# KONGSBERG

## "Optimized wind farm operation"

EERA DeepWind 2015
Trondheim 6 Feb 2015


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# Presentation overview

- This is KONGSBERG
- Kongsberg Wind Farm Management System (WFMS)
  - Performance Monitoring
  - Wind Farm Control
  - Production Forecasting
  - Condition Monitoring
- Contributions from the «Windsense» project
- Cost savings potential

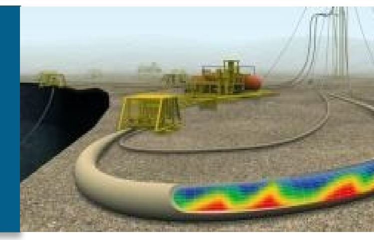
# At its core, KONGSBERG integrates advanced technologies into complete solutions

## Key core capabilities

- **Integrating sensors and software**
- **Supporting human decision making, precision, safety, security**
- **Cybernetics, software, signal processing and system engineering**
- **Project and supplier management**

**Dynamic positioning and vessel automation**

**Real time drilling support**



**Advanced robots**

**Command and control systems**

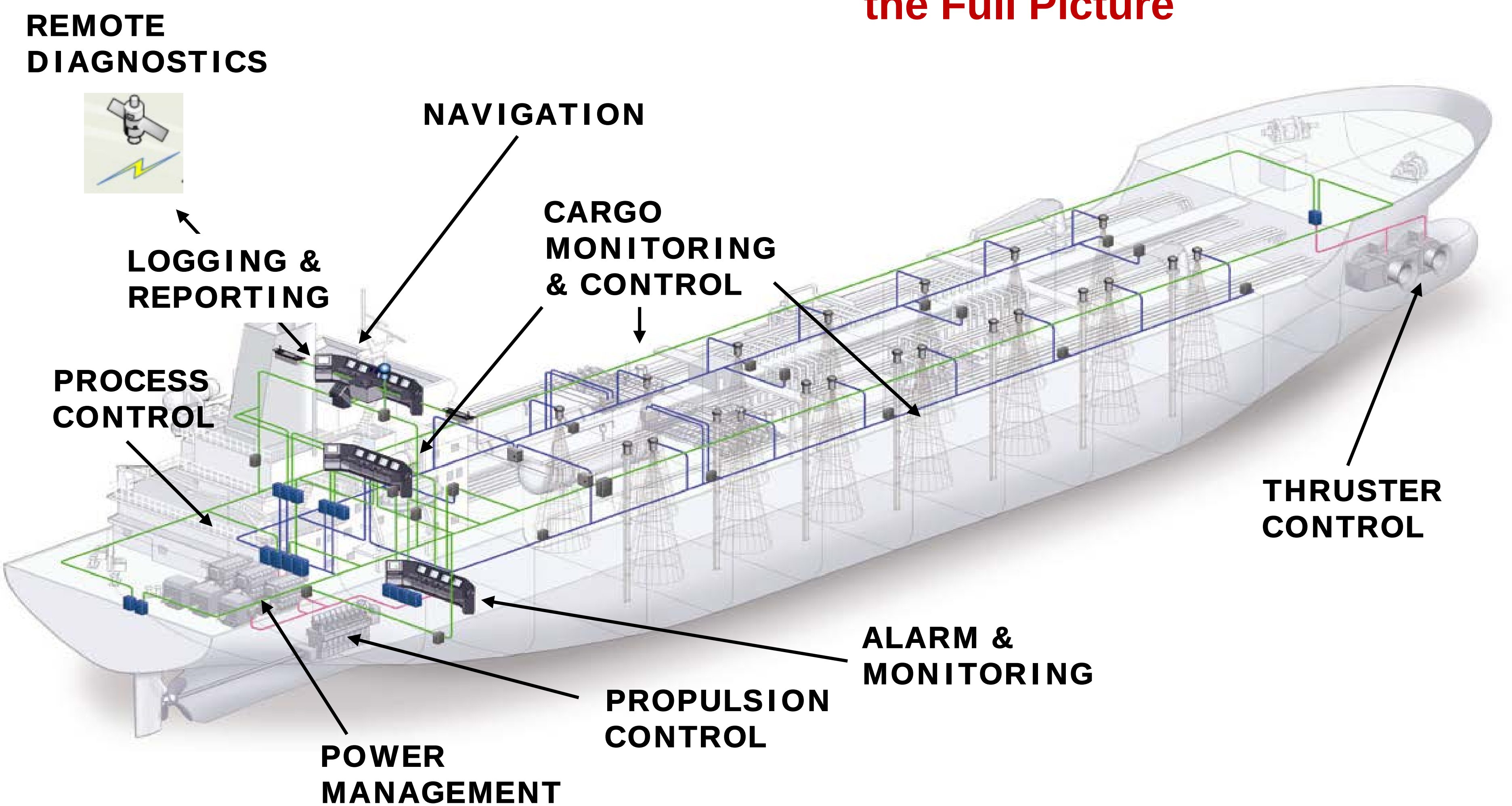
# International high-tech solutions, from deep sea to outer space

Advanced solutions and applications for the maritime, oil & gas, renewable wind, defence and space industry.

*- Extreme Performance for Extreme Conditions -*

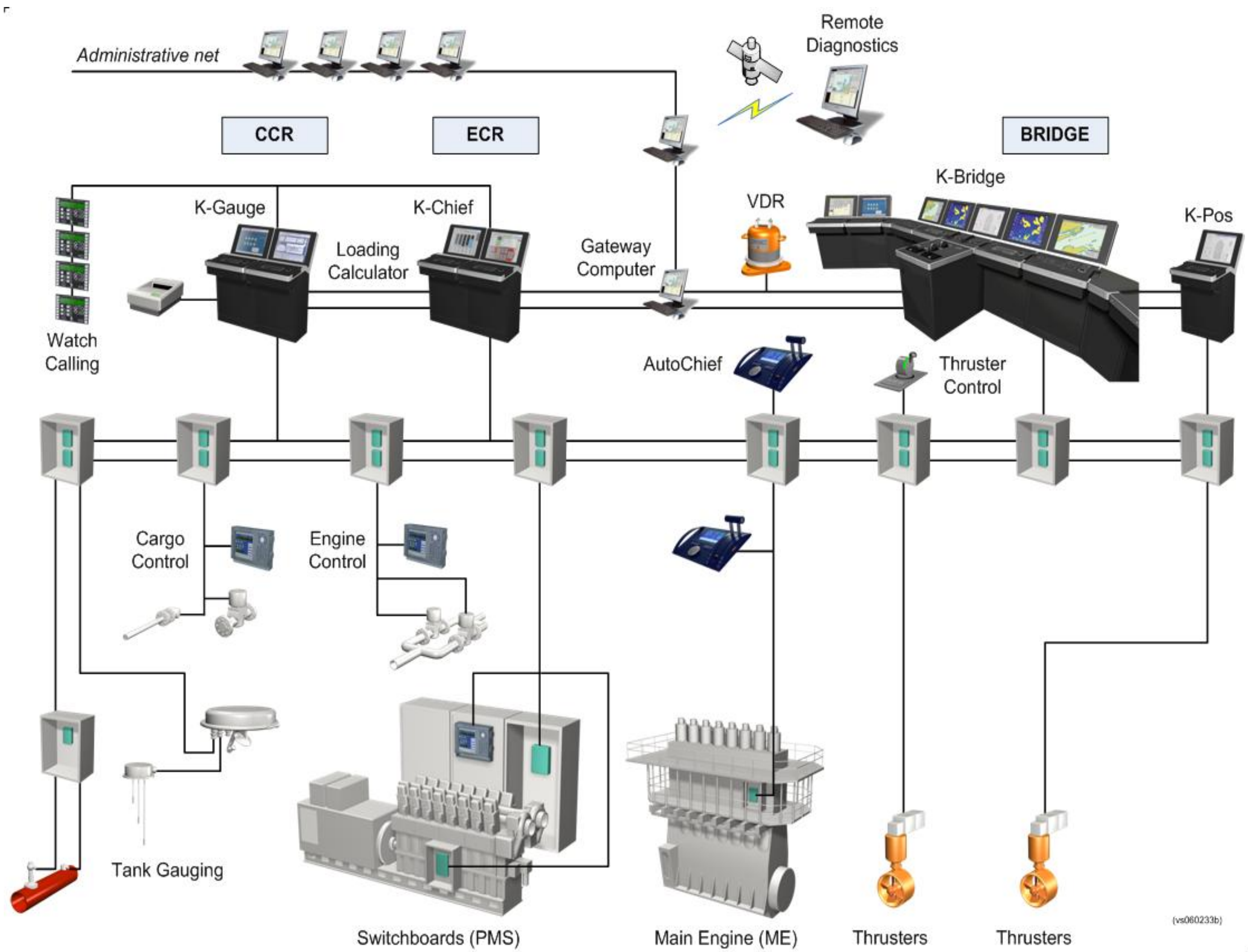
# Kongsberg Maritime - merchant marine products

**Maximizing marine performance by providing the Full Picture**

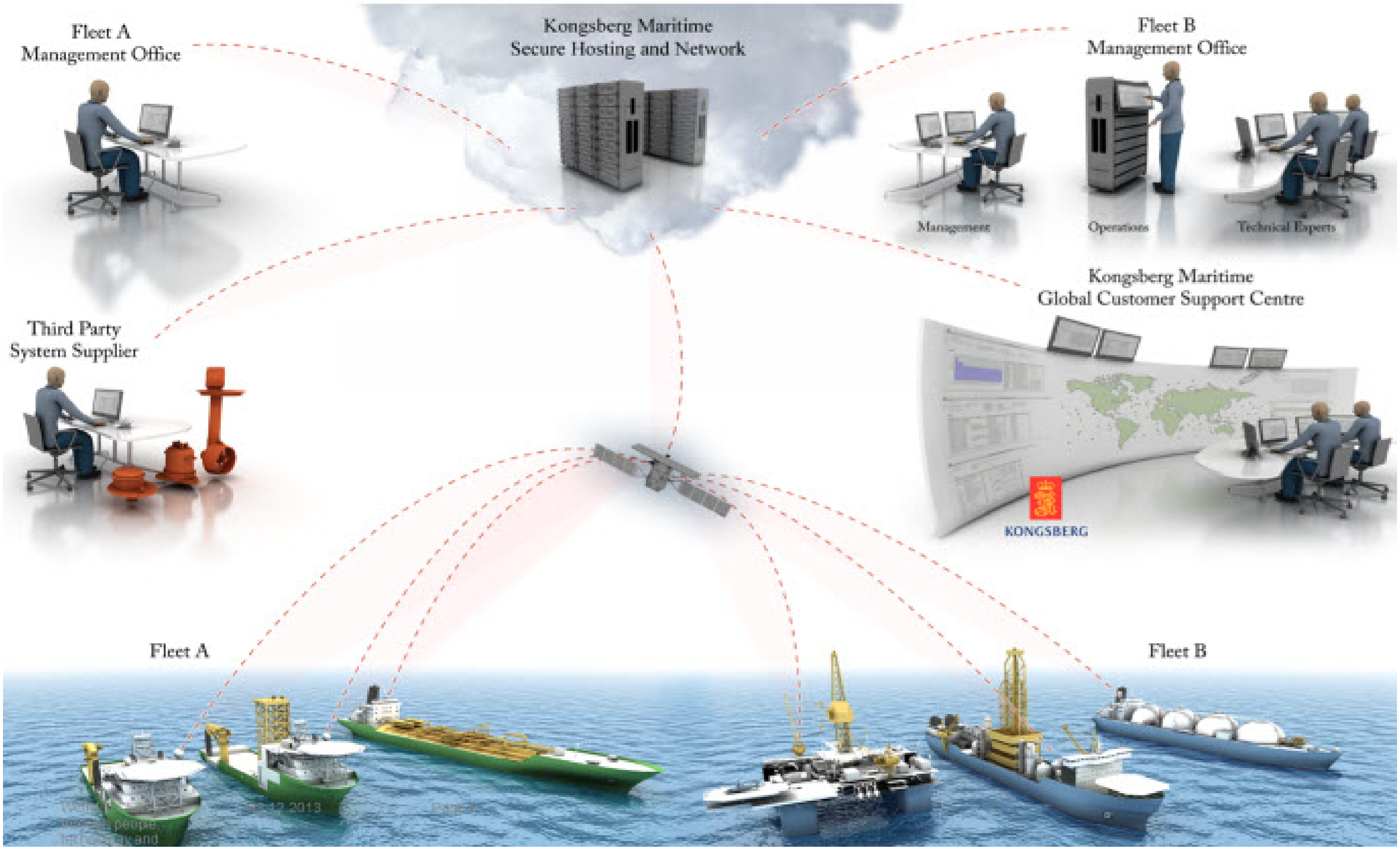


# Kongsberg Maritime

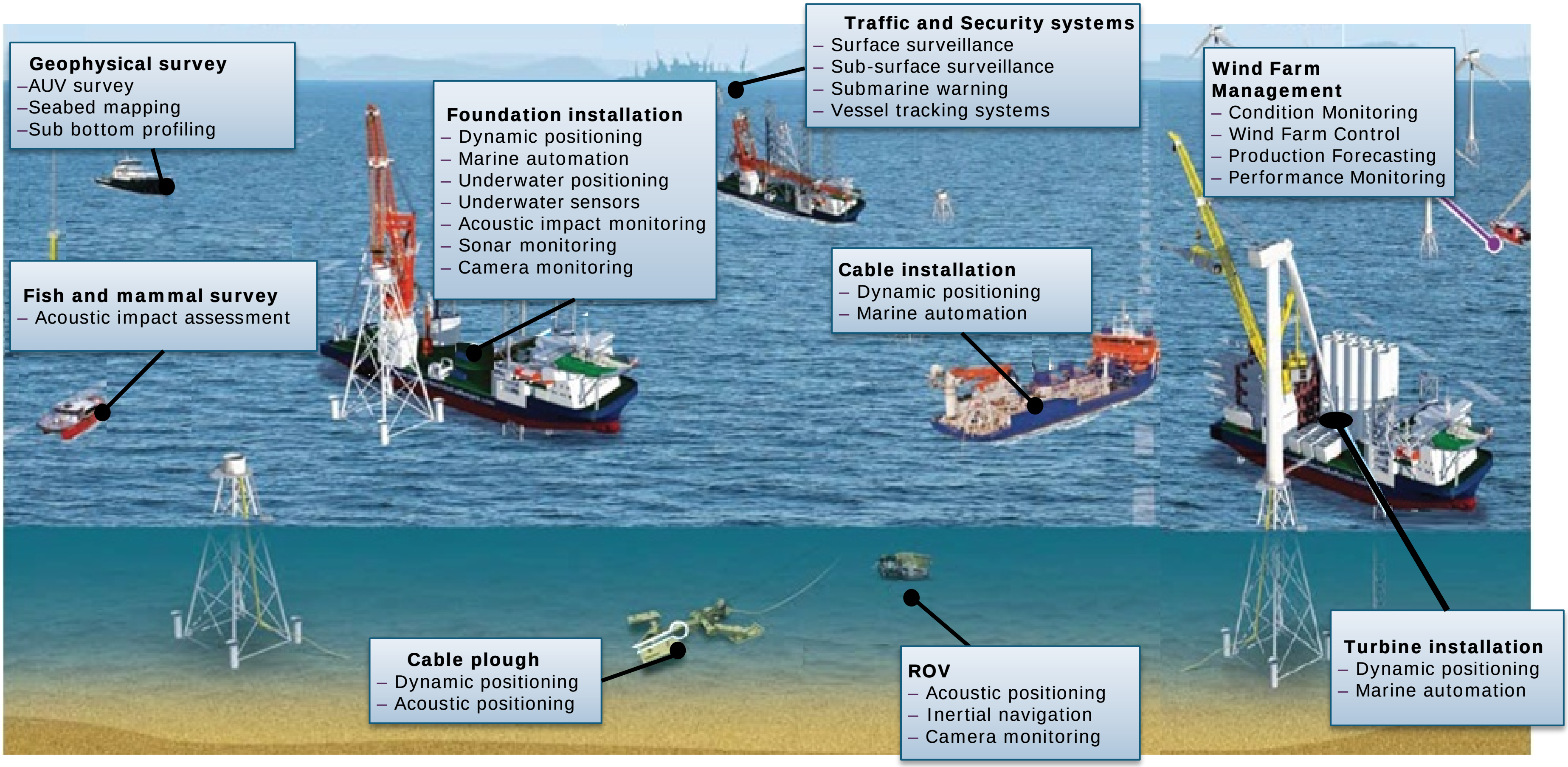
## ”The Full Picture” for Maritime and Offshore applications
## To be extended to Wind Power applications



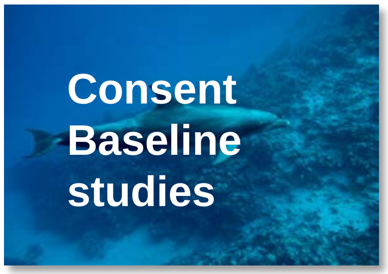
# K-IMS Information Management System



# KONGSBERG Onshore/Offshore Wind



# Kongsberg Maritime Subsea – Geophysical, environmental monitoring & inspection





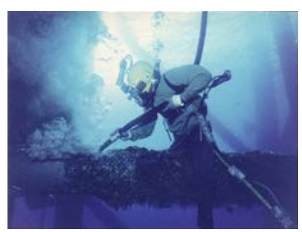


**Products:**

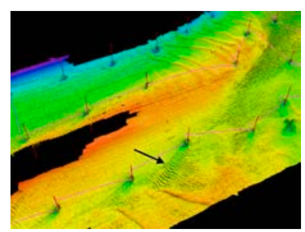
- Sonar’s and echo sounders, multi-beams during inst., sonars, sub bottom profilers, 3D monitoring/inspections
- AUV – inspection survey and monitoring
- C-node sensor network - CMS
- Subsea cameras for inspection – ROV/AUV mounted
- Listening devices – subsea noise, sea mammals

**Corrosion**

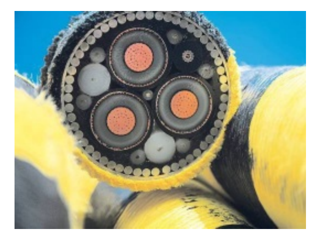
**Deformation**



**Marine growth**



**Scouring**



**Cable tracing & pipe laying**

**Noise**

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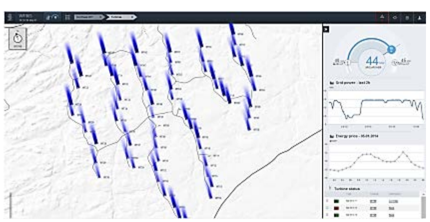
# Kongsberg Wind Farm Management System

**Integrated decision support system for optimal performance and minimized downtime and operational costs**

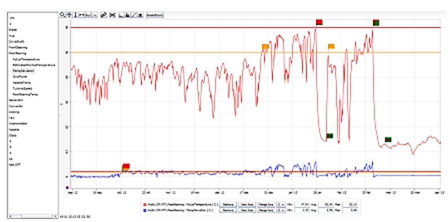
## 5-8% reduction in CoE

## Modules:

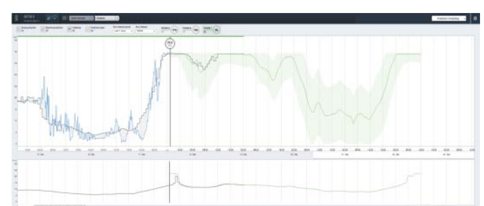
- **Conditioning Monitoring** with enhanced analysis of turbine data
- **Production Forecasting** through improved weather analysing tools/ algorithms
- **Wind Farm Control** with dynamic production optimizer reducing wake and turbine loads
- **Performance Monitoring;** reporting, fault analyses, trending and benchmarking of turbines and wind farms



**Production optimizer, load and wake control**



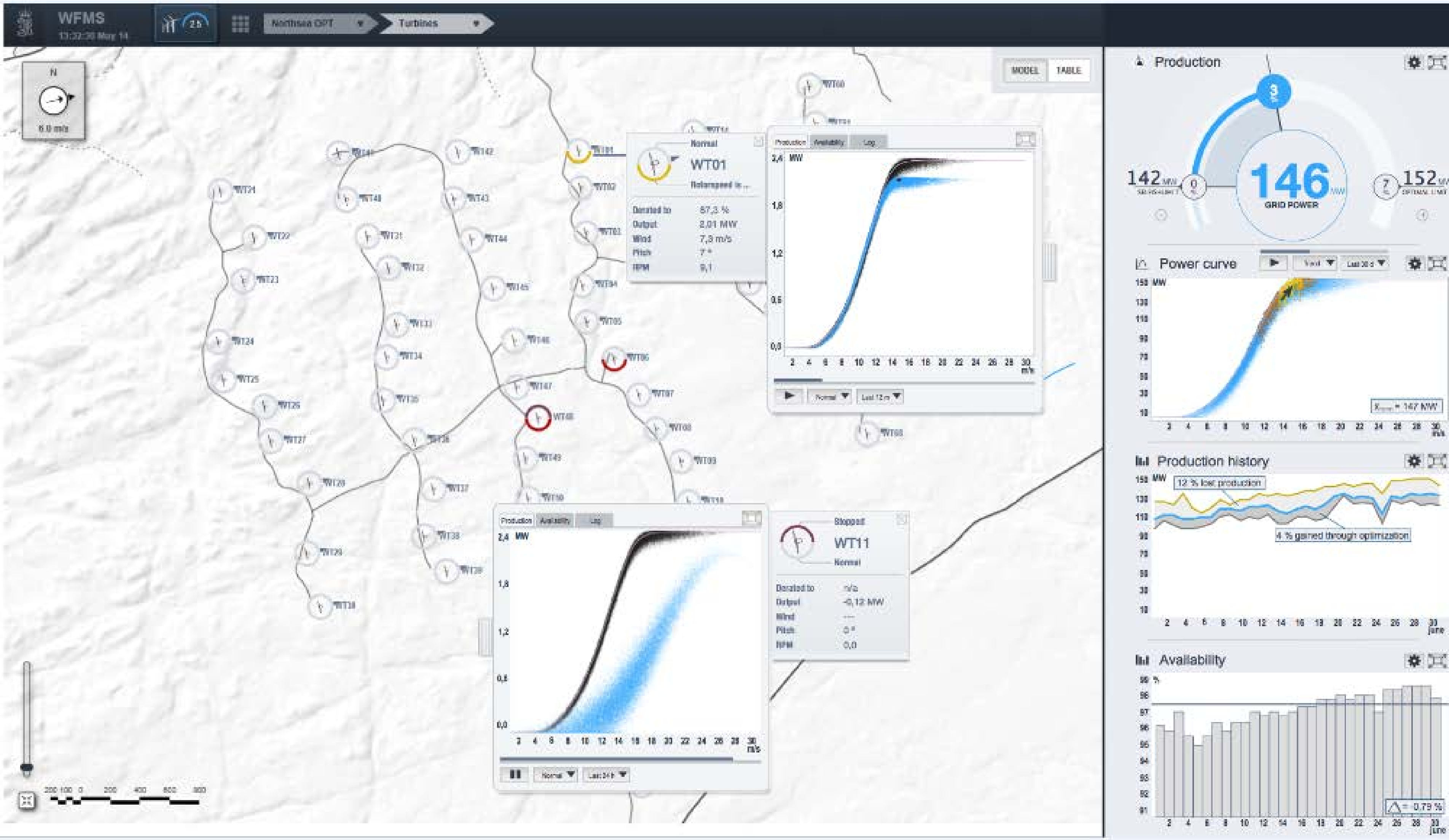
**Reduced down time and operational cost**



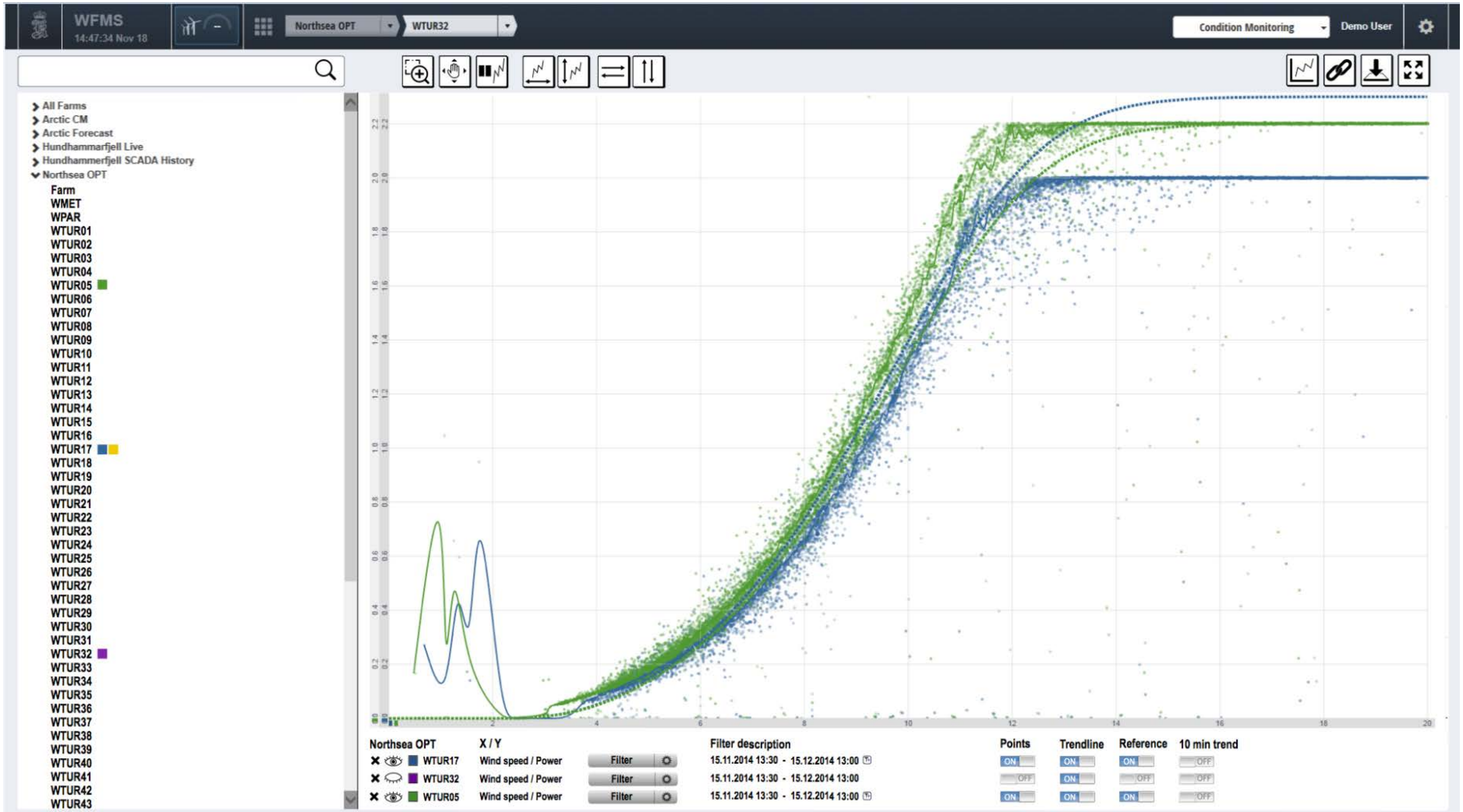
**Reduced imbalance Improved maintenance planning**

**Identify deviations Improved benchmarking**

# Performance Monitoring



# Power curve analysis



# Wind Farm Control

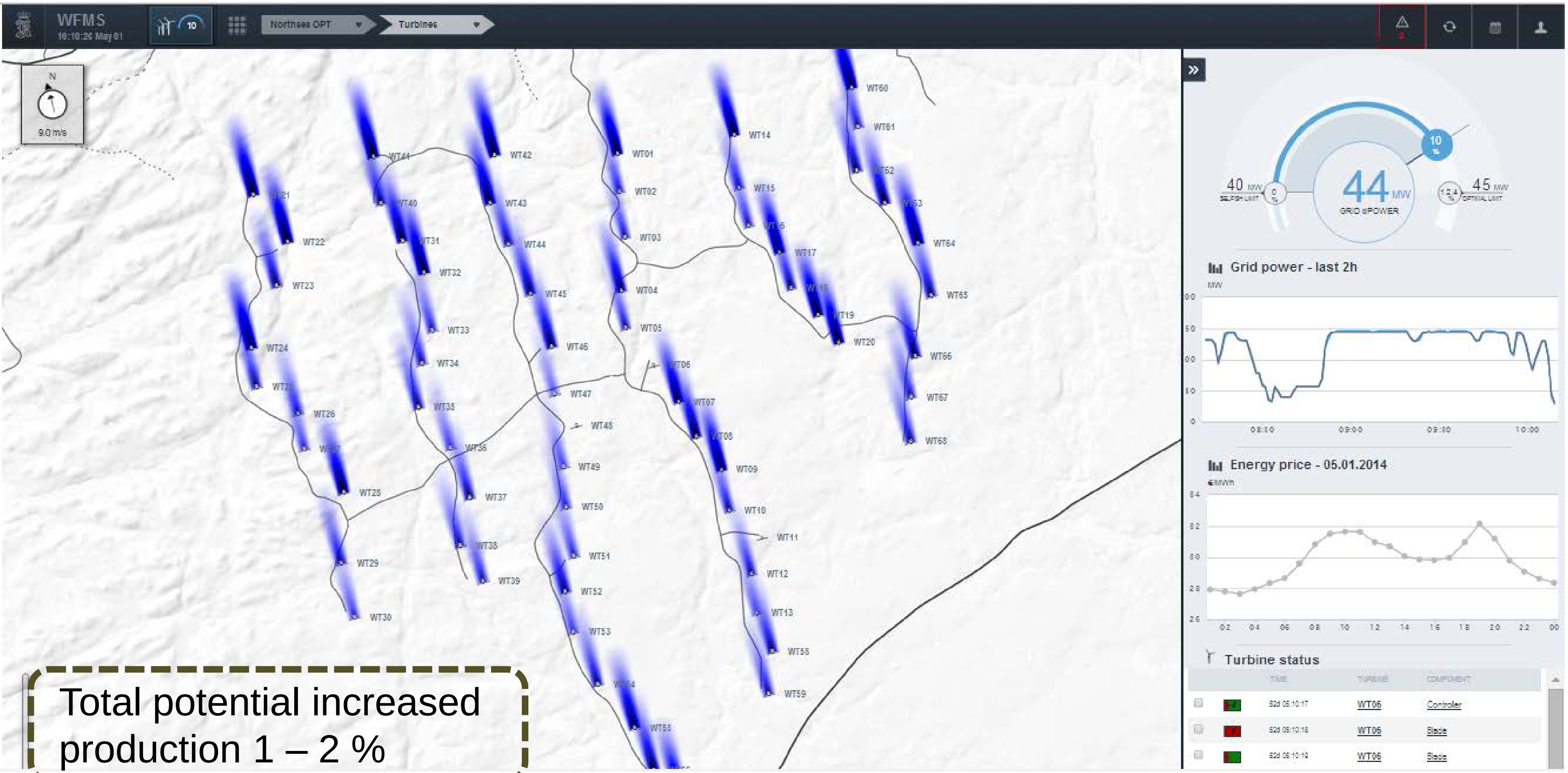
## INCREASED PRODUCTION BY DYNAMIC FARM OPTIMIZER

- **Individual set points for each turbine based on:**
  - ***Actual wind condition***
  - ***Turbine state/condition***

## REDUCED TURBINE WEAR

- **Balancing of loads**
- **Load mitigation**
- **Reduced turbulence wear**

# Wind Farm Control – Production optimiser




Total potential increased production 1 – 2 %

# Production Forecasting

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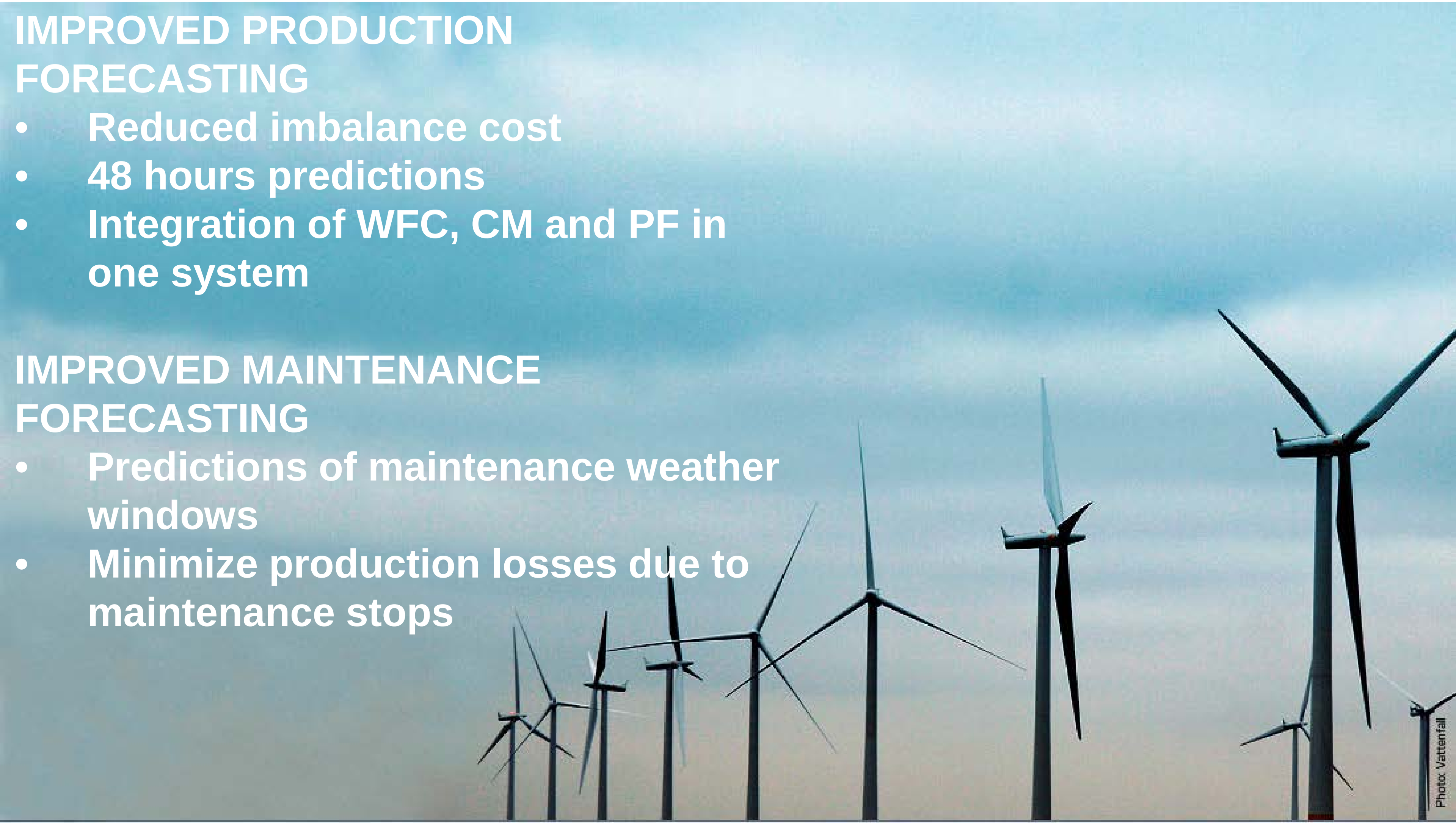



**IMPROVED PRODUCTION FORECASTING**

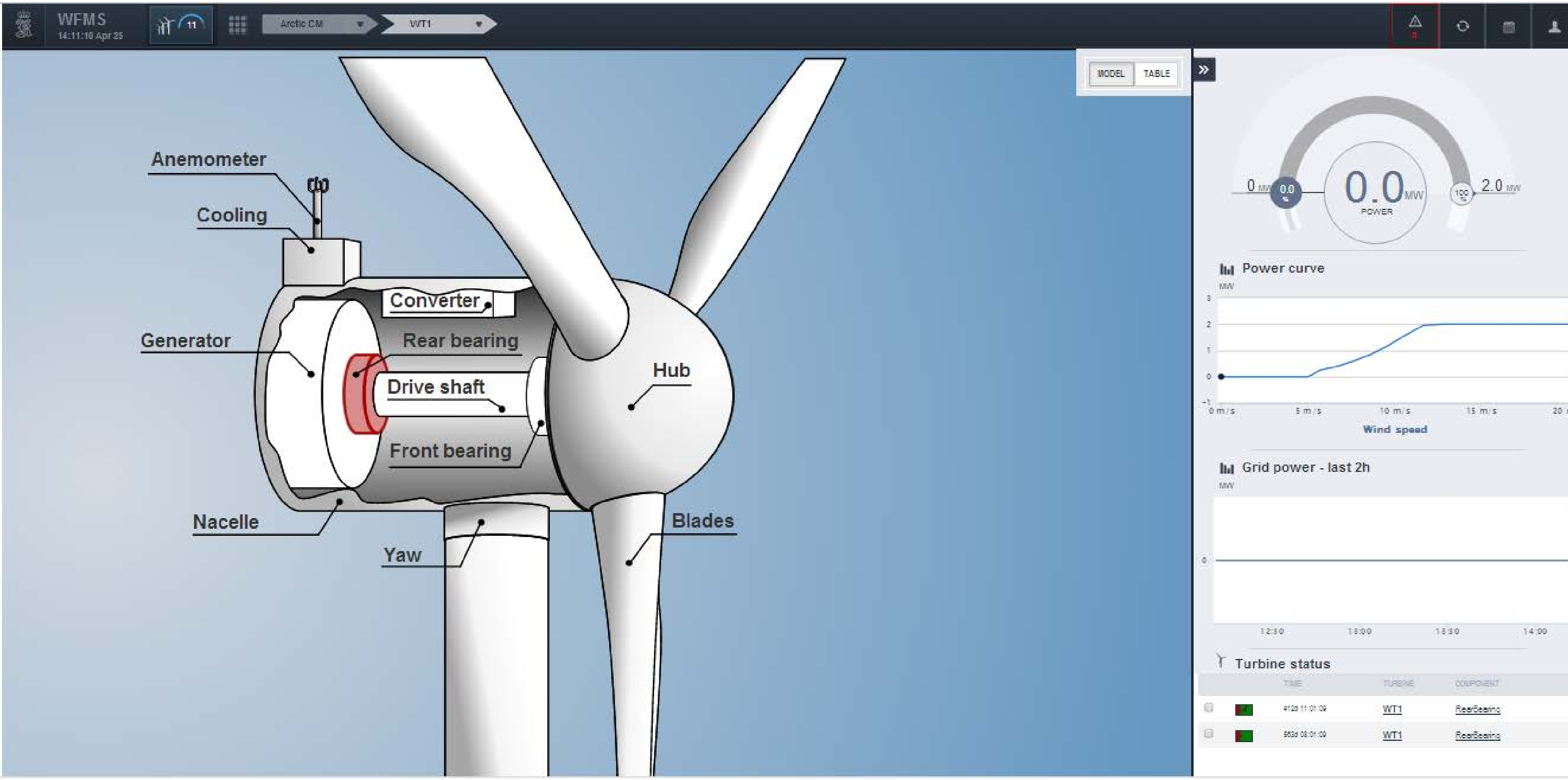
- Reduced imbalance cost
- 48 hours predictions
- Integration of WFC, CM and PF in one system

**IMPROVED MAINTENANCE FORECASTING**

- Predictions of maintenance weather windows
- Minimize production losses due to maintenance stops

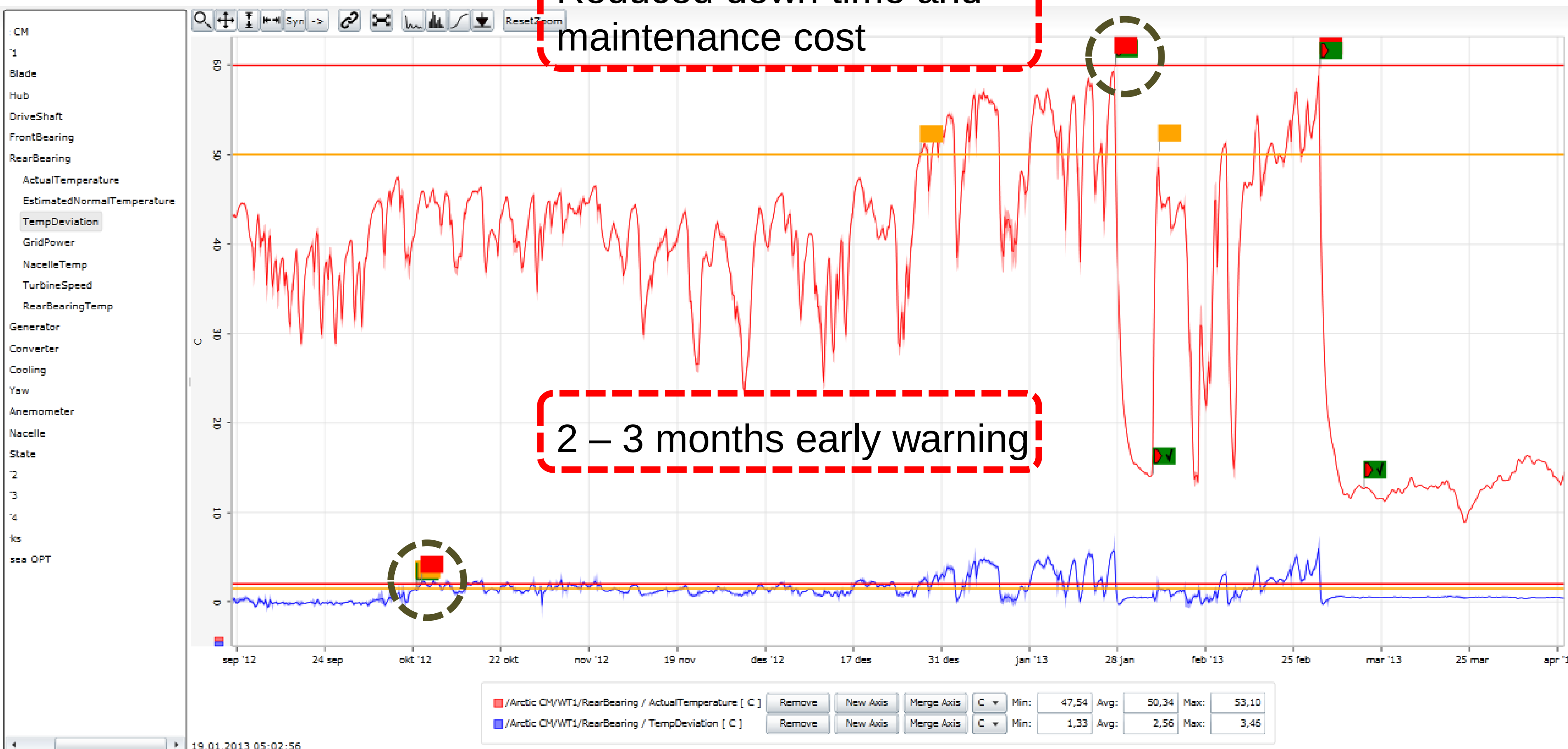
# Production Forecasting

# Condition Monitoring



# Condition Monitoring – analysis tool

Reduced down time and maintenance cost




2 – 3 months early warning

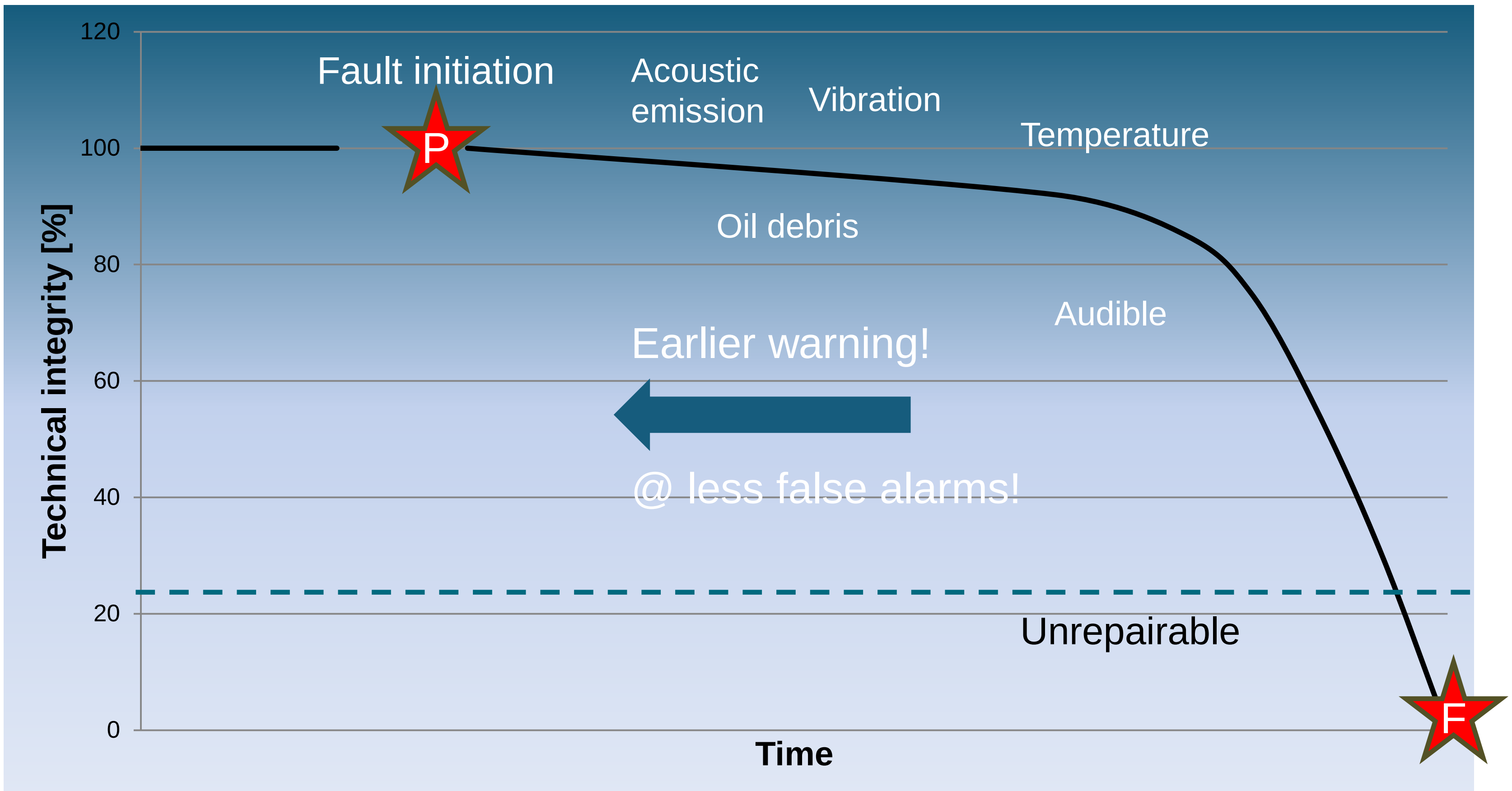
Inspect rear bearing

Change grease €€€

Avoid unrepairable fault

# The P-F curve

## combination of measurement techniques with different detection points




Catastrophic failure

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    - ➢ Methods
- Contributions from the «Windsense» project
- Cost savings potential

# Condition Monitoring
## - online and offline monitoring

- **Sensor input**
  - Existing (SCADA data)
  - Add on sensors
- **Fault detection**
  - Automated analyses
  - Comparison with baseline data
  - Early warning of fault development
- **Diagnostics**
  - Add on high frequency sensors
  - Adaptive diagnostics
- **Prognostics**
  - Time to service
  - Remaining Useful Lifetime
  - Level of service
  - Enable predictive maintenance

# Signal Processing
## - Detection and Prediction

**Earlier detection of faults by improved analysis methods:**

Compensate for process variations and environmental conditions by mathematical modeling

- Artificial Neural Network (ANN)
- Heat balance models
  - bearing temperature
  - electrical converter temperature

**Next step:**

- Improved prediction of remaining useful lifetime (RUL)

# Detection of Rear Bearing Fault using ANN

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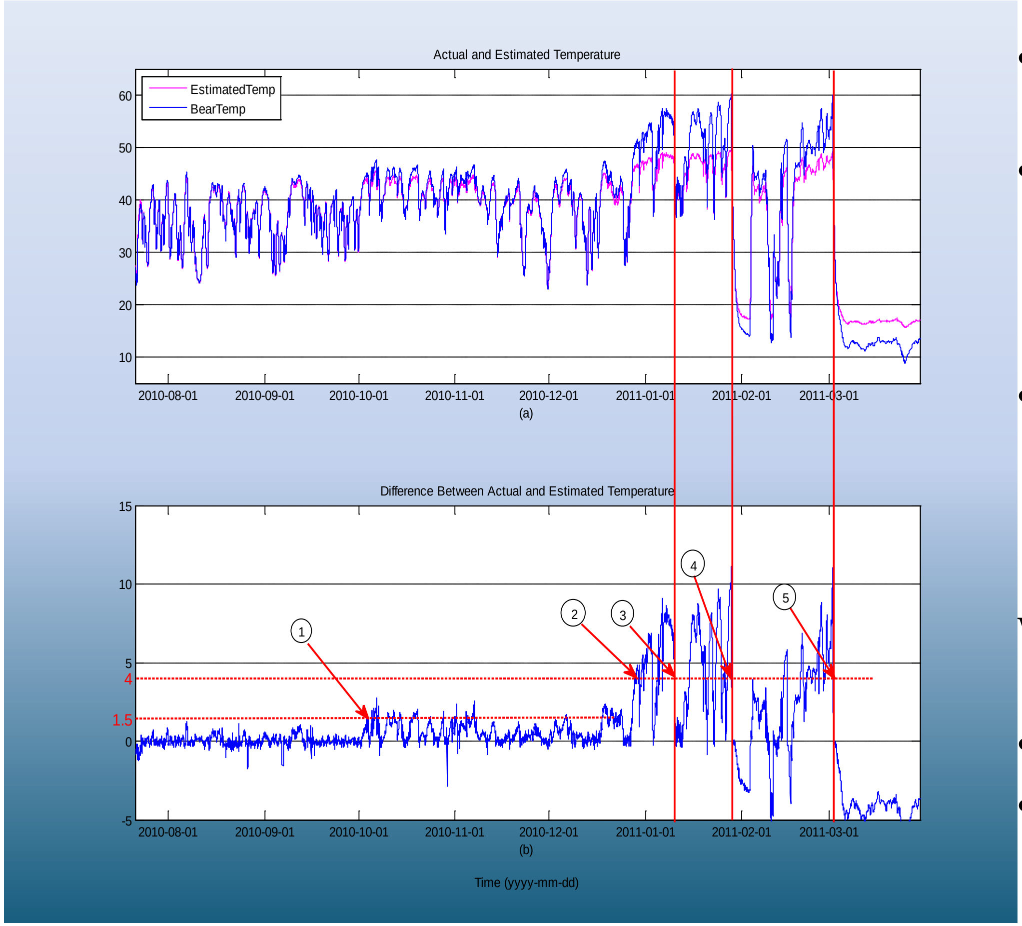



- ①: The first noticeable deviation from the model occurred primo October 2010.
- The turbine stopped due to overheating twice (at ③ and ④) and was restarted by the operator

- ⑤: The turbine was permanently stopped

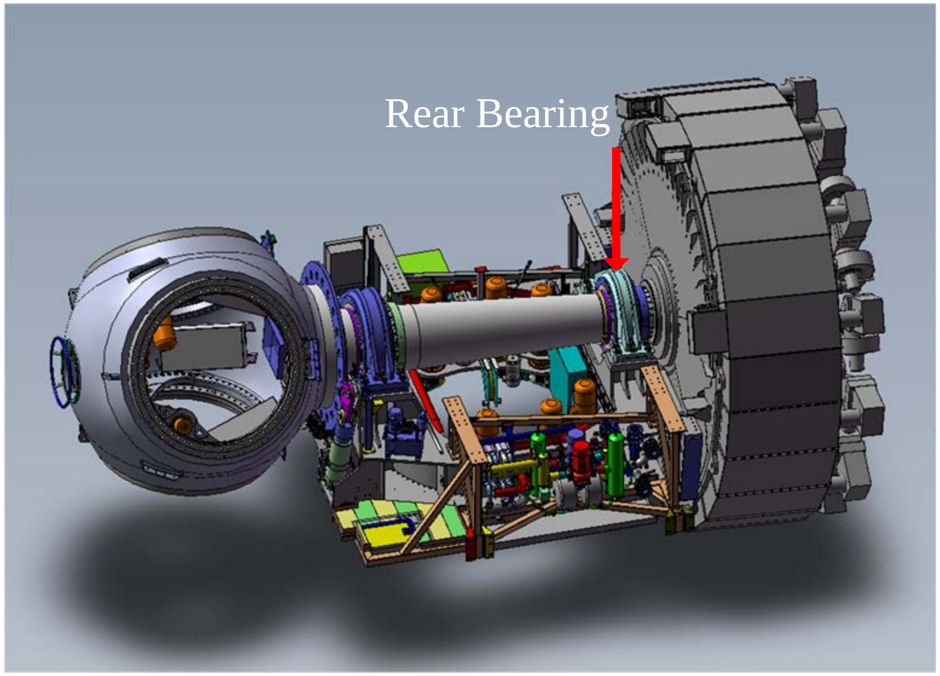
With the chosen thresholds the method gives

- 3 months pre-warning
- 10 days earlier alarm than with standard fixed alarm limits

# Parameter Selection

- Indicator: Temperature

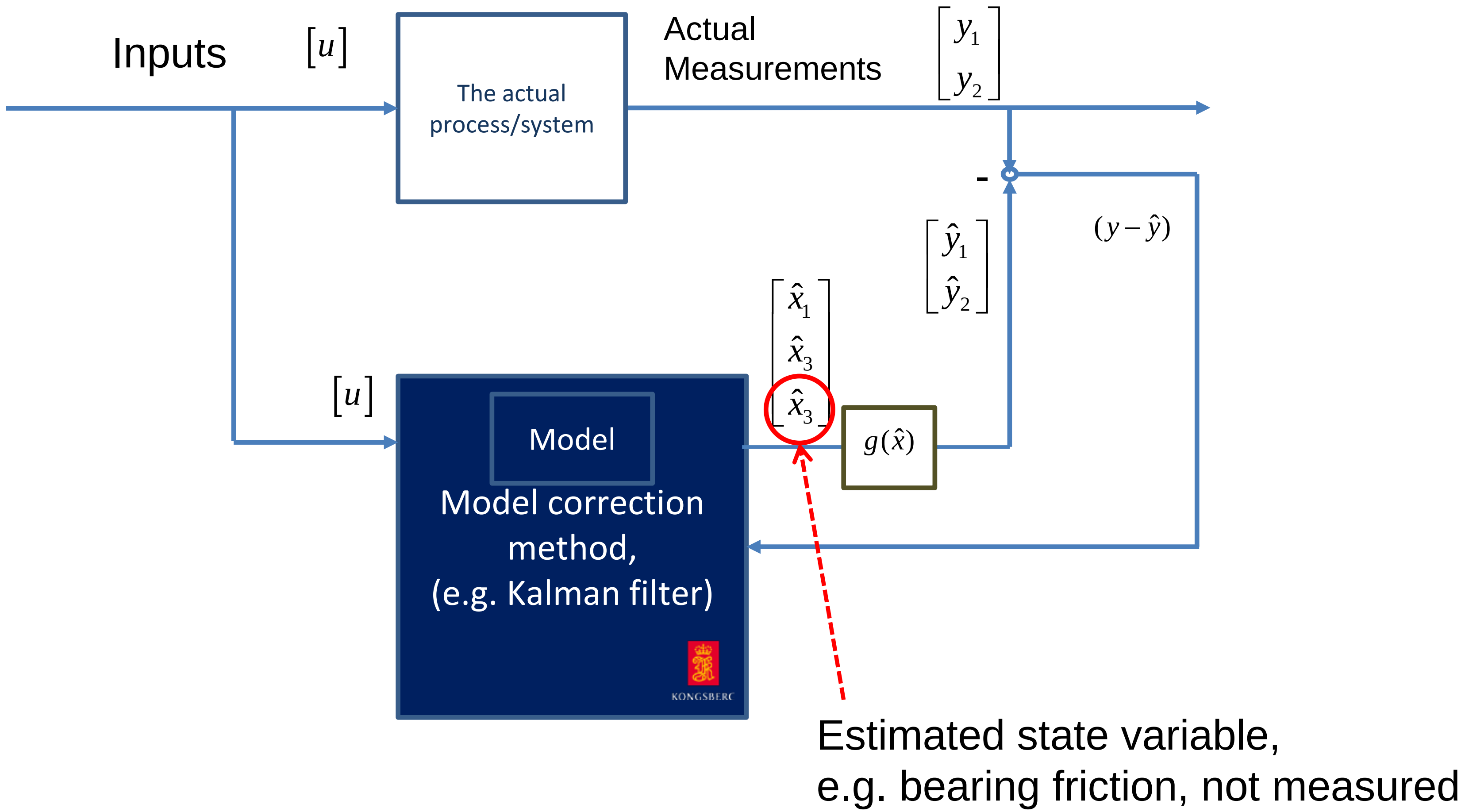
- Parameters that may influence or relate to the indicator:
  - Rear bearing temperature (t-1)
  - Active power output (t)
  - Nacelle temperature (t)
  - Turbine speed (t)
  - ~~Cooling fan status~~



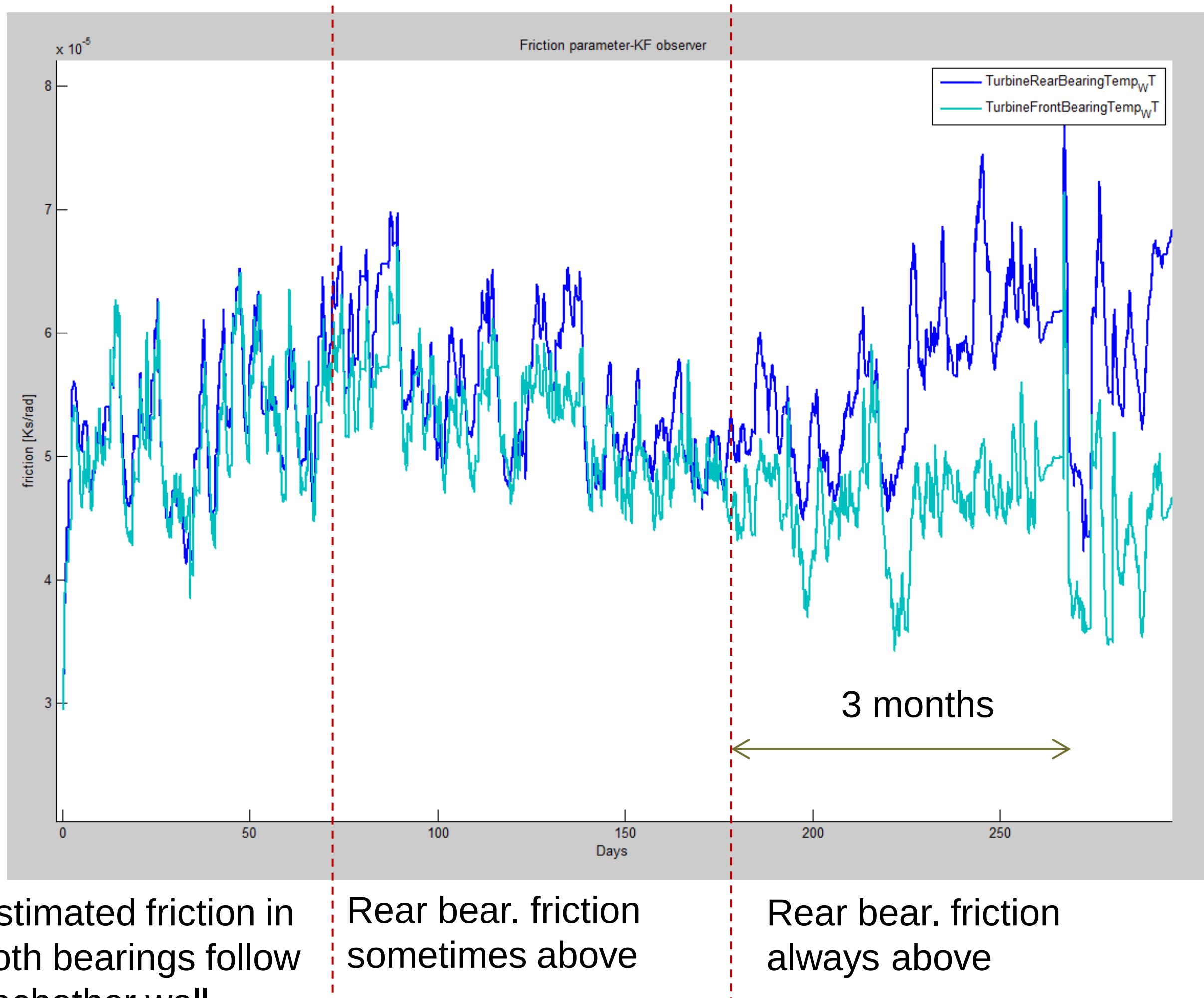

| Model Input |
|---|
| **Rear bearing temperature (t-1)**<br>**Active power output (t)**<br>**Nacelle temperature (t)**<br>**Turbine speed (t)** |

| Model Output |
|---|
| **Rear Bearing Temperature (t)** |

# Model based approach



# Estimation of «bearing friction» front and rear bearing using unscented Kalman filter



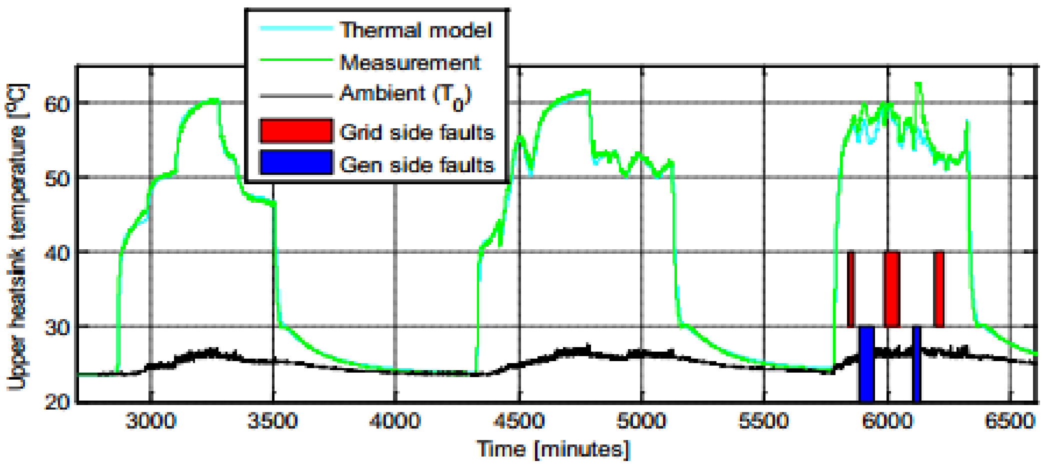

Estimated friction in both bearings follow eachother well

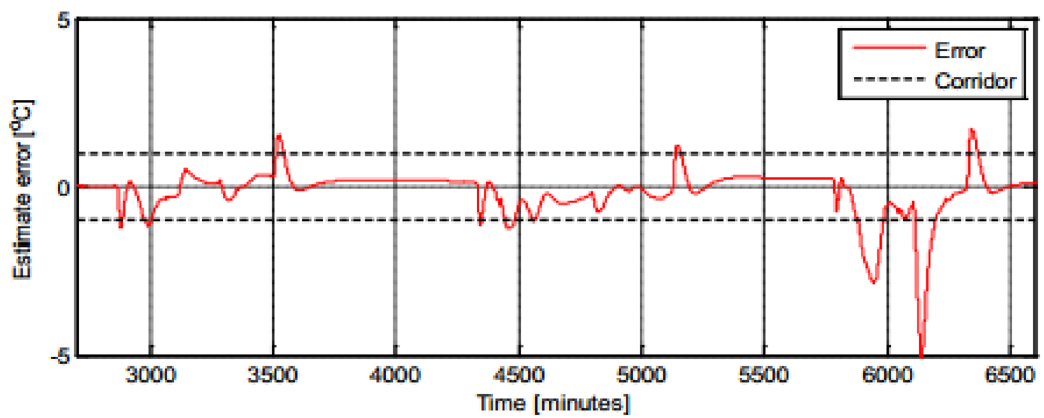
Rear bear. friction sometimes above

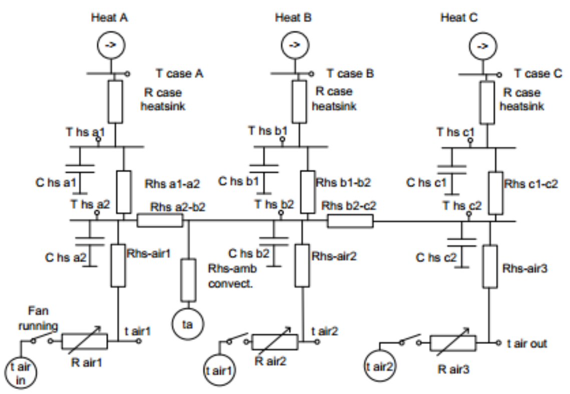
Rear bear. friction always above

# Generator side heat sink temperature of frequency converter with introduced faults

## Measurements vs model

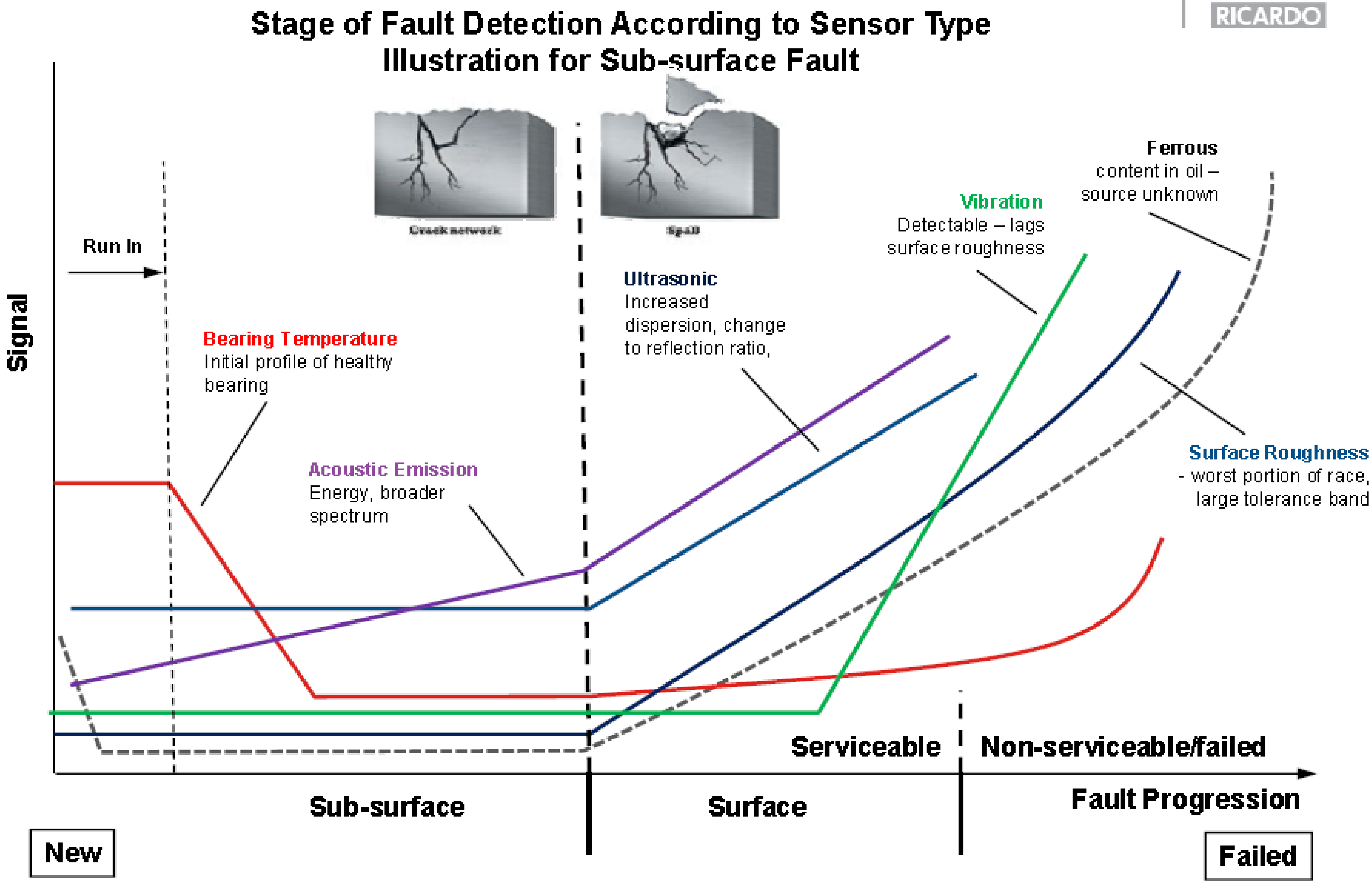



Complex impedance model for heat balance

# Focus on early fault detection
# - Acoustic emission?



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# WINDSENSE

*Add-on instrumentation for Wind Turbines*

***3 year project (2012-2014):***
***Funded by RCN***

***Contribute to a 30 % reduction in Cost of Energy from Offshore Wind***

KONGSBERG
Statoil
NTE
TROLLHETTA
CONTRIBUTING WITH EXPERIENCE
LIGHT STRUCTURES
SINTEF
MARINTEK
SINTEF GRUPPEN
NTNU
Det skapende universitet
HiST
TRONDHEIM
Norwegian Centres of Expertise
NCE Instrumentation

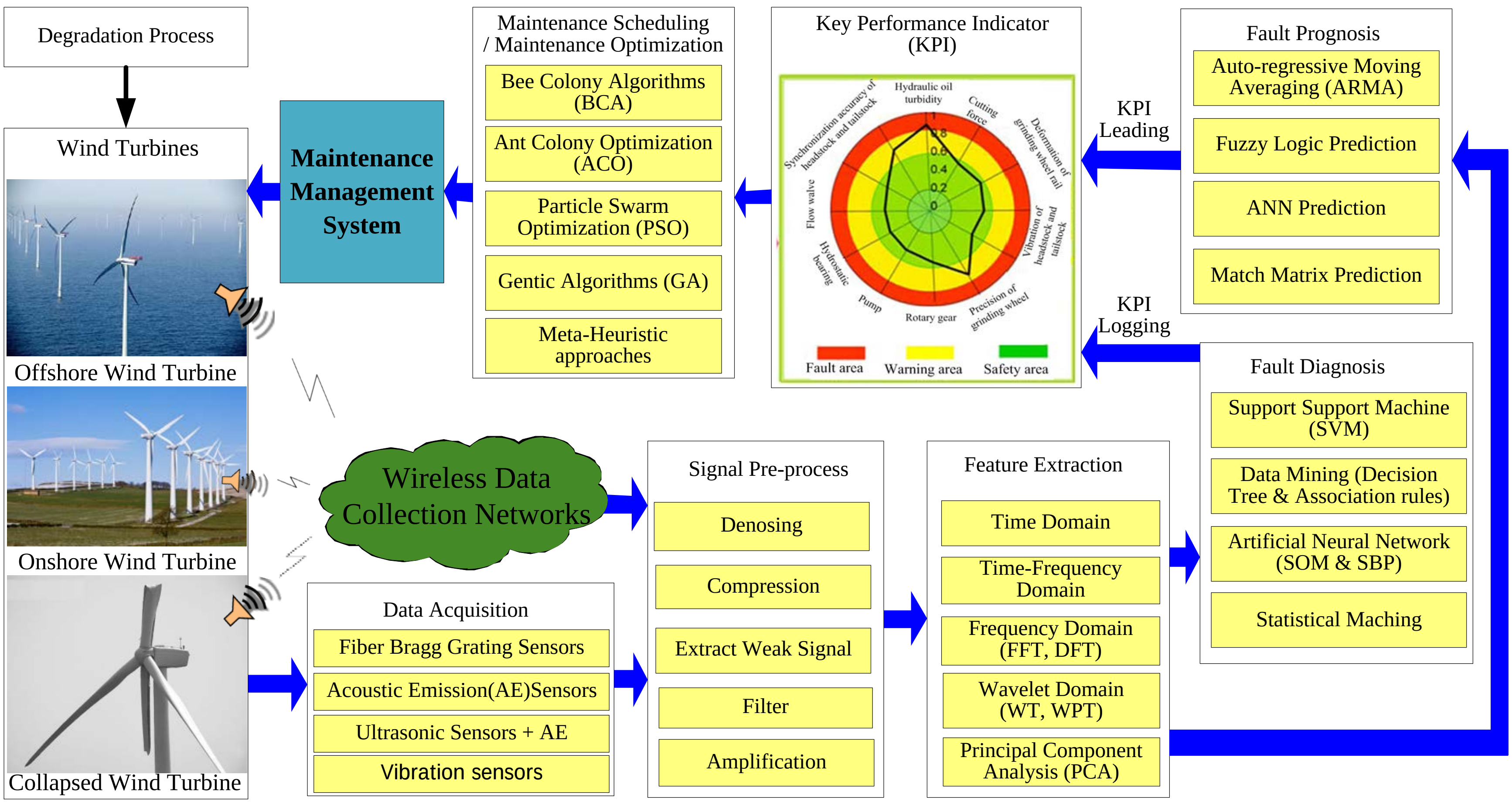
# Windsense

## Work packages and time schedule

| | Work package | Responsible | 2012 | | | | 2013 | | | | 2014 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| WP1 | GAP analysis | MARINTEK | | | | | | | | | | | | |
| WP2 | Functional requirement specification | STATOIL | | | | | | | | | | | | |
| WP3 | Evaluation of sensing methods & eq. | HIST | | | | | | | | | | | | |
| WP4 | Dev. data interpretation algorithms | NTNU | | | | | | | | | | | | |
| WP5 | Implementation in CM system | KM | | | | | | | | | | | | |
| WP6 | Laboratory testing | KM | | | | | | | | | | | | |
| WP7 | Field testing at pilot turbine(s) | STATOIL | | | | | | | | | | | | |
| WP8 | Development of prediction algorithms | SINTEF ER | | | | | | | | | | | | |
| WP9 | Implementation of CBM system | MARINTEK | | | | | | | | | | | | |
| WP10 | Analysis of cost saving potential | KM | | | | | | | | | | | | |
| WP11 | Administration & dissemination | KM | | | | | | | | | | | | |

# Windsense

## Illustration of data acquisition and analysis



# Findings and further work

GAP analysis

- A general lack of high frequency data
- Limited use of advanced signal analysis
- Limited data for lifetime prediction
- Need for improved blade monitoring
- Need for improved monitoring of high voltage components

CM methods – to be evaluated with respect to

- Early and secure detection
- Low false alarm rate
- Reliable diagnostics
- Cost/benefit ratio

# The challenge

## Improved methods and models for lifetime estimation

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### Prediction horizon at different models

| Model | short term ← | prediction horizon | → | long term |
|---|---|---|---|---|
| | << MTTF* | < MTTF | MTTF | ≥ 2 · MTTF |
| **Stochastic models** | | | | |
| • Failure rate models | | | | |
| • Lifetime distributions (Weibull …) | | | | |
| • Stochastic degradation models | | | | |
| **Physical models** | | | | |
| **Artificial intelligence (AI)** | | | | |

* Condition monitoring systems that provide warning and alarms hours, days or months before a failure.

### Prediction capability in dependence of size of populations

| Model | small ← size of population | → large |
|---|---|---|
| | single unit, item | group, population |
| **Stochastic models** | | |
| • Failure rate models | | |
| • Lifetime distributions | | |
| • Stochastic degradation models | | |
| **Physical models** | | |
| **Artificial intelligence (AI)** | | |

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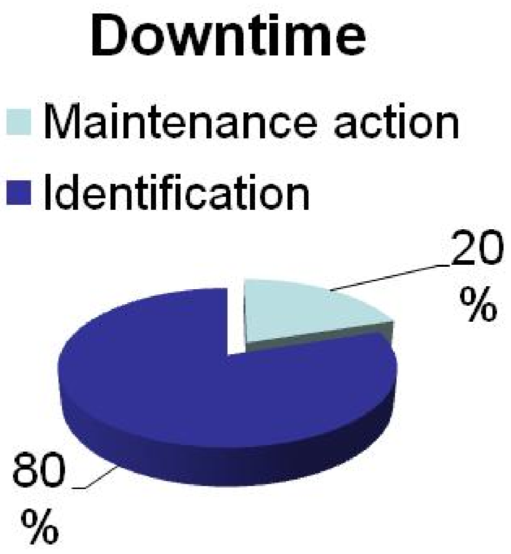
# How will improved CM systems contribute to a reduced Cost of Energy for Wind Power:

- Replace manual inspections with remote on-line measurements and analysis
- Implement automated diagnostics tools
- Limit the number of alarms to those that are significant (KPI’s)




- Reduce consequential damages
- Enable delay of maintenance until proper weather window occur
- Reduce downtime by more efficient fault identification and diagnostics
- Improve maintenance planning by better diagnostics and estimation of remaining lifetime

# Condition Based Maintenance (CBM)

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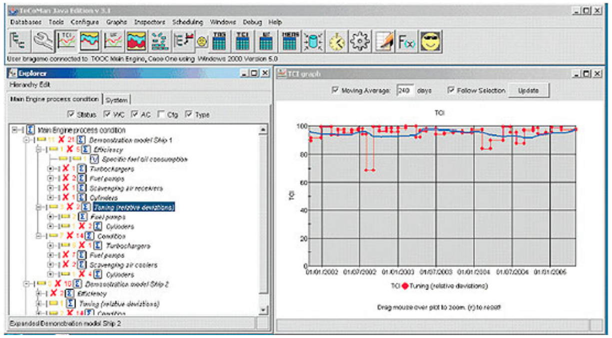


Methods and systems employed in the offshore and maritime industry provides

- An indication of degraded performance or technical condition in a plant
- Efficient drill down capability
- Triggers further investigation with analysis and diagnostics, either through CM system or by manual inspection
- Includes decision support for intervention planning

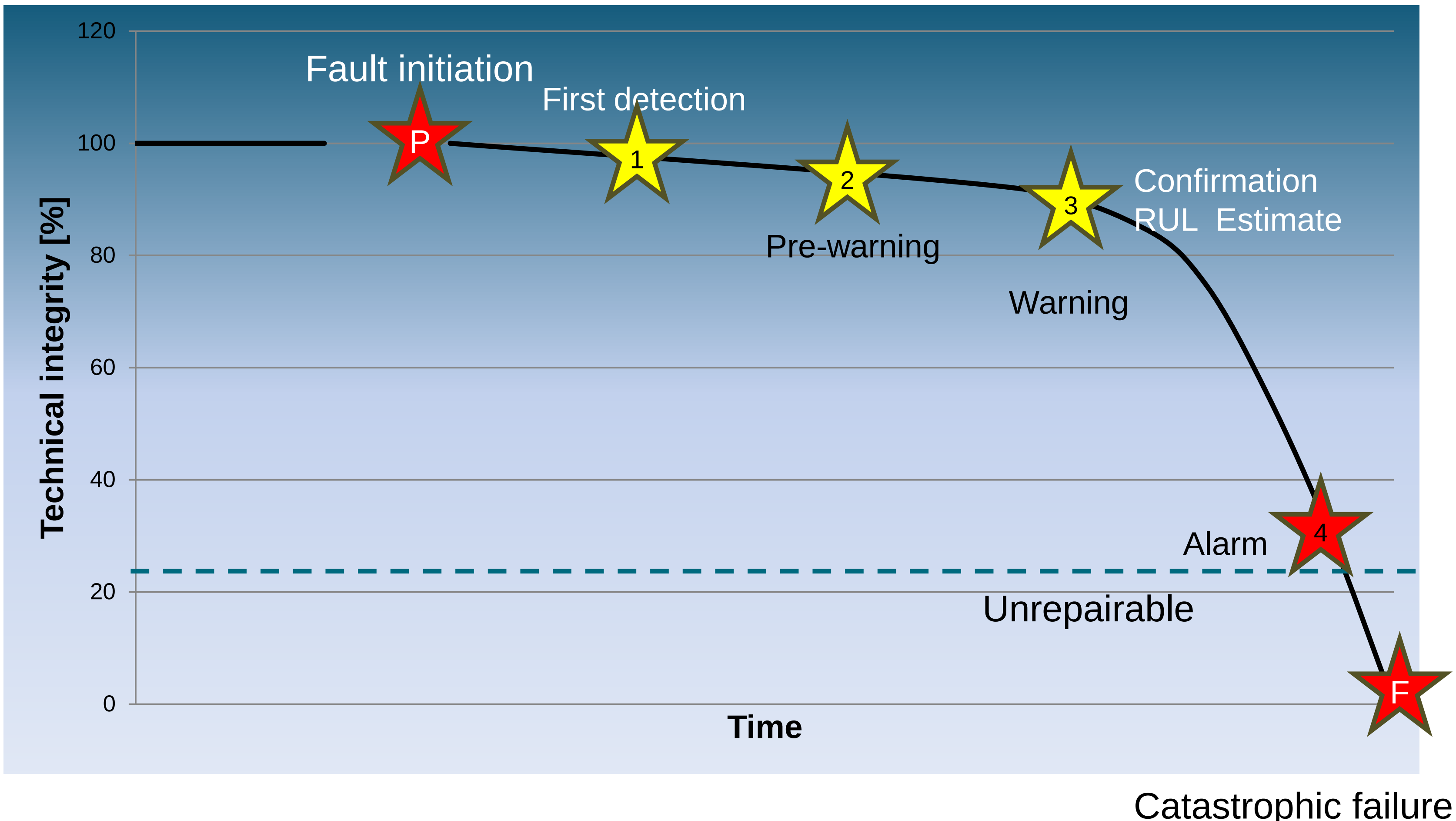
**Goal**

A substantial reduction in maintenance cost and increased energy production for offshore wind turbines by

- A significant reduction in number of unplanned service trips
- A reduced number of stops and less downtime
- Controlled running at reduced load when this is safe rather than full shut down until maintenance can be performed

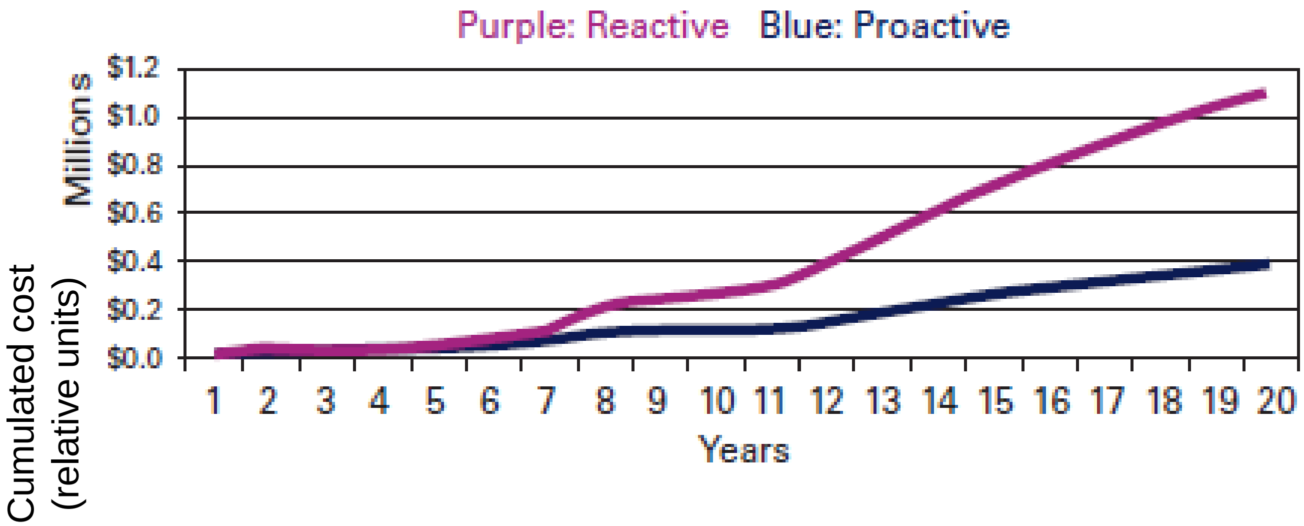
# Output to maintenance system

- Warnings and Alarms
- Fault diagnostics – root cause analysis
- Estimates of remaining useful lifetime (P-F)
- Dynamic updating of technical condition as input to RCM risk assessment



# Operation & Maintenance Costs (O&M)

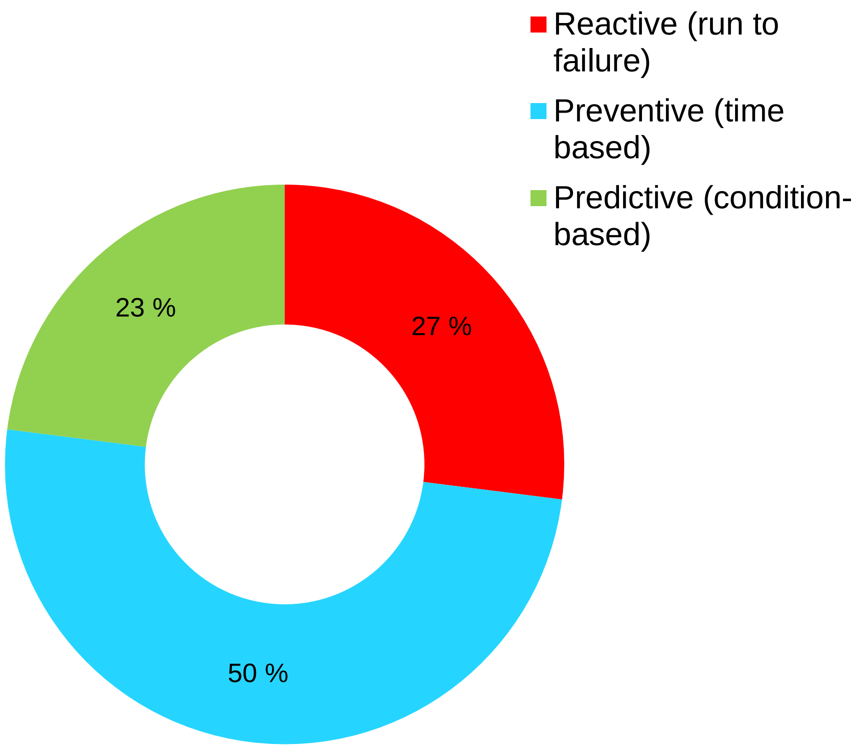
- Condition Monitoring (CM)
- Performance Monitoring (PM)
- Condition based Maintenance (CBM)




Life Cycle Cost: Pro-Active vs. Reactive Maintenance (Roeper 2009 [1])

[1] Source: Wind Energy OM Report 2011

# O&M Strategies for Wind Turbines




*The most common O&M strategies (farm owners)*
*Source: 7th annual Wind Energy O&K Forum*

- 36 % (incl. the 27%) used reactive maintenance to some degree
- 63% used preventive maintenance somewhere in their wind farm portfolio

- Comparision with Oil&Gas (Norwegian sector)
- 60 % of the maintenance is preventive
- Target is 80 %

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Thank you for listening!

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