On probabilistic view of Smart Grid – Smart maintenance for a sustainable power system

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for a sustainable future

MISSION

A forward-looking university of technology with a global outlook that conducts internationally recognised education, basic and applied research and collaborations, integrated with a professional innovation process

Thanks from Stockholm to Istanbul

- ✓ PMAPS - power system reliability family
- ✓ Solving power system challenges

The 9th PMAPS, Stockholm, June 2006 General chair Lina Bertling. (Picture Patrik Hilber)

Content & Summary

- Probabilistic Methods Applied to Power Systems today:
  - Energy system – context
  - Sustainability - driver
  - Smart Grid – solutions

- Availability for new electricity generation from wind
  - preventive maintenance methods
  - condition monitoring systems
  - life cycle cost assessment

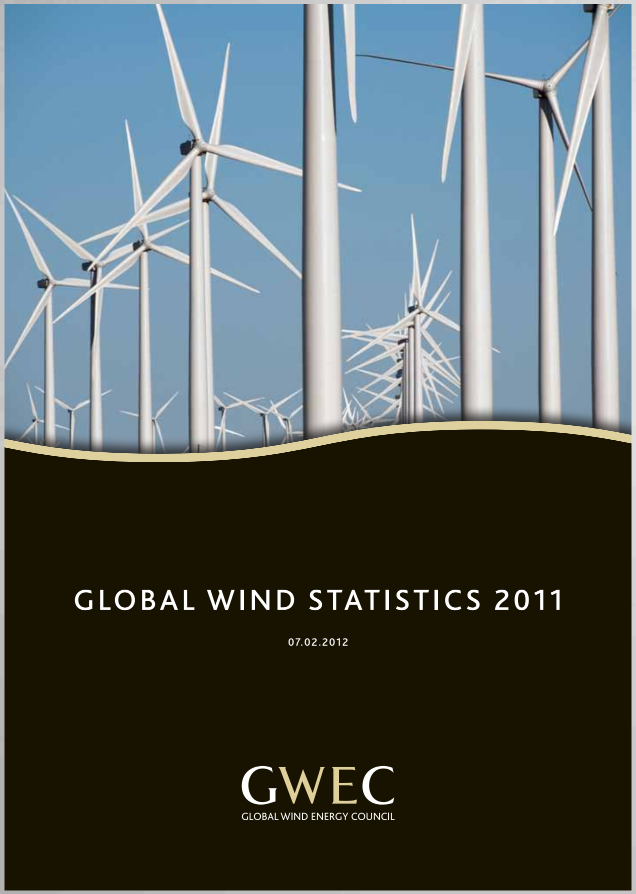
Energy system in change

- The energy system is undergoing a major global change
  - Main driving forces are to meet the political climate and energy goals and to counteract with economic crisis.
- In Europe there are climate and energy goals with targets for 20/20/20/10 by 2020, and different long term targets by 2050 going for 100% renewables
  - Today major investments in new electricity generation from renewables, in large and small scale.
  - New models for energy usage and storage are developed e.g. with electrical vehicles

➢ The Smart Grid is a facilitator to meet these changes by "*more and different use of electricity*"!

Energy system in change

Capacity in wind global



- ✓ Total installed 238 k MW
- ✓ New capacity 2011 41 k MW
- ✓ Top 5 Countries total (new)
  - 26% (44%) China
  - 19.7% (17%) US
  - 12.2% (5%) Germany
  - 9.1% (2.5%) Spain
  - 6.7% (7 %) India
  - (1.9%) Sweden

Source: www.ewea.org

Electric power - challenges

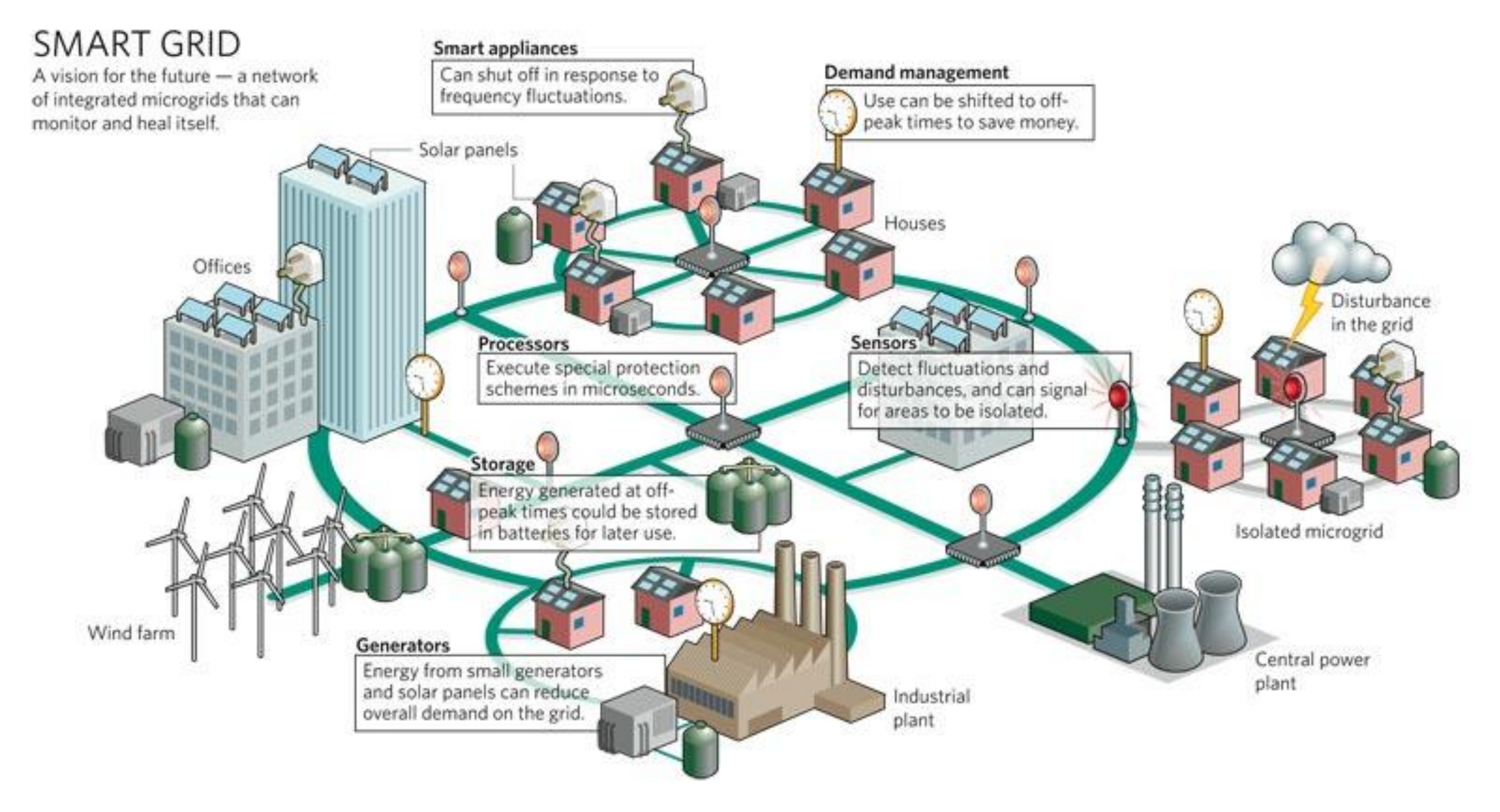
Picture: L. Bertling, F. Besnard at Smöla, Norway, August 2007.

Electric power system: challenges

Challenges and solutions:

- need of reinforcement in the power grid
- more integration between the countries
- more intermittent power generation
- more large and small scale production
- plug in electrical vehicles
- active customers with more information and being both consumers and producers

Electric power system: solutions



Source: www.nature.com/news/2008/080730/images/454570a-6.jpg

Power System Reliability: topics

Probabilistic Methods Applied to Power Systems 1(3)

- Uncertainty Estimation
- Risk Analysis
- Monte Carlo Techniques
- Condition Monitoring, Failure Diagnosis and Reliability Centered Maintenance
- Power System Reliability Analysis
- Probabilistic Power Flow
- Operation, Control and Protection of Power System under Uncertainty
- Probabilistic Approach for Analysis and Design of Electrical Machines and Drives

Power System Reliability: topics

Probabilistic Methods Applied to Power Systems 2(3)

- Energy Storage Design for Electric Power under Uncertainty
- Reliability Analysis in Nuclear Power Plants
- Smart Grid, Micro Grids with Renewable Energy Sources
- Impacts of Renewable Energies and Distributed Generation on Networks
- Probabilistic Methods for Energy Markets and Asset Management
- Network Congestion Management and Transmission Pricing
- Power Quality

Power System Reliability: topics

Probabilistic Methods Applied to Power Systems 3(3)

- Energy management in buildings and home automation
- International Coordination Towards Fully Functioning Interconnected Power Grid
- Energy security and sustainability analyses
- High voltage applications
- Damage Assessment and Restoration Modeling of Power Systems after Earthquakes
- Software and Hardware Reliability, failure prediction
- Probabilistic Methods for Traffic and Transport Planning of Metropolitan Cities
- Educational Applications

Example: research at Chalmers

Technologies (power systems and ICT) that enable smart grids

Optimized operation and control of transmission systems

Management of Active distribution system

Smart Power System

New way of system monitoring, emergency control and protection

Market models for cross-border trading of energy and ancillary services

Planning of future transmission systems

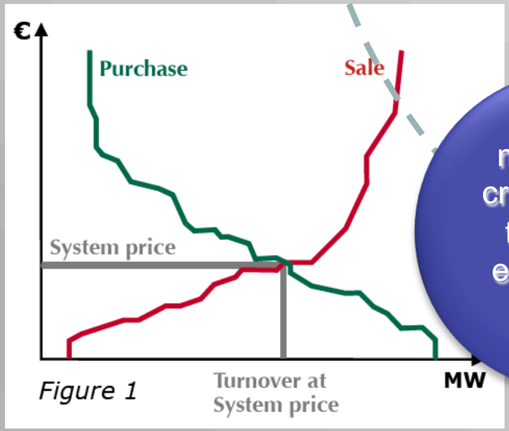


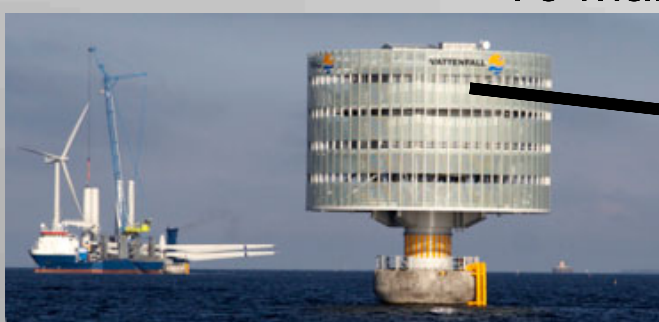
Figure 1

Example: research at Chalmers

Research examples on DC-networks for wind farms

Background:
- dc needed for longer transmission systems
- dc/dc-transformers have much lower weight than classical transformers

Objectives:
- To design a park
- To derive control of a park
- To study efficiency
- To make it fault tolerant



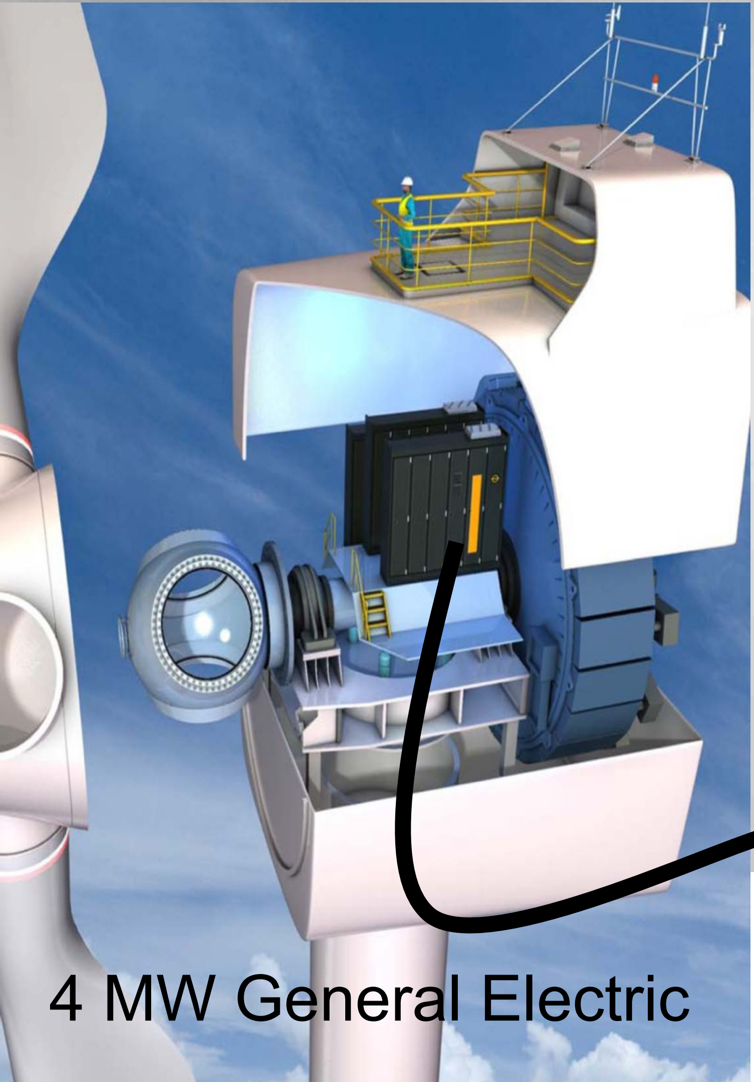
Possibility to remove the platform => huge cost savings

Example: research at Chalmers

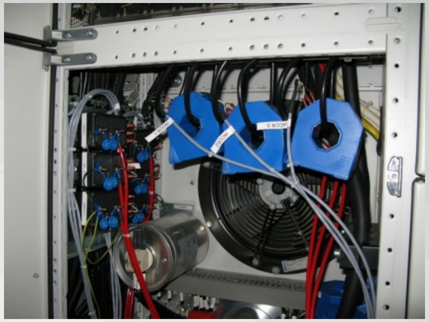
Research examples on Grid Code testing using HVDC

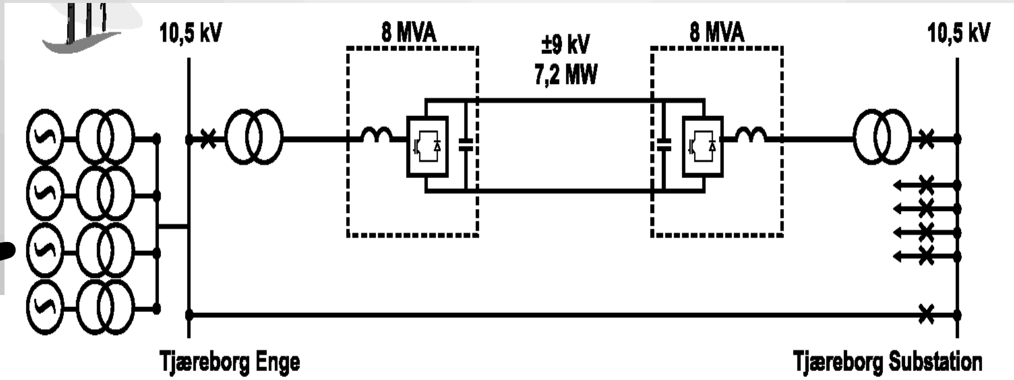
The project develop methods, simulate and test in lab targeting wind turbine to fulfill Grid Codes.

Full scale test.



4 MW General Electric



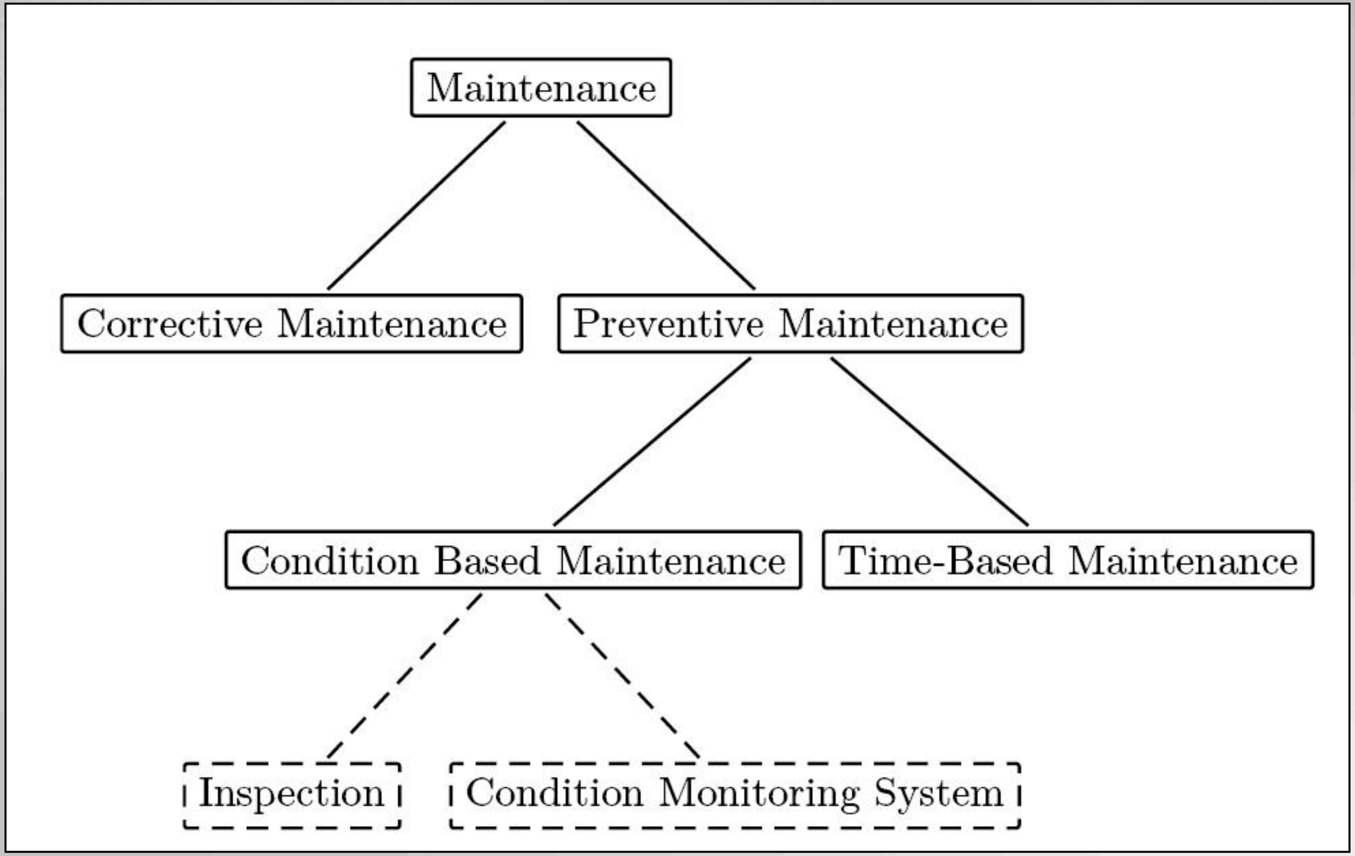


8 MW HVDC-light converter

Example: research at Chalmers

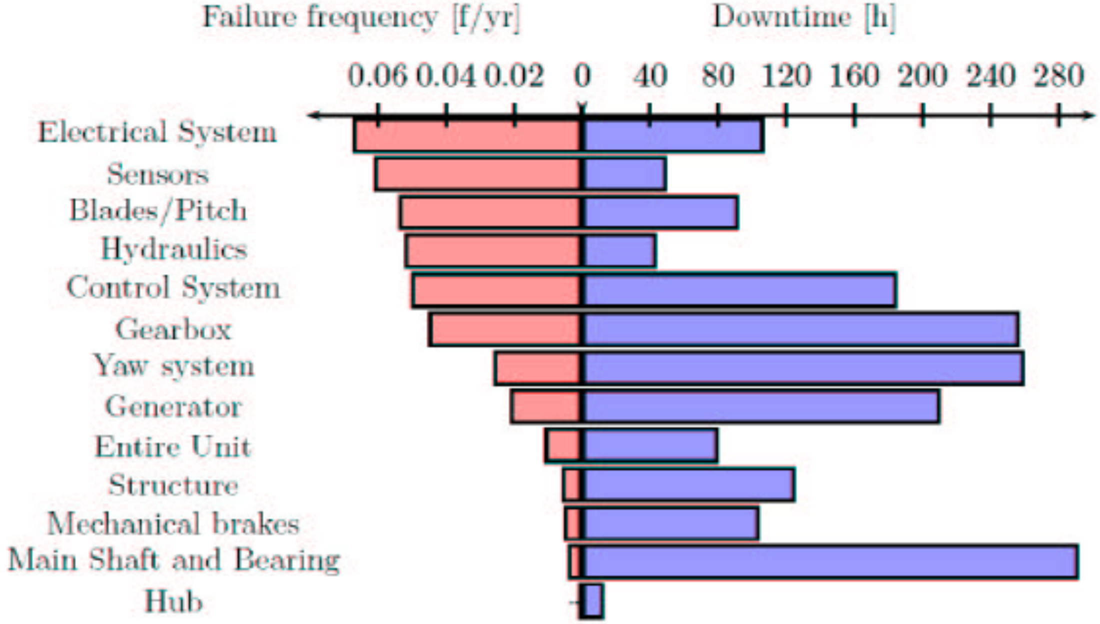
Wind power Asset management (WindAM)

- Reliability Centered Maintenance
- Reliability vs cost/benefit
- Condition Monitoring Systems as input data for RCM



Example: research WindAM

Wind power Asset management (WindAM)



(Adapted from "Survey of failures in wind power systems with focus on Swedish wind power plants during 1997-2005", J. Ribrant and L.M. Bertling, IEEE Transaction on Energy Conversion, vol.22, num.1, 2007)

- ✓ Outage data used to identify critical components in the system
  - Unavailability = failure frequency * outage time
- ✓ Need for optimizing maintenance especially offshore with high transportation costs and accessibility constrained by weather

Example: research WindAM

Profit benefit analysis of CMS for the drive train

The components of the drive train are critical: downtime, transportation and component costs

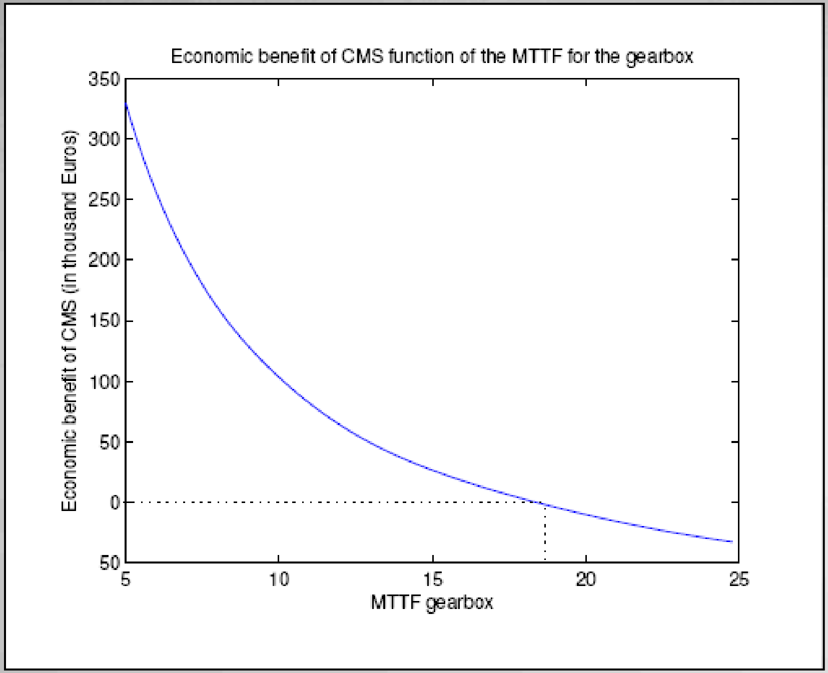
Objective: To estimate the cost benefits of vibration CMS as a function of:

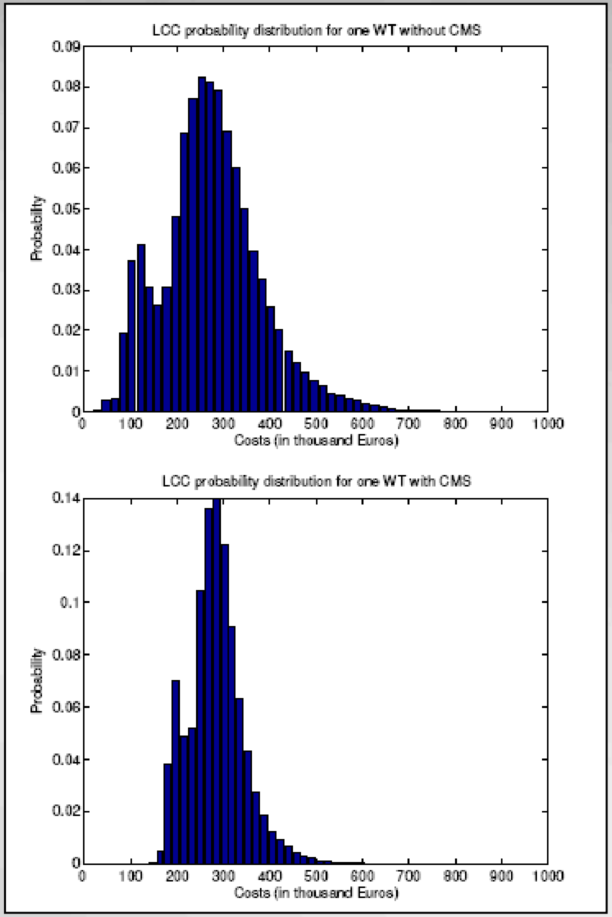
- The failure probability for the components of the drive train (gearbox, generator and main bearing)
- The efficiency of the CMS and benefits on damage reduction
- The advantage on the maintenance planning
- The investment discount rate

Approach: The model is a stochastic Life Cycle Cost.

Example: research WindAM

Profit benefit analysis of CMS for the drive train





Results from "*On the Economic Benefits of using Condition Monitoring Systems for Maintenance Management of Wind Power Systems*", F. Besnard, J. Nilsson and L. Bertling., In proceeding of IEEE conference PMAPS 2010, Singapore, 14th-17th June 2010

- ✓ CMS is beneficial if the MTTF for the gearbox is lower than 18 years
- ✓ CMS lowers the risk for high maintenance cost

Example: research WindAM

Condition Based Maintenance Optimization Applied to Wind Turbine Blades

The size of the blades is increasing → high stress + criticality for safety and cost

Usually visual inspection at service maintenance, or after lightning.

Condition monitoring could be used at inspection (infrared/ultrasound) or continuously (fiber optic sensors) to detect cracks.

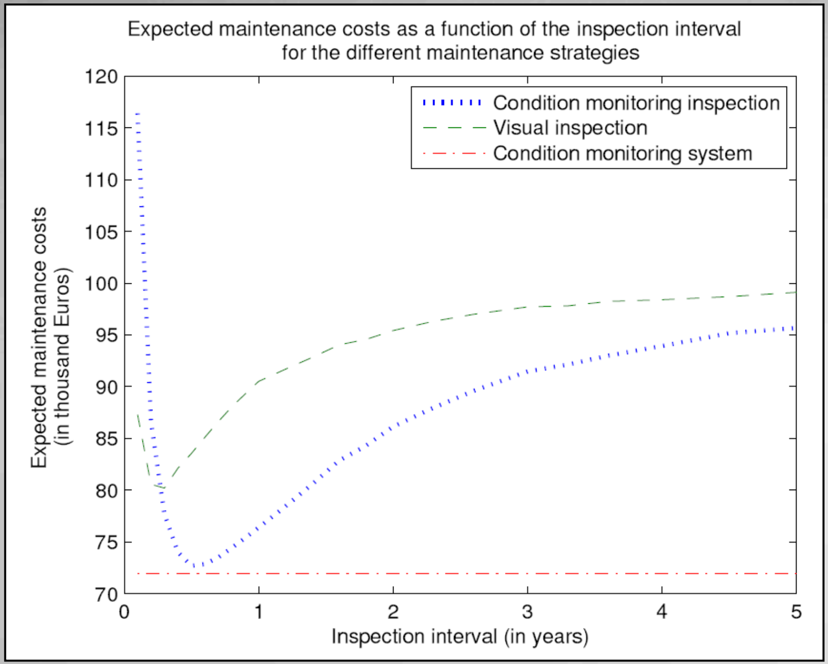
Objective:

- To optimize the inspection interval for inspection strategies
- To compare the expected maintenance costs of visual inspection, inspection with condition monitoring technique and on-line condition monitoring

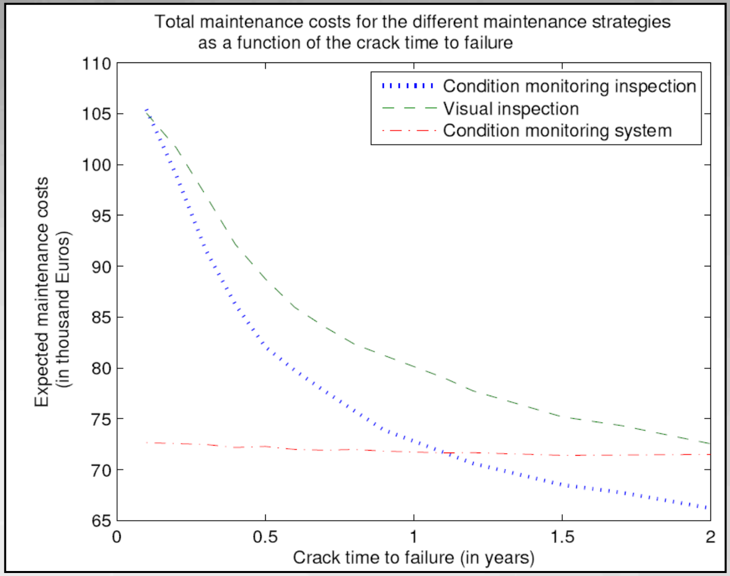
Approach: LCC with Markov chain for the deterioration model. Maintenance is simulated over a finite time horizon.

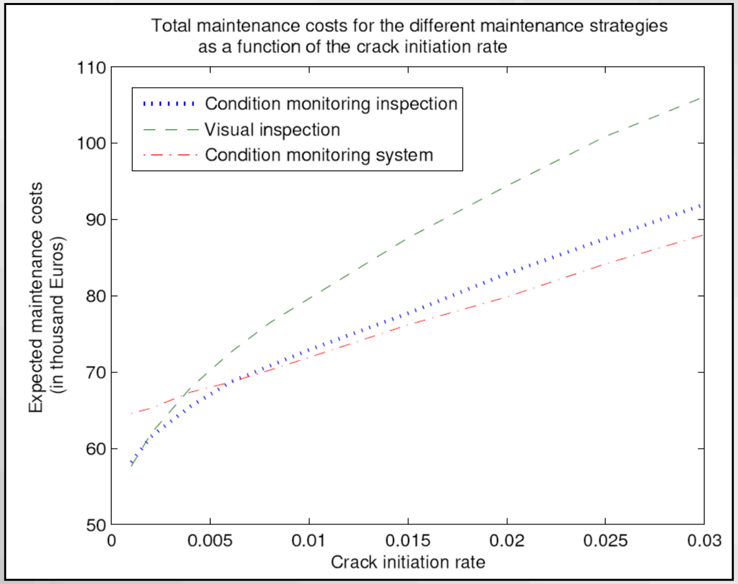
Example: research WindAM

CBM for Blades



Results from '*An approach for condition based maintenance optimization applied to wind turbine blades*', F. Besnard and L. Bertling, IEEE transaction on Sustainable Energy , 2009.





- ✓ The benefits depend much on cost and efficiency of maintenance strategy
- ✓ Sensitivity analysis shows that the optimal solution is specific to the site and wind turbine model

Example: research WindAM

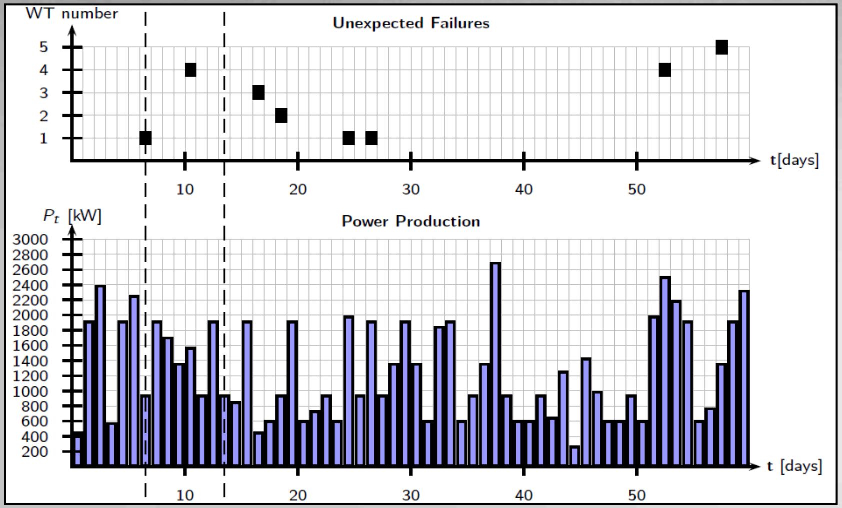
Optimal maintenance planning for offshore wind farms

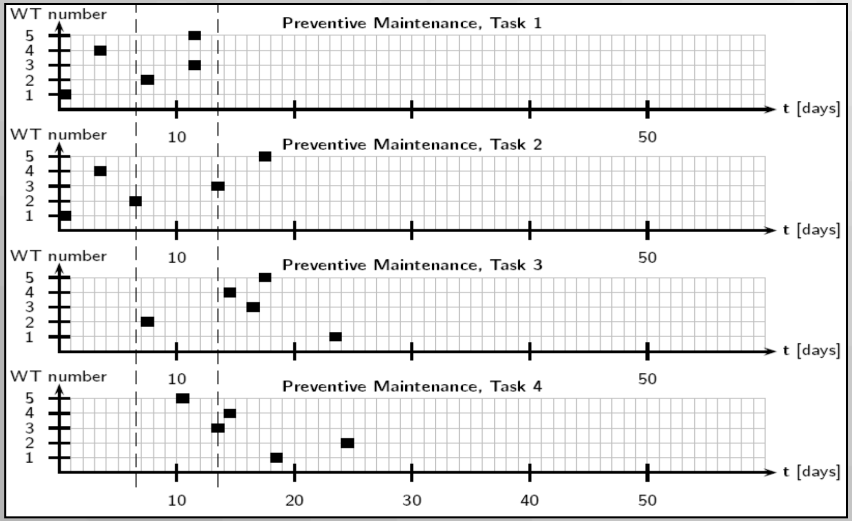
- Scheduled service maintenance is generally performed at fixed time period without consideration for power production.

- **Objective of the model**: To perform service maintenance tasks at the lowest cost possible
- **Main idea**: To take advantage of opportunities at failure and low production forecasts to reduce transportation and production losses
- **Constraints**:
  - Perform the service maintenance activities within a time window (larger than the fixed time period)
  - Inaccessibility in case of harsh weather (specially wave height), or use of helicopter (if cost efficient)
- **Approach**: The model is a stochastic mixed integer linear problem.

Example: research WindAM

Optimal maintenance planning for offshore wind farms



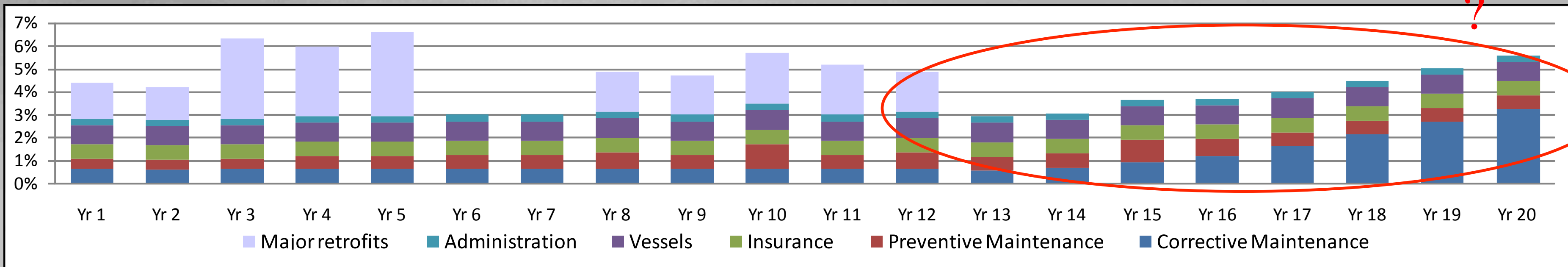


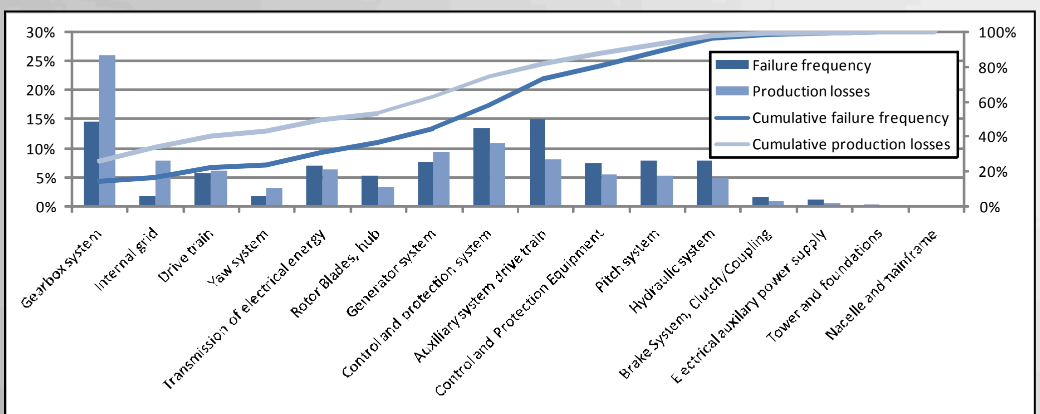
- ✓ Failures are always fixed when they occurs (if accessible) and transportation should be used to perform other service maintenance activities
- ✓ **Results**: Transportation and production losses costs reduced by 7170 €: 32% cost reduction → 20 years lifetime 143,000 €
- ✓ Practical limitation due to the size of the problem: Advance solvers or heuristic optimization methods

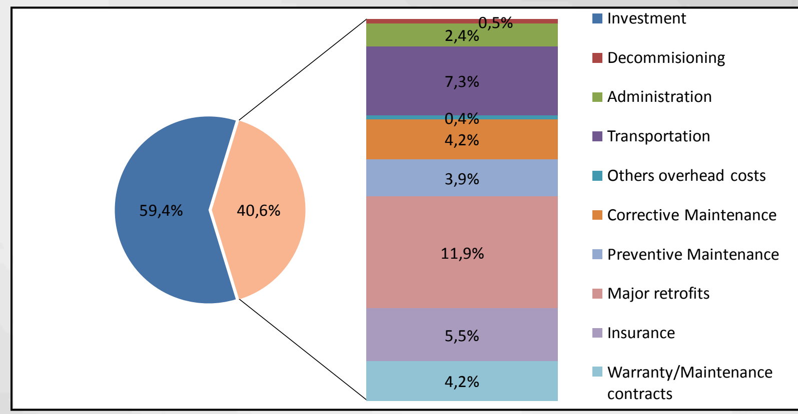
Results from "*A stochastic model for opportunistic maintenance planning of offshore wind farms*", Besnard, François; Patriksson, Michael; Strömberg, Ann-Brith; Wojciechowski, Adam; Fischer, Katharina; Bertling, Lina, In proceeding of *Powertech 2011, Trondheim,19 -23 June 2011*

Example: research WindAM

Life cycle cost analysis for offshore wind farms







- ✓ Example of results from a case study based on Horns Rev (80 Vestas V80 2MW in operation since 2002)
- ✓ Main results will soon be published…Submitted for IEEE Transactions on Sustainable Energy

List of references

1. Ribrant J., Bertling L., “Survey of failures in wind power systems with a focus on Swedish wind power plants, 1997-2005”, IEEE Transactions on Energy Conversion, Vol. 22, No. 1, Pages 167-173, March 2007.
2. Besnard F., Nilsson J. and Bertling L., “On the Economic Benefits of using Condition Monitoring Systems for Maintenance Management of Wind Power Systems”, PMAPS, Singapore, June 2010.
3. Besnard, F.,Bertling L.: An approach for condition- based optimization applied to wind turbine blades, IEEE Transactions on Sustainable Energy, Vol.1, pp. 77 - 83 , 2010.
4. Besnard, F.,Patriksson, M.; Strömberg, A.-B.; Wojciechowski, A.; Fischer, K.; Bertling, L. “A Stochastic Model for Opportunistic Service Maintenance Planning of Offshore Wind Farms”, IEEE PowerTech, Trondheim, Norway, June 2011.

Summary: PMAPS & WindAM

- Reliability and probabilistic approaches are important tools for evaluation of the power system to secure system function and to maximize asset value
- Results for WindAM
  - advanced simulation approaches and optimization tools
  - access to data from monitoring and sensors
  - CMS provides useful data for relating reliability and maintenance
  - LCC gives an important tool for investment and operation planning
- PMAPS and WindAM gives not only power system solutions but energy system solutions

Thanks
Welcome!

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Picture: The Division of Electric Power Enginering, August 2011, Gothenburg, Sweden