Machine Learning for Condition Monitoring at EnBW

Presentation of the department and the services

Operation Services Renewable (T-BEP)
Dr. Martin Kato, Veronika Glitz
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Contacts

Corporate Trainee

Veronika Glitz
Schiffbauerdamm 1
10117 Berlin
v.glitz@enbw.com
+49 170 3675755

Department C-TISE

Dr. Martin Kato
Durlacher Allee 93
76131 Karlsruhe
m.kato@enbw.com
+49 721 63-14167

Agenda

1. **Introducing EnBW**
2. **Condition Monitoring:** Data, monitoring and support
3. **Example of a Clogged Cooling System:** SCADA Analysis
4. **Example of a Bearing Damage:** Vibration Analysis
5. **Software:** In-house Development of a Holistic Condition Monitoring System

This is EnBW

Who we are and what we do (I)

One of the **largest energy supply companies** in Germany and Europe, with **strong roots in Baden-Württemberg.** Our core business: **electricity, gas, heat and water.**

Our business segments

We are vigorously expanding **renewable energies**.

We transport electricity, gas and water across all voltage and pressure levels via our **grids**.

Our **sales department** serves as contact for all energy-related issues of our customers.

In the **trade and generation** segment we optimise our conventional power plants in terms of economy and CO_2 and trade energy for our customers and ourselves on the stock exchange.

We are evolving **from an energy provider to an infrastructure partner.**

Who we are and what we do (II)

Revenue

€20,617.5 million

€2,157.5 million

Number of B2C and B2B customers

About **5.5** million

Internationally

operating in **11** countries

Employees

21,775 (31.12.2018)

Share

€8.1 billion market capitalisation (31.12.2018)

Length of electricity grid

151,000 km

Length of gas grid

24,000 km

Installed power plant capacity

13,399 MW

of which renewable energies

3,738 MW

Fully integrated energy supply company

Electricity

Generation › Trade/ procurement › Transmission/ distribution › Sales

Gas

Import contracts / infrastructure › Storage › Trading / portfolio management › Transport/ distribution › Sales

The other big players in Germany

e·on RWE innogy

1) Earnings before tax, depreciation and amortisation and extraordinary expenses

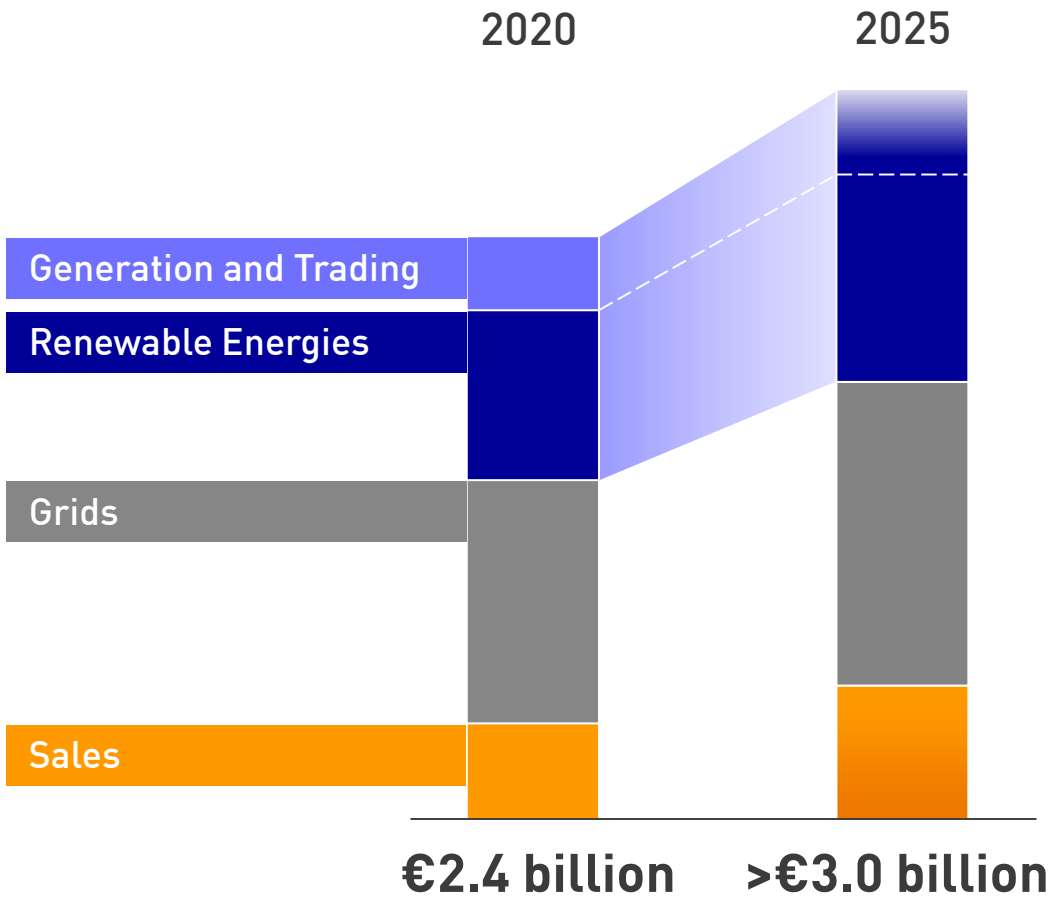
As of: 2018

The foundation of the repositioning was laid in 2013 with the EnBW 2020 strategy

	2012		2020
Generation and Trading	€1.2 billion	–80%	€0.3 billion
Renewable Energies	€0.2 billion	+250%	€0.7 billion
Grids	€0.8 billion	+25%	€1.0 billion
Sales	€0.2 billion	+100%	€0.4 billion
	€2.4 billion		€2.4 billion

in adjusted EBITDA

A balanced portfolio with three strategic fields is built on the basis of EnBW 2020



Adjusted EBITDA

Sustainable generation infrastructure

System-critical infrastructure

Smart infrastructure for customers

Examples of the implementation of the EnBW strategy 2025

E-mobility

- Over 30,000 charging stations
- Largest charging network in the German-speaking countries (D/A/CH)
- Goal: 1,000 quick-charging stations by 2020
- Connected home solutions

Innovation Campus

- Developing and scaling of new business models
  - Connected home
  - Virtual power plant
  - Urban infrastructure
  - Networked mobility
- Accelerator, Innoation Label
- Company Builder

Safety infrastructure

- Piloted safety solutions for the public space
  - Artificial intelligence for hazard recognition
  - Smart bollards access protection
- EnBW “Full KRITIS” service for the protection of critical infrastructures:
  - comprehensive IT safety and cybersecurity product

Renewable Energies

The broad expansion of renewable energies is one of our central goals

Expansion of wind energy in Germany

- Expansion of onshore wind energy with the targets 1,000 MW by 2020 and 2,000 MW by 2025
- Expansion of offshore wind energy with the targets 945 MW by 2020 and 1,845 MW by 2025
- EnBW He Dreiht with 900 MW as the first offshore wind farm without government subsidies
- Selective internationalisation

Solar energy as another building block

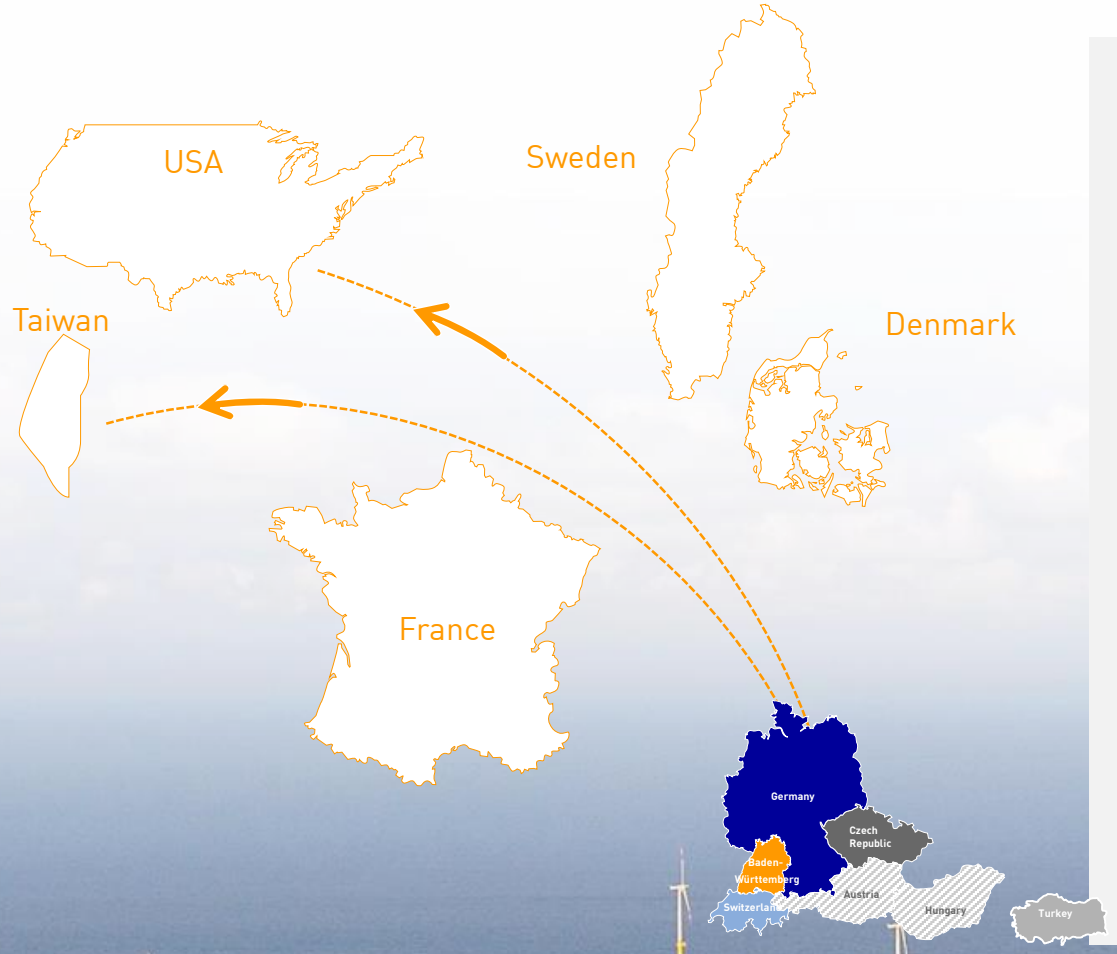
- Own portfolio of 200 MW by 2020 and 600–800 MW by 2025
- Partner of local authorities and companies for the planning, construction and operation of solar parks and solar roofs, solar solution for households

Hydropower as traditional basis

- 67 run-of-river and pumped storage power plants energy for the most part in Baden-Württemberg and Austria

Further activities in the biogas, biomass and geothermal energy segments

Selective internationalisation in the field of renewable energies



From our base in Baden-Württemberg we capture new growth fields in international markets.

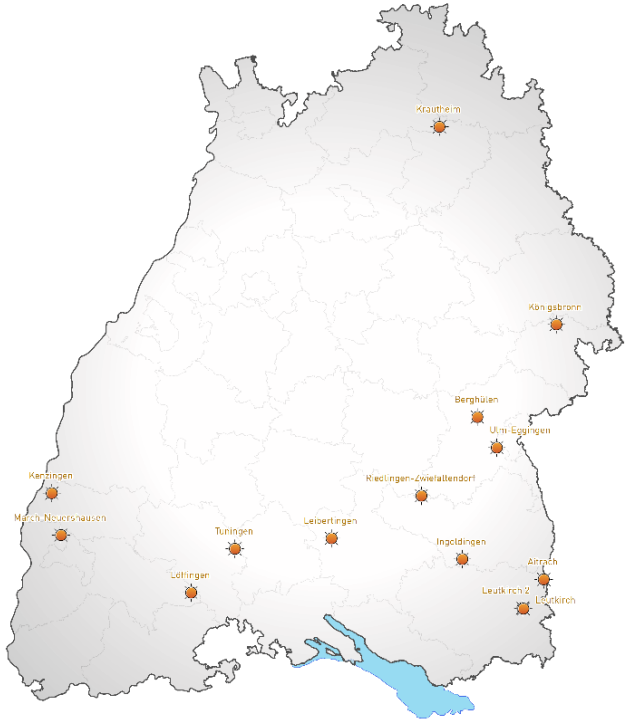
Examples

- Turkey: hydropower, onshore wind energy, photovoltaics; installed output: 495 MW
- Sweden: onshore wind energy, installed output: >100 MW
- USA: establishment of a national subsidiary and of representative offices in different regions; development partnership to build floating foundations for offshore wind power
- France: establishment of a representative office and start of project development
- Taiwan: establishment and building of EnBW Asia Pacific Ltd. and development of offshore projects with local partners
- Denmark: expansion of the service range to companies specialising in the maintenance and repowering of wind power plants

EnBW solar portfolio to grow significantly by 2025

- Accelerated expansion in Germany
- 2017/2018: 6 new solar parks placed into operation (Group: 10 new solar parks)
- End of 2018: about 99 MW (Group) connected to the grid
- 600–800 MW by 2025
- Citizen participation possible
- First non-subsidised and at the same time largest solar park in Germany (Wessow-Willmersdorf/Brandenburg) with 175 MW at the planning stage

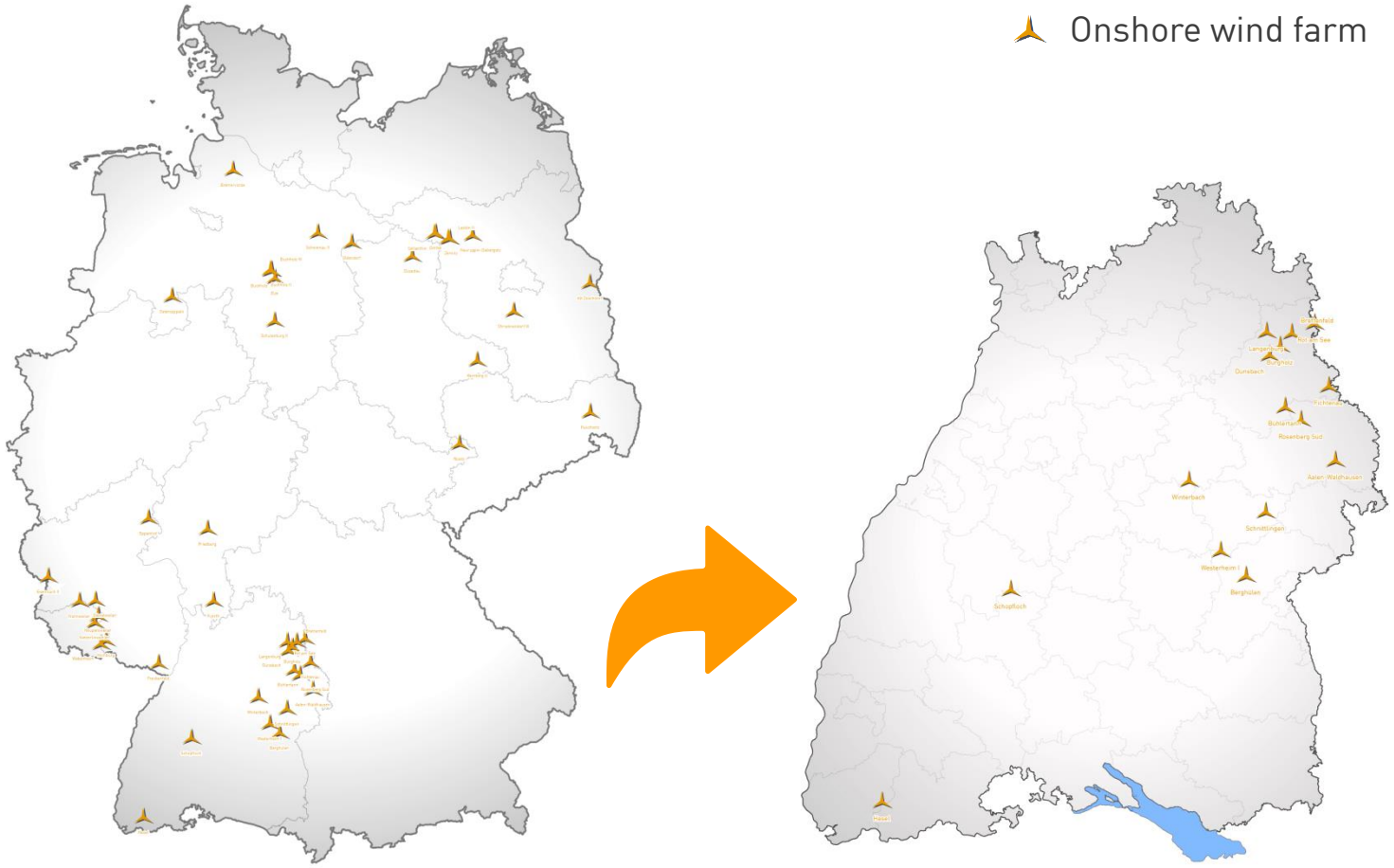
Germany



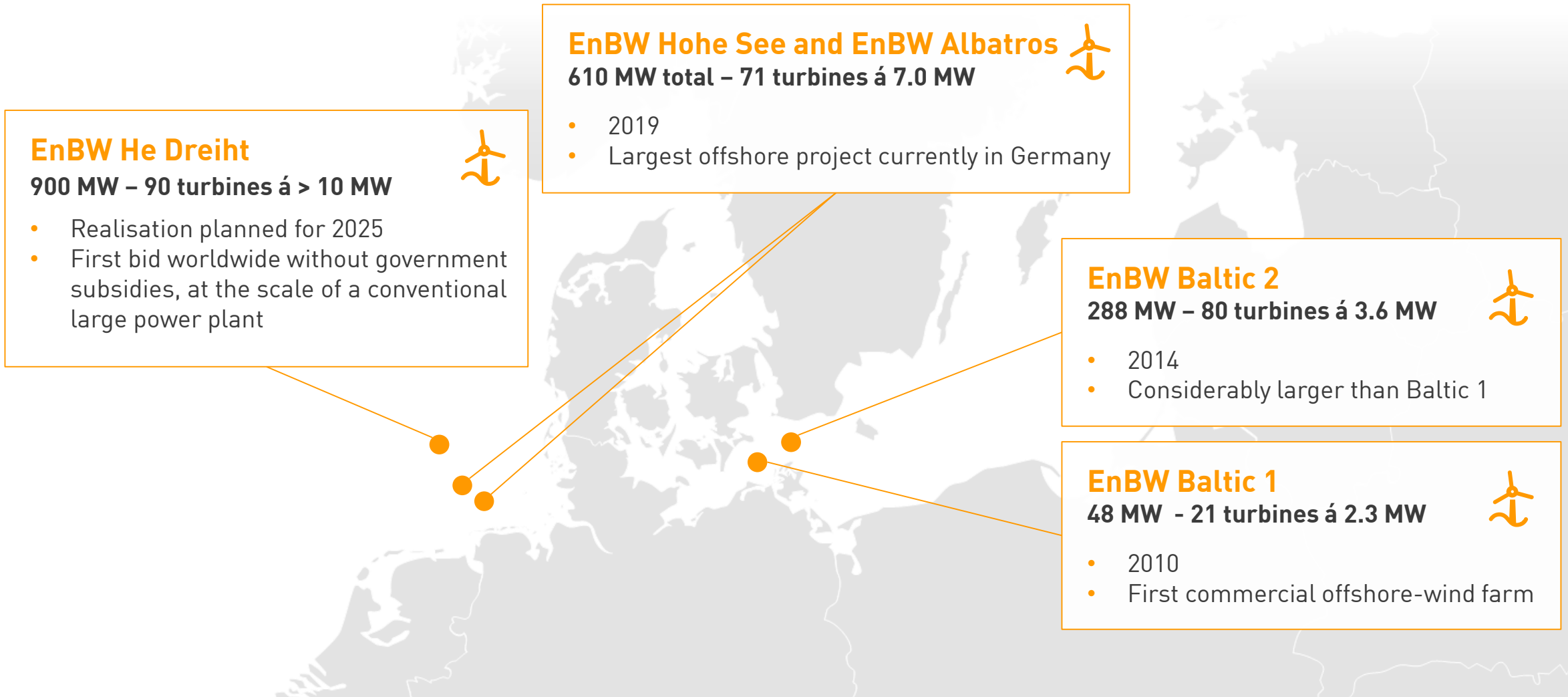
Baden-Württemberg

Onshore wind power in Germany

- Continuous expansion in Germany
- 2017: 16 new wind farms placed into operation (Group: 21 new wind farms)
- End of 2017: about 540 MW (Group) connected to the grid
- Leading project developer: no. 3 in Germany
- Complete value chain: planning, construction and operation
- We make citizen participation possible



EnBW offshore wind power in the German North and Baltic Seas



EnBW Hohe See and EnBW Albatros

610 MW total – 71 turbines á 7.0 MW

- 2019
- Largest offshore project currently in Germany

EnBW He Dreiht

900 MW – 90 turbines á > 10 MW

- Realisation planned for 2025
- First bid worldwide without government subsidies, at the scale of a conventional large power plant

EnBW Baltic 2

288 MW – 80 turbines á 3.6 MW

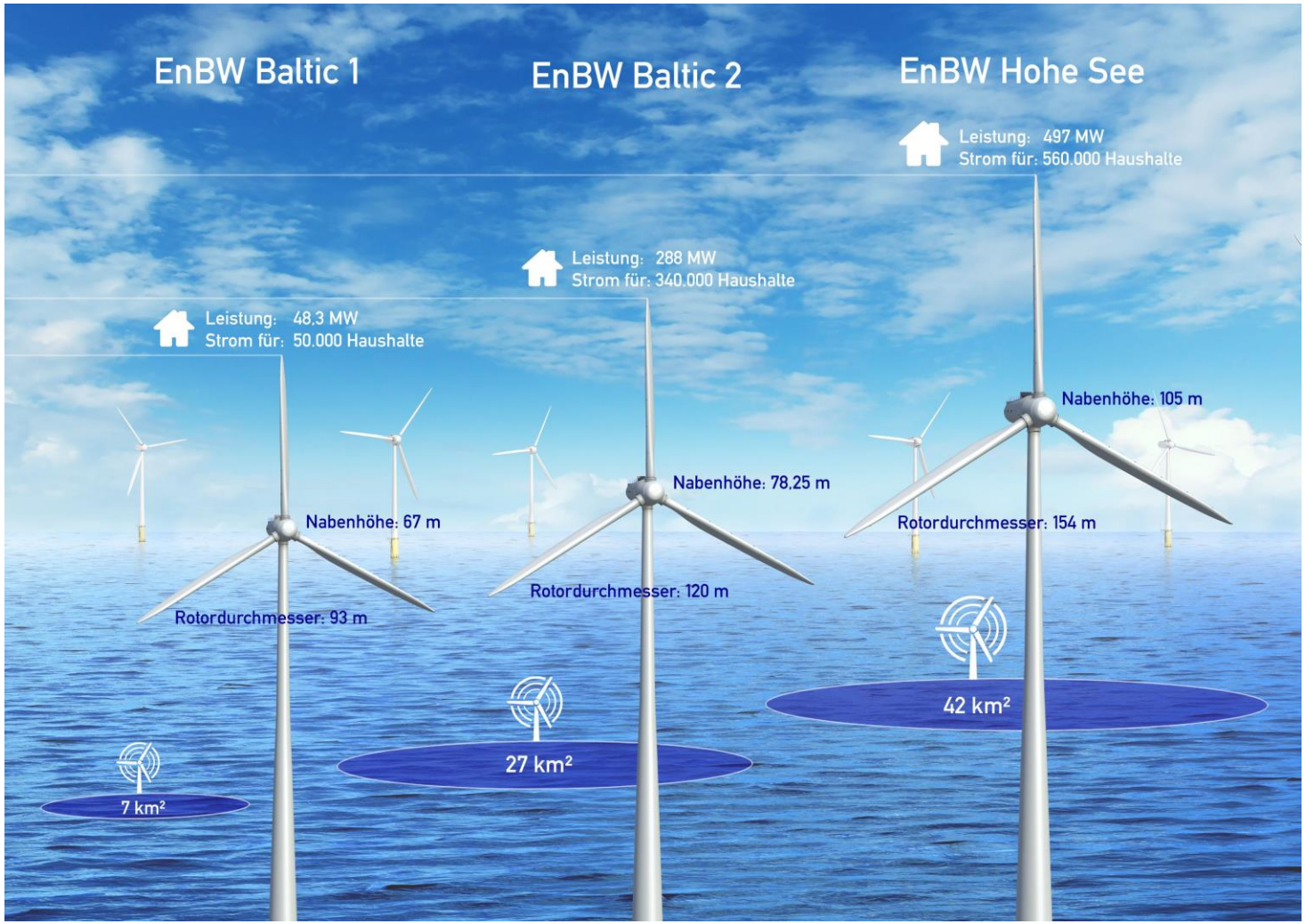
- 2014
- Considerably larger than Baltic 1

EnBW Baltic 1

48 MW - 21 turbines á 2.3 MW

- 2010
- First commercial offshore-wind farm

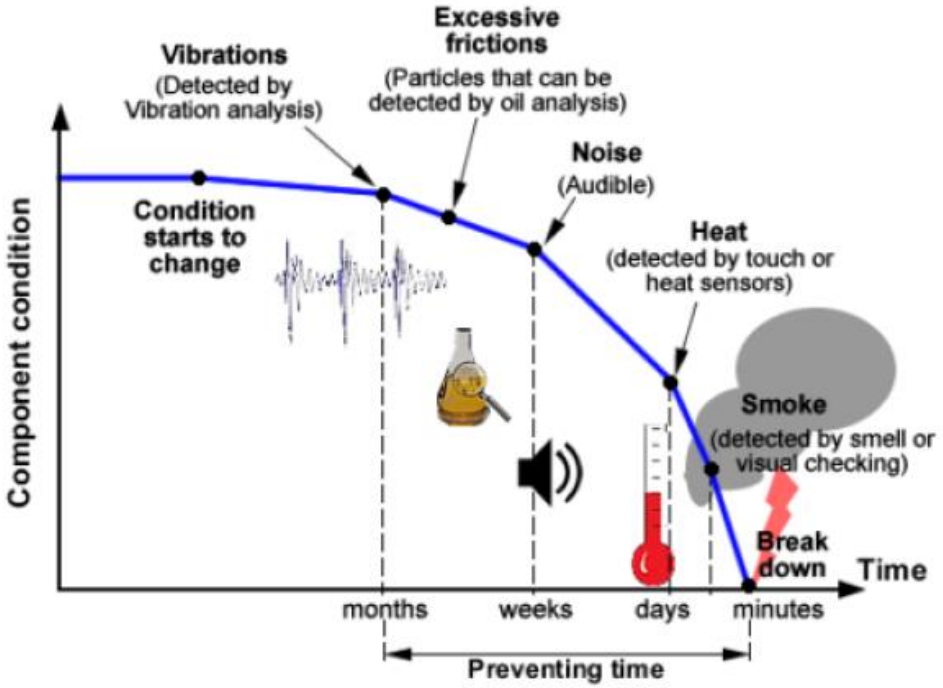
Increasing Sizes of Wind Turbines



Condition Monitoring for Wind Turbines

Introduction to Condition Monitoring

- Rotating machinery
- Goal: condition-based maintenance
- Online or offline
- Example of methods
  - Vibration analysis
  - SCADA data analysis
  - Oil analysis
  - ...
- SCADA = Supervisory Control and Data Acquisition system



Source: Tchakoua, P., Wamkeue, R., Ouhrouche, M., Slaoui-Hasnaoui, F., Tameghe, T., & Ekemb, G. (2014). Wind turbine condition monitoring: State-of-the-art review, new trends, and future challenges. Energies, 7(4), 2595-2630.

Holistic Condition Monitoring of Wind Turbines

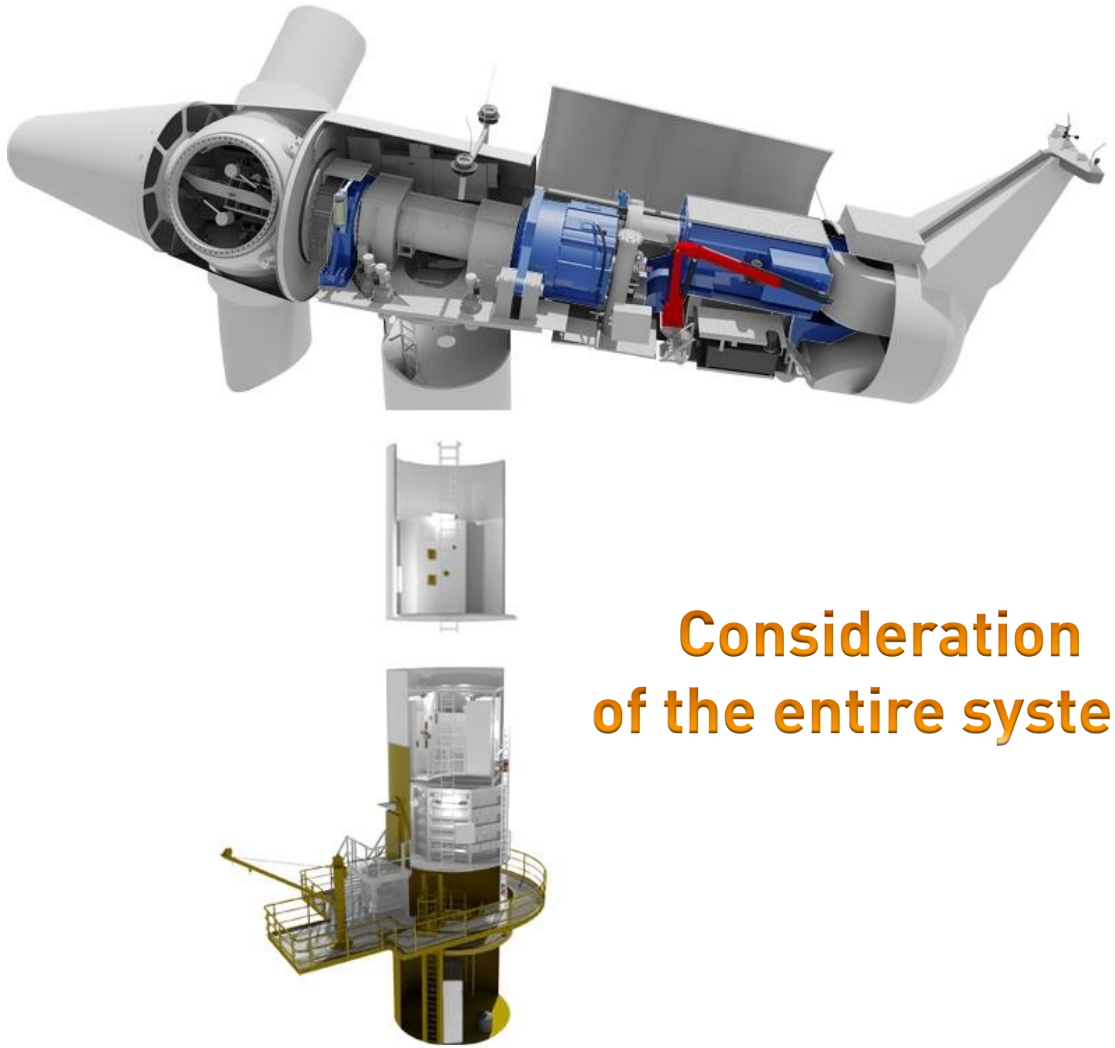
Status Quo

- > 600 MW / 210 WEC monitored
- Monitoring of all relevant components
- Industry standard and self-developed methods
- Inhouse analysis software (ADAZ)

Our Mission

- Monitoring of all WEC operated by the EnBW
- Usage of all available data for monitoring & optimization
- Continuous improvement
- Minimization of operational cost and risks
- Maximizing lifetime of assets

High degree in specialized knowledge, technical know-how and specialised tools (algorithms + software) for the interpretation of data is required.



Consideration of the entire system

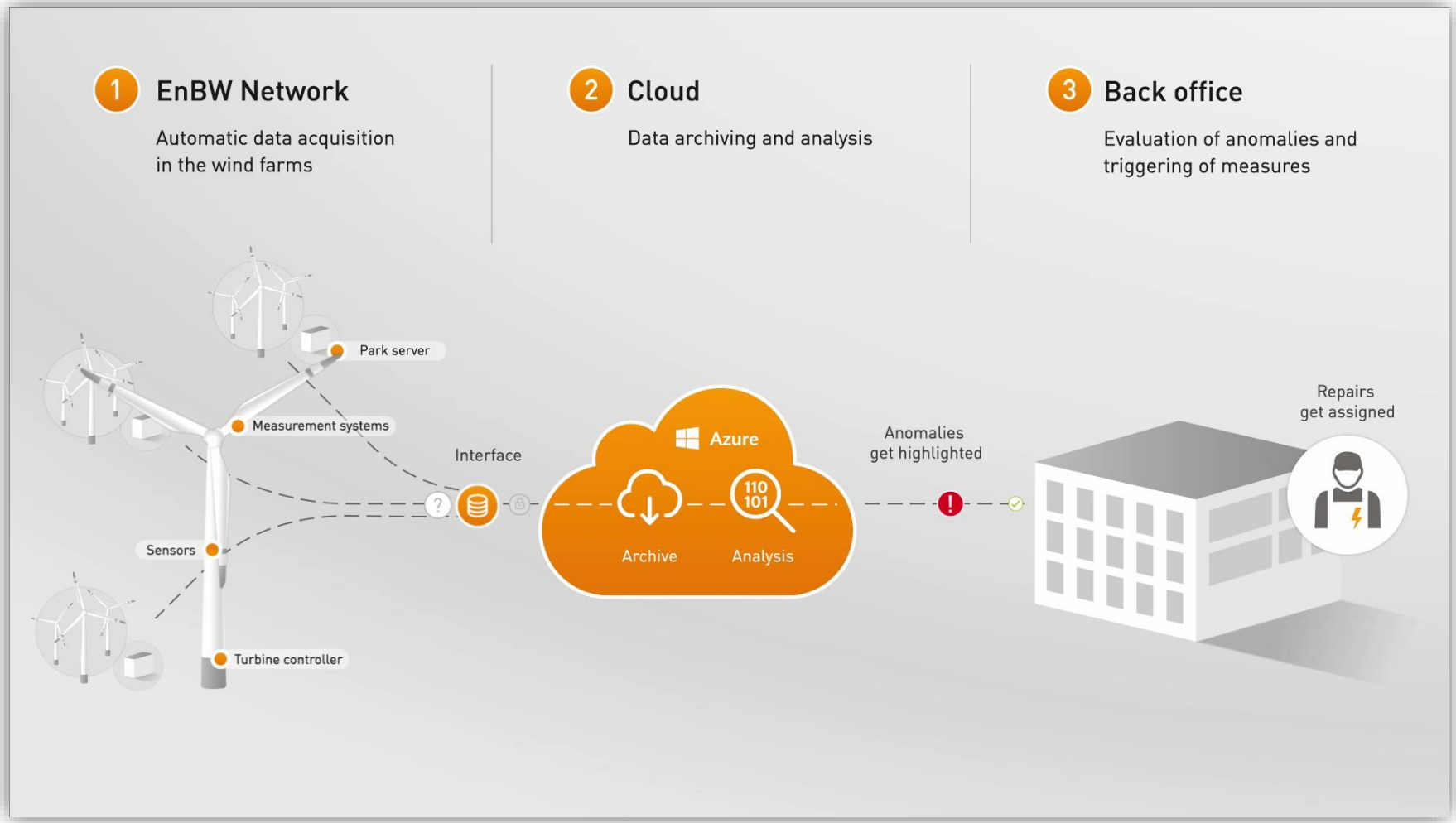
Monitoring Applications

- SCADA data monitoring
  - Basic: 10-20 signals per WEC
  - Medium: 20-80 signals per WEC
  - Advanced: 80+ signals per WEC
- Vibration monitoring
- Oil monitoring (particles, quality)
- Rotor blade monitoring
- Structural monitoring (offshore)
- Material analysis and root cause analysis

Depth of analysis depends on existing maintenance contracts.

Strong partners for measurement equipment

End-To-End Responsibility



Data services

- Import from park servers
- Data consolidation
- Storage and backup
- Data access

Analysis services

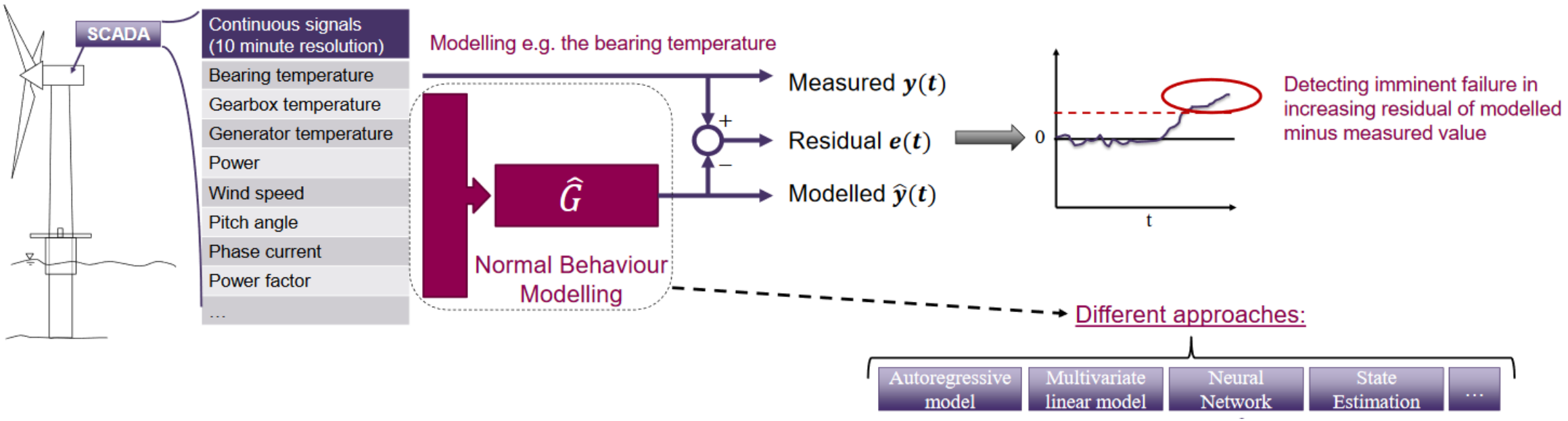
- SCADA Data analysis
- Vibration analysis
- Analyses on demand

Support services

- Root cause analysis
- Fleet optimization

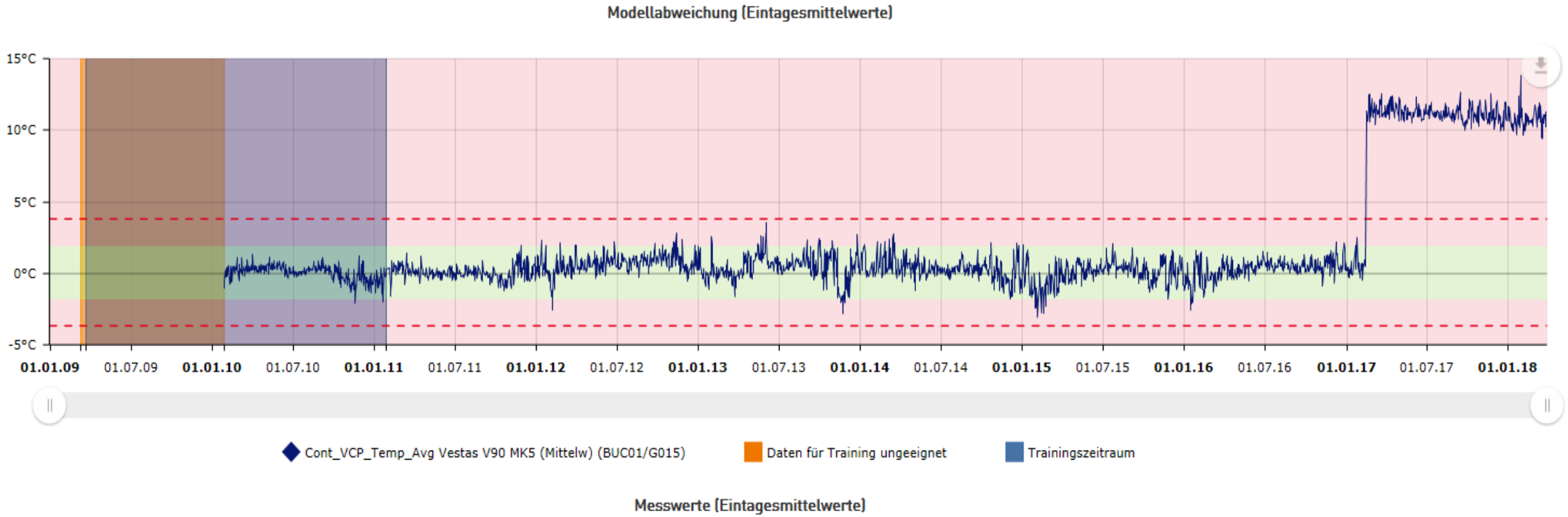
Condition Monitoring with SCADA Data Example Clogged Cooling System

Methods
SCADA | Vibration



Source: Weinert, J and Watson, SJ (2015) Wind Turbine Fault Detection by Normal Behaviour Modelling, Midlands Energy Consortium Postgraduate Student Conference. Full text: https://dspace.lboro.ac.uk/2134/22532

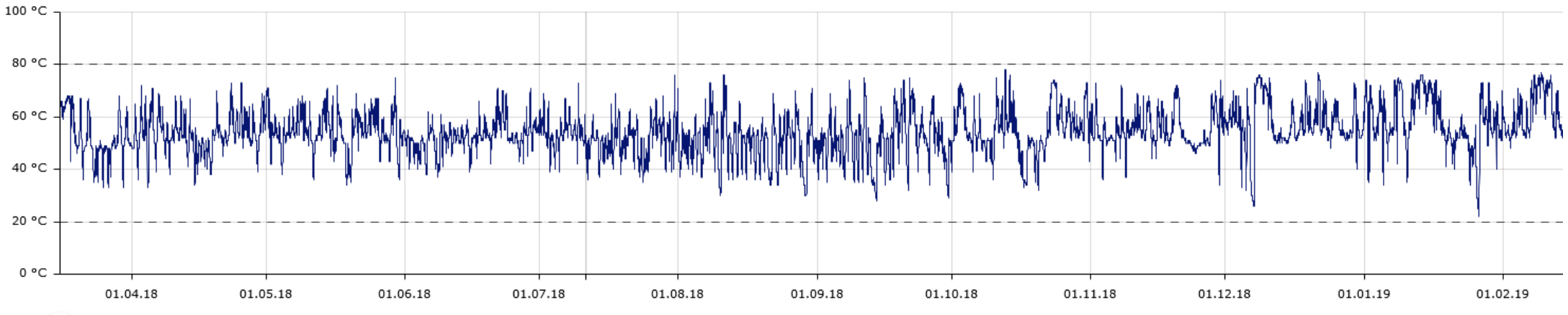
Detection of Clogged Cooling System



Condition Monitoring with Vibration Data
Example: Bearing damage

Bearing damage: Temperature of generator bearing (SCADA)

- Temperature of a bearing in the generator
- 10-minute average values



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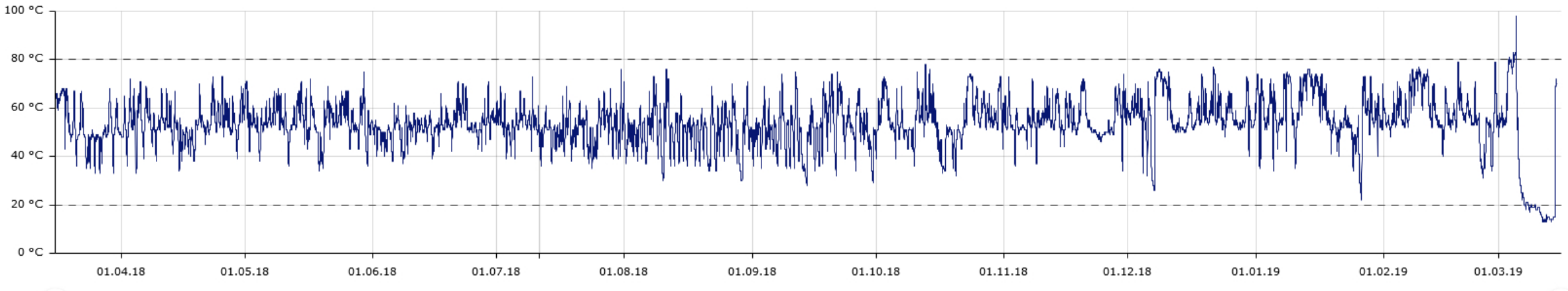

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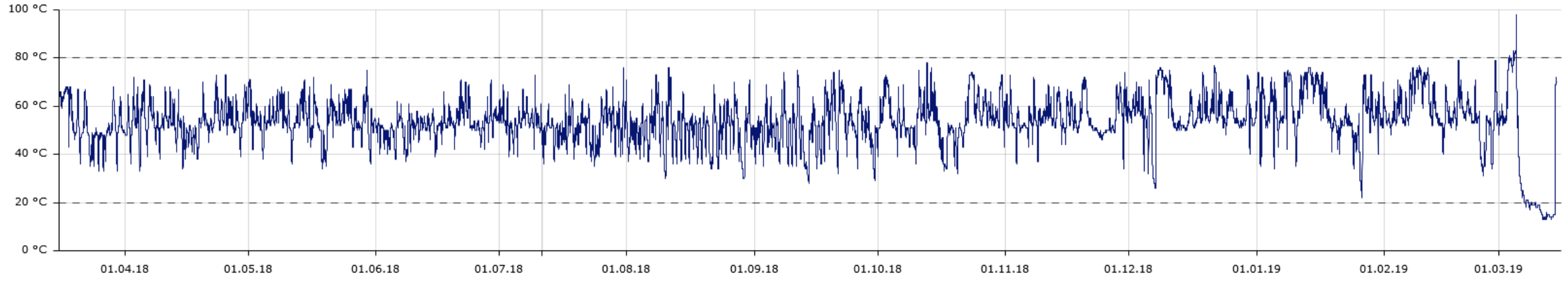
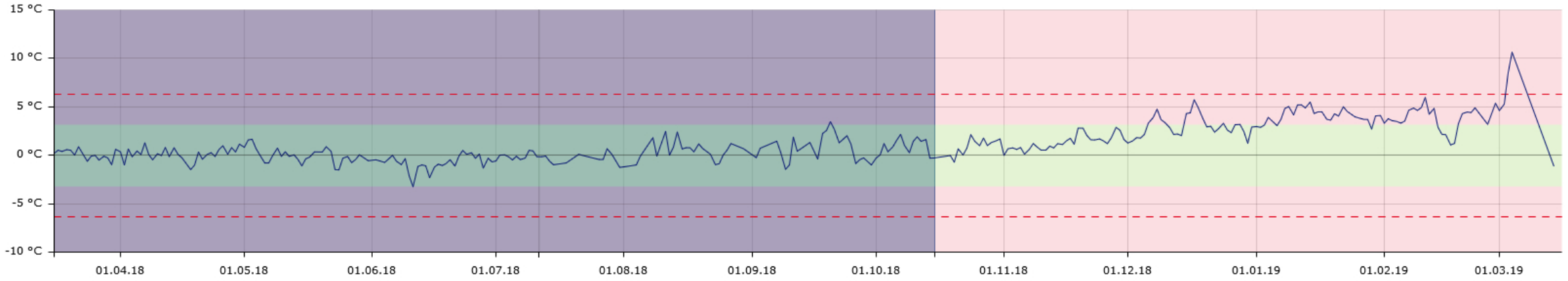
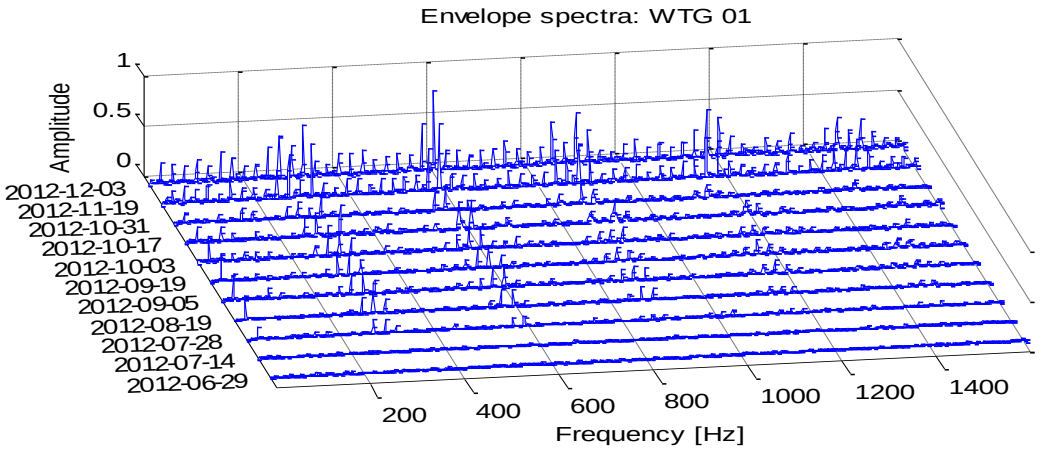


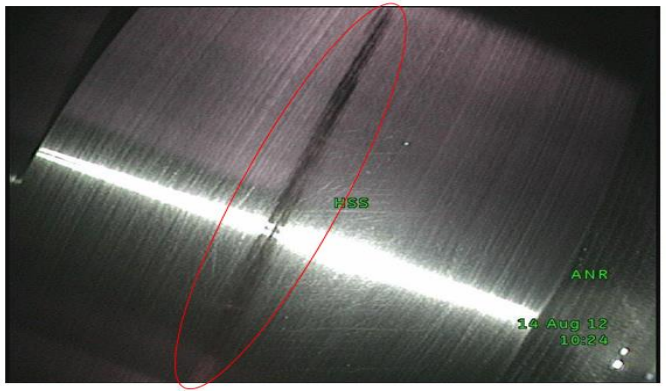
Derivation of measurement data from normal behavior model (daily average):

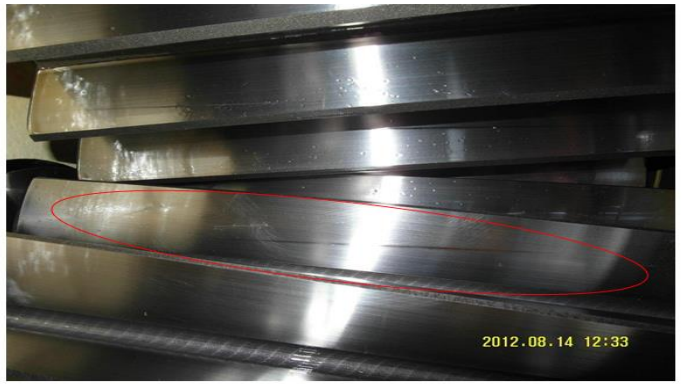


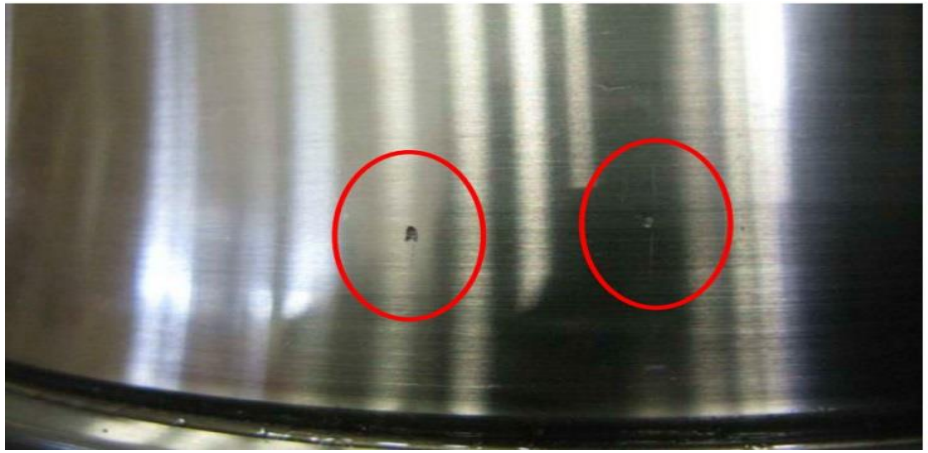
Methods
SCADA | Vibration

- Discontinuous, high resolution acceleration measurements
- Order analysis to compensate for variable speed
- Analysis of the envelope spectra (Bearing damage)
- Time synchronous averaging process (Gearing damage)
- Kepstrum (Gearing damage)



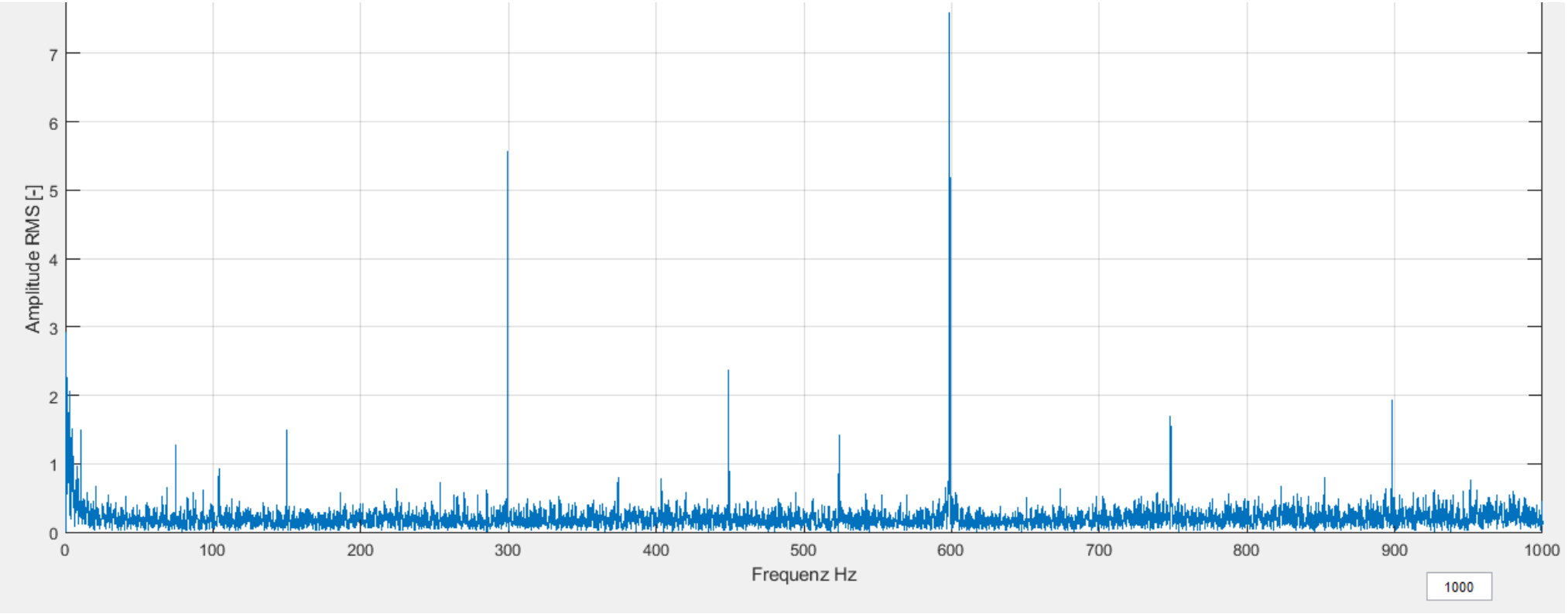






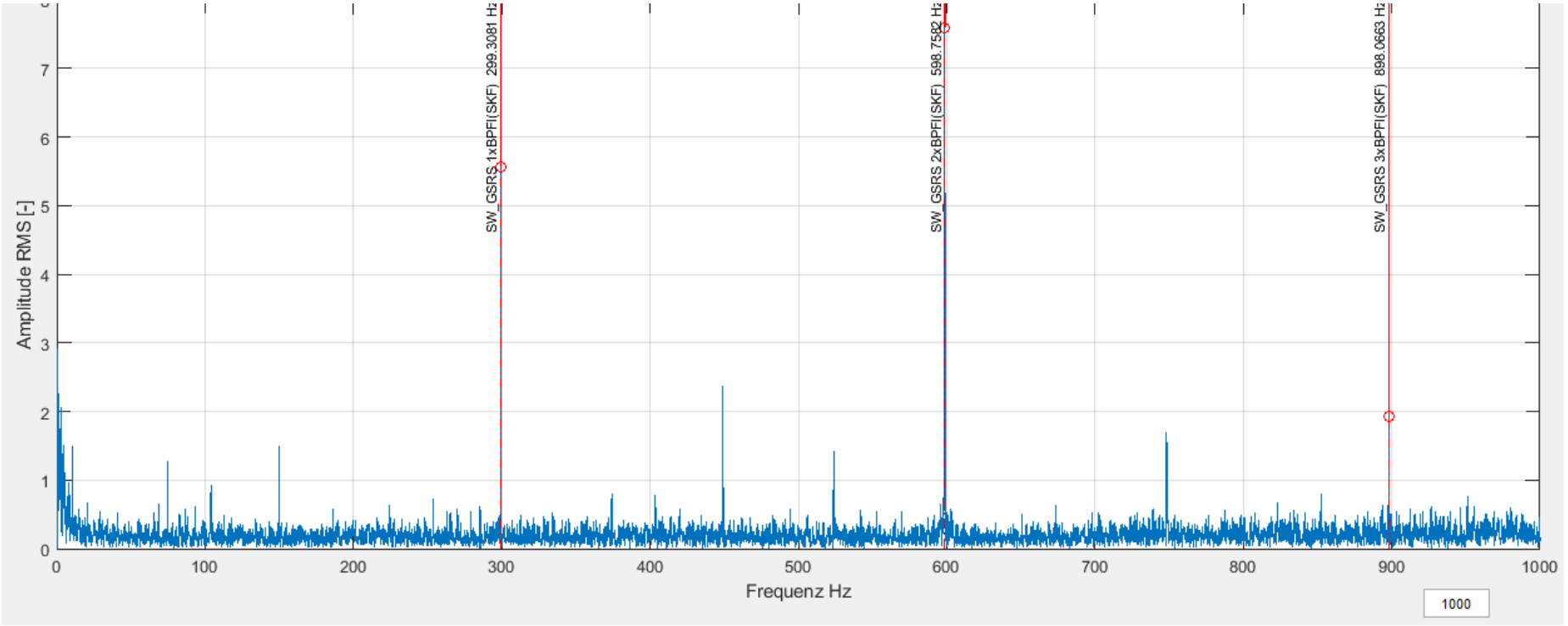
Bearing damage: Vibration analysis

- Discontinuous acceleration measurements (50kHz, 10s, rpm constraints)
- Envelope spectra of acceleration measurements



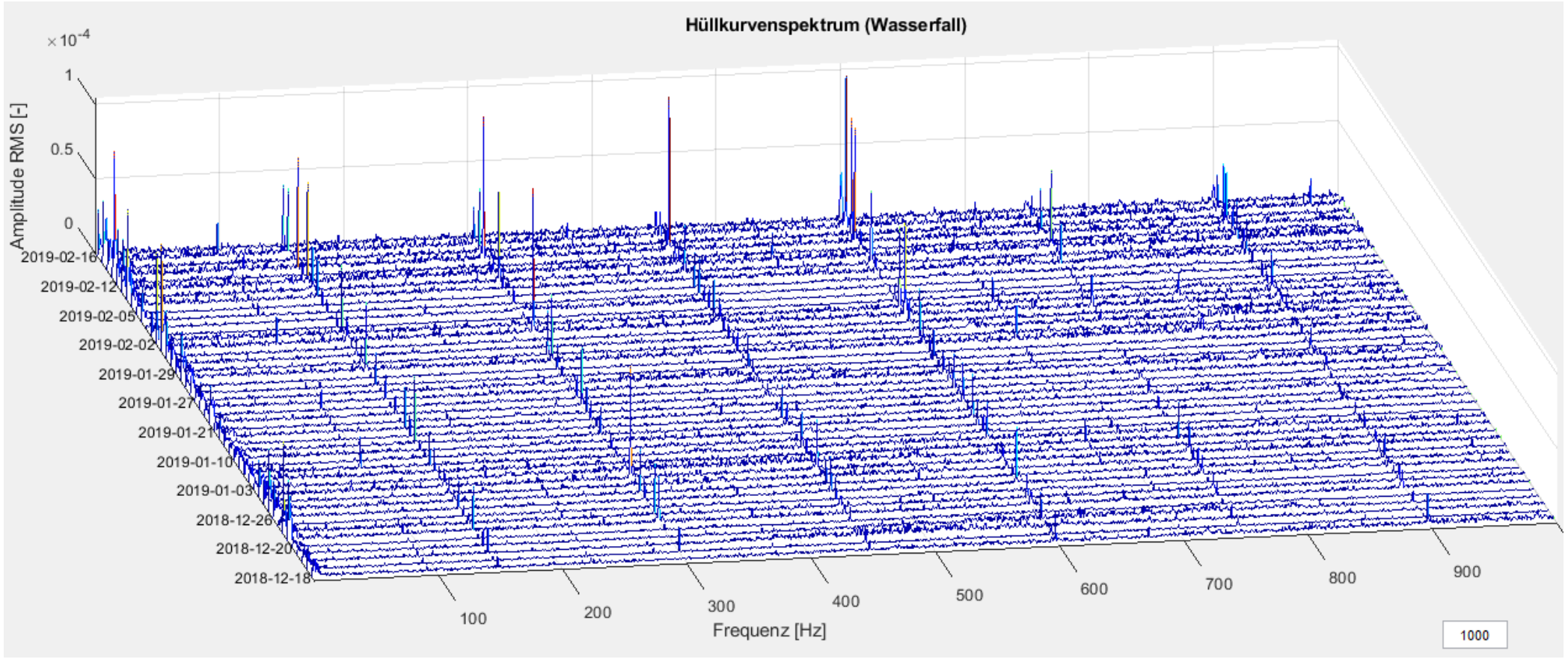
Bearing damage: Vibration analysis

- Identification with kinematic data
- Characteristic frequencies, harmonics, sidebands

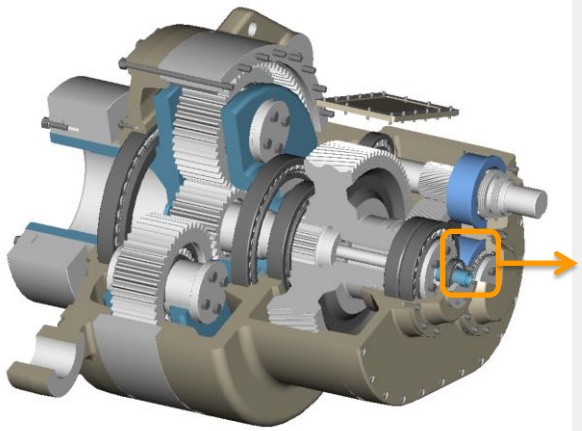


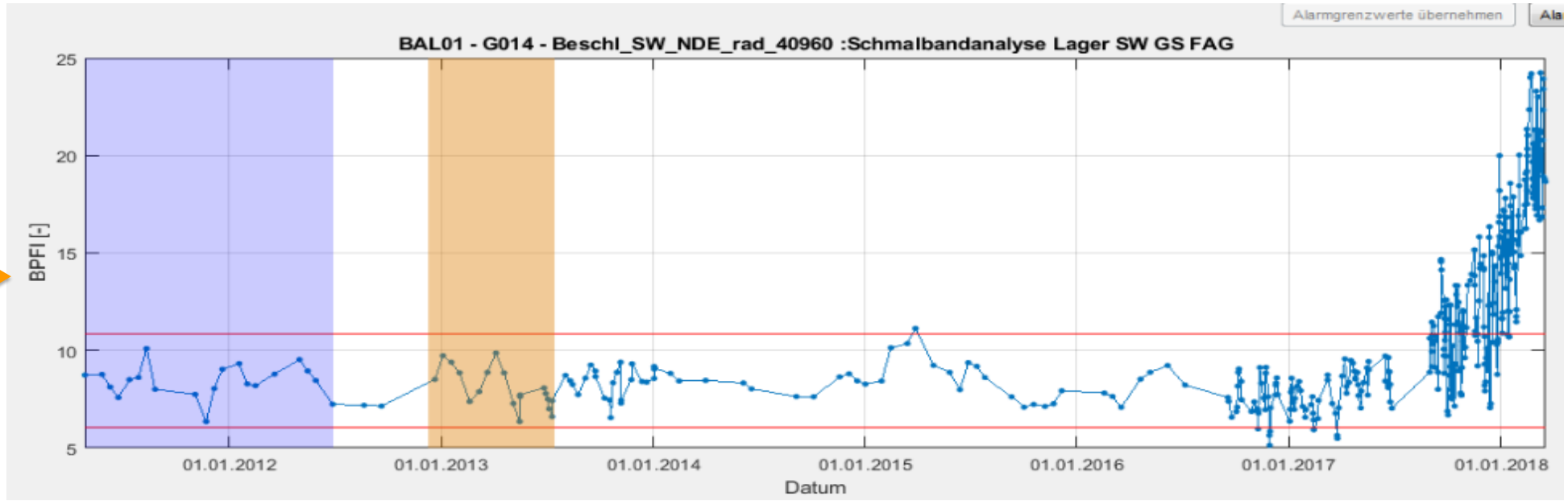
Bearing damage: Vibration analysis

- Spectrogram / waterfall diagram



Trending Bearing Damage Indicator

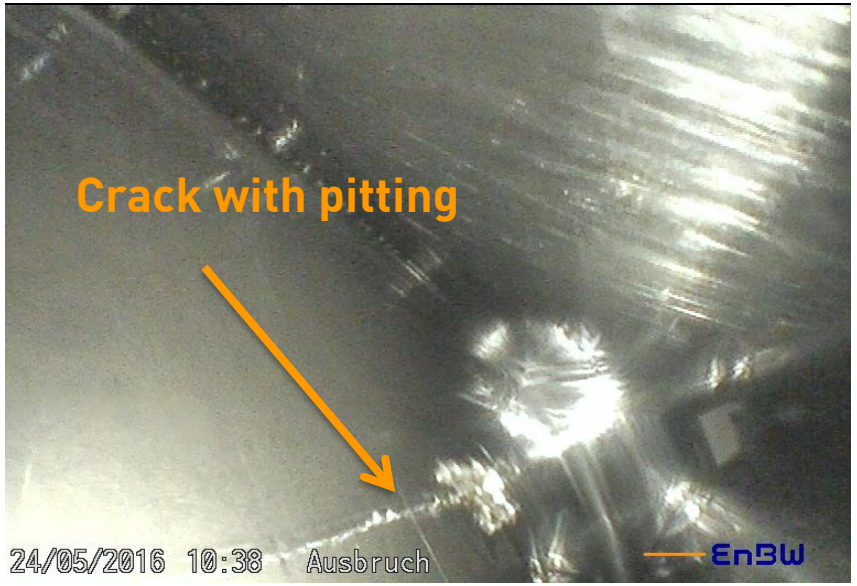




Later: Endoscopy confirming CMS diagnosis

Axially crack in the intermediate gear shaft of an offshore WEC

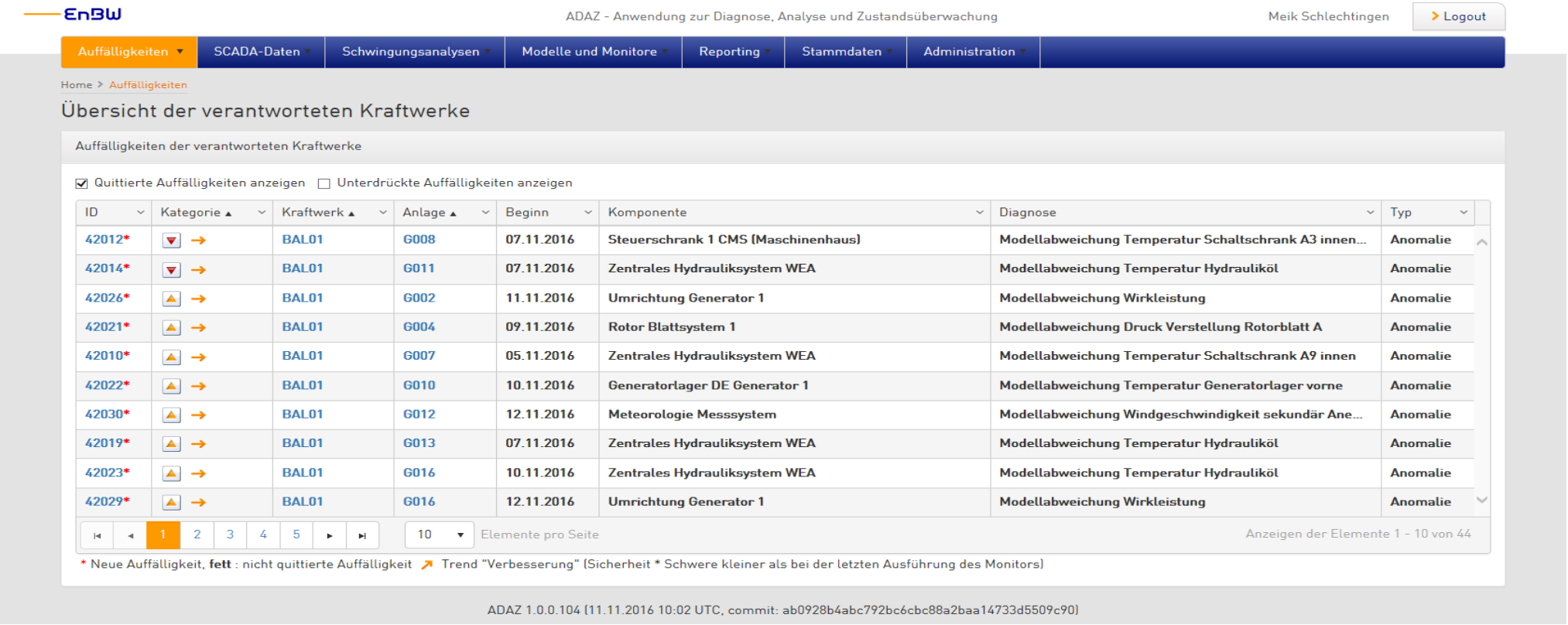
In February 2016 a bearing of the intermediate shaft at the generator end was noticeable in the CMS. The CMS from the manufacturer, which was operating additionally, didn't show abnormalities. As an insurance of the diagnosis, a bearing endoscopy was performed by EnBW. Thereby a dull raceway with numerous overrun particles and a corresponding axial crack with pittings were found. The further operation was limited to a maximum of 12 weeks under observation.



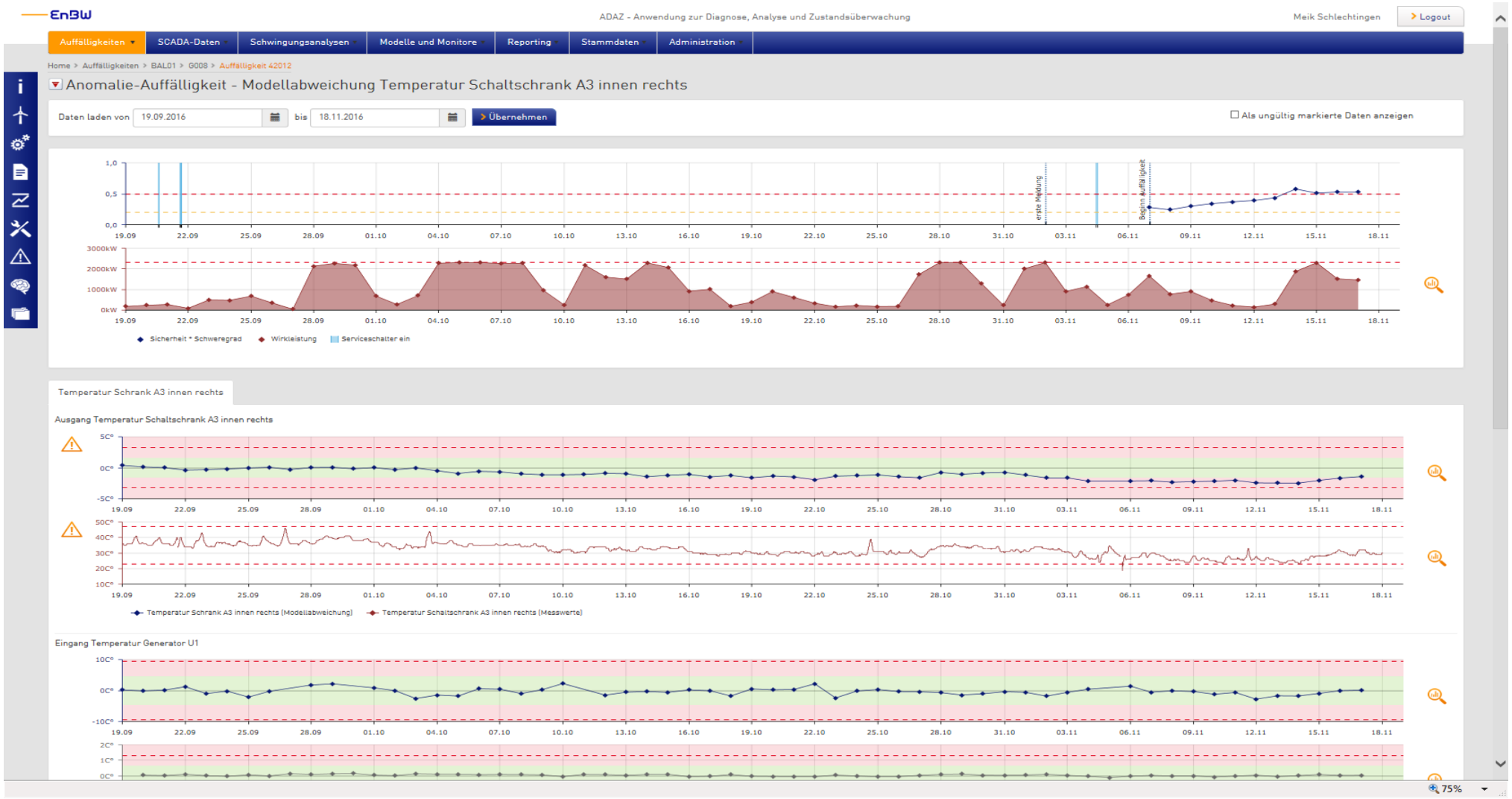
Software

Our condition monitoring software: EnBW Asset RADAR

- Platform for condition monitoring
- Detailed analysis and fleet comparisosn



EnBW Asset RADAR

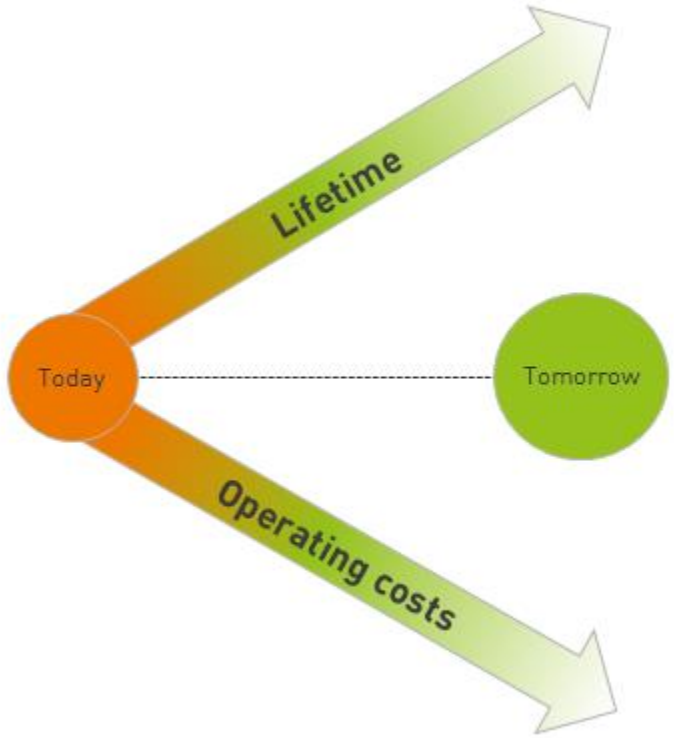


Development on Azure Cloud

- Access to newest technology
- scaleable
- Efficient and cost optimal
- 360° monitoring
- full CI/CD support
- ...

Summary

- Condition monitoring is crucial to reduce operational costs and extend the lifetime of our assets
- High degree of specialized knowledge and technical know-how needed
- Our large database enables developments targeted to the current needs
- Continuous improvement of our analysis capabilities and development of new methodologies



The End

Kontakt

Department T-BEP

Dr. Lisa Ziegler
Fischertwiete 1
20095 Hamburg
l.ziegler@enbw.com
+49 40 533 268-353

Department C-TISE

Dr. Martin Kato
Durlacher Allee 93
76131 Karlsruhe
m.kato@enbw.com
+49 721 63-14167

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