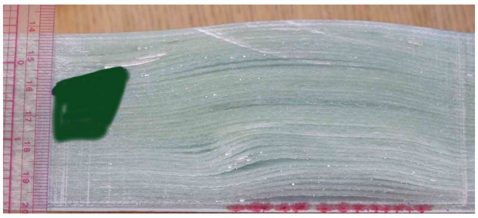
Test Data Population

Megawatt-scale blades

Designs representative of current in-field designs

Blade testing in accordance with IEC 61400 -23 Standard

- Loading above IEC envelop not included
- Fatigue testing above target damage equivalent loading not included



Definition of Failures (IEC 61400-23)

- Catastrophic Failure
  - Breaking of primary blade structure
  - Complete failure of structural elements, internal or external bond lines, skins, shear webs, root fasteners
  - Major parts become separated from the main structure
- Functional Failure
  - Reduction in stiffness (5 to 10%)
  - Permanent deformation
  - Substantial permanent change of cross-sectional shape
  - After unloading the blade, a mechanism is no longer capable of performing its design objective
- Superficial Failure
  - Small cracks not causing significant strength degradation or bond line weakening
  - Gel coat cracking
  - Paint flaking
  - Surface bubbles
  - Minor elastic panel buckling
  - Small delaminations

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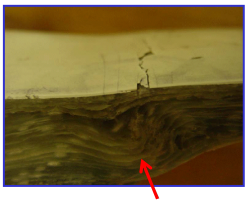
Representative Failures



Laminate Fabric Wrinkle

Bondline Failures

Material Failures

Buckling Stability

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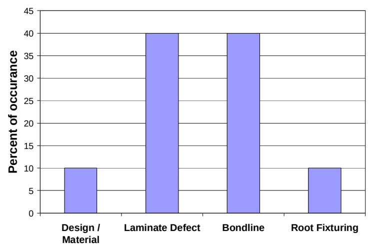
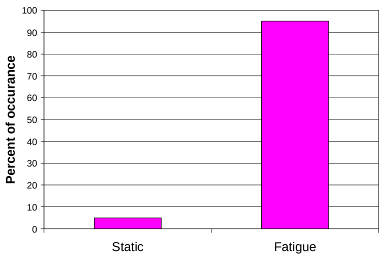
Aggregate Catastrophic or Functional Failure Modes Under Test Conditions





- Often failures are not critical or are repaired
- One test article may have multiple failure modes

Design / Material
- Inadequate Design
- Ply Drops
- Panel Stability

Laminate Defect
- Waves
- Voids
- Dry Spots

Bondlines
- Shear Web
- Leading Edge
- Trailing Edge

Root Fixing
- T-bolts
- Barrel Nuts
- Flanges

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Observations from Blade Testing

- Majority of laboratory failure events occur during fatigue testing
  - 95% discovered in fatigue
  - Laminate waves/wrinkles and debonds dominate failure modes
  - In lab, debond failure modes progress but may not be as catastrophic as wrinkles

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Challenges for Full Scale Testing

- 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
  - Full-scale static and fatigue testing will still be needed
- Due to time and cost, typically only one test is performed
  - No information regarding statistical variability within a production run is gained
- Introduce uncertainty due to test load calculations
  - Fatigue test acceleration (using Palmgren-Miner rule)
  - Uniaxial or biaxial loading vs. true combined loading
  - Load introduction points prevent testing entire blade accurately

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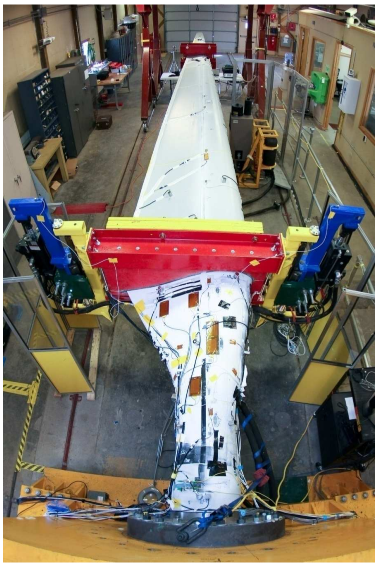
Laboratory ⟷ Wind farm

- Under what conditions do turbines fail in the field?
  - Are accelerated test failures representative?
  - What are the actual loads experienced?
  - What are the actual conditions that produce failures?
- Goals
  - Improve test techniques to better match real turbine blade loads
  - Use blade testing results to better understand field failure causes
- Needs
  - Turbine failure data to include conditions under which it occurred



Blade fatigue test with many different sensors at NWTC

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Recommendations

- Data collection and analysis that supports technology and test methodology improvement
- Consider comparison between laboratory test results and field testing
  - Compile aggregate failure results for full-scale tests internationally
- Field data collection for mechanical turbine failures to include conditions under which failure occurred when possible

NREL – National Wind Technology Center Boulder CO

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ESReDA Project Group

Wind Power production reliability

2011-03-30

1 | Project Group on Wind Power reliability | Lasse Pettersson | 2011.03.30

Project Group on Wind Power production to be started

This is an announcement of a new group and an invitation to participate.

- Host ESReDA
- Subject Reliability aspects on Wind Power production
- Time schedule To be started May 2011, normally working 3 years
- Result Normally a book and 1 or 2 conferences

2 | Project Group on Wind Power reliability | Lasse Pettersson | 2011.03.30
Confidentiality - None (C1)

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European Safety, Reliability & Data Association

The foundation of ESReDA is its Project Groups
- Any 4 members can initiate a PG
- Decision in General Assembly
- Open for others than members
- Not research, rather state-of-the-art
- Normally work for 3 years
- Result is Normally a Book and a Seminar

ESReDA Project Groups
- About ESReDA Project Groups
- Land Use Planning PG
- Accident investigation PG
- Website PG
- Aging PG
- Fire risk analysis PG
- Maintenance PG
- Structural reliability PG
- Uncertainty PG
- Asset Management PG
- *New PG Wind*

Such Seminar twice/year
- Small with a clear focus

40th ESReDA Seminar

Risk Analysis and Management Across Industries

25th and 26th May 2011

BEM Management School Bordeaux, France

3 | Project Group on Wind Power reliability | Lasse Pettersson | 2011.03.30
Confidentiality - None (C1)
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ESReDA

ESReDA is a European Association established in 1992 to promote research, application and training in Reliability, Availability, Maintainability and Safety (RAMS). The Association provides a forum for the exchange of information, data and current research in Safety and Reliability and a focus for specialist expertise.

The Safety and Reliability of processes and products are topics which are the focus of increasing interest Europe wide. Safety and Reliability Engineering is viewed as being an important component in the design of a system. However the discipline and its tools and methods are still evolving and expertise and knowledge dispersed throughout Europe. There is a need to pool the resources and knowledge within Europe and ESReDA provides the means to achieve this.

ESReDA was formed from the combined forces of EuReDatA (European Reliability Data Bank Association) and ESRRDA (European Safety and Reliability Research and Development Association). The integration of the two provides a strong basis for furthering the understanding, development and dissemination of RAMS research and methods throughout Europe.

4 | Project Group on Wind Power reliability | Lasse Pettersson | 2011.03.30
Confidentiality - None (C1)
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ESReDA aims to

- Promote research and development, and the applications of RAMS techniques.
- Provide a forum to focus the resources and experience in safety and reliability dispersed throughout Europe.
- Foster the development and establishment of RAMS data and databases.
- Harmonise and facilitate European research and development efforts on scientific methods to assess, maintain and improve RAMS in technical systems
- Provide a source of specialist knowledge and expertise in RAMS to external bodies such as the European Union.
- Provide a centralised and extensive source of RAMS data
- Further and contribute to education in Safety and Reliability.
- Contribute to the development of European definitions, methods and norms

5 | Project Group on Wind Power reliability | Lasse Pettersson | 2011.03.30
Confidentiality - None (C1)

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Scope of this Project Group

PG still not officially started (expected May 2011)

Until further developed the task could be in 2 parts: Wind Turbine reliability and Grid aspects related to Wind Mills. Draft outline.

<u>Wind Turbine Reliability</u>

- Treating dependability at the design phase, structural reliability, reliability of wind turbines, ageing, optimization of maintenance, operating experience, reliability data, health monitoring.

<u>Wind Mills and the Grid – reliability aspects</u>

- Subjects are reliability of networks, risk/criticality analysis, smart grid, impact of natural events. More subjects may be added.

6 | Project Group on Wind Power reliability | Lasse Pettersson | 2011.03.30
Confidentiality - None (C1)

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Work in a Project Group

Normally
The Group decides on the topic (within given frames).
Each participant announces possible contributions.
Description of state-of-the-art made by active specialists.
2 meetings per year. Most communication via mail.

Finance
Each participant takes own cost
Support possible for extra journeys etc for ESReDA members

End result
A public Seminar during the work or to present the result.
Conference proceedings printed by EU (Research Centre Ispra)
A Book.

Participants welcome

http://www.esreda.org/

Lasse.pettersson@vattenfall.com

RAMS database for Wind Turbines

2011-03-30

Lasse Pettersson, Jan-Olof Andersson, Cecilia Orbert, Svenne Skagerman
Vattenfall Management Consulting

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RAMS-database for Wind Power

- Feasibility study as a mission from Elforsk – Vindforsk III
- Spring 2010 at Vattenfall Power Consultant
  - Approved September 2010 (entirely according to plan)
- Reference group with repr from
  - Vattenfall (Wind)
  - Statkraft
  - Sintef
  - Chalmers
  - Elforsk
  - Vattenfall R&D (adj)
  - Inspecta (adj)
- Report (Swedish) can be downloaded from elforsk.se

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Summary of the task

- In order to perform maintenance in an efficient manner, access to knowledge of components and their properties in the current environment is needed. A RAMS database is one such source of knowledge. It can also be very useful during operation, investment, construction and development of plants
- A feasibility study aiming to illuminate different ways of implementing a RAMS database for wind power and how these ways can be expected to affect the benefits and costs for stakeholders.

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What is a RAMS-database

- Reliability, Availability, Maintainability and Serviceability/Safety
- We have chosen to use
  - Component Reliability Database
- We think this is a useful description
- There are also, for example
  - Availability databases
  - Computerised Maintenance systems
  - RCM-databases

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Project plan in 4 parts

- Possible forms and levels of ambition
  - A number of possible forms and limitations are discussed and evaluated
- Use of reliability data within Wind Power today
  - What data is collected today and who is in front
- Description of some existing reliability databases
  - Examples from nuclear, offshore oil/gas, aviation (and grid)
- Stakeholders
  - Who can benefit from a reliability database
  - Who can contribute

- Note 1. Not IT focus.
- Note 2. Mainly from operator-perspective. Not supplier-perspective.

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Possible forms and levels of ambition

- May be divided into 3 parts
  - Who is the intended user
  - How can the database be managed – by whom
  - Focus - ambition - boundaries

- Outline of the chapter (in the report):
  - Which alternatives exist
  - Alternative A
    - Presentation
    - Advantages
    - Disadvantages
    - Conclusion
  - Alternative B etc

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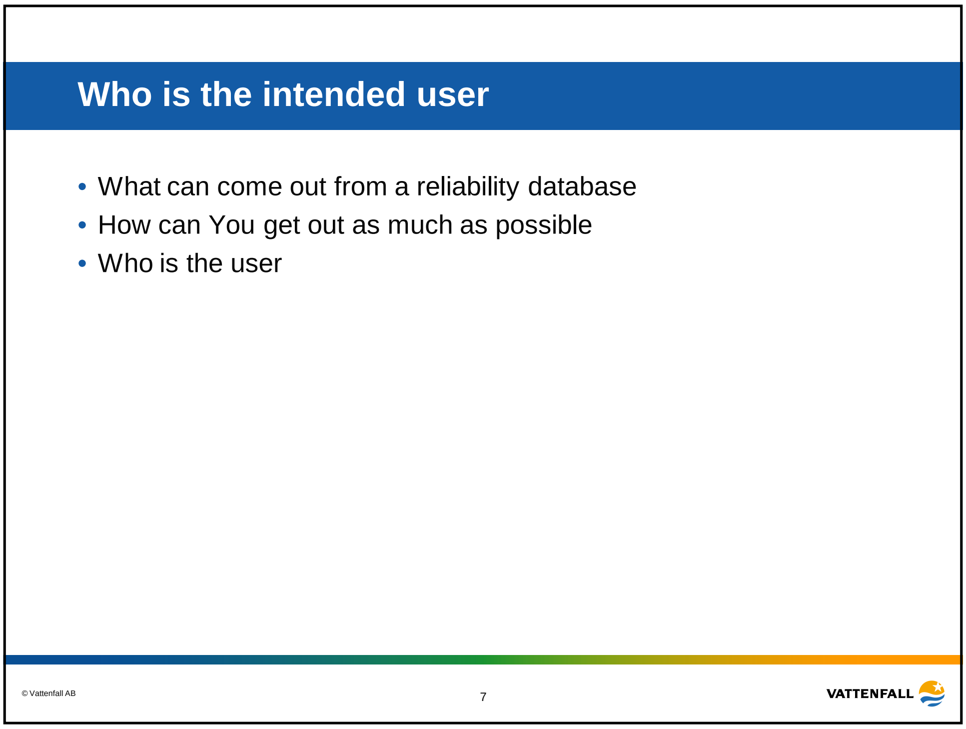
Who is the intended user
• What can come out from a reliability database
• How can You get out as much as possible
• Who is the user
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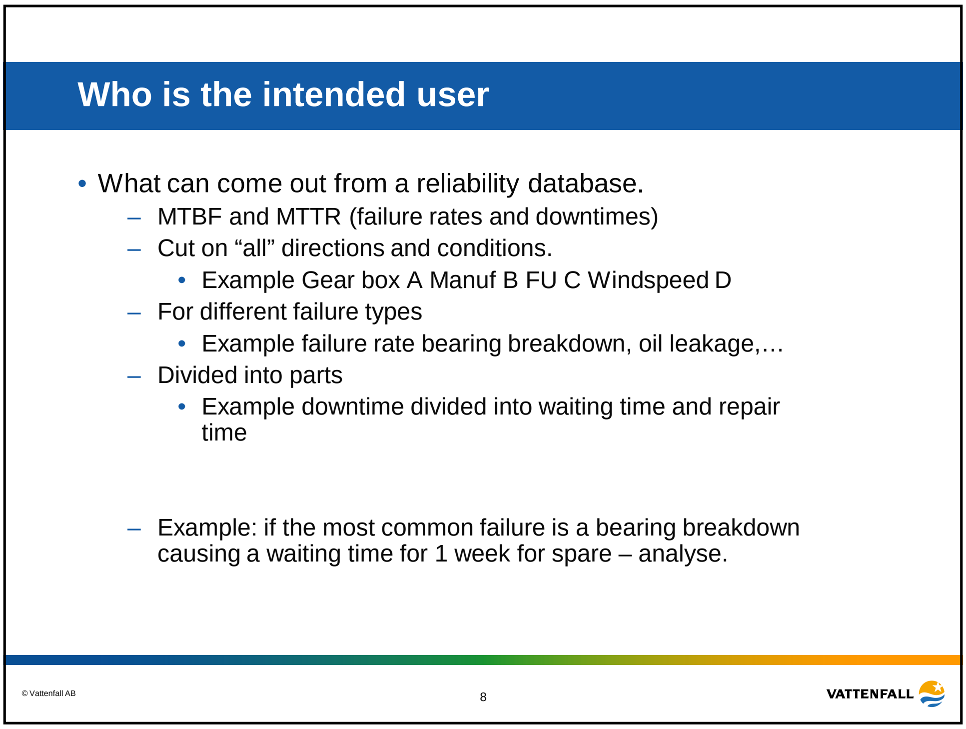
Who is the intended user
• What can come out from a reliability database.
– MTBF and MTTR (failure rates and downtimes)
– Cut on "all" directions and conditions.
• Example Gear box A Manuf B FU C Windspeed D
– For different failure types
• Example failure rate bearing breakdown, oil leakage,…
– Divided into parts
• Example downtime divided into waiting time and repair time
– Example: if the most common failure is a bearing breakdown causing a waiting time for 1 week for spare – analyse.
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How can You get out as much as possible

- Some criteria to maximize use of data
  - Easy to make Your own selection of components You wish to study.
  - Easy to select time period.
  - Good statistical tools. For ex. Bayesian technique valuable.
  - Graphical output. Trends.

  - Example: within Swedish Nuclear there are Computerised maintenance systems. A new support system using graphical output has increased the use of maintenance analyses a lot.

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Who is the user

- Our conclusion is that the maintenance organisation is the primary user of a reliability database.
  - A lot of work in many parts of the power industry (and elsewhere) is used for maintenance today. A good maintenance is worth a lot of money. This applies to wind turbines as well. Good maintenance is often mentioned as a priority for the coming years. To achieve this, good information is requires and a reliable database would be an important source of good information
- Other users
  - Other possible users are for example:
    - Designers
    - Purchasers
    - Operation department
    - Investment calculations
  - One conclusion from the analysis is that the information that the maintenance organisation needs is sufficient for “Other users”.

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Possible forms and levels of ambition

- May be divided into 3 parts
  - Who is the intended user
  - How can the database be managed – by whom
  - Focus - ambition - boundaries

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Focus - ambition - boundaries

- Approx 10 aspects are discussed; advantages and disadvantages.
- We give a number of recommendations
- Besides this low or high level of ambition can be chosen.
  - The high level is suitable if a ”real” RCM-work will be performed.
    - Tracing individuals
    - Follow-up to the same level of detail as the maintenance system
    - Supplier information
    - Environmental parameters as wind speed, temperature
  - The low level is suitable for a lower level of maintenance development
    - Low level of ambition is not recommended

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General recommendation 1

- The database should not be limited to Sweden but all wind turbines from participating companies may be included, no matter localisation
- Focus should be large turbines but it is up to every participant to decide if they also wish to include smaller units
- Both new and old units
- All types of design should/may be included
- Turbines from all manufacturers may be included
- All localisations may be included – on-shore and off-shore

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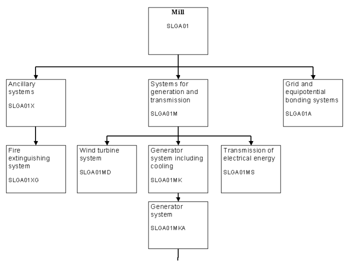
General recommendation 2

- RDS-PP should be used as designation system.
  - Keep track of what goes on internationally (Reliawind)
- Create a set of failure data codes to use
- Every supplier of data should have access to their own data plus a generic information
- Source of data should be computerised maintenance systems and other computers
- Availability- and production information should be included
- No economic data should be included



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State-of-the-art

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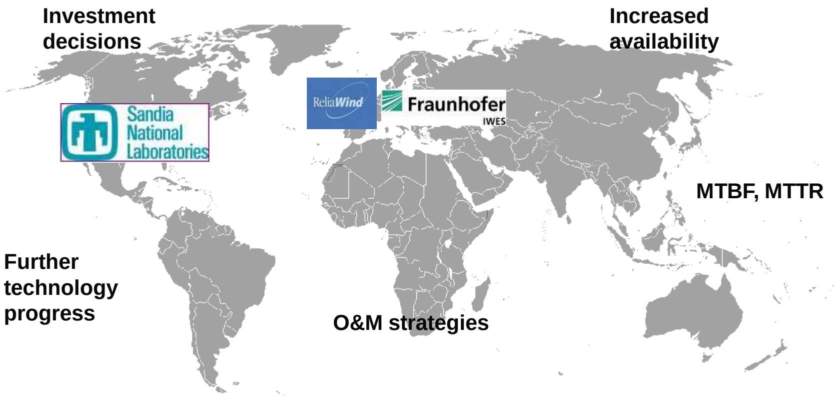
State-of-the-art



•**Aim**: To build a database with information on **component level** that can allow statistically reliable analyses of the performance of the wind turbines.

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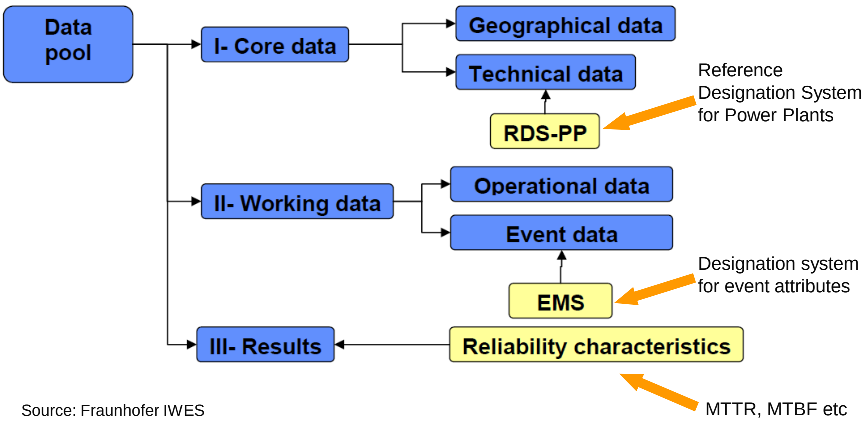
Data structure OWMEP

Fraunhofer IWES



Source: Fraunhofer IWES

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State-of-the-art

- OWMEP(Fraunhofer), Reliawind and CREW(Sandia) databases are government funded
- Data collection is voluntary
- Collaboration initiated between Fraunhofer and Reliawind, and between Sandia and Reliawind
- Taxonomy is an essential issue since there are three different types, RDS-PP, Reliawind and EBS
- How the results will be delivered, and to whom, are not yet determined
- How to involve the manufacturers is a challenge

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Some existing reliability databases

- Databases most similar to our imagined database
- Organisation TUD
  - Data and financing from Swedish and Finnish nuclear
  - Steering Group with repr from all participants. Adj authorities
  - All practical aspects (input data control, quality, IT) handled be secretariat at VMC
- Organisation OREDA
  - Project organisation supported by 8 international oil and gas companies
  - Steering Group with repr from all companies
  - Basic and yearly fee for participation
  - Project leader and IT-costs financed
  - Data collection (ad hoc) according to decision in Steering Group
  - Data input and quality control made by data suppliers
- Other information – see the Report

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Stakeholders

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Stakeholders. Who can support?

- General
  - A big advantage with a Component Reliability Database is that it can contain data from different environments / operating conditions / maintenance etc.
  - This makes it possible to measure reliability and relate this to environment / operation / maintenance / …
  - This increases the value dramatically compared to having data only from a limited number of units thay mat be operated under similar conditions.

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Resources

- To create and operate a reliability database takes:
  - Data
  - Financing
- Data
  - All data fetched from other computers
  - Information owner must agree to use it
  - Some data created only for reliability database (failure codes..)
  - Some adjustments of format as failure codes must be made in the basic data
  - Transmission routines created and maintained
- Financing - resources
  - TUD uses just over one person full time plus IT-costs
  - OREDA uses approx ½ person full time plus IT-costs

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Stakeholders

- End of feasibility study. Ongoing discussion on forms for a possible continuation.

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Questions – comments?

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Influence of uncertainty in failure data on modelling O&M aspects

IEA Topical Expert Meeting on international statistical analysis on wind turbine failures, March 30-31, 2011 Kassel

R.P. van de Pieterman
T.J.J. van der Zee
ECN Wind

5-5-2011

www.ecn.nl

ECN

Contents

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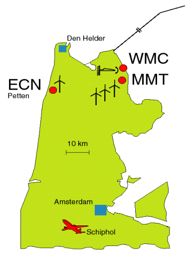
ECN

Introduction: ECN Wind Energy

1. Rotor and wind farm aerodynamics
2. Integrated wind turbine design
3. Operations and Maintenance
4. Materials and structures
5. Measurements & Experiments

Research activities



EWIS (ECN Wind Energy Industrial Support)	ECN Wind energy Industrial Support
EWTW	ECN Wind turbine Test Site Wieringermeer
Knowledge Centre WMC	Wind Turbine Materials and Constructions

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ECN

O&M developments at ECN

- Flight leader: cost-effective method for estimating load accumulation in all turbines of offshore wind farm
- FOBM: fibre optic blade monitoring
- O&M Tool: analyse O&M aspects of offshore wind farms (planning phase)
- OMCE: analyse O&M aspects of operational offshore wind farms

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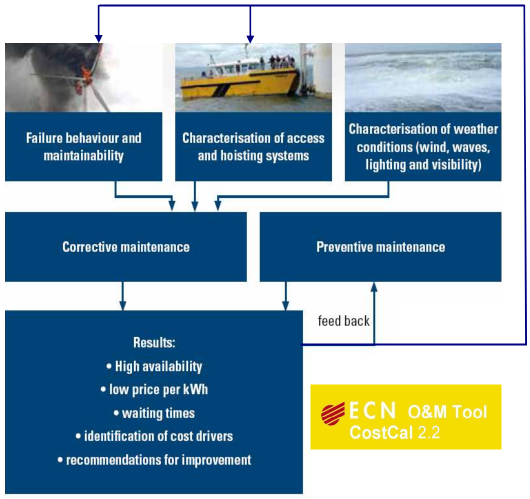
ECN

ECN O&M Tool

- Input:
  1. Failure behaviour and maintenance strategy
  2. Access and hoisting equipment
  3. Weather conditions
- Output:
  1. Availability
  2. O&M costs
- Uncertainty analysis (@RISK): effect of uncertainty in input on calculated results



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O&M Tool – Probabilistic baseline

- Generic baseline scenario for wind farm with 33 2.8 MW turbines
- Probabilistic cost analysis using Monte Carlo simulations
- Uncertainty in following input parameters (Pert distribution):
  - Logistic time and travel time of equipment
  - Cost of equipment
  - Material costs
  - Labour costs
  - Repair time
  - Logistic time spare parts
  - **Annual failure frequency**

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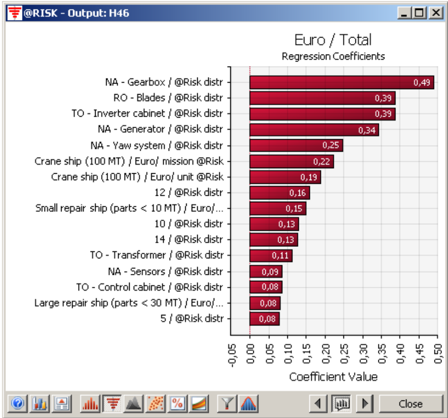
O&M Tool - @RISK

- Probabilistic output:
  - Cumulative distribution function
  - Regression coefficients ζ:

    a change in input variable X of one standard deviation σ_X results in change $\zeta \cdot \sigma_Z$ of output variable Z



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O&M Tool – Reduced uncertainty in input

- 3 dominant components with reduced uncertainty

Component	Annual Failure Frequency main components			
	@Risk	min	ML	max
NA - Hydraulic system	0.1800	0.0600	0.1201	0.5400
NA - Top box	0.2251	0.0750	0.1501	0.6750
NA - Accessoires	0.0450	0.0150	0.0300	0.1350
NA - Yaw system	0.3151	0.1050	0.2101	0.9450
NA - Cooling system	0.0450	0.0150	0.0300	0.1350
NA - Sensors	0.4501	0.1500	0.3002	1.3500
NA - Crane system	0.0225	0.0075	0.0150	0.0675
NA - Gearbox	0.3601	0.1200	0.2401	1.0800
NA - Rotor brake system	0.1575	0.0525	0.1051	0.4725
NA - Generator	0.2701	0.0900	0.1801	0.8100
NA - Shaft/bearing/slip ri	0.0900	0.0300	0.0600	0.2700
NA - Support structure	0.0900	0.0300	0.0600	0.2700
RO - Blades	0.4051	0.1350	0.2701	1.2150
RO - Pitch mechanism	0.0675	0.0225	0.0450	0.2025
RO - Rotor structure	0.1125	0.0375	0.0750	0.3375
TO - Control cabinet	0.5101	0.1700	0.3402	1.5300
TO - Transformer	0.2251	0.0750	0.1501	0.6750
TO - Inverter cabinet	0.7502	0.2500	0.5003	2.2500
TO - Structural parts	0.1800	0.0600	0.1201	0.5400
	0.0000			
Total	4.5010			

Component	Annual Failure Frequency main components			
	@Risk	min	ML	max
NA - Hydraulic system	0.1800	0.0600	0.1201	0.5400
NA - Top box	0.2251	0.0750	0.1501	0.6750
NA - Accessoires	0.0450	0.0150	0.0300	0.1350
NA - Yaw system	0.3151	0.1050	0.2101	0.9450
NA - Cooling system	0.0450	0.0150	0.0300	0.1350
NA - Sensors	0.4501	0.1500	0.3002	1.3500
NA - Crane system	0.0225	0.0075	0.0150	0.0675
NA - Gearbox	0.2851	0.1500	0.2401	0.6000
NA - Rotor brake system	0.1575	0.0525	0.1051	0.4725
NA - Generator	0.2701	0.0900	0.1801	0.8100
NA - Shaft/bearing/slip ri	0.0900	0.0300	0.0600	0.2700
NA - Support structure	0.0900	0.0300	0.0600	0.2700
RO - Blades	0.4167	0.2000	0.3500	0.9000
RO - Pitch mechanism	0.0675	0.0225	0.0450	0.2025
RO - Rotor structure	0.1125	0.0375	0.0750	0.3375
TO - Control cabinet	0.5101	0.1700	0.3402	1.5300
TO - Transformer	0.2251	0.0750	0.1501	0.6750
TO - Inverter cabinet	0.5918	0.2500	0.5003	1.3000
TO - Structural parts	0.1800	0.0600	0.1201	0.5400
	0.0000			
Total	4.2792			

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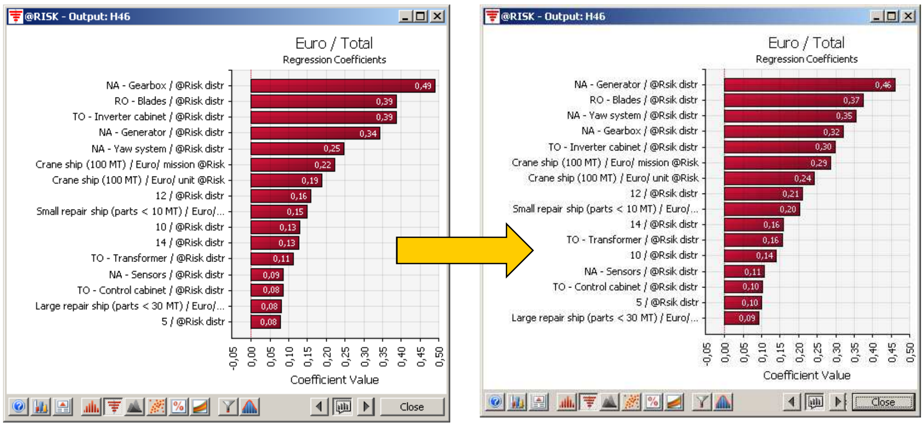
ECN

O&M Tool – Reduced uncertainty in output

- Regression coefficients significantly reduced



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ECN

Data collection

- Uncertainty in failure rate statistics dominates uncertainty in O&M costs
- Decrease uncertainty in failure rate statistics of wind farm under consideration by operational data collection and analysis
- **Method(s) required!** => Operation & Maintenance Cost Estimator (OMCE)

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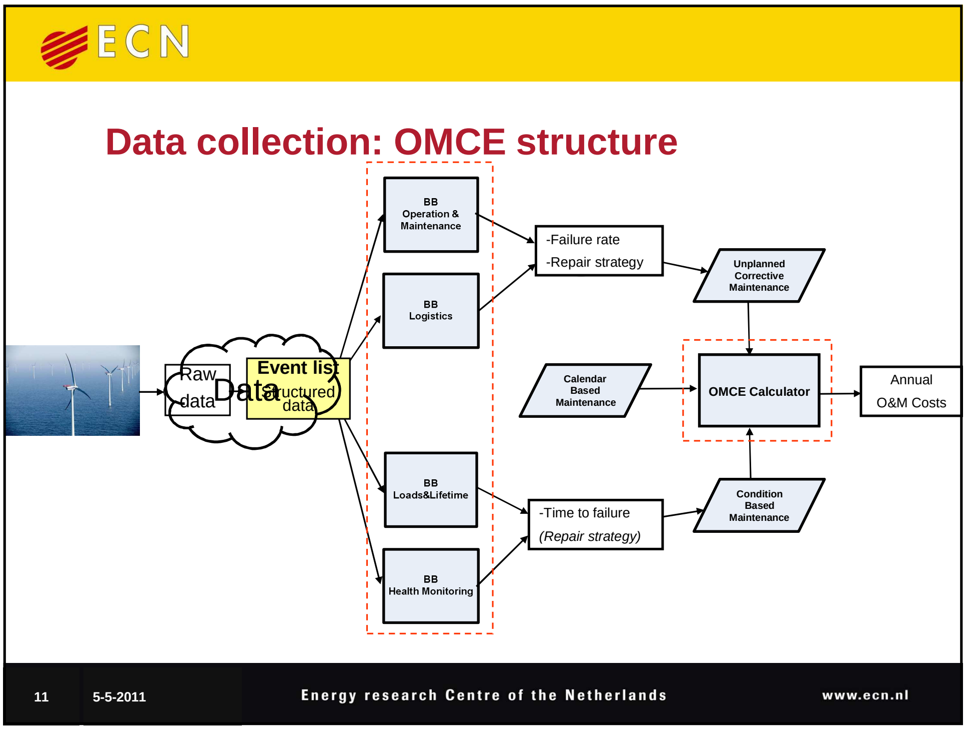
ECN
Data collection: OMCE structure
BB Operation & Maintenance
BB Logistics
BB Loads&Lifetime
BB Health Monitoring
Raw data
Data
Event list
Structured data
-Failure rate
-Repair strategy
Unplanned Corrective Maintenance
Calendar Based Maintenance
OMCE Calculator
Annual O&M Costs
-Time to failure
(Repair strategy)
Condition Based Maintenance
11
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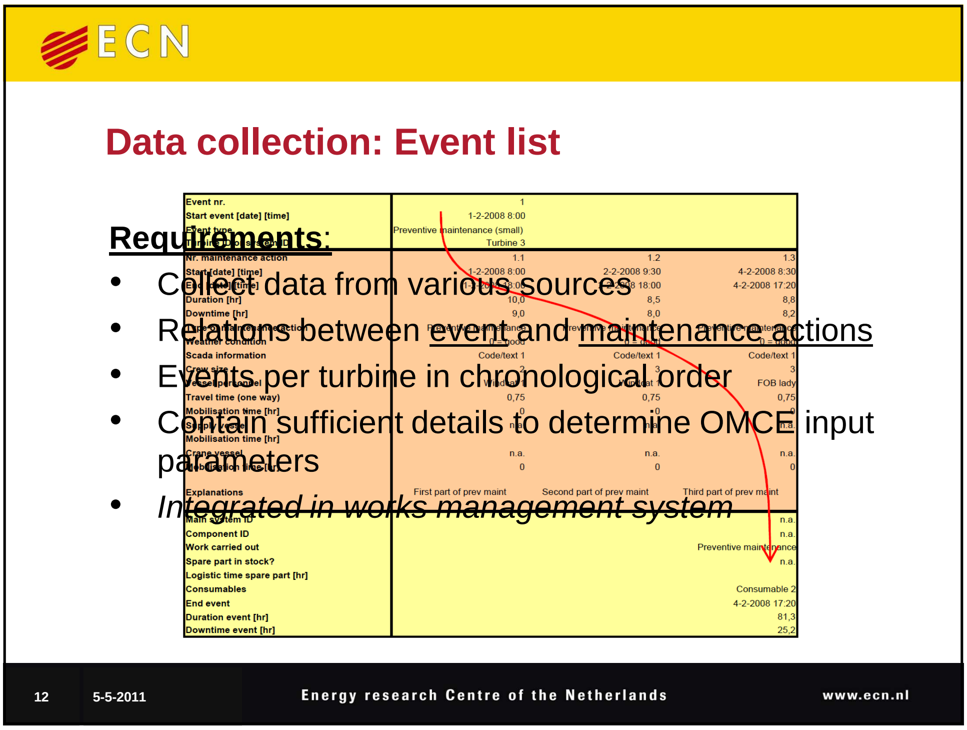
ECN
Data collection: Event list
Requirements:
• Collect data from various sources
• Relations between event and maintenance actions
• Events per turbine in chronological order
• Contain sufficient details to determine OMCE input parameters
• Integrated in works management system
Event nr.
Start event [date] [time]
Nr. maintenance action
Start [date] [time]
Duration [hr]
Downtime [hr]
Weather condition
Scada information
Travel time (one way)
Mobilisation time [hr]
Explanations
Component ID
Work carried out
Spare part in stock?
Logistic time spare part [hr]
Consumables
End event
Duration event [hr]
Downtime event [hr]
12
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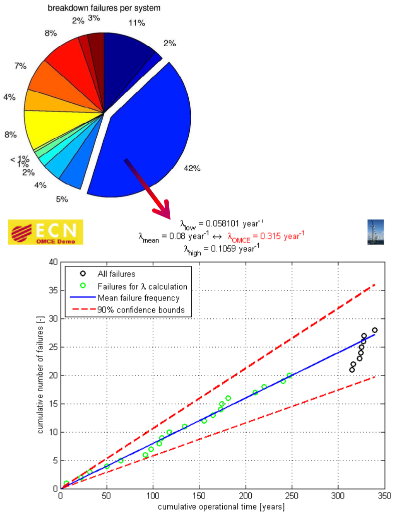
ECN

Data collection: BB ‘Operation & Maintenance’

- Goal:
  - Estimate failure frequencies of the different wind turbine components
- Method:
  - Structured collection of O&M data in ‘Event list’
  - Ranking of systems
  - Trend analysis using CUSUM-plots
  - Determine failure frequencies & confidence intervals



ECN

Experiences with RDS-PP

- For operation & maintenance cost modelling and data collection a functional breakdown structure (FBS) of the turbines under consideration is recommended
- Multiple purposes with respect to Operation & maintenance:
  1. Input for O&M cost models (O&M Tool, OMCE)
  2. Collect failure data from operational experience (OMCE BB)
  3. Cross compare failure statistics and O&M cost estimates between turbine types
  4. Study the effects of failures on higher system levels
- ECN suggests to use RDS-PP to create a FBS

ECN

Experiences with RDS-PP

- Reference Designation System for Power Plants (RDS-PP) is based on sector-specific standards (IEC, ISO/TS, IEC/PAS).
- Application guidelines wind power plants are developed by VGB PowerTech e.V. and a revision 2 is under development
- Example of full equipment breakdown for Pitch Drive of blade assembly A:

	BL 0	BL1	BL2			Conf. Mgm.	Count	Designation
	WTG ID	(sub)System	Object		Product	Prod.no.	Quantity	
=	A01	MDC11	GL001					Pitch drive assembly A
=	A01	MDC11	GL001	-	BE01		1	Sensor battery voltage
=	A01	MDC11	GL001	-	BS01		1	Sensor low speed axle measurement
=	A01	MDC11	GL001	-	BS02		1	Sensor high speed axle measurement
=	A01	MDC11	GL001	-	CC01		?	Auxliary Power Unit (APU/battery)

Etc.

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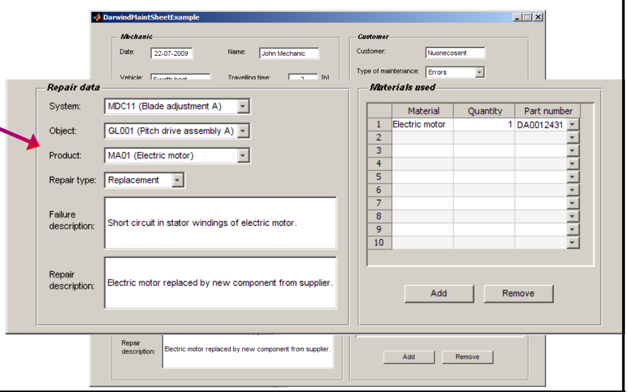
ECN

Experiences with RDS-PP

- The RDS-PP system may be applied in predefined maintenance data sheet (e.g. edited by maintenance manager)
- By integration with Event List failure statistics can be obtained

Product code is lowest level of data collection



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ECN

Conclusions

- Improved certainty in failure rates results in more accurate O&M cost estimates
- By structuring raw data in an Event List format operational failure statistics can be obtained with OMCE Building Block O&M
- The RDS-PP is a suitable system for creating an FBS for O&M analysis due to standardized nomenclature

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ECN

Questions?

?

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INTERNATIONAL STATISTICAL ANALYSIS ON WIND TURBINE FAILURES

March 30-31, 2011
Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

Jens A B Lauesen,
Risk management Serious Incidents to Vestas Products

Serious Incidents to Vestas Products

The system I manage in Vestas is about Serious Incident involving a WTG, which can create a risk by working at a WTG or to WTG surroundings.

We have a independent system for managing industrial injuries and registration of H&S near miss.

Technical failures (component failures with no personnel risk) are managed at Vestas at our CIM system (continuous improvement management).

Additionally we monitor WTG regarding operation log and failure logs.

A reportable 'serious incident to Vestas product' is

- A *serious* injury, involving and/or affected by a Vestas product or Vestas specification; causing hospitalisation probable resulting in: *a)* - treatment and rehabilitation period of more than four weeks, *b)* - disabling, *c)* - fatal consequence.
- A WTG incident which shows a latent *serious* safety risk (inside WTG or to WTG surroundings), and/or acute need for immediate precautionary activities.
- A WTG incident where defects to a component or a SW-program-malfunction causes disabling or mal-function of a crucial WTG emergency/safety functionality.
- A WTG incident causing *serious* damages, resulting in an expected loss of more than 1 mill €.

In the above, *"serious"* means that the incident affect the public's interest, or that authorities and/or insurance might intervene or request to lead/be part of the investigation.

Examples: i) fatal incidents, ii) persons might become disabled, iii) major visible damages to a Vestas product, iv) Health & Safety authorities intervene, v) "Breaking news" - Journalists inquire details, or there is a major risk of negative press, vi) great general public fear of wind turbines or Vestas activities.

An incident is *a sudden and/or unexpected event,* with damage or injury, located by time, place and circumstances.

Id. /naming *of a Serious Incident:* 'Year.Month.Date - Site name, Country code' (acc. to ISO3166).

3 Name of presentation **Wind.** It means the world to us.™

Classification of a Serious Incident event

Vestas classified serious incidents seen from different perspectives

H&S risk during the event divided into

1) Red – if people are on site during the event which are or could have been affected,
2) Yellow – if nobody on site but if they have they could have been affected,
3) Green – if no risk when following instructions given.

Risk to the surroundings to a WTG by registration of the size of area around the WTG affected by parts from the WTG + tip high of the WTG

& kind of risk to the surroundings are divided into fires to nacelle, blade incidents, loose part fall, other external (run-away etc) and internal only.

Severity to Vestas business divided into

1) Serious Incident with a known risk,
2) Major serious incident
3) Crisis – Serious incident with high risk of escalation.

- which set up the procedure for how we manage a new serious incident.

4 Name of presentation **Wind.** It means the world to us.™

Classification of the results of an investigation

Kind of accident to WTG:

- Human (initiated) failure
- Component (failure) accidents
- System accidents
- Normal accidents

WTG SI Root causes definitions

(Re: DEPOSE model - Design, Equipment, Procedures, Operators, Supplies, Environment)

• Design & verification	Design
• New knowledge/Not foreseen	Design
• Equipment & tools etc.	Equipment
• Procedures & Instructions	Procedures
• Transport & handling	Operators
• Installation & Commission	Operators
• Service & Maintenance	Operators
• Manage WTG plants (incl. miss use)	Operators
• Supplies – properties	Supplies
• Supplies – manufacturing	Supplies
• Overloaded (beyond WTG specifications)	Environmental
• Gods will (extreme weather etc)	Environmental

Summary about Vestas managing serious incidents to products

From Vestas activities around the world

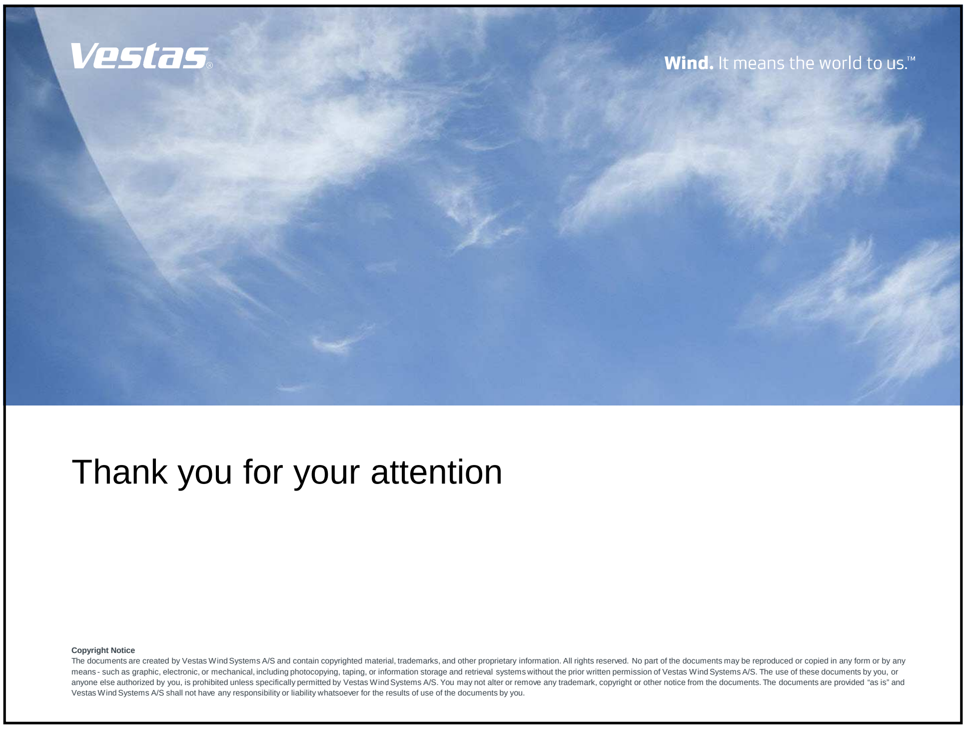
We have registered more than 485 serious incidents since year 2000

We received information about serious incidents from around 38.000 WTG

We have initiated a lot of "Serious Alerts" to Vestas employees and created lot of CIS (customer information) about new detected risks.

We have reduced the risk major serious incidents (run-away & fires) to especially new WTG.

Technology R&D have today employed five Special investigators who are responsible for both - investigating the event - and for manage developments and implementation of solutions preventing reoccurrences.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Business from technology

Wind energy statistics in Finland

INTERNATIONAL STATISTICAL ANALYSIS ON WIND TURBINE FAILURES
Kassel, Germany
March 30-31, 2011

VTT Technical Research Centre of Finland
Anders Stenberg

Wind Energy Statistics in Finland

- VTT is in charge of the wind energy statistics in Finland
- The content of VTT database
  - Statistics of production since 1992
  - Statistics of failures since 1996
    - Confidential information → only figures for the whole Finland can be published
  - Technical specification of the wind turbines
  - Information about ownership and site location
  - Wind energi index (Finnish Meteorological Institute)
- The statistics are available at http://www.vtt.fi/windenergystatistics/
- Monthly and yearly reports
- Published in *Windstats Newsletter* and in wind energy magazines in Finland
- The statistics are used in national and international energy statistics of wind power

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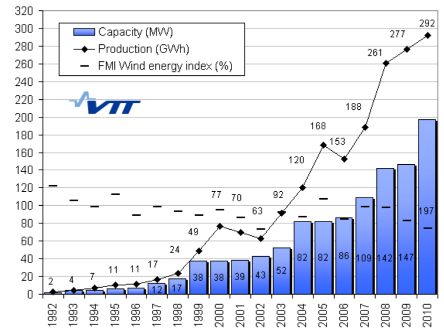
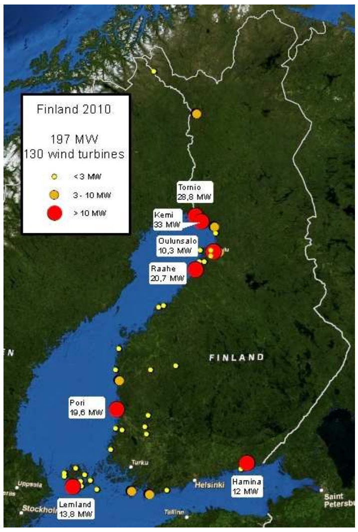
Wind power capacity in Finland by the end of 2010



Key statistics, Finland

- Wind power capacity: 197 MW
- Number of turbines: 130 turbines
- Installed capacity in 2010: 50 MW
- Average wind turbine size: 1,520 kW
- Electricity produced in 2010: 292 GWh
  - 0,3 % of the Finnish electricity consumption



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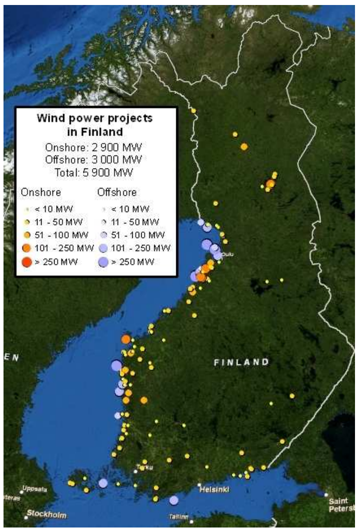
Wind power projects in Finland in January 2011

- The target for wind power in the climate and energy strategy set in 2008 is 6 TWh/yr (2,500 MW) by 2020
- This would be about 6% of the total electricity consumption in Finland
- A feed-in premium (83.5 €/MWh) entered into force on 25 March 2011
- There is also an increased level of 105.3 €/MWh until the end of 2015 (maximum 3 years) to encourage early projects

- The volume of data will grow fast in the near future, a new structure of the database and way of reporting is needed to manage the volume of data



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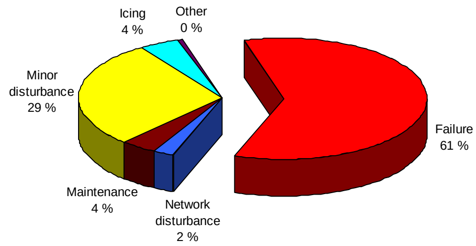
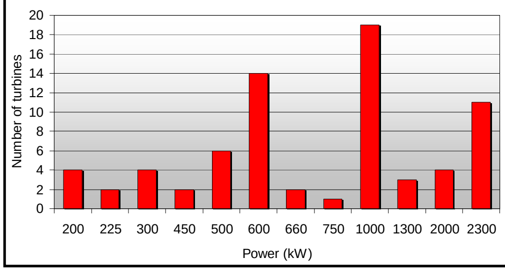
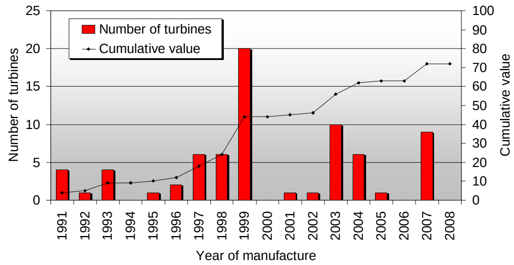
Analysis of wind turbine statistics in Finland

- Master thesis, written for VTT with funding from Tekes
  - Includes 72 of the 116 wind turbines in Finland 2008
  - Total capacity 73 MW of 142 MW
  - Average turbine size 1 014 kW
  - Data correspond to 617 years of operation
  - Failures that need repair work have caused 60% of all downtime.

Total downtime in survey 253 789 hours
Downtime due to failures 152 428 hours







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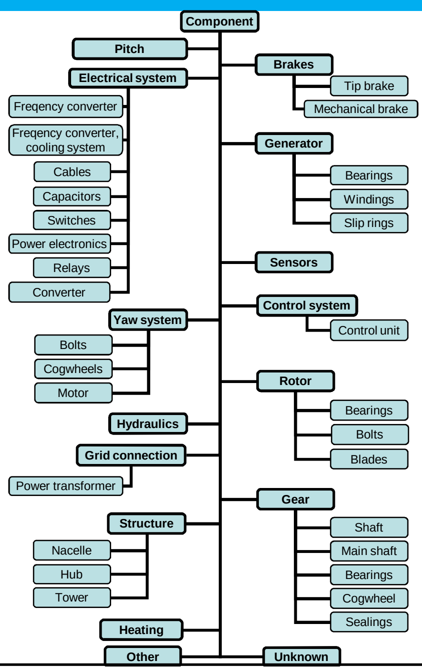
Categorization of components

- Categorization is necessary to maintain control of the information
- Only technical failures that have required repairing are sorted according to the defect component
- A total of 15 categories of which 13 are components
  - Components can also contain subcomponents
- Sorting data into other subcategories like turbine type, power or manufacturer are restricted due to confidentiality – also general conclusions cannot be drawn from a limited amount of data.



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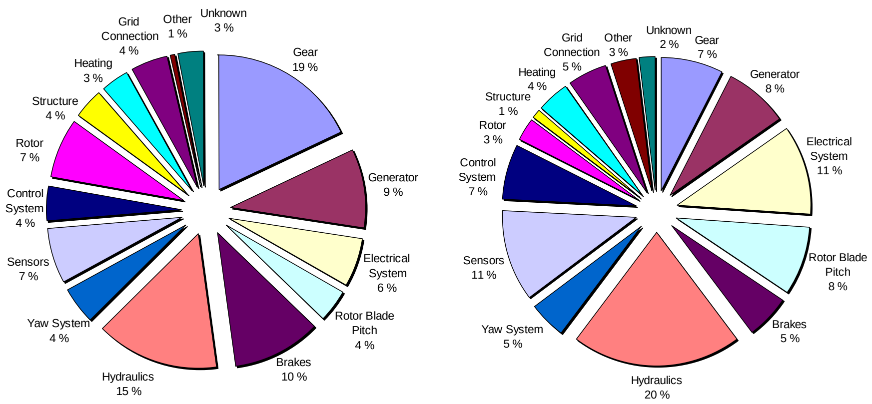
Distribution of downtime and number of failures



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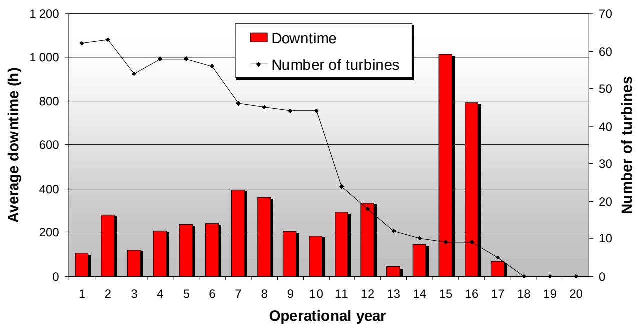
Total downtime due to failures as function of turbine age

- A total of 152 428 hours, 617 turbine years
- Black line represents the number of turbines each year
- About 200 hours of downtime due to failures per year and turbine in average
- The reason for the increased downtime from operational year 15 is failures in the hydraulic system and tip brakes



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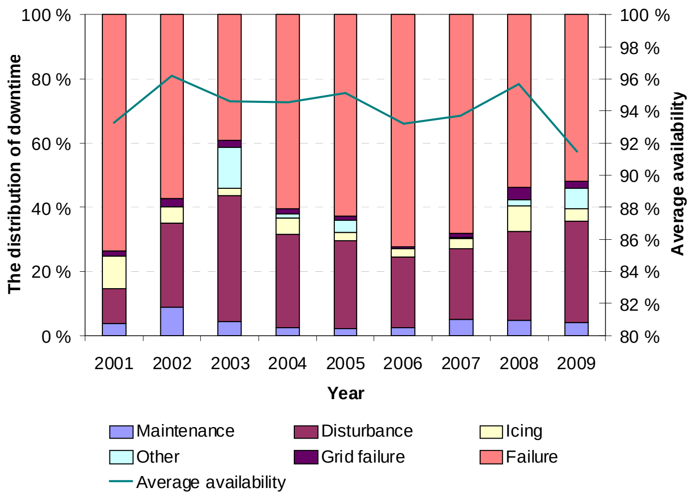
Availability and downtime distribution for wind turbines in Finland



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Wind turbine failure statistics – Which way to go?

- Data / Information
  - What is the information we want? Information about the failure and reason for failure?
  - Who reports data? Wind turbine owners? Manufacturers?
  - All turbines or a chosen sample of turbines?
- Database
  - Who will manage the database?
  - Who will have access to the database?
- What kind of information should we be able to get from the data?
  - Overall technical availability as a function of year etc.
  - Reliability analysis: average time to failure for all the components, ...

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International collaboration

- Standardised and harmonised way to collect statistics
  - We need more data and better reports
- Wind turbine operators are the key actors in providing data
  - Depends on the commitment of the person in charge how well failures are reported
- Wind turbine manufacturers are also crucial:
  - If there would be more standard way of automatic reports from turbines, the failure statistics could be more automised

VTT creates business from technology

SPECIAL ENTERPRISE RISKS
TAILWIND FOR THE WIND INDUSTRY

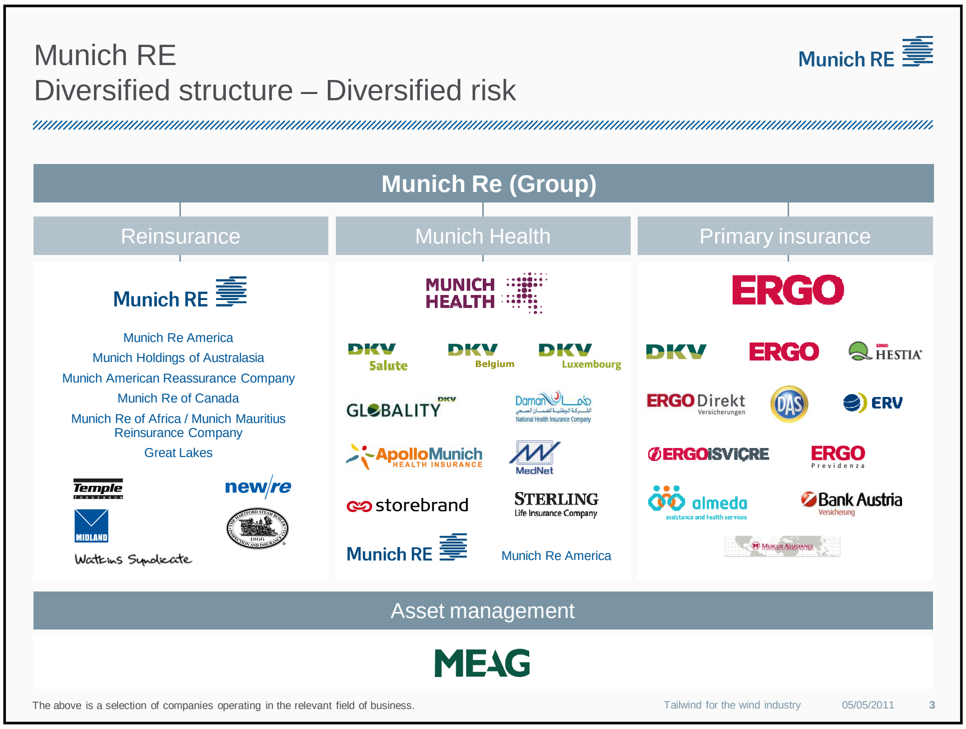
Michael Schrempp

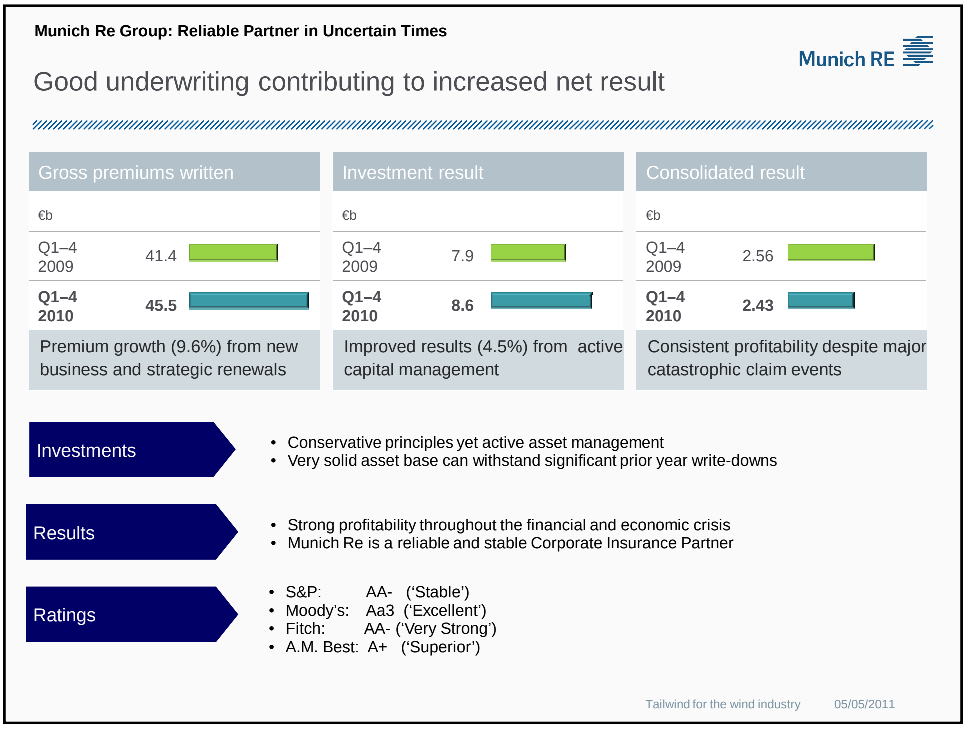
Munich RE

Content

Munich RE

1. Munich RE - Special Enterprise Risks
2. How to insure serial losses for the wind industry


Munich RE
Diversified structure – Diversified risk
Munich RE
Munich Re (Group)
Reinsurance
Munich Health
Primary insurance
Munich RE
Munich Re America
Munich Holdings of Australasia
Munich American Reassurance Company
Munich Re of Canada
Munich Re of Africa / Munich Mauritius Reinsurance Company
Great Lakes
Temple
new re
MIDLAND
Watkins Syndicate
MUNICH HEALTH
DKV Salute
DKV Belgium
DKV Luxembourg
GLOBALITY
Daman
ApolloMunich HEALTH INSURANCE
MedNet
storebrand
STERLING Life Insurance Company
Munich RE
Munich Re America
ERGO
DKV
ERGO
HESTIA
ERGO Direkt
DAS
ERV
ERGOISVIÇRE
ERGO Previdenza
almeda
Bank Austria
Asset management
MEAG
The above is a selection of companies operating in the relevant field of business.
Tailwind for the wind industry
05/05/2011
3


Munich Re Group: Reliable Partner in Uncertain Times
Munich RE
Good underwriting contributing to increased net result
Gross premiums written
Investment result
Consolidated result
€b
€b
€b
Q1–4 2009
41.4
Q1–4 2009
7.9
Q1–4 2009
2.56
Q1–4 2010
45.5
Q1–4 2010
8.6
Q1–4 2010
2.43
Premium growth (9.6%) from new business and strategic renewals
Improved results (4.5%) from active capital management
Consistent profitability despite major catastrophic claim events
Investments
• Conservative principles yet active asset management
• Very solid asset base can withstand significant prior year write-downs
Results
• Strong profitability throughout the financial and economic crisis
• Munich Re is a reliable and stable Corporate Insurance Partner
Ratings
• S&P: AA- ('Stable')
• Moody's: Aa3 ('Excellent')
• Fitch: AA- ('Very Strong')
• A.M. Best: A+ ('Superior')
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05/05/2011

Corporate Insurance Partner: Traditional products and individual risk solutions available

Munich RE

General Property

- Property damage
- Business interruption
- Machinery breakdown
- Nat Cat covers
- …

Casualty

- General liability
- Product liability
- Directors' & officers' liability
- …

Energy

- Property damage
- Business interruption
- Offshore in combination with onshore
- Mining
- …

Special Enterprise Risks

- Supply chain interruption
- Coverage against reputational damage or loss of brand value
- Non-physical damage BI
- …

Engineering

- Contractors' all risks
- Erection all risks
- Builders' risks
- Advanced loss of profit
- Delay in start-up
- ….

Tailwind for the wind industry 05/05/2011 5

Special Enterprise Risks (SER): Full support for your individual challenges

Munich RE

- SER offers **innovative solutions for new risks** that have hitherto been uninsurable
- SER develops **tailor-made insurance cover** for your individual risk mitigation needs
- SER targets **industry clients** with dynamic growth potential
- SER is part of Munich Reinsurance Company
- **Insurance cover** will generally be arranged with the involvement of a primary insurer in the **Munich Re Group**

Tailwind for the wind industry 05/05/2011 6

Examples of our insurance solutions

Munich RE

Penalty aggregate cover
For Steelbridge Inc.

Contractual guarantee cover
For Bottleneck Corp..

Extended Warranty Cover
For Pinksun Ltd.

Supply chain interruption cover
White Vehicle Ltd.

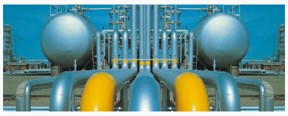
Serial loss cover
For Windocean Corp.

Contingency cover
For Extreme-Submarine Inc.

Reputational risk cover
For Giant Delight Ltd.

Pandemic non-damage BI cover
For Come-Back-Airline

Power plant availability cover
For Silverfuel corp.



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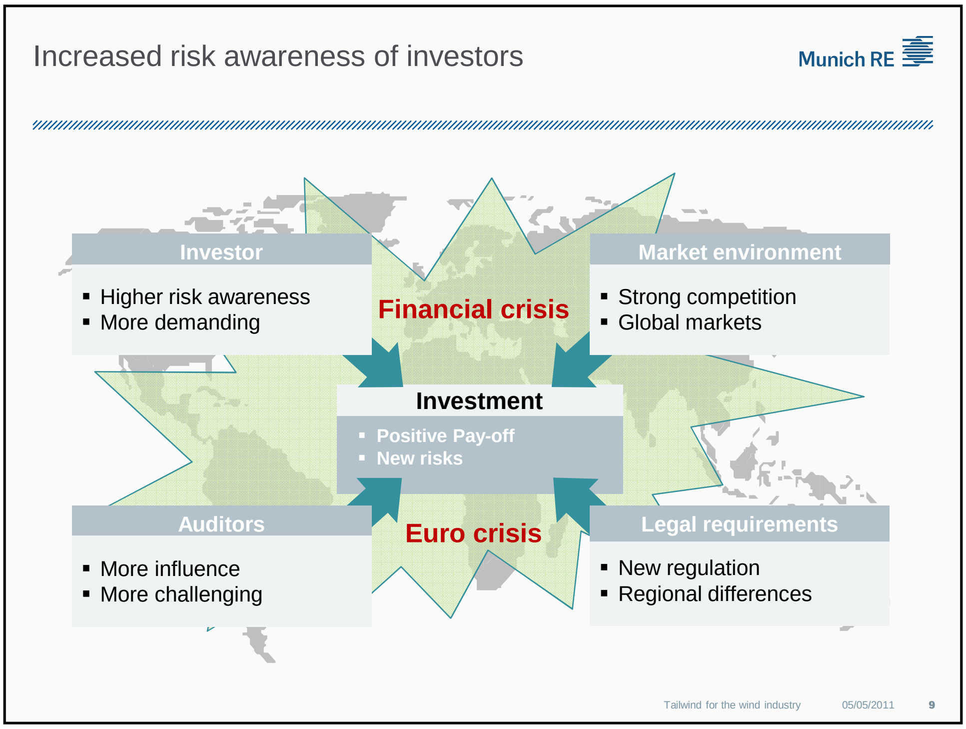
SERIAL LOSS COVER
FOR THE OFFSHORE WIND INDUSTRY


Increased risk awareness of investors
Munich RE
Investor
Higher risk awareness
More demanding
Financial crisis
Market environment
Strong competition
Global markets
Investment
Positive Pay-off
New risks
Auditors
More influence
More challenging
Euro crisis
Legal requirements
New regulation
Regional differences
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05/05/2011
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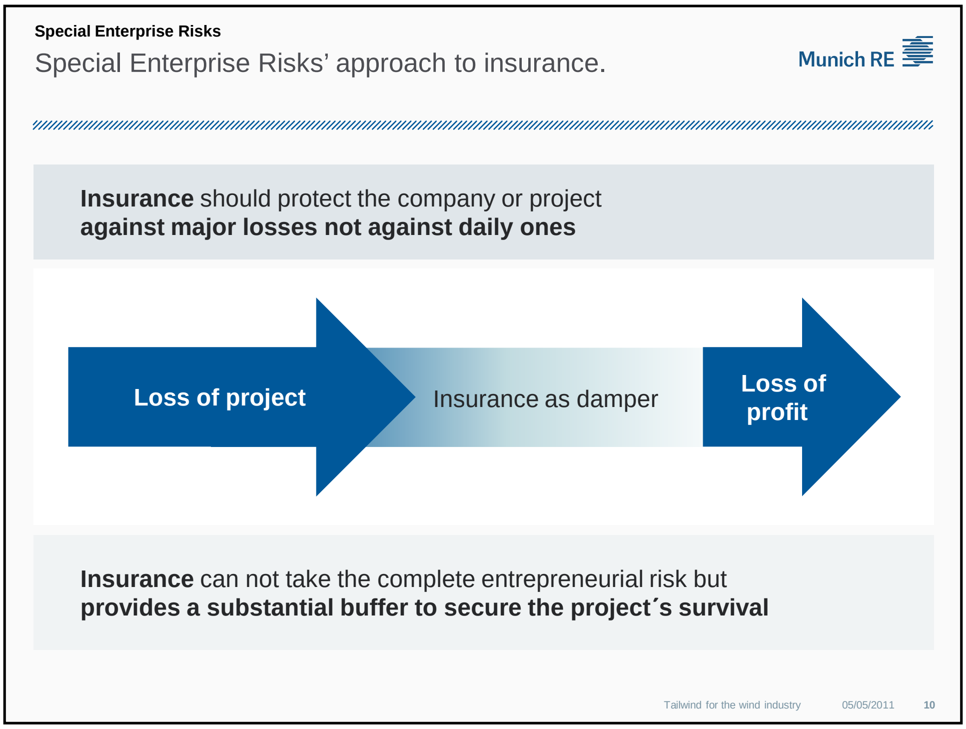
Special Enterprise Risks
Special Enterprise Risks' approach to insurance.
Munich RE
Insurance should protect the company or project
against major losses not against daily ones
Loss of project
Insurance as damper
Loss of profit
Insurance can not take the complete entrepreneurial risk but
provides a substantial buffer to secure the project´s survival
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05/05/2011
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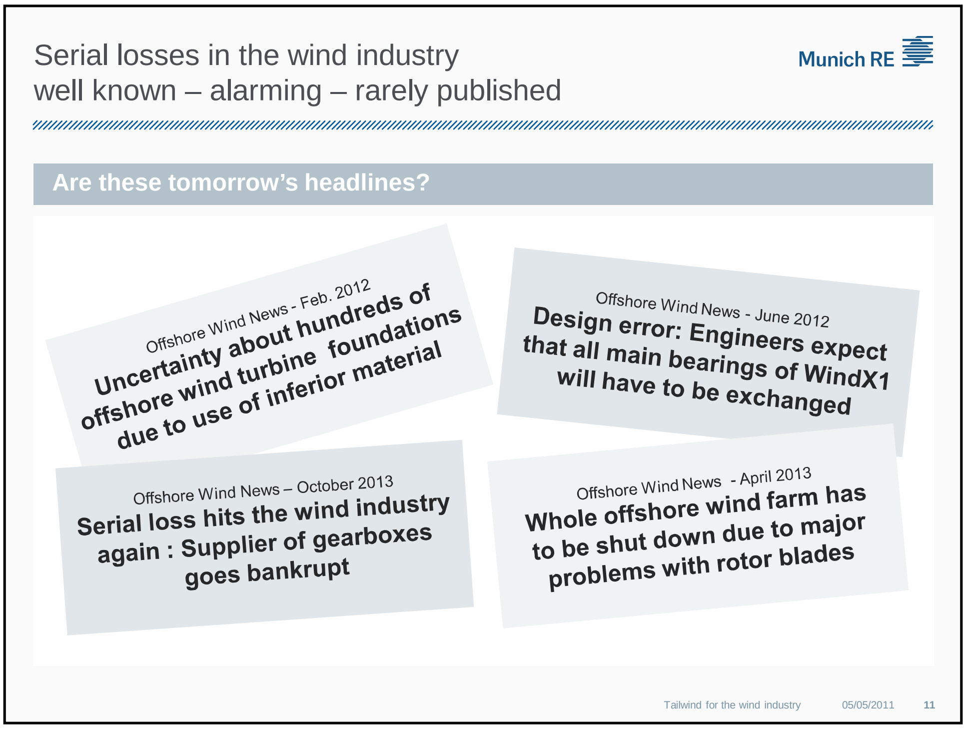
Serial losses in the wind industry
well known – alarming – rarely published
Munich RE
Are these tomorrow's headlines?
Offshore Wind News - Feb. 2012
Uncertainty about hundreds of offshore wind turbine foundations due to use of inferior material
Offshore Wind News - June 2012
Design error: Engineers expect that all main bearings of WindX1 will have to be exchanged
Offshore Wind News – October 2013
Serial loss hits the wind industry again : Supplier of gearboxes goes bankrupt
Offshore Wind News - April 2013
Whole offshore wind farm has to be shut down due to major problems with rotor blades
Tailwind for the wind industry
05/05/2011
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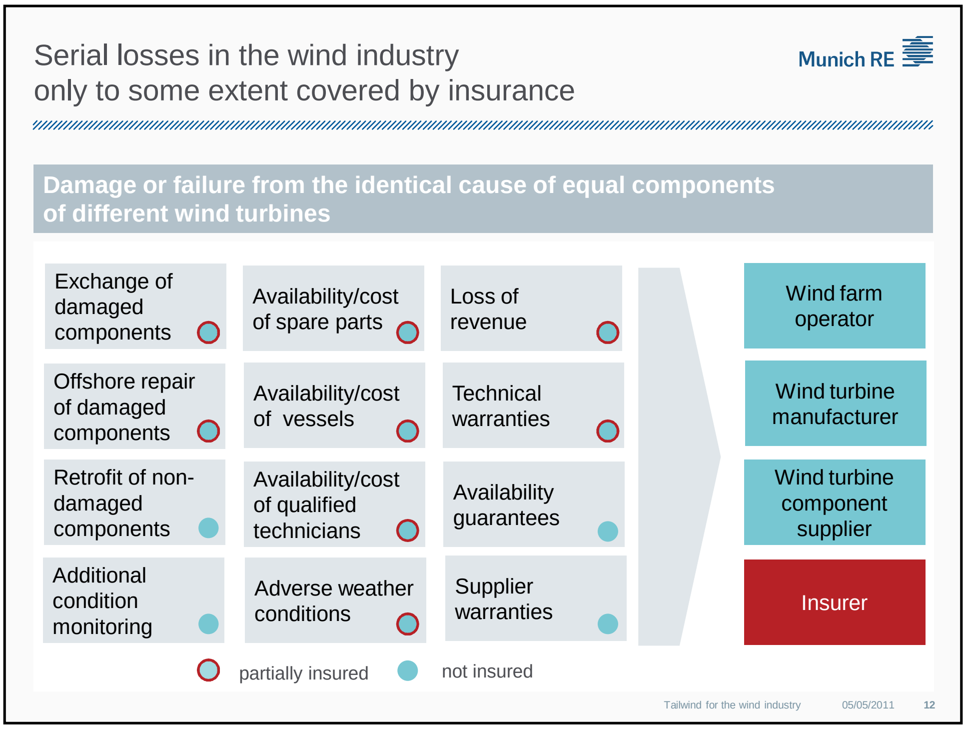
Serial losses in the wind industry
only to some extent covered by insurance
Munich RE
Damage or failure from the identical cause of equal components of different wind turbines
Exchange of damaged components
Availability/cost of spare parts
Loss of revenue
Offshore repair of damaged components
Availability/cost of vessels
Technical warranties
Retrofit of non-damaged components
Availability/cost of qualified technicians
Availability guarantees
Additional condition monitoring
Adverse weather conditions
Supplier warranties
Wind farm operator
Wind turbine manufacturer
Wind turbine component supplier
Insurer
partially insured
not insured
Tailwind for the wind industry
05/05/2011
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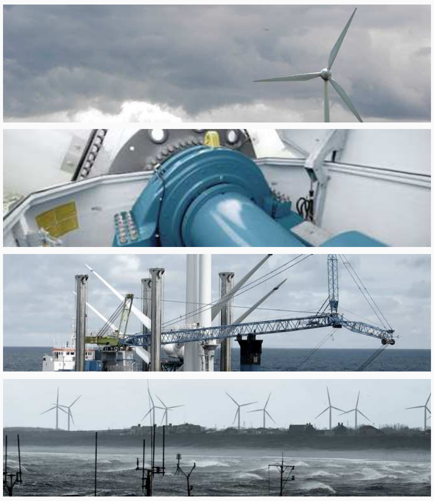
What's new from the insurer's side?

Munich RE



A serial loss is defined and handled as one event

Almost all costs related to a serial loss can be covered:

- **Physical damage**
- **Loss prevention** and **retrofits** for all components in the series
- **Offshore costs** such as jack-up-barges
- **Availability guarantees**
- Lack of access due to **adverse weather conditions**

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Which risks are covered?

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Insured penalties must be triggered by clearly defined named perils

Serial loss
(e.g. 10 or more losses with identical failures)

plus

- **Design error**
- **Bad workmanship**
- **Faulty material**
- **Non-performance of main suppliers due to insolvency**
- **Faulty instructions**

... etc.

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How does the cover work?

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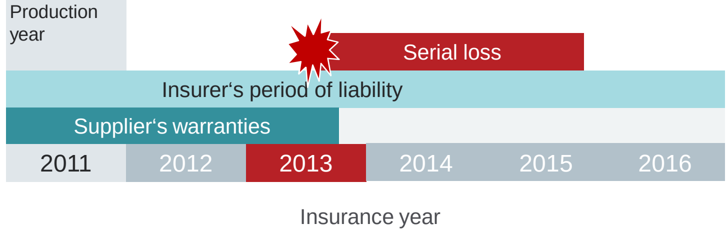
Cover for guarantee payments due to a serial loss



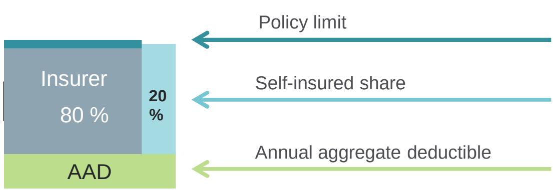
- **Multi-year** cover will be signed for each production year
- **Insurer cannot cancel the cover** due to insurance claims
- Any **serial loss will be allocated to the year the first loss** occurs

How much is insurable?

Munich RE

Serial loss cover

Insurance can not take the complete entrepreneurial risk but **provides a substantial buffer to secure the project's survival**



- Insurance cover on an event basis in excess of the AAD
- In excess of the AAD the client keeps a proportional participation

Overview of insurance policies

Munich RE

Cover characteristics	Property cover	Machinery guarantee	Serial loss cover
Fire	yes	-	-
NatCat	yes	-	-
Physical damage	-	yes	yes
Single failures	-	yes	-
Serial losses	-	limited	yes
Retrofits	-	-	yes
Faulty material	-	-	yes
Faulty design	-	-	yes
Bad workmanship	-	-	yes
Multi-year cover	-	limited	yes
Insurer may terminate policy after claims made	yes	ususal	-

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Advantages of the new serial loss cover

Munich RE

Advantages of the serial loss cover

- **Cover** for **major losses** and **unexpected accumulations** of serial losses
- **Increased planning reliability** of the project and operational phase
- **Optimized risk management strategy**
- **Liquidity** through insurance coverage → Increased security is valued by financing institutes
- **Competitive advantage** → Wind farm operators appreciate increased QA management and higher reliability of the guarantee
- **Reduction of provisions** for large guarantee losses in the balance sheet

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Munich Re

We provide unparalleled support for our clients' enterprise risk management

Munich RE

INVITATION

We look for **pilot clients** to continue our development of new insurance solution such us:

- **Serial loss cover** for wind turbines
- **Weather risk cover** for offshore projects

During **project-orientated collaboration** we will:

- Analyse your **risk situation** and assess your exposure
- Develop a **tailor-made insurance solution**
- Provide an **insurance policy** by using Munich Re Group's primary insurer

Tailwind for the wind industry 05/05/2011 19

THANK YOU.. ANY QUESTIONS? JUST FOLLOW-UP!

Michael Schrempp
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ADDITIONAL SLIDES

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Construction off-shore windpark

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1 **Offshore windparks**
- Strong growth
- High potential

2 **Hurdles**
- Legal issues
- Material defects

3 **Challenges during construction**
- Strong wind and high waves
- Availability of ships

4 **Insurance**
- Planning security
- Competitive advantage

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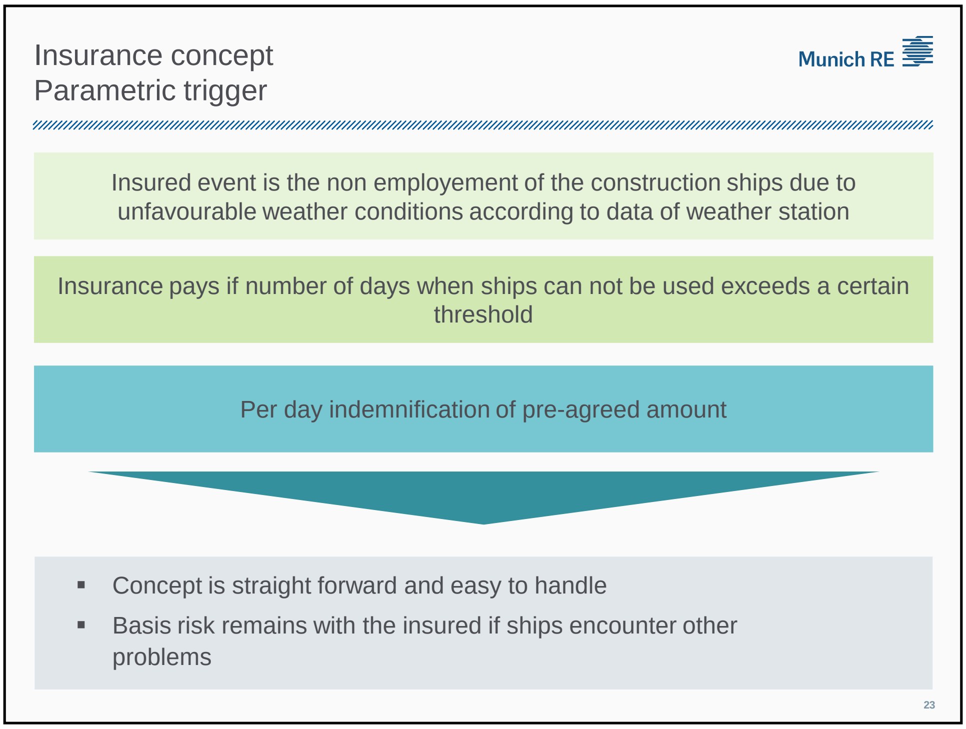
Insurance concept
Parametric trigger
Munich RE
Insured event is the non employement of the construction ships due to unfavourable weather conditions according to data of weather station
Insurance pays if number of days when ships can not be used exceeds a certain threshold
Per day indemnification of pre-agreed amount
Concept is straight forward and easy to handle
Basis risk remains with the insured if ships encounter other problems
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Life Cycle Cost for Offshore Wind Farms

François Besnard, Chalmers, PhD student
Thomas Stalin, Vattenfall, Senior Project Manager

IEA Expert Meeting "International Statistical Analysis on Wind Turbine Failures"
30 March 2011
Kassel, Germany

VATTENFALL

Vindforsk

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Outline

- Background
- Model
- Case Study
- Data Collection
- Conclusions

Photo: Lina Bertling

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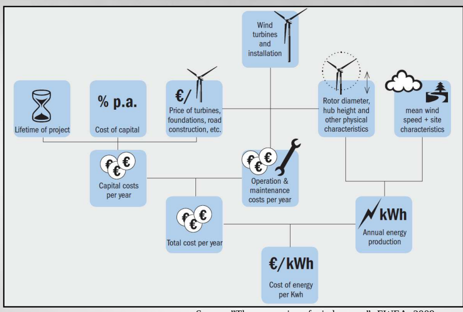
Besnard, Stalin
31 March 2011
1/18

Background (1)

Life Cycle Cost (LCC) and profit analysis is a method to evaluate the economic of a project by considering all the costs over the lifetime and taking into account the value of money through time.

- Investment (CAPEX)
- **O&M (OPEX)**
- Incomes
- (Repowering)
- Decommissioning



Source: "The economics of wind energy", EWEA, 2009

Applications:

- Cost benefit analysis of a project
- Continuous evaluation of the economic value of a project
- **Analysis of O&M**: Reliability/maintainability, maintenance strategies, design improvement, supportability, warranty/insurance/maintenance contracts

Background (2)

The basis for the LCC model is the **ECN O&M tool** implemented in Excel

- Model forecasting yearly O&M costs
- Certified by Germanischer Lloyd

Vattenfall bought a license in 2007

- First case study for Horns Rev (Baudish, 2007-2008)
- Multiple scenario analysis for comparison of wind farms, wind turbines, vessels and accommodation (Baudish, 2010)
- Extended to life cycle cost and profit analysis, and updated case study Horns Rev (Stalin, Besnard, 2010)

The LCC model was developed in parallel with the data collection and analysis for Horns Rev from work orders, SCADA data and interviews

Model ↔ Case study

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Model - Overview

The model focuses especially on the O&M phase:

- Simple investment and decommissioning model
- Simple energy yield model (based on capacity factor + availability)
- Simple electricity price scenarios (incentive system + prognosis)

O&M cost structure:

- Corrective maintenance
- Service/Preventive maintenance
- Retrofits
- Catastrophic/serial failures

(Corrective maintenance, service/preventive maintenance, retrofits and catastrophic/serial failures:) **Direct costs**: Staff, material, vessel/equipment
Indirect costs: Revenue losses

- **Fixed costs** (administration, transportation, logistic, O&M facilities, insurance, maintenance contracts…)

Insurance/Warranty/Maintenance contracts cover part of the costs

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Model - Input Data (1)

Corrective maintenance:

- Frequency maintenance events (repair, replacement, preparation)
- Maintenance procedure for each event:
  - Spare part logistic time
  - Vessels and equipment, and duration of use during repair
  - Number of technicians
  - Repair times
  - Option for splitting activity
- Cost for the material and spare part
- Option detection by CMS (i.e. grouping activities)
- Seasonal distribution (i.e. planning with CMS information)
- Applicable retrofit
- Applicable Warranty/Insurance (spare part, vessels, production losses)

Data structured according to RDS-PP, VGB, 2007

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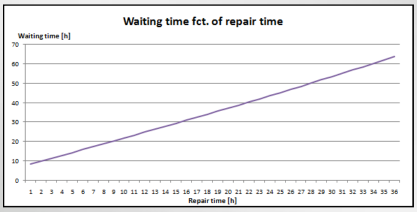
Model - Input Data (2)

Vessel characteristics and costs:

- Weather constraints (wind and waves)
- Logistic and travelling times
- MOB/DEMOB costs and daily rate
- Use for clustering

The accessibility is modeled as a **waiting time** depending on the weather constraints and calculated based on **wind and wave statistics**



Preventive maintenance activities:

- Seasonal distribution
- Duration
- Cost, staff, equipment

General wind farm data (capacity factors/seasons, staff costs and working hours, number of wind turbines), **overhead costs**

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Model - Input Data (3)

RDS-PP	Description of Repair Task	Failures Frequency [per y]	Material Costs [Euro/repair]	Crew Size	Repair Time [hrs]	Logistic Time Spare Parts [hrs]	Equipment *1st device*	Equipment *2nd device*	Equipment *3rd device*	Time [hrs] equipment is used *1st device*	Time [hrs] equipment is used *2nd device*	Time [hrs] equipment is used *3rd device*
MKA, MKJ, MKY												
	Remote Reset	X	X	1	2	0	10					
MKA10GA020-WN001	Preparation rotor cables	X	X	2	16	0	1					
MKA10GA020-WN001	rotor cables	X	X	0	8	48	1					
MKY10WD001	slipring	X	X	2	8	0	1					
MKA10UP001	bearings 1pc	X	X	2	4	0	1					
MKY10WD001	bruches	X	X	2	8	0	1					
MKY10QA001	Q8 breaker	X	X	2	4	0	1					
MKA10	generator complete	X	X	3	8	168	1	6	7			3
MKA10	preparation generator exchange	X	X	2	16	0	1					

	Maintenance type 1		Minor service maintenance		
Number of occurances during lifetime of 20 years		20	year		
Duration of maintenance		24	hrs		
Crew size		2,4	-		
Mat. Costs		X	Euro		
Type of equipment		2	service boat 2		
Travel time to or from the wind farm (one-way) [hr]		1	hrs		
Distribution over seasons		winter	spring	summer	autumn
		5%	20%	65%	10%
Length of working day [hr]	8,00	8,00	8,00	8,00	8,00
Working period	3,00	0,15	0,60	1,95	0,30

- Examples of some input data for corrective and preventive maintenance

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Model - Input Data (4)

The life cycle cost scenario:

- Investment costs (development, installation, WTs, foundations, grid), decommissioning costs, WF lifetime
- Real discount rate
- Electricity price scenarios
- Failure distribution for each corrective maintenance activity:
  - Constant failure rate (cf. "failure description")
  - Continuous improvement
  - Renewal process with Weibull distribution

  (the first three: + Retrofits)
  - Alternative for flexibility: Defined for each year
- Service/preventive maintenance activities performed each year
- Service and corrective maintenance, contracted availability during warranty
- Possibility to use historical costs (overwrite calculated costs)

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Model - Output

- O&M Cost distributions with and without warranty and insurances
- Cumulative incomes and costs

$$NPV = \sum_{t=1}^{N} \frac{I_t - C_t}{(1+r)^t} - C_{inv} \text{ with } C_t = C_{inv,t} + C_{O\&M,t}$$

Project performance indicators:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Profitability Index (PI)
- Break-even year
- Levelized Cost of Energy (CoE)

$$PI = \frac{C_{inv} + \sum_{t=1}^{N} \frac{I_t - C_t}{(1+r)^t}}{C_{inv}}$$

- Remaining economic value
- Possibility to focus on a specific year

$$CoE = \frac{NPV}{\sum_{t=1}^{N} \frac{E_t}{(1+r)^t}}$$

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Case Study

- 80 V80-2MW at Horns Rev in operation since 2002
- Located around 15km off the coast in Denmark
- Scope: Wind turbines and internal grid until circuit breakers on platform
- Connection to grid owned and operated by Energinet.dk

- Sources of data:
  - Wind and Significant Wave Height: Met mast and buoy 2002-2007 + Correction
  - Failure rates: Work orders from 2009 (age 8 years) + Transformers and Gearbox
  - Maintenance procedures: Interviews
  - Component costs: Data from spare part manager
  - Vessels characteristics and costs: Data from maintenance manager
  - Overheads costs: Data from maintenance manager

- Some data are assumptions of what could happened during the remaining lifetime (especially for grid connection, alternative Cired studies)

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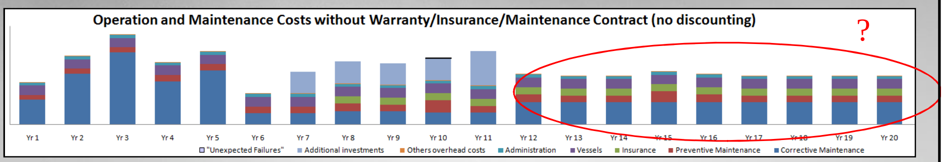
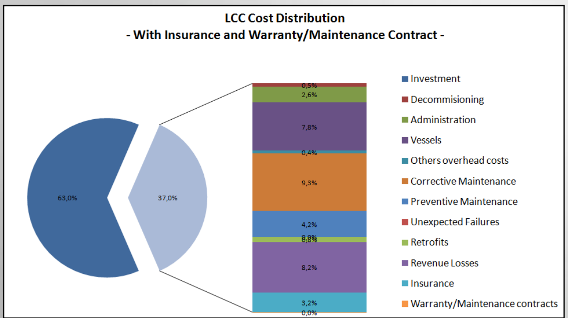
O&M Costs Results





- O&M cost contributors:
  - Corrective maintenance
  - Revenue losses
  - Transfer vessels
  - Preventive maintenance

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Data Collection (1)

- Need for structured and automated data collection of failure and maintenance events
- A standard designation is necessary for internal and external benchmarking, e.g. to adopt:
  - RDS-PP for functional structure
  - EMS for failure and maintenance event data
- Level of details should enable component lifetime analysis
- Training of maintenance personnel for proper data collection (Code bars)
- Reporting should be compulsory, with compulsory information fields

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Data Collection (2)

- Link failure/maintenance events with SCADA data for downtime (logistic, waiting, repair), and production losses
  - Require selection in SCADA alarm list for starting and end of failure event?
  - Statistical mapping of alarm codes and failures could be used for remote diagnosis
- Link maintenance events with personnel, spare parts, vessels and equipments use and their costs
- Requirement to be used by manufacturers during warranty period (especially for cost forecasting at the end of warranty)

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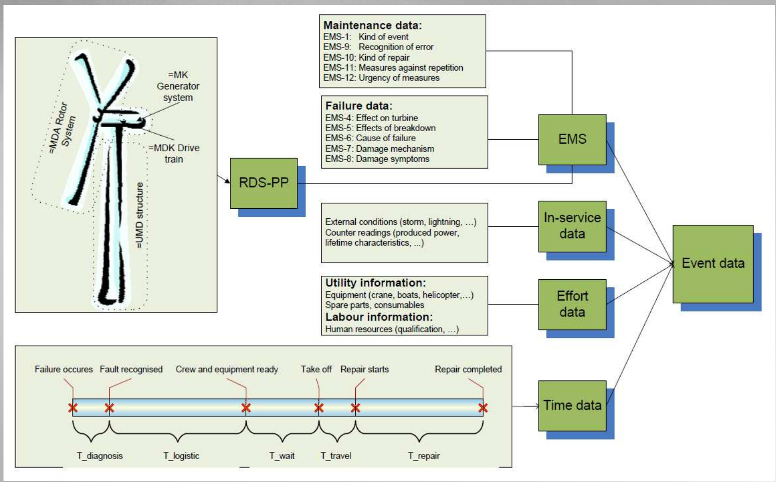
Data Collection (3)



Source: "*Suitable failure statistics as a key for improving availability*", S. Faulstich & al., EWEC 2009

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Conclusions

- A tool for life cycle cost and profit analysis with special focus on O&M
- A case study was possible with available data but hard work on analysis and required discussion for data validation
  - Need for structured and automated failure and maintenance data collection + link to SCADA
  - Training maintenance personnel for data collection
- Statistical analysis of component failures for long term prognosis or maintenance strategy optimization requires detailed level of information
- Further data analysis at Horns Rev 2009-2010

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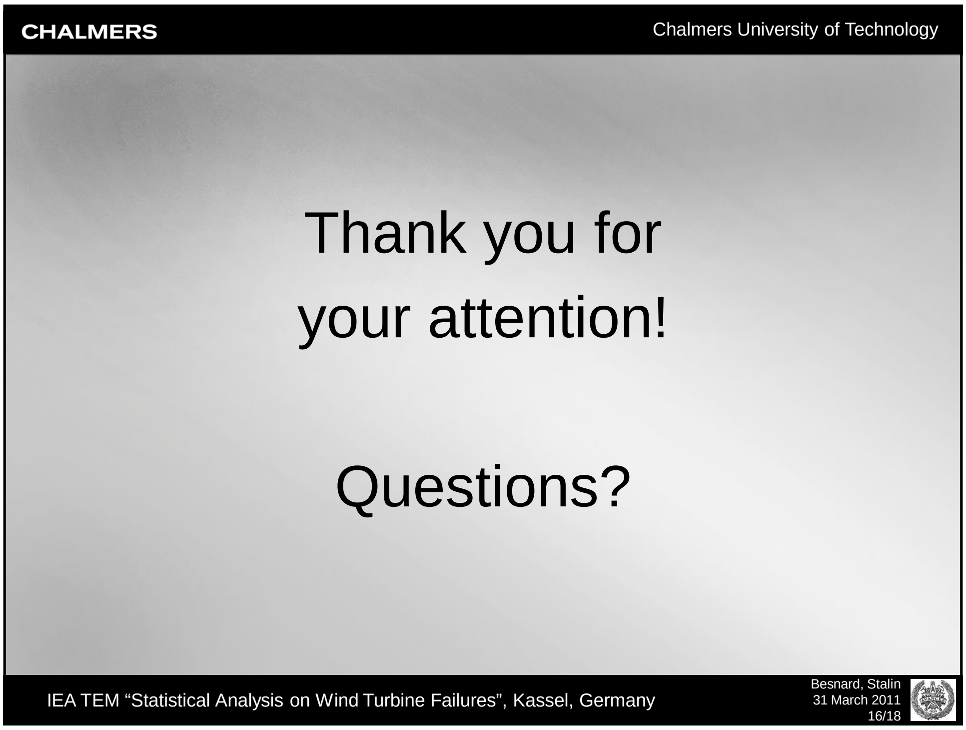
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Thank you for
your attention!
Questions?
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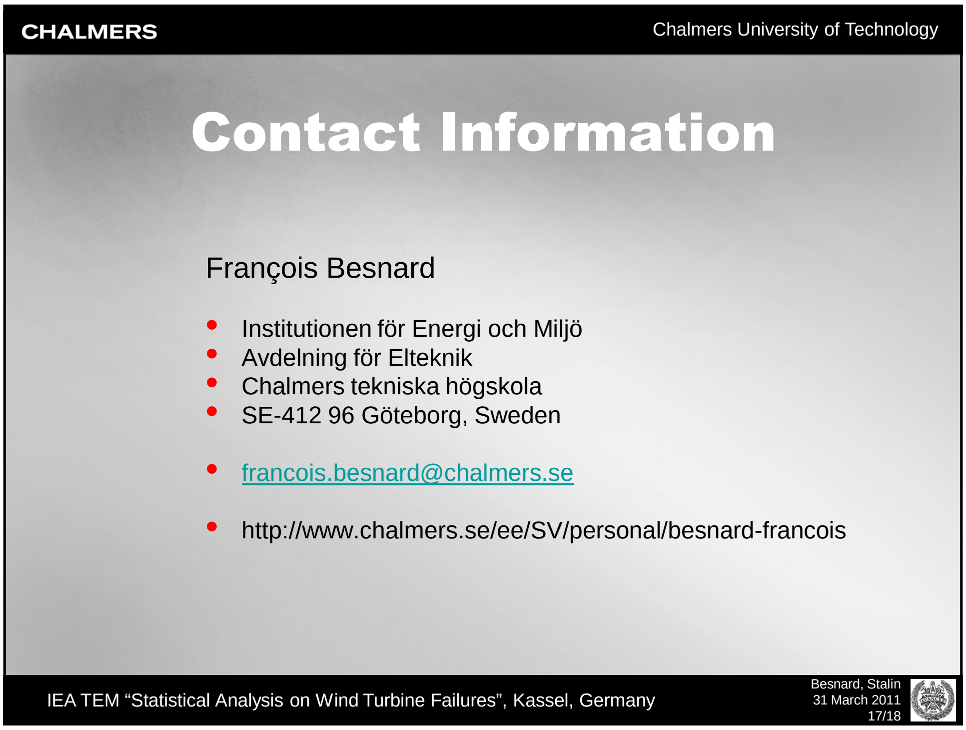
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Operator’s requirements for maintenance and inspection

Axel Ringhandt
Konrad Iffarth

VGB - Konferenz Instandhaltung von Windenergieanlagen 23./24. Februar 2011 in Hamburg

ENERTRAG

- **720 Megawatt in operation**
- **440 WTG erected**
- **1500 GWh annual energy production**
- **which cover the demand of 1.5 mio people**

- **250 Mio. Euro annual turn over**
- **Total investment 1000 Mio. €**
- **370 employees and 16 apprentices**

VGB - Konferenz Instandhaltung von Windenergieanlagen 23./24. Februar 2011 in Hamburg

Windstrom

- **428 Megawatt in operation**
- **248 WTG in operation**
- **817 GWh annual energy production**
- **which cover the demand of 0.8 mio people**

- **75 Mio. Euro annual turn over**
- **Total investment 550 Mio. €**
- **60 employees**

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ENERTRAG

Control Room Dauerthal

Monitoring of app. 950 WTG

15 Specialists - 24 / 7

ENERTRAG Windfarm companies
- 400 WTG
- GE – GE 1,5s, sl
- Vestas – V80, V90
- Nordex / Südwind – N60, N90, S70/77
- Enercon E40, E58, E66; E70, E82
- DeWind – D4, D6, D8

Customers across Europe
- 550 WTG
- DeWind D4, D6, D8
- Tacke – TW 600

Windstrom

Control Room Alvesse

Monitoring of app. 250 WTG

4 Specialists - 16 / 7

Windstrom Windfarm companies
- GE – GE 2.3, 1.5sL
- Vestas – V80; V90
- Nordex – N60; N27
- Enercon E40, E66; E70, E82
- AN Bonus – 1.3, 2.0, 2.3VS
- NEG Micon - NM1000

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ENERTRAG WindStrom Betriebs- und Verwaltungs-GmbH

Operator / Maintenance duties

Targets

- Optimal reliability and availability of WTG
- High performance of wind farm
- Optimal expenses for maintenance
- Preventing damages from the environment
- Securing health and safety of the employees

How to do

- Operation and monitoring
- Inspections
- Monitoring of maintenance
- Organisation of repair
- Technical improvements

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ENERTRAG WindStrom Betriebs- und Verwaltungs-GmbH

Objectives / Basis of requirements

Reduce costs of Energy

Increase content of information

Increase maintenance process efficiency

- **Qualification of personnel**
- **Automation of repeating activities**
- **Help from statistical databases**
- **Maintenance strategy customisation**
  - **- Requirements**
  - **- Provider**
  - **- Price**
  - **- Frequency**

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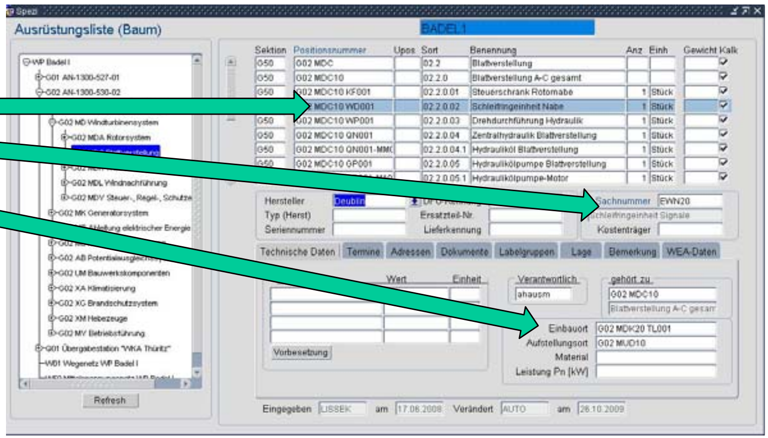
Tools to meet the objectives

Structuring principles for
- **Functions**
- **Object types**
- **Locations**
- **Incident types**



Definition of interfaces between the participants
- **Operators**
- **Supplier of services**
- **Independent experts**
- **Owner's engineer**
- **Local authorities**

RDSPP - for wind power plants Status of work & outlook (1)

RDS-PP: Designation grammar for all power plant types

General rules fixed in IEC 81346 -1 and -2 and ISO TS 16952

Looks at aspects (function, location, connection, document …

Mostly tree structures („belongs to – rule")

„Problems" for wind energy:
- **Benefit only if unique designation**
- **Harsh discipline required**
- **Serial production objects**
- **High number of generating plants**

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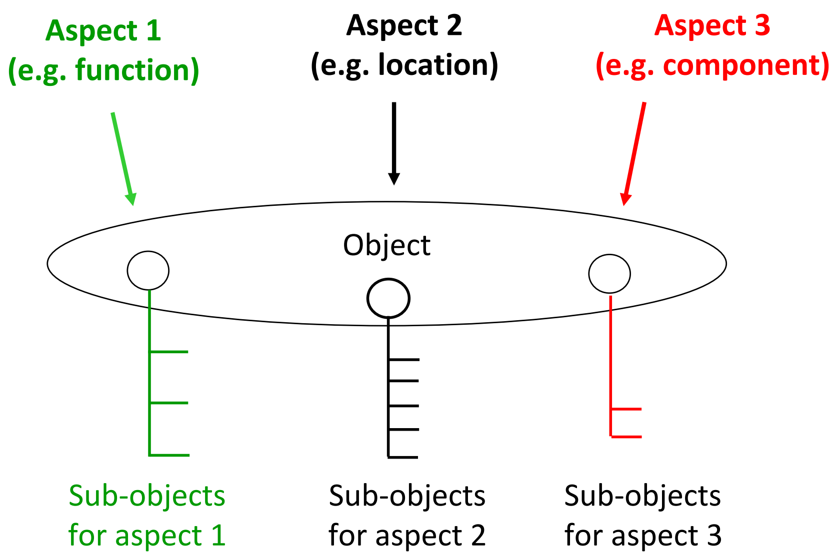
RDSPP - for wind power plants Status of work & outlook (2)



object + aspect + rules = structure

RDSPP - for wind power plants Status of work & outlook (3)

Solution: clearer set of rules by master lists and better help documents

1. **Ongoing revision by VGB-group**
   of RDS-PP application recommendations B116 D2
2. **Working group around SIEMENS Wind Power**
   (DONG, Statkraft, e.on UK, Statoil, centrica)
   Structuring of SIEMENS 2.3 VS and 3.6, advanced
3. **Fast Track User Group**
   (Enercon, REpower, Multibrid, RWE Innogy, e.on D, Vattenfall, EnBW, WindStrom, Enertrag, FGW, ...

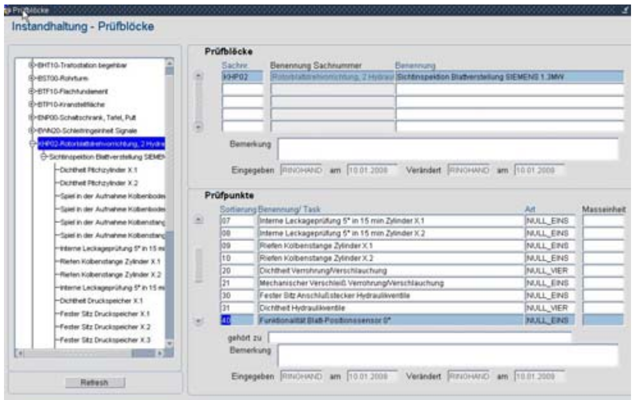
General approach for **all** renewable power plants & all turbine types
Conjoint designation, level zero and level one finished
Masterlist for all turbine type structures ongoing
Internet portal to download finished structures by mid 2011

ENERTRAG WindStrom Betriebs- und Verwaltungs-GmbH

Catalogue of objects

No standard for wind energy existing so far

- VGB catalogue B102 covers only part of necessities
- Systematic approach through functions till products



WindStrom example from international plant building

- Basis for design of master check lists for inspection and maintenance
- Standardised scope for similar objects
- Will be generated in EVWII Project till 2012

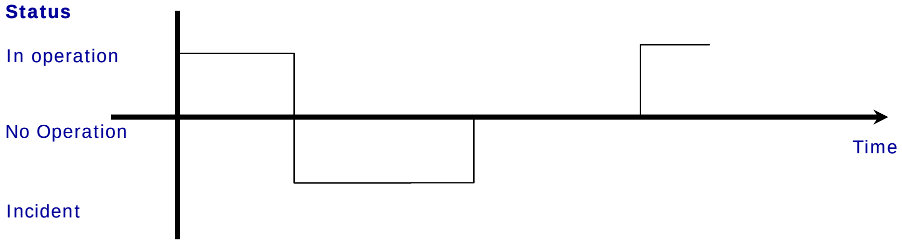
ENERTRAG WindStrom Betriebs- und Verwaltungs-GmbH

Snap-shot Market overview RDS-PP future use

13 medium to large operators inquired with 3700 WTGs and 6200 MW
3 expert organisations with a total of 4500 WTGs/a

1. **Would you use standardized RDS-PP templates for WTG's?**
   88 % voted yes,
   Average introduction time, 1.6 years
2. **How much would you spend for a template?**
   Answers varied between 150 € and 1000 €/template
   Average about 420 €/type, volume discount proposed
3. **Would you require others to use RDS-PP in communication?**
   59% of the organisations voted yes,
   some concern about effort required to succeed

Incident caused status modification (ICSM)

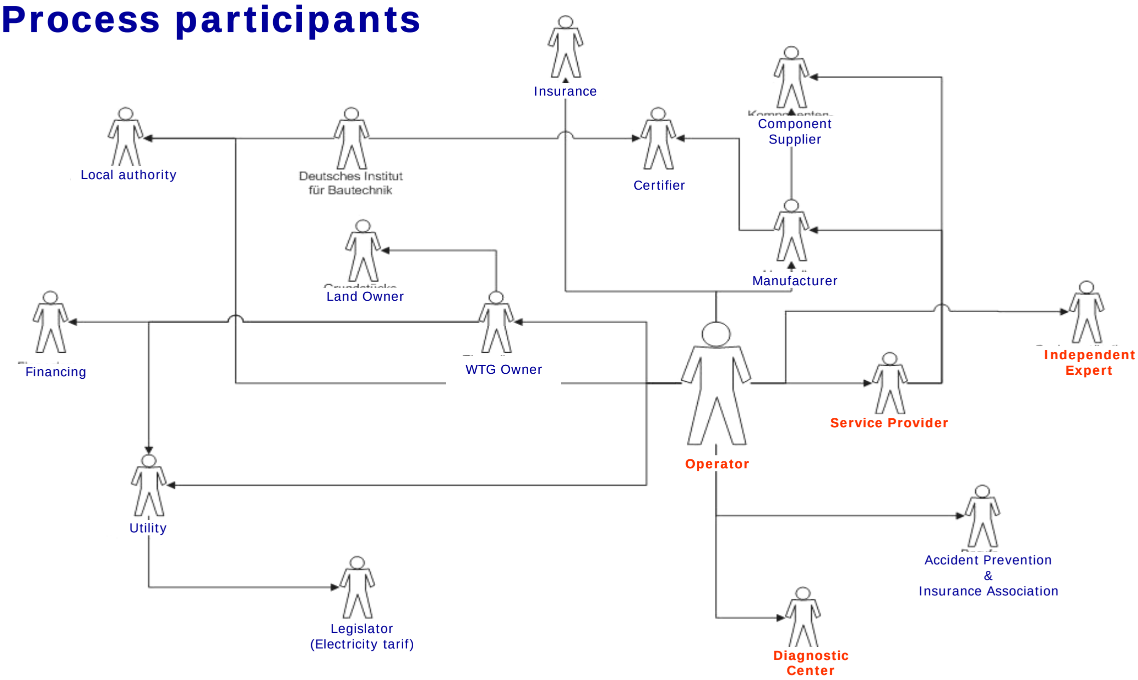


Every incident which is a failure is **caused** by an object (RDS-PP - component) and has a **reason** for the malfunction of the component.

Funktionszustand	Details	BB Funktions-zustand-Code	Bemerkung
Funktionsfähiger Zustand	in Betrieb	00	
Funktionsfähiger Zustand	mit Auffälligkeiten	01	Beobachten, rechtfertigt aber noch keinen Handlungsbedarf
Eingeschränkter Funktionszustand	mit Auffälligkeiten	02	Sehr gering: Auffälligkeit kann zu nächsten Inspektion/Wartung beseitigt werden
		03	
	ohne Leistungsreduktion	04	Klare Defekte: mit der nächsten Wartung sollte Instandsetzung erfolgen
	ohne Leistungsreduktion	05	Bei interner Störung: schwere Defekte: Instandsetzung sollte unverzüglich erfolgen
	mit Leistungsreduktion	07	
	mit Leistungsreduktion	08	
Störung	Außer Betrieb	09	
Gefährlicher Zustand	Außer Betrieb	10	Instandsetzung muss unverzüglich erfolgen

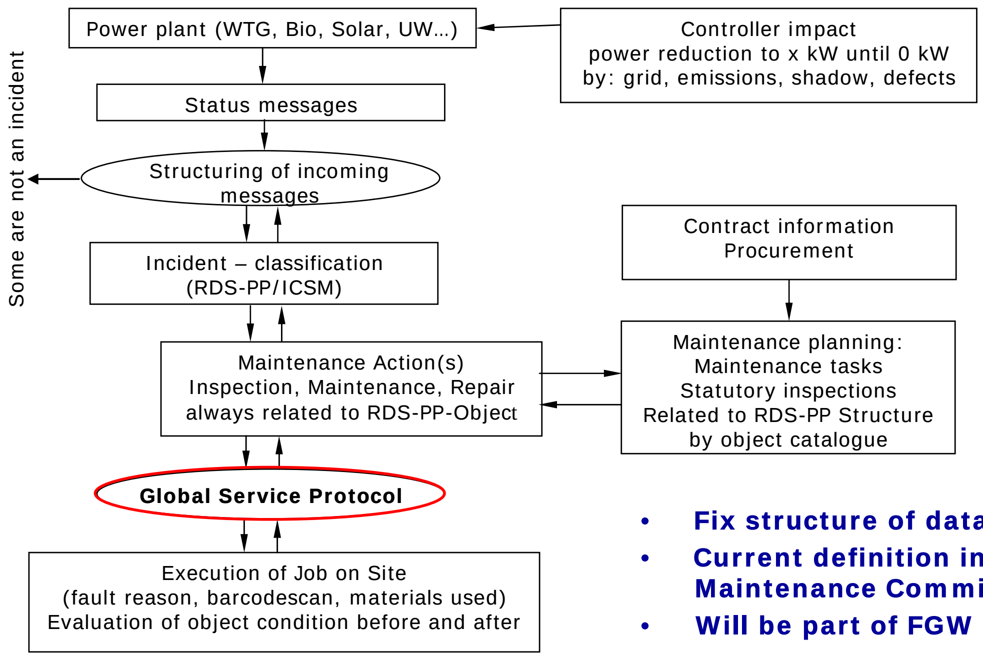
Standard data transmission

Process participants



Digital data transfer required for red marked participants.

Global service protocol



- **Fix structure of data transfer**
- **Current definition in Maintenance Committee of FGW**
- **Will be part of FGW TR7**

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Snap-shot Market overview RDS-PP future use

13 medium to large operators inquired with 3700 WTGs and 6200 MW
3 expert organisations with a total of 4500 WTGs/a

1. **Would you use or im-/export digital inspection protocols?**
   81 % voted yes,
   Average introduction time, 1.8 years
2. **Would you use a custom handheld w/ software for these tasks ?**
   Answers varied between already in use til never, solid scepticism
   Average about 60 % yes

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Operation and monitoring requirements for Control Room

Basis: easy to monitor graphs for normal operation parameters
(power curve, subsystem main health parameters,
green- yellow-red conditions,)

1. Operation outside normal parameters:
Identification of inspection or maintenance / repair activity

Tools:
1.1 expert system on status, faults, health parameters
1.2 know-how of function of unhealthy object (documentation)
1.3 structures (activity classes, RDS-PP, ISS Incident status system)

2. Ticketing (generation of required activity / job)

Tools:
2.1 direct link or integration of ERP-system
2.2 coding of job by GSP

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Inspection

ENERTRAG Service GmbH
PROTOKOLL INSPEKTION

	ja	nein		Foto beigefügt
8.7 Getriebe / Ölpumpe / Kühlung				
Ölschauglas verschmutzt				
Ölstand überfüllt				
Ölstand unterfüllt				
Schläuche undicht				
Verschraubungen undicht				
Leitungen undicht				
Ölaustritt Getriebeeingang				
Ölaustritt Abtriebswelle				
Undichtigkeit Getriebegehäuse				
Undichtigkeit Getriebeölpumpe/filter				
Gebläsekühlung Lüfterrad frei				
Ölaustritt Kühler				
Wasserkühlung (wenn vorhanden)				
Kühlsystem undicht				
Verschraubungen Kühlsystem undicht				
Leitungen des Kühlsystems undicht				
Entfeuchter Verschleißanzeige >90%				
Nebenstromfilter (wenn vorhanden)				
Schläuche Nebenstromfilter undicht				
Verschraubungen Nebenstromfilter undicht				
[illegible]				
Pumpe auf Dauerbetrieb				
8.8 Hydraulische Bremse				
Aggregat undicht				
Schlauch undicht				
Verschraubung undicht				
Bremskolben undicht				
Bremsbelag + Trägerblech in mm			Maß: mm	
Bremsscheibe Dicke in mm			Maß: mm	
Luftspalt Belag Scheibe Rotors.(RS) > 1,5 mm			Maß: mm	
Luftspalt Belag Scheibe Genos.(GS) > 1,5 mm			Maß: mm	
8.9 Generator				
Generatorlager A				
Fettauffangbehälter Genlager A vorhanden				
kein Fett im Auffangbehälter				
Dunkelfärbung des Fettes				
Permaschmierung Generatorlager A vorhanden			Datum:	
Fettstand Strich und Datum vorhanden				
Veränderung Fettstand vom letzten Eintrag bis jetzt				
Fettstand Strich und Datum angezeichnet				
Generatorlager B				
Fettauffangbehälter Genlager B vorhanden				
kein Fett im Auffangbehälter				
Dunkelfärbung des Fettes				
Permaschmierung Generatorlager B vorhanden			Datum:	
Fettstand Strich und Datum vorhanden				
Veränderung Fettstand vom letzten Eintrag bis jetzt				
Fettstand Strich und Datum angezeichnet				
Riss am Generatorgehäuse				
Riss o. Undichtigkeit Generatorkühlung				
Wasserkühlung vorhanden				
Kühlsystem undicht				
Verschraubungen Kühlsystem undicht				
Leitungen Kühlsystem undicht				

Watching **necessary** components:

Modular composition of total inspection tasks,
depending on purpose (overall job)
on RDS-PP main system level (ie: Yaw System)

Documentation of actual conditions:

Routine inspections and special ad-hoc investigation
- type of object catalogue
- classification of findings catalogue (EVWII)
- return of findings in digital form (GSP)

Evaluation of inspection results:

Connection to quality assurance applications
- database use for responsibility assignment & communication
- classification of remedy methods (EVWII)

Data interchange with
manufacturer's or independent service organizations

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Maintenance

ENERTRAG WindStrom Betriebs- und Verwaltungs-GmbH

Maintenance Strategy

Combination of planned and predictive Maintenance

Analysis of WTG Operational Data via:
- CMS
- Performance Data
- Frequency and Type of Failures

Work Identification

Technical Modification
- Maintenance Technology
- Design Modification
- Third party supplier

Work Control

Field Testing
- Measurements
- Analysis of Performance Data
- Analysis of Type and Frequency of Failures

Work Execution

Implementation
- Design Modifications of serial products
- Modification of Maintenance Procedures or Quality
- Modification of Operational Procedures
- Modification of third Party Suppliers

Identifying the Problems

MTBF Detection

Root Cause Failure Analysis

Quality and Quantity of Maintenance

Technical Cause of Failure
- Design
- Operation
- Quality
- Operational Cause of Failure

Solving the Problems
- Testing and Evaluation
- Implementation to Serial
- Retrofit to running WTG

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Structure

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Maintenance Component Engineering
- Gearboxes / Main Bearings
- Generators
- Converters
- Blades
- Control system

Quality Management System

Health - Environment - Safety

Purchasing & Logistics
- Spare Parts
- Equipment / Tools

Commercial and Technical Management
- Customer support
- Contract design
- Controlling

Condition Monitoring
- Gearboxes / Main bearing
- Converters
- Generators
- Rotor Blades

Remote Control and Operation

ENERTRAG PowerSystem

WindPlant
- Statistics
- Performance Reporting
- Basic data for analysis

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Future conditions

Weather forecast on WTG level
by EWC, Meteo, DWD, …….

Two ways of selling electrical energy
- **Acc. EEG regulations**
- **Direct marketing to customers**

Offshore Operation of WTG
- **Weather conditions → accessibility !**
- **Maintenance interval**

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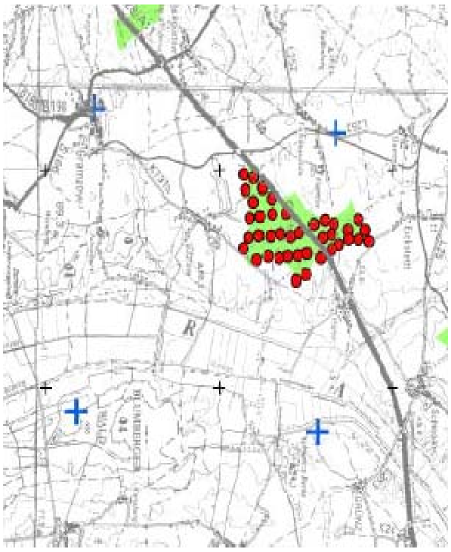
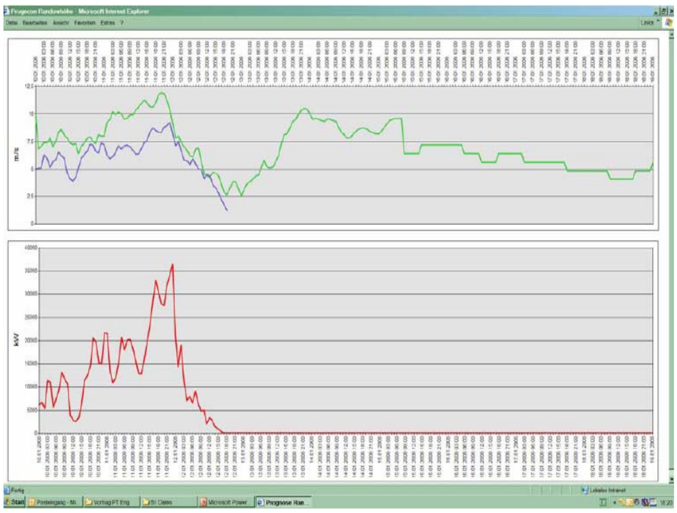
Statistical conditions

Data based supported operation of WTG

→ Wind forecast





Forecast of wind speed and power output

A tool for planning and maintenance

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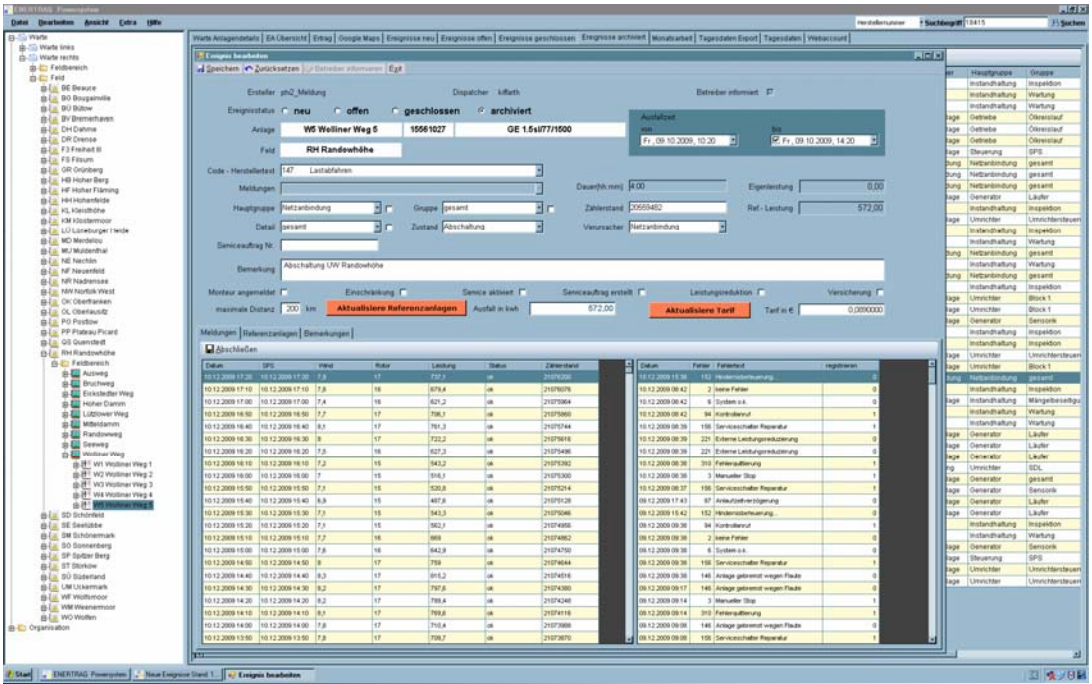
ENERTRAG WindStrom Betriebs- und Verwaltungs-GmbH

ENERTRAG PowerSystem - Incident information



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OLAP – Incidents evaluation

Fields: RDS_PP_E1, RDS_PP_E2, RDS_PP_E3, RDS_PP_E4, RDS_PP_E5, RDS_PP_E6, Anlagentypen, Windzonen, Landschaftskategorien, Anlagentypgruppen, Altersklasse, Anlagenkonzepte, Anlagenhersteller, Ereignisarten, Fehler_, Leistungsregelung, Drehzahlverhalten, Generatorbauart, Leistungsklassen

RDS_PP_E1	RDS_PP_E2	RDS_PP_E3	RDS_PP_E4	Ereignisanzahl Σ Summe Σ Agg. value
+				28.312
− =MD Windturbinensystem	− =MDY Steuer-, Regel-, Schutzeinrichtung	− =MDY10 Elektrische Steuerung	+	3.045
			+ =MDY10 WD001 Steuerkabel Haupt-Topschrank	603
			+ =MDY10 QA001 Haupt-Schrank	493
			+ =MDY10 BE001 Leistungsmessung	47
			+ =MDY10 Elektrische Steuerung	1
			Gesamt	4.189
		+		2.283
		Gesamt		6.472
	− =MDK Triebstrang	+ =MDK20 Getriebe		1.450
		+ =MDK30 Bremssystem		1.436
		+ =MDK10 Rotorwelle		634
		+ =MDK40 Kupplung		316
		+		101
		Gesamt		3.937
	+ =MDC Blattverstellung			3.568
	+ =MDL Windnachführung			2.308
	+ =MDA Rotorsystem			1.955
	+ Andere			17
	Gesamt			18.259

ENERTRAG WindStrom

Qualifications / Standards – future prospects

Standardized information interchange by all market participants

Competence unifying and improvement of the market actors

Accreditation acc. FGW TR 7

Acceptance of operators knowledge and experience by:

- **Insurance companies**
- **Local authorities**
- **Financing institutions**

VGB - Konferenz   Instandhaltung von Windenergieanlagen   23./24. Februar 2011 in Hamburg

Approach to systematically record O&M Data for Offshore Wind Farms

Workshop: International Statistical Analysis on Wind Turbine Failures

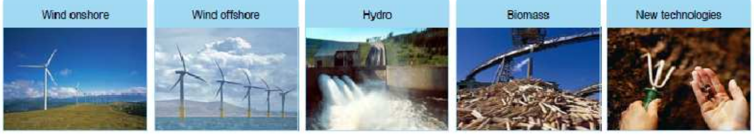
Kassel, 30th - 31st of March, 2011

Agenda

1. Introduction of RWE Innogy and Innogy Offshore
2. Introduction of Offshore Operations and Maintenance Strategy
3. Failure Databases for Offshore Wind Turbines
4. Computerised Maintenance Management System (CMMS)
    1. RWEI's Approach on Data Collection
    2. RDS-PP (Consistent Asset Coding Structure)
5. Summary and Outlook

RWE Innogy

- Established in February 2008 as the Renewable Energy Group business of RWE AG and is divided into the following technologies:

	Wind onshore	Wind offshore	Hydro	Biomass	New technologies
Business Area					
Focus and Strategy	Key technology for capacity growth Focus on organic growth Focus markets include UK, Spain, Germany, France, Italy, Central- and South-Eastern Europe	Key technology for capacity growth Organic growth strategy leveraging strong position in UK Focus markets include UK, Germany and Netherlands	Run-of-river projects and storage plants Development of hydro power projects Focus areas are Central- and South-Eastern Europe	Development of biomass plants (> 5 MW) Regional focus on RWE core markets and Central- and South-Eastern Europe	Ventures and R&D Emerging technologies Carbon neutral generation Efficient energy storage

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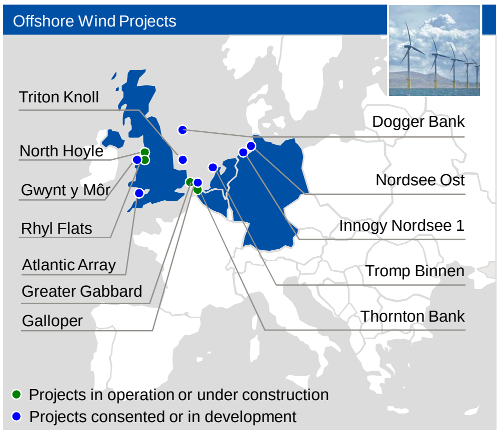
RWE Innogy Offshore Wind Projects



RWE Innogy Offshore Wind Pipeline

- 0.76 GW installed capacity in 2013
- At the beginning of 2015 minimum of 1.7 GW consented for Installation before 2020 – based on a project-pipeline of ca. 4.5 GW

Impact on Offshore O&M

- 1.7 GW own capacity equals ca. 3.4 GW shared capacity with other partners
- 3.4 GW equals ca. 800 locations of turbines for an average size of 4.3 MW
- Scope of work: 800 foundations and 800 turbines have to be installed and operated in future

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RWE Innogy Offshore Wind

Actual Project Development for Offshore Wind in Germany and UK

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	Beginning of first electricity production scheduled for early 2011, fully operational 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.

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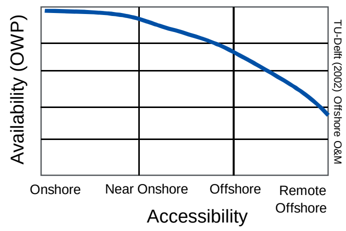
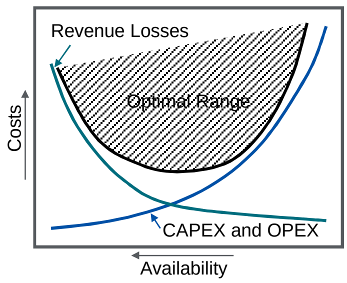
Offshore Operations and Maintenance

Overcome the 95% availability approach

- Shore distance has a negative impact on accessibility
- Frequency of failure occurrences is a key driver
- Therefore more effort in O&M is required to provide a high availability
- Balance availability with O&M costs in the long-run
- Well scheduled O&M planning is needed to establish synergies and high availability
- Establish reliability awareness over the life-cycle of an OWP





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Databases for Offshore WT

Influencing Factors on Reliability

- Size
- WT concepts
  - Gearbox vs. Direct Drive
- Complexity in electronics
- Offshore conditions
  - Average wind speeds
  - Extreme Loads
  - Wake effects
  - Corrosion etc.

Type of OWT	Size [MW]	dRotor [m]	Power Control	Generator	Gearbox
Siemens 3.6	3.6	107	Pitch with active Stall	AG	3-level-combined gear set
Repower 5M	5	126	Pitch with active Stall	DFIG	3-level-combined gear set
Multibrid 5000	5	116	Pitch with active Stall	SG	1-level-planetary gear set
Bard 5.0	5	122	Pitch with active Stall	DFIG	3-level-combined gear set
Repower 6M	6	126	Pitch with active Stall	DFIG	3-level-combined gear set

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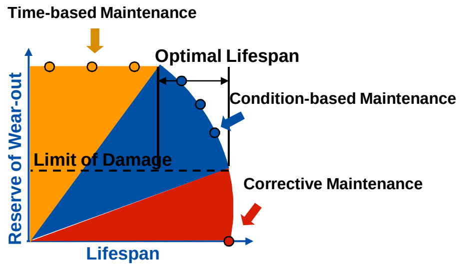
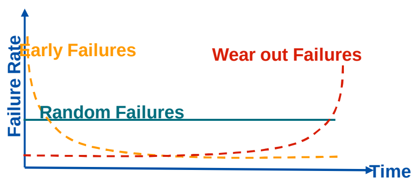
Databases for Offshore WT

In Order to define Proactive Maintenance Strategies at an early stage





- Collect and evaluate failure data
- Focus on life-cycle approach and failure analysis
- Establish trends and estimations for the lifespan of OWTs, their assemblies and components
- RWE Innogy Approach:
  Set up a system and start in-house data collection

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Computerised Maintenance Management System

Key Drivers for the Implementation of CMMS (SAP-PM)

- Capture WT performance history
- Capture WT maintenance history
- Establish maintenance strategies for complex machines
- Analyse reliability of WT assemblies, subassemblies and components
  - MTBF
  - MTTR
- Capture aspects on availability (generation & downtime)
- Measure additional requirements
  - Health & Safety
  - Asset Management
  - Procurement and more….

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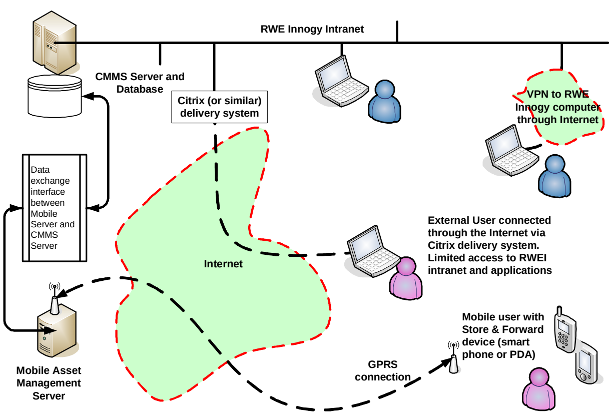
CMMS (SAP-PM)

Proposed Technology Infrastructure



- Simple and intuitive Graphic User Interface (GUI)
  - To simply enter the data on a "day job"
- Database available across RWE Innogy via
  - Intranet and Citrix
- Report Creation for other functions in RWE Innogy as,
  - Operations & Maintenance
  - Asset Management
  - Materials Management
  - Contract Management

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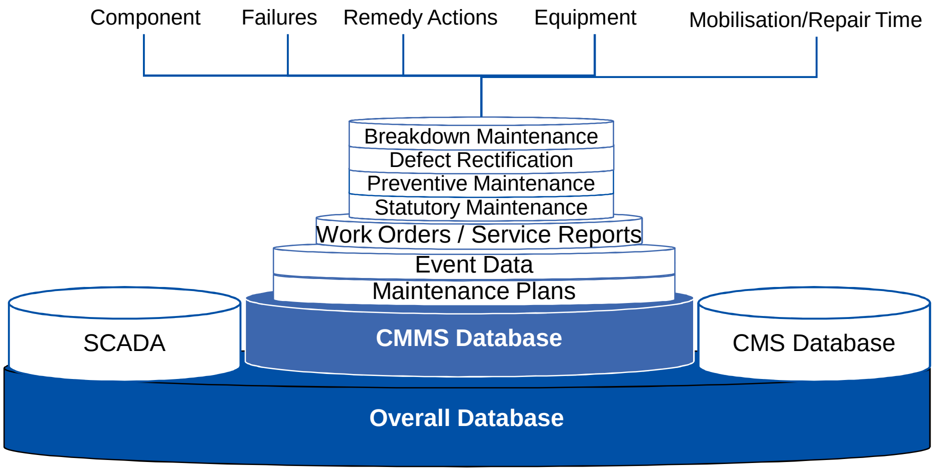
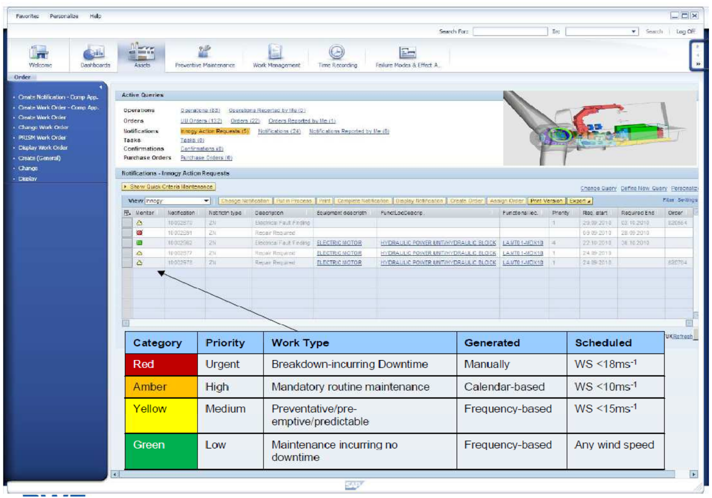
Data Collection of Own Assets

CMMS (SAP-PM)



CMMS Scheduling

Example: Wind Speed Based Work Scheduling



Category	Priority	Work Type	Generated	Scheduled
Red	Urgent	Breakdown-incurring Downtime	Manually	WS <18ms^{-1}
Amber	High	Mandatory routine maintenance	Calendar-based	WS <10ms^{-1}
Yellow	Medium	Preventative/pre-emptive/predictable	Frequency-based	WS <15ms^{-1}
Green	Low	Maintenance incurring no downtime	Frequency-based	Any wind speed

First Steps for CMMS Integration

- Agree on consistent RDS-PP coding structure
  - Joint Employment Project – Guidelines to Application (February, 2011)
- Agree on consistent structure for failures, causes and remedy action
  - Failure Tree Analysis (FTA)
  - Failure Mode Effect Analysis (FMEA)
- Set up Pilot Systems to prove and pioneer the CMMS and respective processes (beginning of 2012)
  - Offshore O&M base in UK (Mostyn)
  - Onshore Wind Farms in Spain (70 x 2.0 MW)

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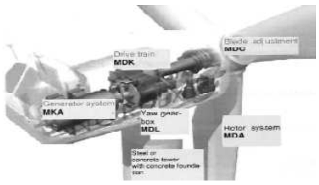
Reference Designation Coding System

Fast Track Users Group

Statkraft DONG energy e·on centrica Statoil SIEMENS Siemens Wind Power RWE

- Creation of a ‚Master RDS-PP coding structure', from which all turbine models can be compiled (SCADA, CMMS, IM)
- VGB Power Tech and ISO/IEC 81346
- The master RDS-PP code will be made up of all components from all turbines. It is to represent a „full" list of possible system component combinations
- Coding of WTG and extending the coding to BoP
- Accurate record of installed equipment, track maintenance, component life, link to information sources etc.



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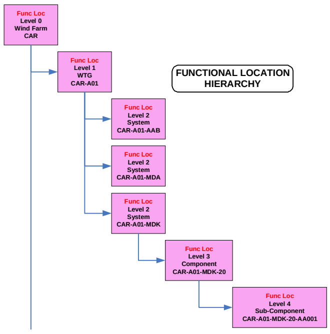
Functional Locations RDS-PP Coding

Alignment on Functional Location Hierarchy for WT



- Agreement on function and product codes (latin capital letters)
  - Overall System (level - 0)
  - System/Subsystem (level – 1)
  - Technical Equipment (level – 2)
- Agreement on location codes (numbers)

Function codes, F = Function				Product codes, P = Product		
Prefix	F0	F1	F2	Prefix	P1	P2
=	ANN	AAANN	AANNN	-	AANNN	AANNN
	Overall sys-tem	System /subsystem	Technical equipment		Product	Product

A = Latin capital letters, not including I and O
N = Numerals, 0 to 9.

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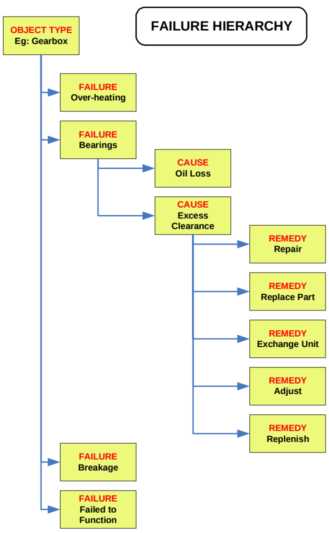
Failure Hierarchy

Alignment on Failure Hierarchy is still missing



A failure hierarchy comprises several levels:

- Top level is the Object Type
- Level 2 defines the PROBLEM or Failure
- Level 3 shows the CAUSE of the failure
- Level 4 denotes the REMEDY applied

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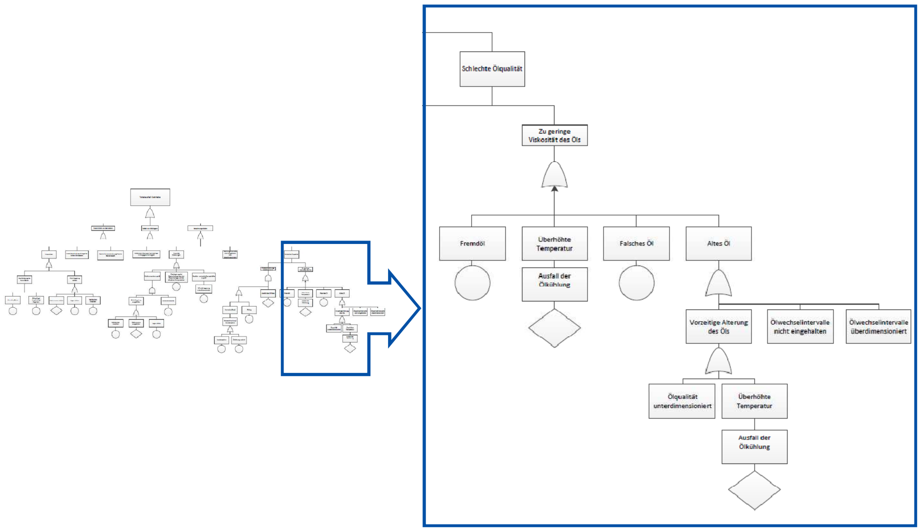
Example: Failure Tree Analysis - Gearbox



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Summary

- Very limited data is available to estimate the reliability of Offshore Multi-megawatt Turbines
- More time is required to establish an Offshore Reliability Database
  - Limited number of existing OWP
  - Limited access to existing failure data
  - Set-up CMMS and other systems to collect data over the lifespan of an OWP
- Wind industry needs to set-up a consistent coding system
  - WT and BoP (in a detailed level)
  - Failure Events, Causes and Remedy Actions
  - Agree on main parameters to capture

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Question

- How shall we proceed to evaluate reliability for offshore wind turbines now ?
  - Statistical Methods
  - Test facilities
  - Know-How from other industries

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THANK YOU FOR YOUR ATTENTION

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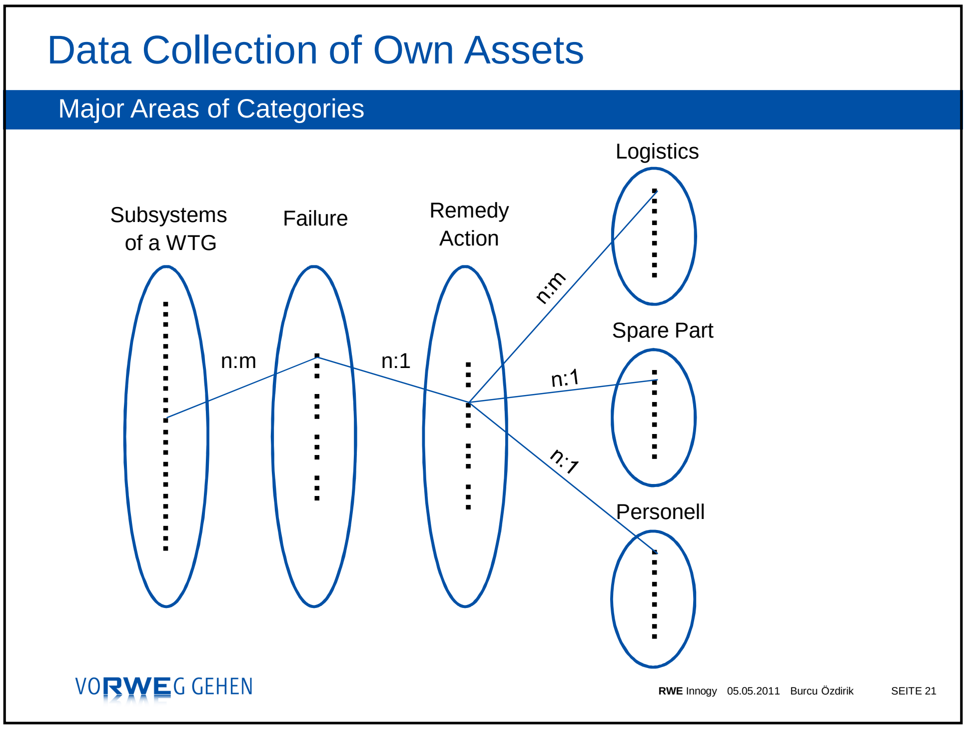
Data Collection of Own Assets
Major Areas of Categories
Subsystems of a WTG
Failure
Remedy Action
Logistics
Spare Part
Personell
n:m
n:1
n:m
n:1
n:1
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IEA Wind expert meeting:

International statistical analysis on wind turbine failures

SKF a driving force in wind energy

Presented by Matthias Hofmann

Global Application Engineer Wind

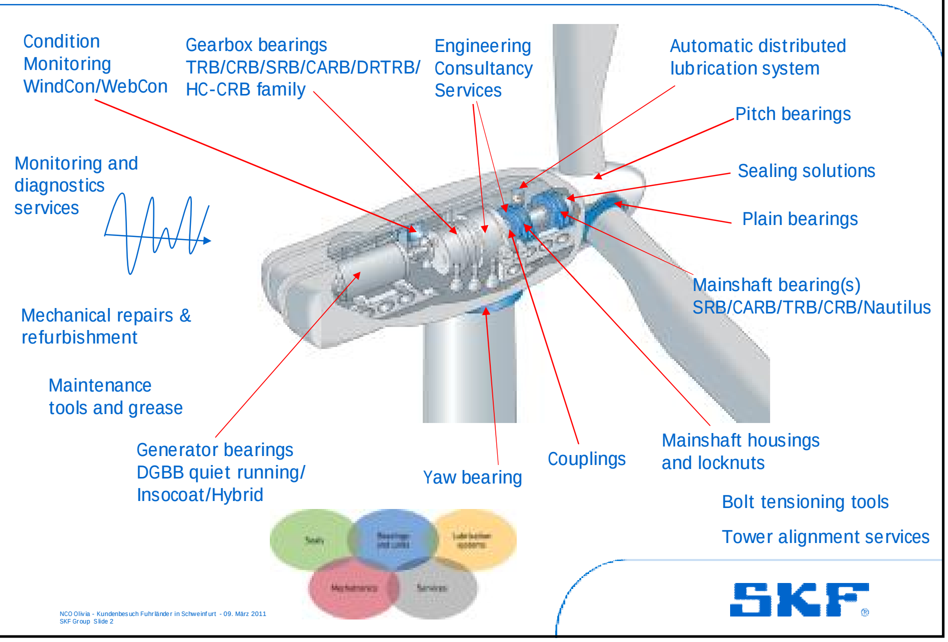
2011-03-31

SKF – A truly global company

Established:	1907
Sales 2010:	SEK 61 000 million (~6 500 M€)
Employees:	44,742 (FTE by end 2010)
Production sites:	120 in 28 countries
SKF presence:	In over 130 countries
Distributors/dealers:	15,000 locations
Global certificates:	ISO 14001
	OHSAS 18001 certification

SKF

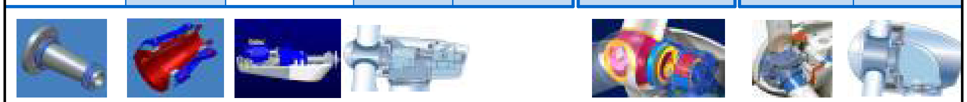
SKF contribution to wind turbine technology



NCO Olivia - Kundenbesuch Fuhrländer in Schweinfurt - 09. März 2011
SKF Group Slide 2

Main bearing arrangements

Turbines with gearbox					Hybrid Turbine	Direct Drive	
2-point suspension		3-point suspension	Moment bearing (no shaft)		Moment bearing (no shaft)	2-point suspension	Moment bearing
2 separate housings	1 joint housing	1 bearing in gearbox	separate	Integrated in gearbox	Full integration	Common hub + axis	No axis
SRB+CARB	DRTRB+CRB	SRB	DRTRB	DRTRB	DRTRB	DRTRB+CRB	DRTRB
(SRB+SRB)	TRB+TRB					TRB+TRB	



NCO Olivia - Kundenbesuch Fuhrländer in Schweinfurt - 09. März 2011 ©
SKF Group Slide 3

Main wind turbine gearbox concepts

- Main wind turbine gearbox concepts
  - Parallel shaft gbx
    - Single output
    - Single output – split torque
    - Multiple output – split torque
  - Hybrid planetary gbx
    - One planetary stage
    - Two planetary stage
    - Differential gearbox
  - Full planetary gbx
    - One planetary stage
    - Two planetary stages

SKF

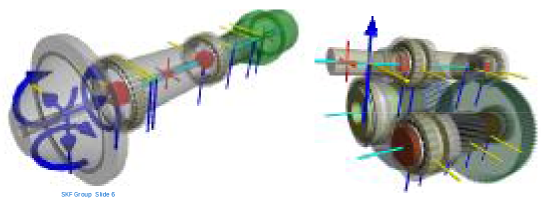
Main issues and trends - turbines

- Reliability is more and more becoming a major issue – less components less risk of failures?
- Emerging offshore taking off – increased need of high reliability
- Reduce O&M cost, low maintenance efforts, lower lifetime cost/kWh electricity
- Requirements for increased service life
- Expanding turbine warranty periods
- Easy maintainability and replaceability
- Optimize turbine efficiency
- Drive train integrations
- Reduce nacelle weight (compact designs)
- Reduce turbine cost
- Supply chain and logistics constraints
- Shift in new turbines designs in favor of stiff rotor bearing arrangements

SKF

Bearing selection & verification

- § **Evaluation of first customer ideas, concepts or modifications in respect to bearing type and arrangement. Insert of new application knowledge or product features.**
- § **Advanced bearing analyse by considering of all relevant standards and specifications.**
- § **Service support during prototype testing of rotor, gearbox and generator bearings. Mainly mounting issues, inspections on customer side and lab analysis.**



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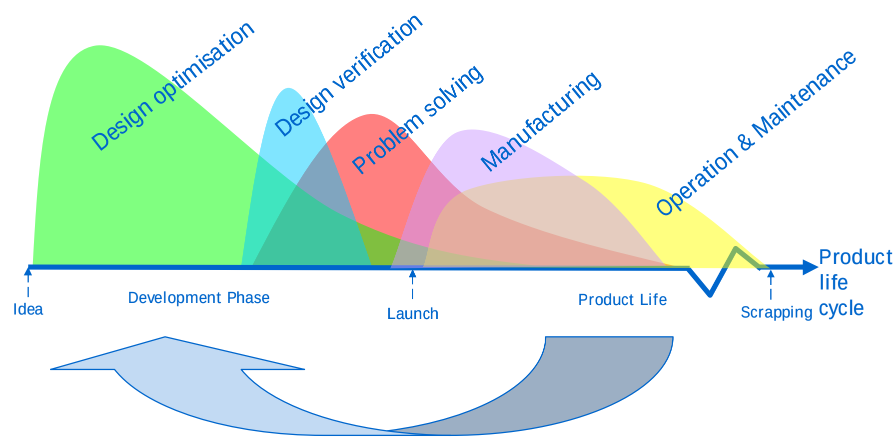
SKF

SKF involvement in wind turbine life cycle



"Beside all advanced bearing engineering tools and lab testing we collect more & more field experience and include that in turbine developments".

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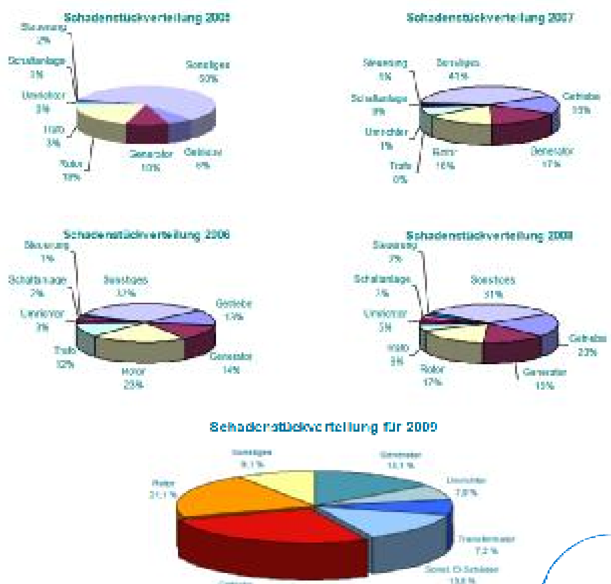
2011-03-31 © SKF Group Slide 4

SKF

Wind turbine failure statistic 2005 to 2009



Source: Gothaer

NCO Olivia - Kundenbesuch Fuhrländ
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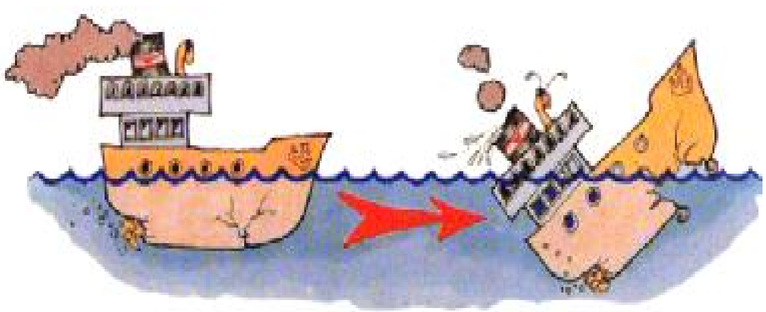
SKF

Root cause <-> Consequential damage



NCO Olivia - Kundenbesuch Fuhrländer in Schweinfurt - 09. März 2011 ©
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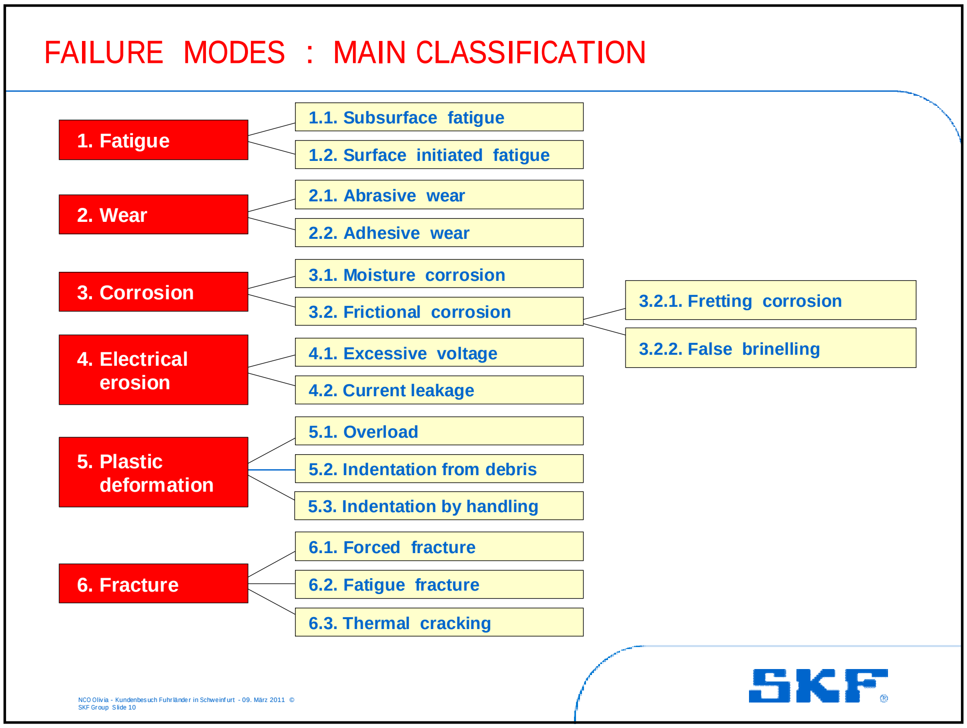
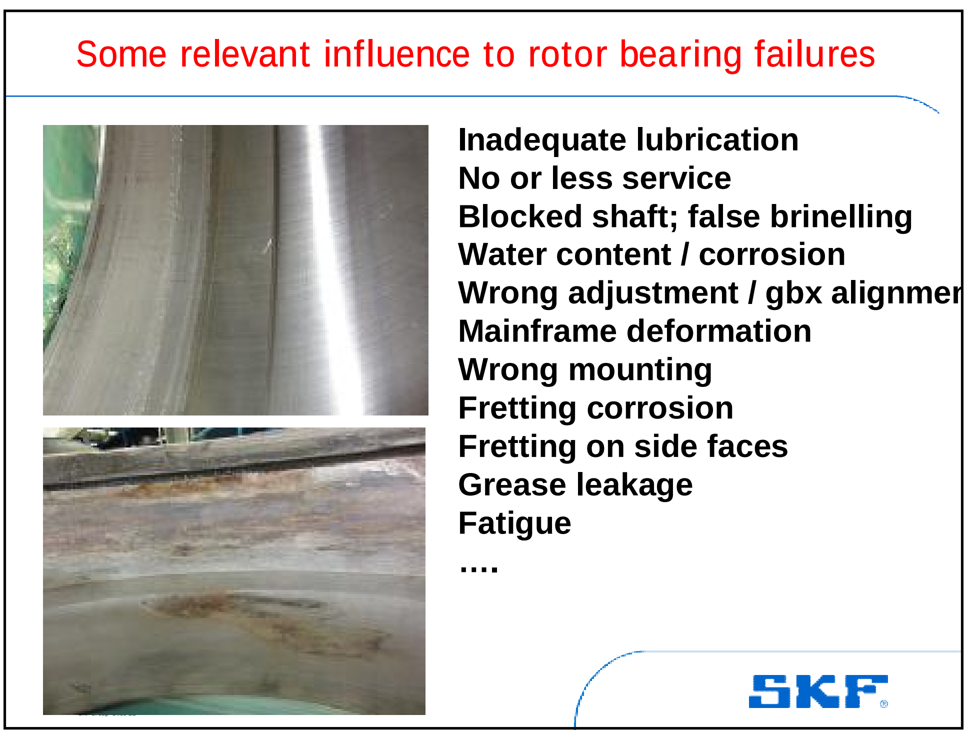
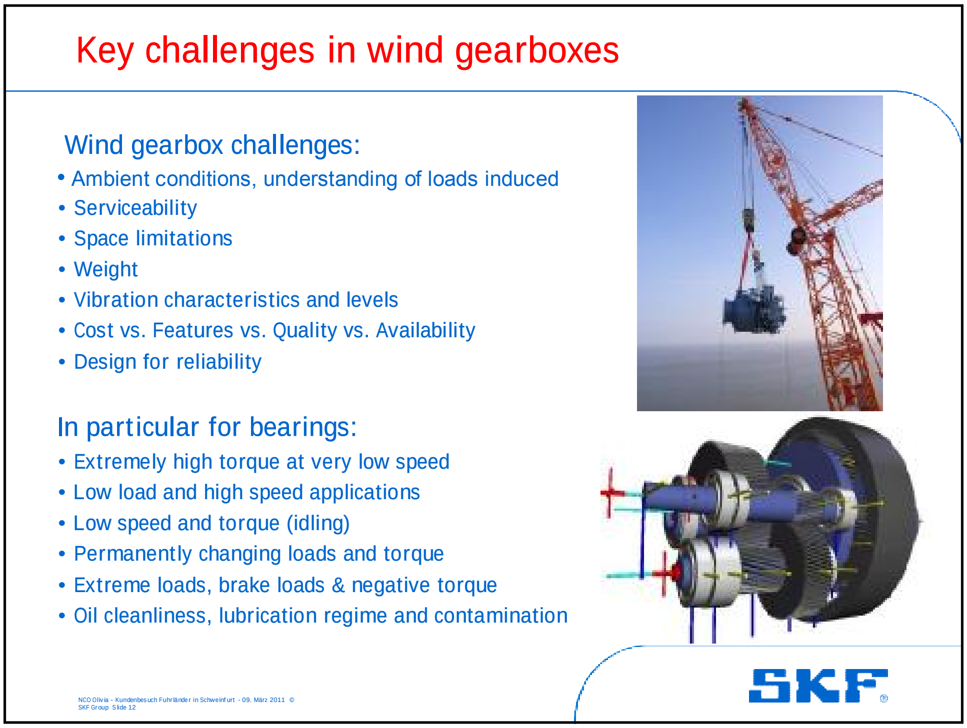
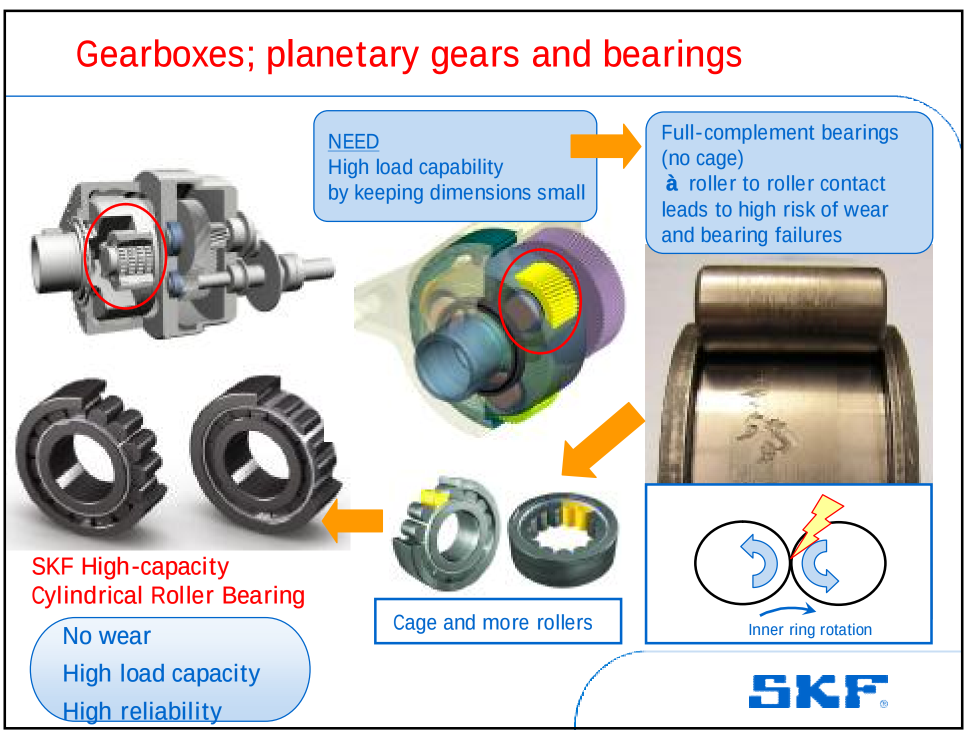

FAILURE MODES : MAIN CLASSIFICATION
1. Fatigue
1.1. Subsurface fatigue
1.2. Surface initiated fatigue
2. Wear
2.1. Abrasive wear
2.2. Adhesive wear
3. Corrosion
3.1. Moisture corrosion
3.2. Frictional corrosion
3.2.1. Fretting corrosion
3.2.2. False brinelling
4. Electrical erosion
4.1. Excessive voltage
4.2. Current leakage
5. Plastic deformation
5.1. Overload
5.2. Indentation from debris
5.3. Indentation by handling
6. Fracture
6.1. Forced fracture
6.2. Fatigue fracture
6.3. Thermal cracking
SKF


Some relevant influence to rotor bearing failures
Inadequate lubrication
No or less service
Blocked shaft; false brinelling
Water content / corrosion
Wrong adjustment / gbx alignmen
Mainframe deformation
Wrong mounting
Fretting corrosion
Fretting on side faces
Grease leakage
Fatigue
….
SKF





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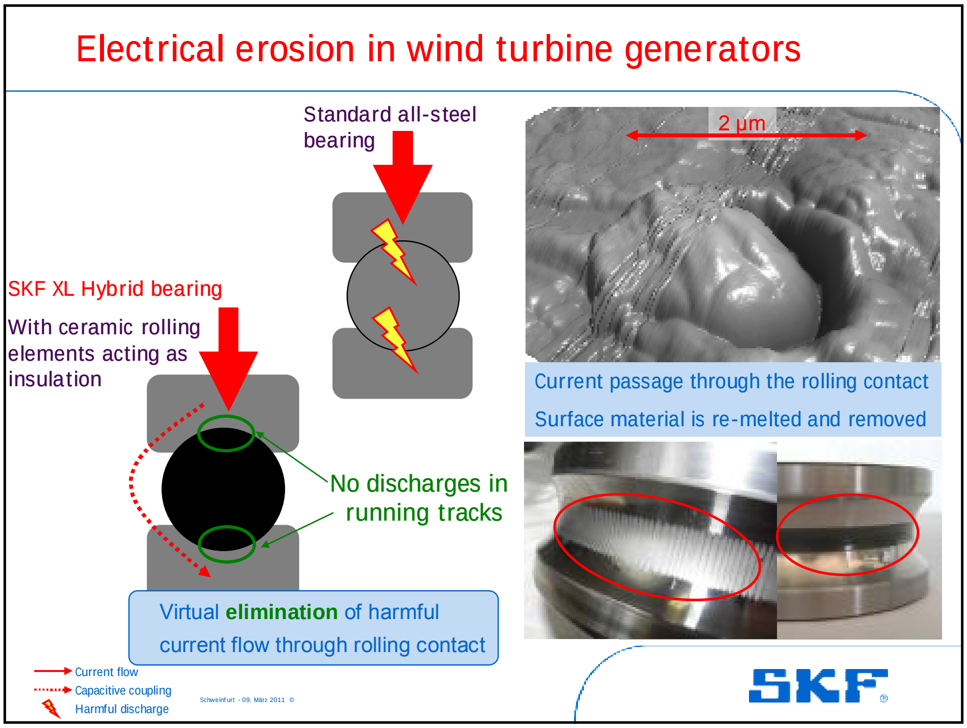
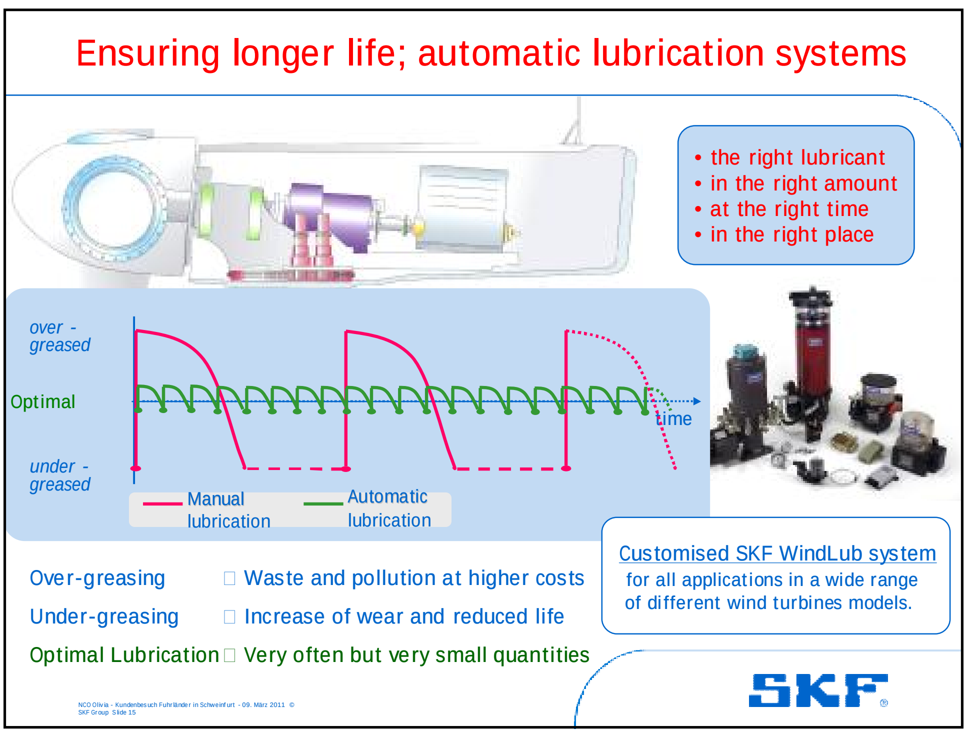
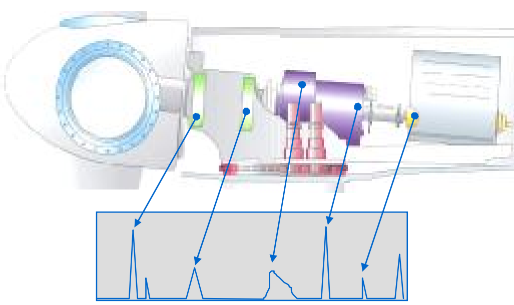

Electrical erosion in wind turbine generators
Standard all-steel bearing
2 µm
SKF XL Hybrid bearing
With ceramic rolling elements acting as insulation
Current passage through the rolling contact
Surface material is re-melted and removed
No discharges in running tracks
Virtual elimination of harmful current flow through rolling contact
Current flow
Capacitive coupling
Harmful discharge
SKF


Ensuring longer life; automatic lubrication systems
• the right lubricant
• in the right amount
• at the right time
• in the right place
over - greased
Optimal
under - greased
time
Manual lubrication
Automatic lubrication
Customised SKF WindLub system
for all applications in a wide range of different wind turbines models.
Over-greasing Waste and pollution at higher costs
Under-greasing Increase of wear and reduced life
Optimal Lubrication Very often but very small quantities
SKF

Early warning of turbine problems; SKF WindCon



Benefits & Values:

- Vibration measurement to detect initiating failures before they lead to major breakdowns
- Monitor all mechanical components and sub-systems
- With predictive maintenance, better utilisation of service teams on shorter planned stops
- Reduce overall costs for maintenance, repair and sparepart in the windfarm
- Improve overall uptime of the windturbine
- Increase overall returns on windfarm investments

SKF Service:

Installation - Monitoring – Analyzing – Predictive maintenance – "top-of-turbine" repairs, spare part management

SKF Wind Industry Service Centers all over the world are monitoring around 1000 turbines

SKF

Some comments about statistical analysis & database of turbine failures from our perspective

-We created our own SKF database which is much concentrated on drive train components in details incl. experience collection.

-Detailed component data (eg. bearing types & exact designations) and turbine modifications (retrofits of gearboxes) are normally confidential and very specific. How do get get that?

-General data are useless when you have to find route cause for failures; more details will be needed.

-We have much interest to get access or results about further detailed failure rate statistics; also about operational or event list data.

-In the last 5 to 10years many gearbox design modifications were done to improve the situation. General statistical analyses we have but do not today represent that.

NCO Olivia - Kundenbesuch Fuhrländer in Schweinfurt - 09. März 2011 © SKF Group Slide 17

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Statoil

Blade failures and the lack of control

TEM Kassel 30-31 March 2011

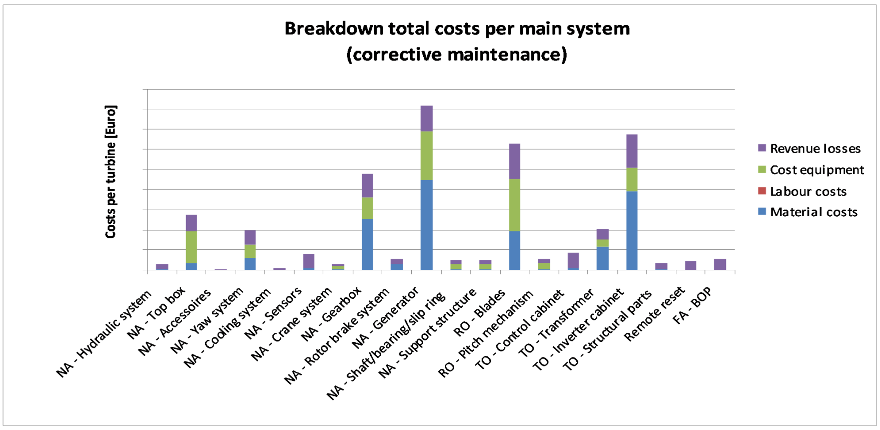
Short on Statoil

- Mainly an oil and gas company
- New entrant in the wind industry
  - 40 MW Havøygavlen (in operation since 2003)
  - 2.3 MW Hywind demo (in operation since 2009)
  - 317 MW Sheringham Shoal (under construction)
  - 9-13 GW Doggerbank (early phase development)

Current O&M strategy in the wind industry results in high OPEX

- Current strategies are dominated by "**Run To Failure**" principles
  - Corrective maintenance is dominating (approx 70%)
  - Scheduled maintenance is carried out by fixed lists
- Turbine vendors are conducting O&M and controlling data streams
  - OEM's are operating **without owner involvement**
- Current O&M contract format **does not** give incentive for improvements in maintenance execution

Moving offshore – costs related to heavy components dominates



New and bold target

"80% of all stops should be planned and preventive in nature"

Principles for sustainable operational model

Organisation	Contractual obligation must reflect organisational capabilities for both OEM's and Statoil
Technology	Asset owner must take responsibility for technical integrity
Cooperation	Asset owner support OEM's effort in standardisation and lean manufacturing
OEM's	Key account principle for both commercial and technical support Active retrofit program

Havøygavlen wind farm - 40 MW

7 - Classification: Internal 2011-03-31

Statoil

2008: Blade failure at Havøygavlen

- Rotor blade broke
  - Damage to tower
  - Machinery exposed to significant loads
- Entire turbine taken down
- Likely cause: Fatigue
- Extensive inspection of all blades carried out
- 3 years repair program

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Statoil

Status rotor blades (inspection 2008)

- From 47 blades, 44 have white stripes
- 2/3 of the blades : transversal cracks in the laminate on the pressure side
- 4 blades have cracks on the suction side
  - 50 mm – 3000 mm ➔ long cracks regarded critical
- All blades have transversal cracks at the trailing edge
  - originate from the glue ➔ regarded not critical
- 13 blades have longitudinal cracks in the trailing edge
  - cracks longer than 500 mm regarded critical
- Some blades have lightning strikes at the tip

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Transversal cracks in the laminate

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Transversal cracks in the laminate

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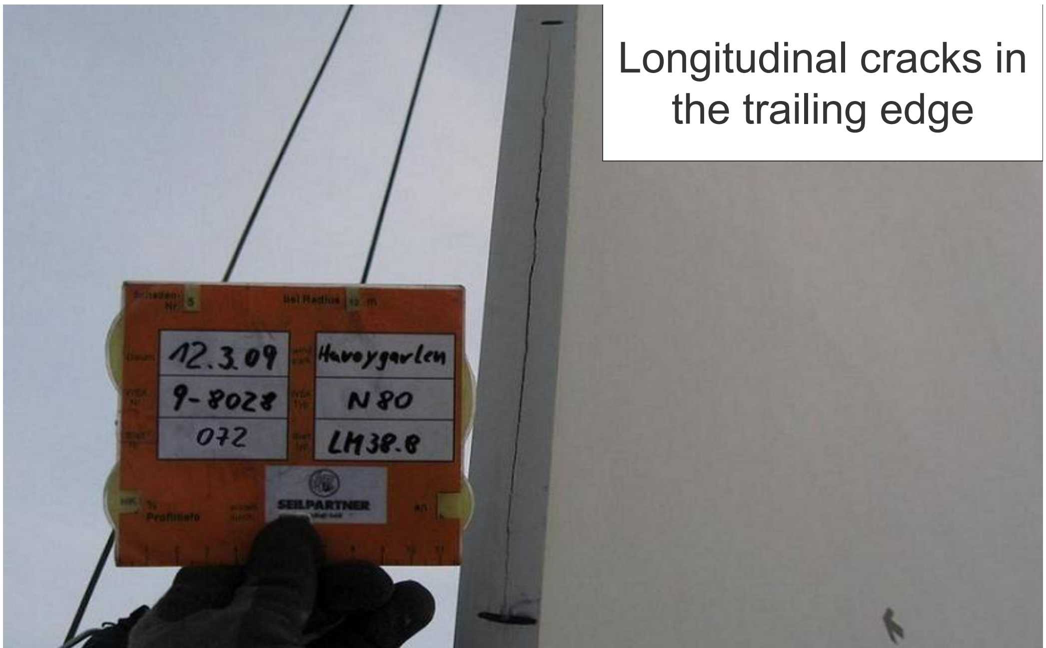
Statoil

Longitudinal cracks in the trailing edge



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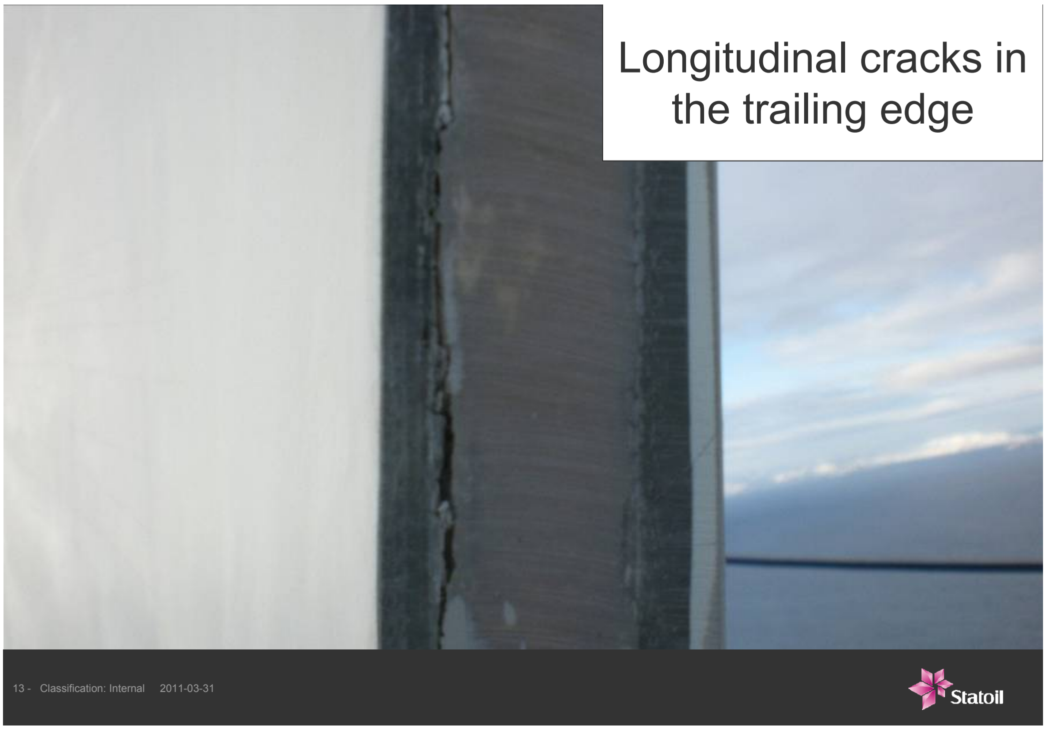
Statoil

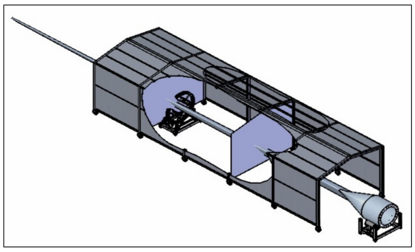

Longitudinal cracks in the trailing edge
13 - Classification: Internal 2011-03-31
Statoil


Laminate cracks at the web
14 - Classification: Internal 2011-03-31
Statoil

Laminate cracks at the web

Extensive repair

- Repair on the ground for larger maintenance
  - Tents and floor plates (closed area)
  - 1/3 of the blades
- Repair at the turbine for smaller maintenance
  - TSP (man basket)
  - The rest of the blades according to needs



And of course – delays!

- Start of lifting operations 12th of August
  - not possible due to high wind speed
- Break down of 200t crane on the 13th of August
- Break down of 350t crane on the 6th of September
- Fog problems
- High wind speed
- Initial tent area to small due to the weather conditions
- **The damages on the blades are bigger than expected**
- **There are more damages on the blades than expected**

Status autumn 2010

Time and money spent.

Most of the planned maintenance finished.

Some additional inspections left.

And then it happens again (Jan. 2011)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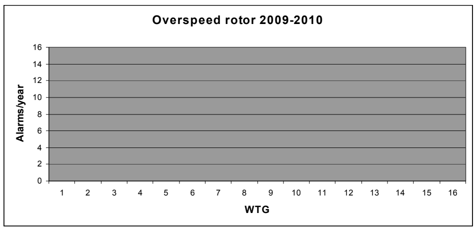
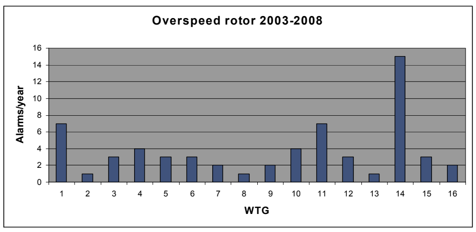
Lack of control

- Lack of historical data on failures and repairs
  - Previous strategy and contracts means that OEM is the only one with full knowledge of the history -> difficult to analyse loads and estimate remaining lifetime etc.
- Lack of knowledge of the actual condition
  - Only a snapshot – no accumulated loads etc.





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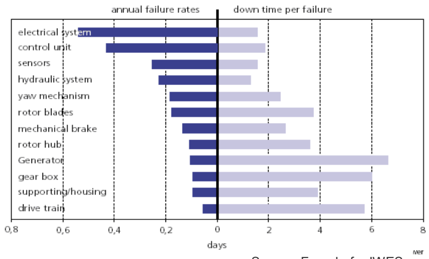
Lack of control

- Lack of knowledge about blade quality and the effect of defects on the lifetime
  - Inspection recorded only “slight damage” to the blade that failed in 2011
- Immature maintenance industry
  - Three inspections was made of the blades in the repair period – all leading to new discoveries



Source: Fraunhofer IWES

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
No.	4	6	15	13	15	12	16	22	20	25	18

Source: Caithness windfarms information forum, www.caithnesswindfarms.co.uk

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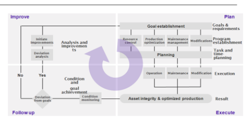
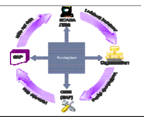
Areas of Improvement

Areas	Implication for Wind	Process Requirements
Maintenance and Inspections	• Establish procedures to enable transparency in O&M execution • Ensure failure analysis is done after each repair and introduce system for effective follow up • Introduce measures to develop multi skilled technicians	
Integrity Management **Condition Management**	• Improve preventive maintenance program by introducing condition management • Establish effective measures for component lifetime assessment and health management	
Performance Management **Management Systems**	• Define information collection system • Establish KPI set that support overall goals and work processes • Establish requirements to facilitate IO implementation	
LCI	• Establish Engineering Numbering System for Wind • Define system for reliability data collection • Establish ERP system for Wind • Establish documentation storage for wind	

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Thank you

Blade failures and lack of control

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www.statoil.com

Summary of IEA RD&D Wind – 65th Topical Expert Meeting

Félix Avia, CENER

a) Participants

A total of 22 persons attended the meeting from Germany, Sweden, Norway The Netherlands, Denmark Finland and USA.

The participants represented a great variety of stakeholders related to the topic. Those were: manufacturers, wind farm operators, research organizations, universities and consultants.

A total of 16 presentations were given:

1. **Introductory Note**
   Dipl.-Ing. M.Sc. Stefan Faulstich. Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

2. **Definition of a database of offshore wind farm**
   Philip Lyding, Fraunhofer IWES, Germany

3. **Definition of a database of offshore wind farm operational and failure data (EERA)**
   Jorn Heggset, SINTEF, Norway

4. **What can the offshore wind industry learn from the OREDA project run for 25 years in the offshore oil and gas industry?**
   Jorn Vatn, NTNU Norwegian Univ. Of Science & Technology, Norway

5. **Towards cost-effective maintenance of wind power systems**
   Katharina Fischer, Chalmers University of Technology, Sweden

6. **Turbine blade reliability and failure assessment through accelerated testing**
   Nathan Post, NREL, USA

7. **RAMS Database for Wind Turbines**
   Lars Petterson, Vattenfall Power Consultant AB, Sweden

8. **Influence of uncertainty in failure data on modeling O&M aspects**
   Rene van de Pieterman, ECN, The Netherlands

9. **Serious Incident to Vestas Products**
   Jens Lauesen, Vestas Wind System A/S, Denmark

10. **Wind energy statistics in Finland**
    Andres Stenberg, VTT Technical Research Centre of Finland, Finland

11. Presentation Munich Re
Michael Schrempp, Munich Re, Germany

12. Life cycle cost analysis for offshore wind farm

Francois Besnard, Chalmers University (seating Vattenfall Wind), Sweden

13. Operator's requirements for maintenance and inspection
Axel Ringhandt, Enertrag – Windstrom, Germany

14. Approach to systematically record O&M Data for Offshore Wind Farms
Burcu Özdirik, RWE Innogy, GermanY

15. SKF a driving force in wind energy
Matthias Hoffmann, SKF, Germany

16. Blade failures and the lack of control
Kunt Anstrom, Statoil, Norway

b) Discussion

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

In particular, the following topics were discussed, in order to decide which are the priorities for future work:

- Standardization of the structure of the data bases (DB):
- Definition of subassemblies and failures.
- Level of detail of the DB
- Confidentiality and access to the DB
- Harmonization of data analysis

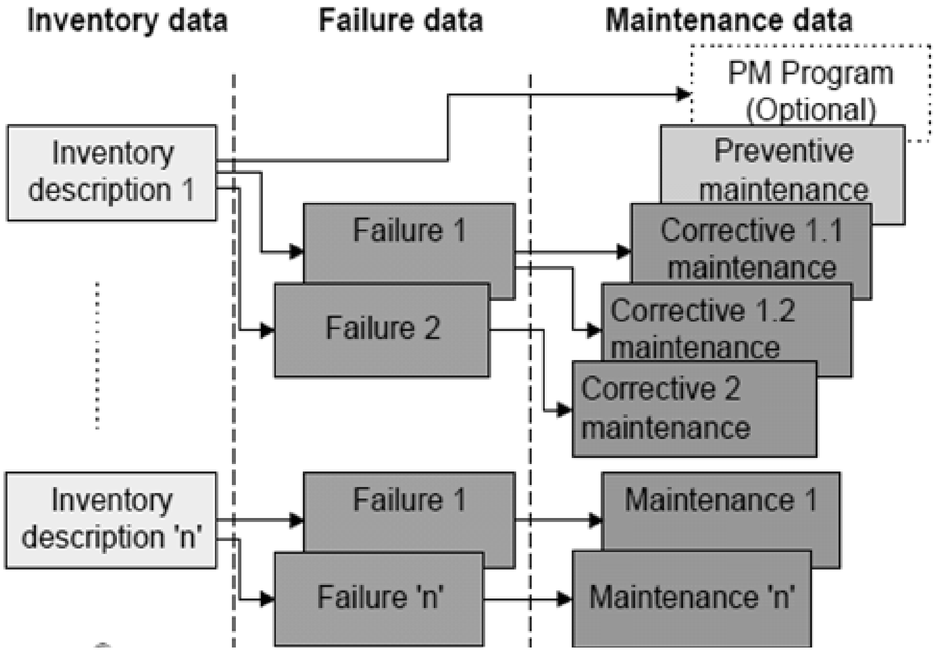
-

Standardization of the structure of the data bases (DB).

The RAMS databases (Reliability, Availability, Maintainability and Safety) exist in other fields such as the oil and gas industry or the nuclear power field.

According with the information supplied by the participants in the meeting, there are several projects on going regarding the development and implementation of reliability databases. The initiative to collect reliability data is mainly initiated by research institutes in order to create a large statistical database which will facilitate further technological progress. There are several reliability databases with varying level of the amount and type of data collected.

The existing databases differ in the definition of subassemblies and failures, in the level of detail and in the overall structure.

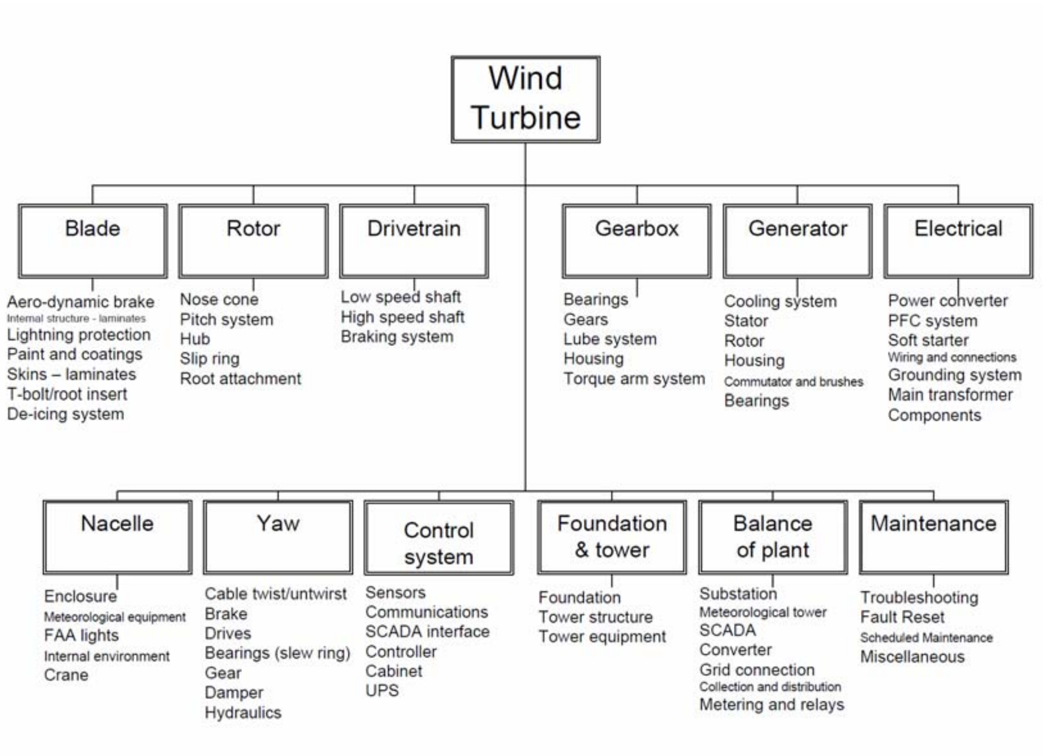


Ref: Jorn Vat presentation (NTNU Norwegian Univ. of Science & Technology)

For the time being there are not standards defining the structure of RAMS databases for the wind energy sector, as the standard ISO 14224 for the oil and gas sector. However there are several initiatives defining optimised structures for the databases, as the EVW project in Germany, the CREW project in USA or the actions performed by the ESReDA.

There was a general consensus among the participants about the necessity to harmonise the structure of RAMS databases.

• Definition of subassemblies and failures.

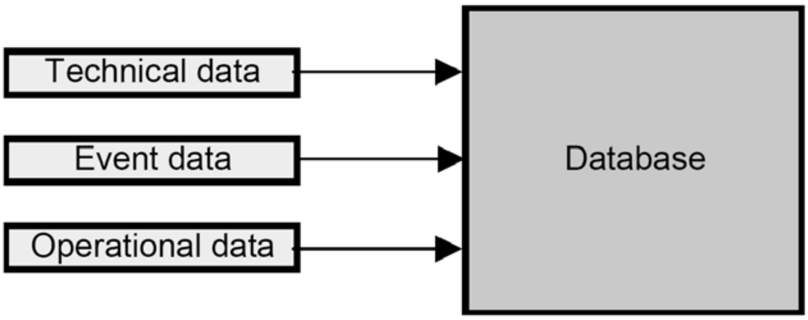


Ref: SANDIA REPORT SAND2009-1171

The taxonomy of the wind farms and in particular of the wind turbines should be also harmonised. Some of the new database have adapted the RDS-PP (Reference Designation System for Power Plants) to designate and structure the components and subassemblies in a standardised way [1].

On the other hand the definition of type of events, failures, causes, etc, need also a clear harmonization work.

- **Level of detail of the DB**



Ref: RAMS-database for Wind Turbines – Elforks report 10:67

The success of the database depends on the collection of statistically significant amounts of information and processing that data so that it can be used for reliability analyses and aggregation of individual inputs into industry baseline reports.

The potential amount of information collected could be vast, and the expectations for the database will depend on the focus of the analysis required. Data is needed for many different purposes at many differing periods throughout the plant life. Initially, data needs could include environmental parameters, design configurations, performance data, system faults and repair times.

Due to the strong effort required to get large quantity of data, the level of detail should be limited and the information should be generated automatically.

It was discussed about the possibility to have several levels of detail in the database, that will be used for different type of analysis.

- **Confidentiality and access to the DB**

It is acknowledged that failure information is sensitive and throughout this process no individual wind plant, turbine manufacturer, or subcomponent vendor will have its reliability information released.

General consensus between the participants in the meeting about that the information to the database should be supplied mainly by the owners and operators of the wind farms, and not from wind turbine manufacturers.

It also was discussed the possibility to have different levels of access to the databases, depending the target use of the data. For instance, for research centres and universities involved in R&D projects should be permitted to have access to the raw data of the database ensuring protection of the information obtained.

- **Harmonization of data analysis**

Once data is gathered, normalized, and entered into the DB, it is ready for analysis. Individualized reporting and analysis will be performed for each user. Reports containing graphs, charts and analysis results should be harmonised to allow comparing the results obtained by different users and using different DB.

c) Future actions under the umbrella of IEA Wind

It was decided to launch a new Task under the umbrella of the IEA Wind on "Databases for Wind Turbine Failures". Stefan Faulstich from the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) is the leader of the working group that will prepare the proposal for the new task, in collaboration with SINTEF and NREL.

TEM # 66 "Statistical Analysis on Wind Turbines Failures"

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The International Energy Agency Implementing Agreement for
Co-operation in the Research, Development, and Deployment of Wind Energy Systems