# Durch professionelle Datenanalyse clever optimieren – sensitive Eis- und Schadenserkennung am Rotorblatt

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**Wölfel Wind Systems**

*Workshop Profi[t] am Wind, Linstow, November 2015*

# Vibration experts

Vibrations

Structural dynamics

Acoustics

90+ employees

800+ projects / year


Engineering services

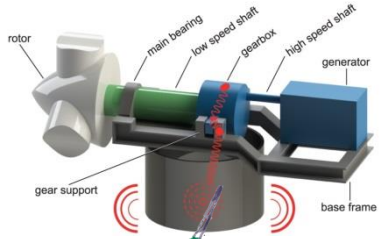
Systems

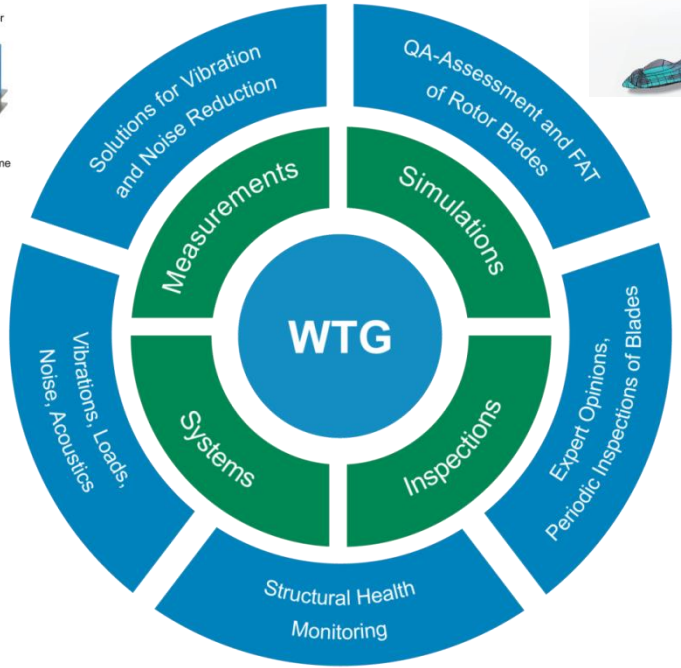
Software

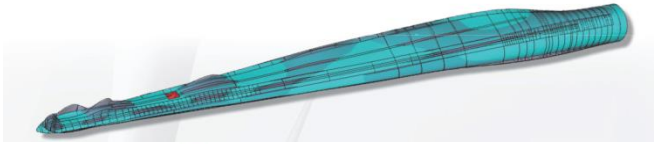
for SME and industrial customers

in Europe + internationally

# Wind energy systems



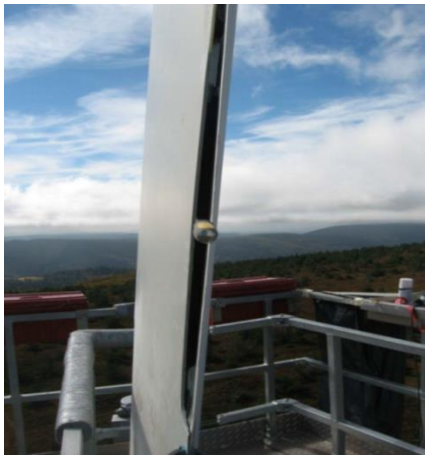
# Motivation – Why do we need Monitoring Systems

Acoustic inspection of gearbox

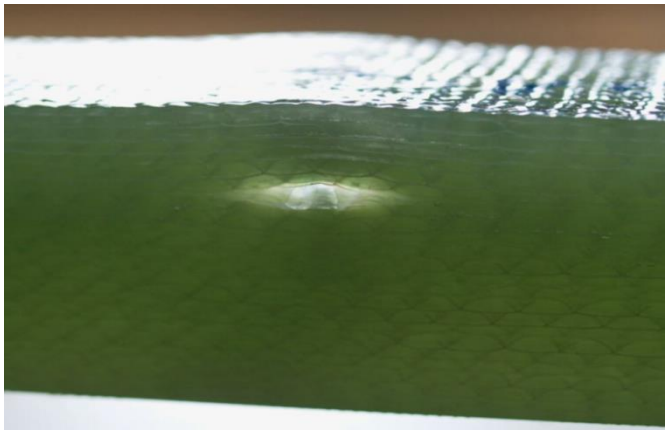

Inspection of offshore WT

Inspection of rotor blade


# Motivation – Why do we need Monitoring Systems



open trailing edge



resin blister / wrinkle in spar cap

blocked drainage line

total failure

# Monitoring based on vibration analysis

## Blades, foundation, tower

# Blade monitoring

## IDD.Blade®

### Ice detection


## SHM.Blade®

### Damage indication

### Imbalance detection

TÜV NORD

GL

**Type Certificate TC-GL-015A-2013**

# Blade monitoring

**Physical basis**

- **Rotor blade vibrations** give us information about the state of the structure
  - **Damage of the structure**
  - **Ice**
  - **Imbalance**

- *Structural damages* and *ice* change the **eigenfrequencies**: $\omega = \sqrt{k/m}$
  - Structural damages reduce the **stiffness** $k$
  - Ice increases the rotor blade **mass** $m$
  - Imbalance influences **1Ω** (periodic excitation)

- **Vibration monitoring for detection of changes in the state of rotor blades:**
  - Detection of changes in **eigenfrequency**
  - Detection of changes in the **dynamic response**

# Blade monitoring

**For reliable and sensitive detection of rotor blade changes there are two sophisticated challenges:**

## 1. Automatic detection of eigenfrequencies with high resolution

**Spectrum-based:**
**Fourier transformation**

- Resolution of $\Delta f$ = 0.001 Hz required
- $\Delta f = {}^{1}/_{T} \rightarrow T$ = 1000 s per window
- 5 windows @ 50 % overlap:
  $T$ = 3000 s = 50 min DAQ time
- Sharp resolution only when EOC do not change in DAQ time

↓

↘ Inherently limited sensitivity
↘ No fault tolerance
↗ Simple and fast procedure

**Time-based:**
**System identification (TDSI)**
**Patented signal processing of IDD.Blade®**

- Time domain system identification
- Time data is directly transferred into a state space model
- Modal data is extracted directly from the state space matrix

↓

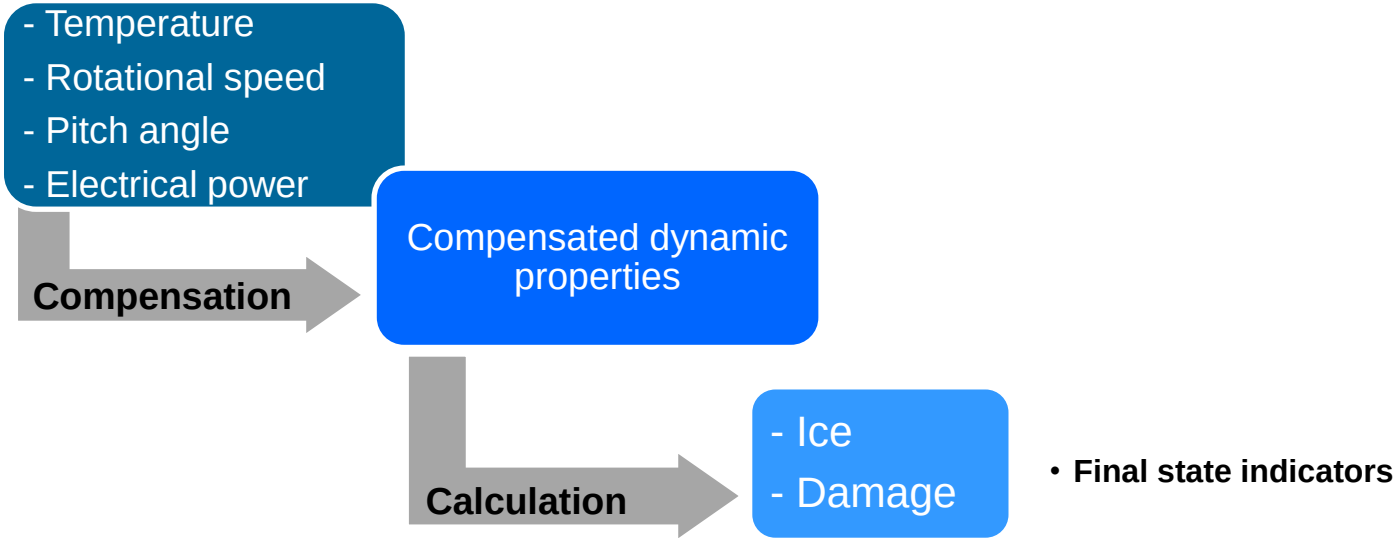
↗ Direct relation to blade dynamics
↗ No limitation in sensitivity, numerically robust
↘ Complex algorithms,
high computational power required

# Blade monitoring

**For reliable and sensitive detection of rotor blade changes there are two sophisticated challenges:**

## 2. Compensation of influences from operation and environment

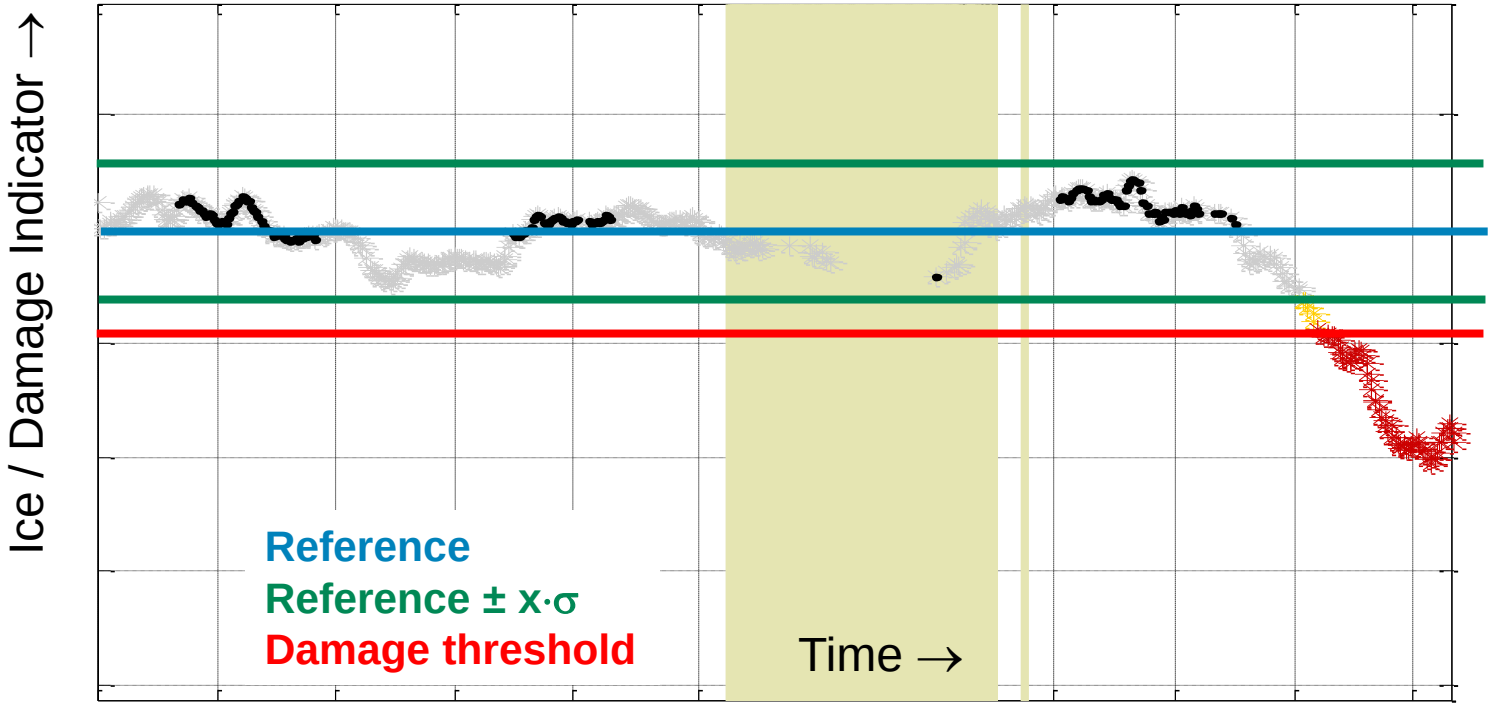
- **Dynamic properties depending on**




- **Final state indicators**

# Blade monitoring

## How does IDD.Blade® and SHM.Blade® works?



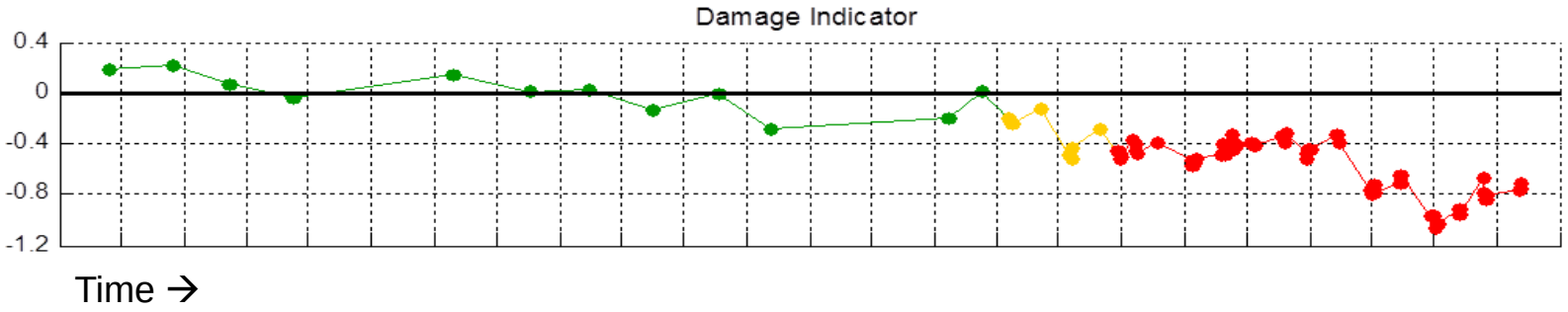
## Rotor blade of 60 m length - weight of 12 t

| Mode | Direction | Frequency | Modal mass | Detectable changes (modal) | | |
|---|---|---|---|---|---|---|
| 1 | flap | 0,63 Hz | 2.500 kg | 0,2% | 0,0013 Hz | 10 kg |
| 2 | edge | 0,75 Hz | 3.500 kg | 0,2% | 0,0015 Hz | 14 kg |
| 3 | flap | 1,70 Hz | 1.800 kg | 0,2% | 0,0034 Hz | 7 kg |
| 4 | edge | 2,20 Hz | 1.800 kg | 0,2% | 0,0044 Hz | 7 kg |

# Sensitivity of SHM.Blade®

## Detected: Crack at Trailing Edge

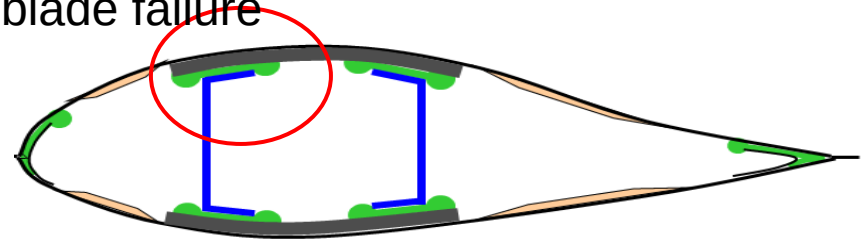
- Crack was detected at early stage
- Length about 35 cm orthogonal to trailing edge at 12m radius
- Rope access repair was possible

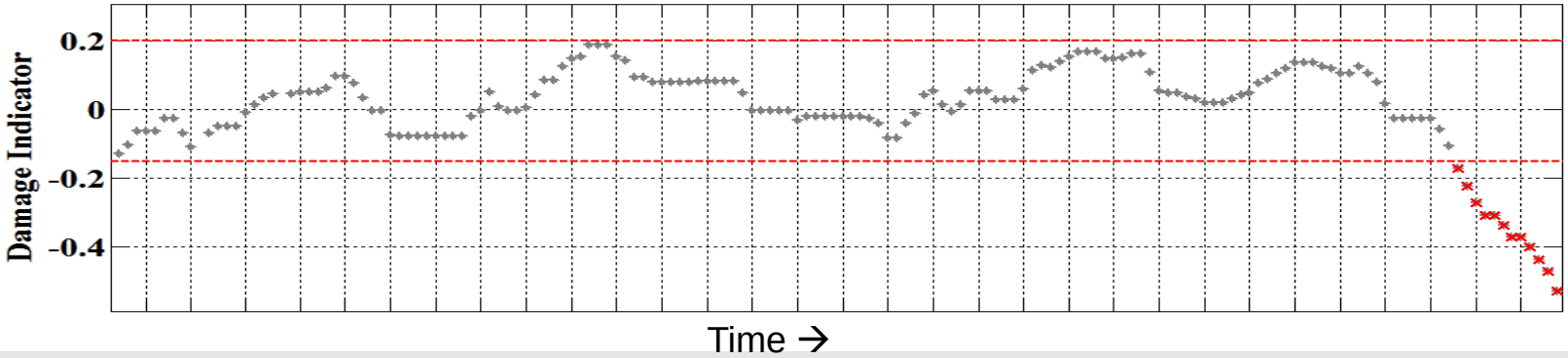


# Sensitivity of SHM.Blade®

## Detected: Girder Failure

- Failure with fast growing rate was detected
- Turbine shutdown before total blade failure





# Ice on rotor blades

## German regulations:

- Federal Immission Control Act § 5, clause 1, No. 1 (BImSchG) → **“Proof and verification of public safety”**

## Definition of areas with high risks of ice shedding:

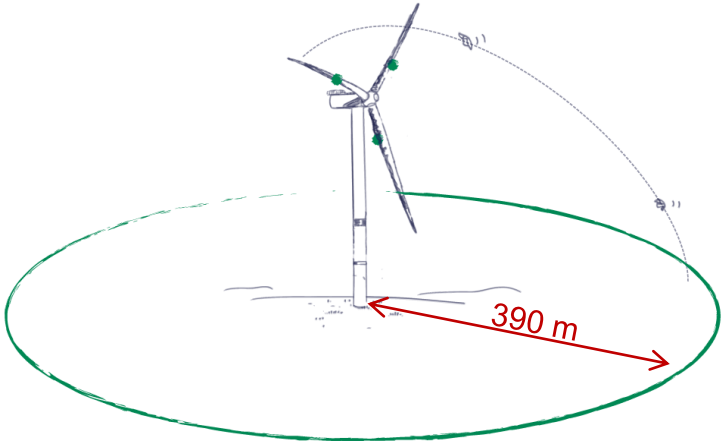
- Technical standards (DIBt) “ Musterliste der Technischen Baubestimmungen – Fassung März 2014”

**Wind turbines that are located within a distance of 1.5 x (hub height + rotor blade ø) to traffic and building infrastructure have to be equipped with an ice detection system**

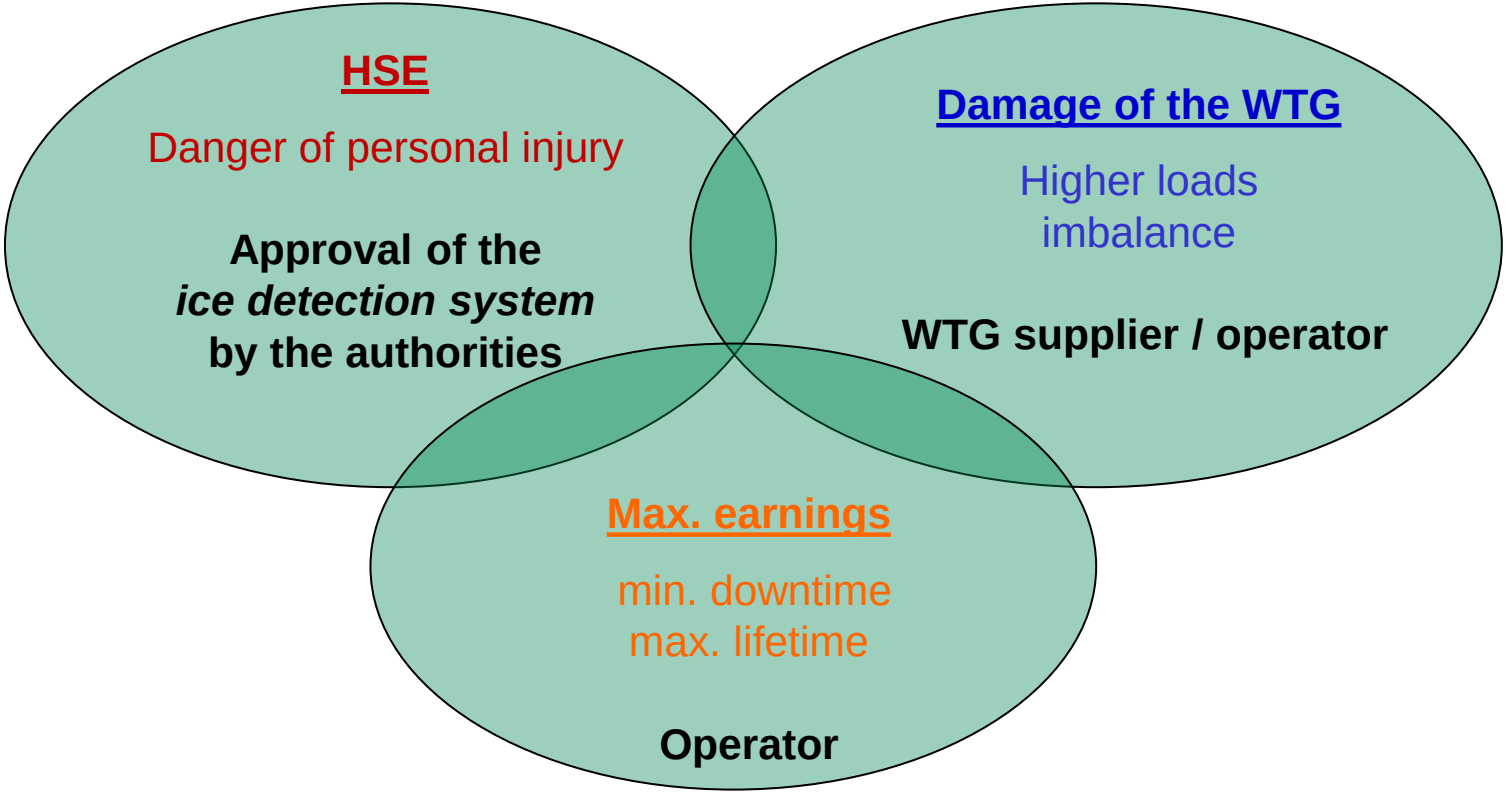
Hub height: 120 m

Rotor blade **ø**: 140 m

→ **Distance: (120+140) m x 1.5 = 390 m**



# Ice on rotor blades



# Ice on rotor blades

## Ice detection technologies

| | |
|---|---|
| Metrological | • No direct and quantitative ice detection at the rotor blade<br>• Not approved for automatic restart of the WTG |
| Visual | • No automatic ice detection<br>• Not approved for automatic restart of the WTG |
| Power curve | • No direct and quantitative ice detection at the rotor blade<br>• Automatic restart of the WTG not possible |
| Rotor blade vibration | • Direct and sensitive ice detection at the rotor blade<br>• Automatic restart of the WTG possible |

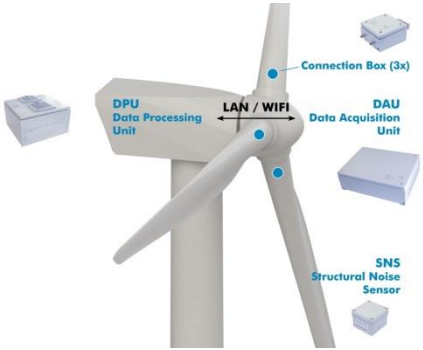
# Wölfel blade monitoring system

IDD.Blade®

SHM.Blade®

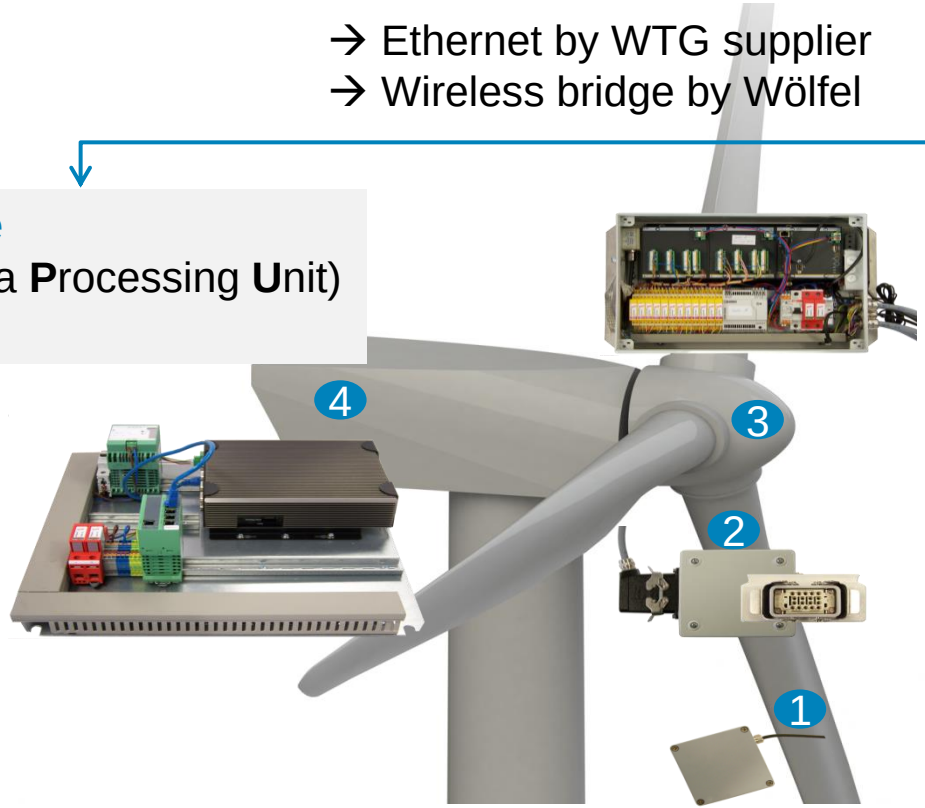
GL

Type Certificate
TC-GL-015A-2013



→ Ethernet by WTG supplier
→ Wireless bridge by Wölfel

4) Nacelle
DPU (**D**ata **P**rocessing **U**nit)



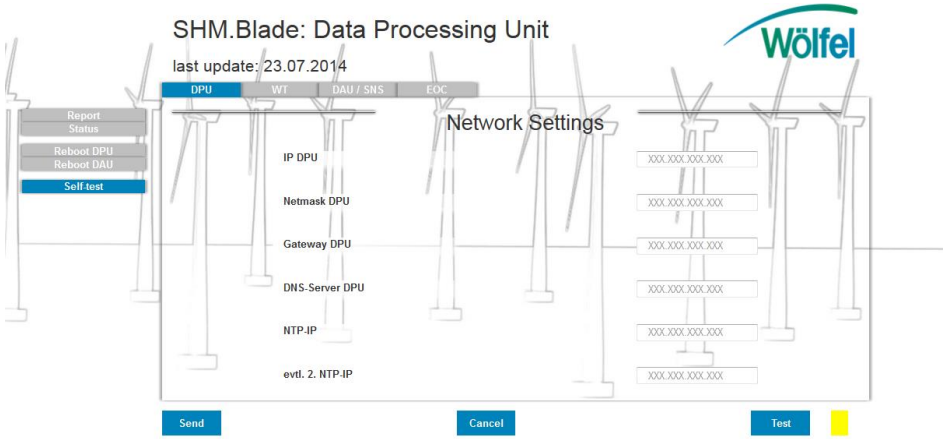

3) Hub
DAU (**D**ata **A**cquisition **U**nit)

2) Blade root
CB (**C**onnection **B**ox)

1) Rotor blade
SNS (**S**tructural **N**oise **S**ensor)

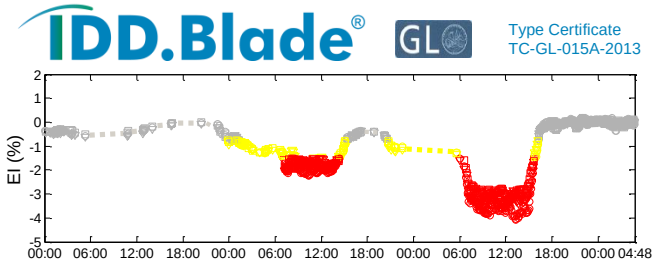
## Integration – Installation – Commissioning

- Suitable for retrofitting and series manufacturing
- Assembly time (retrofitting) approx. 1 to 1.5 days (2 technicians)
- Easy configuration and commissioning via web interface
- Interface to turbine control required for data transfer



# Return on investment

## Cost efficiency at typical German sites



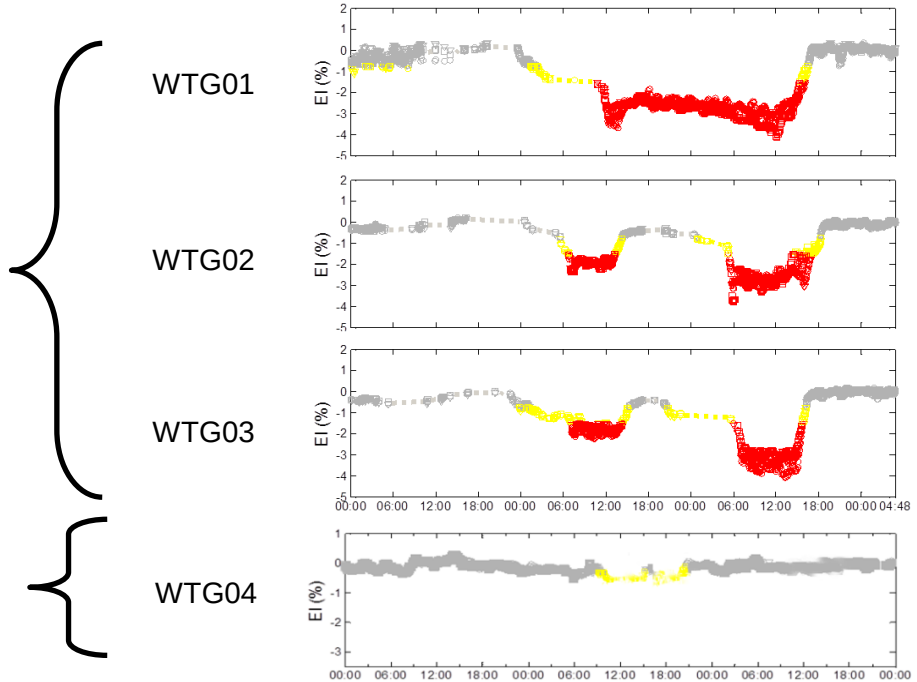
# Return on investment – Cost efficiency at typical German sites

## Individual observation of each wind turbine in a wind farm

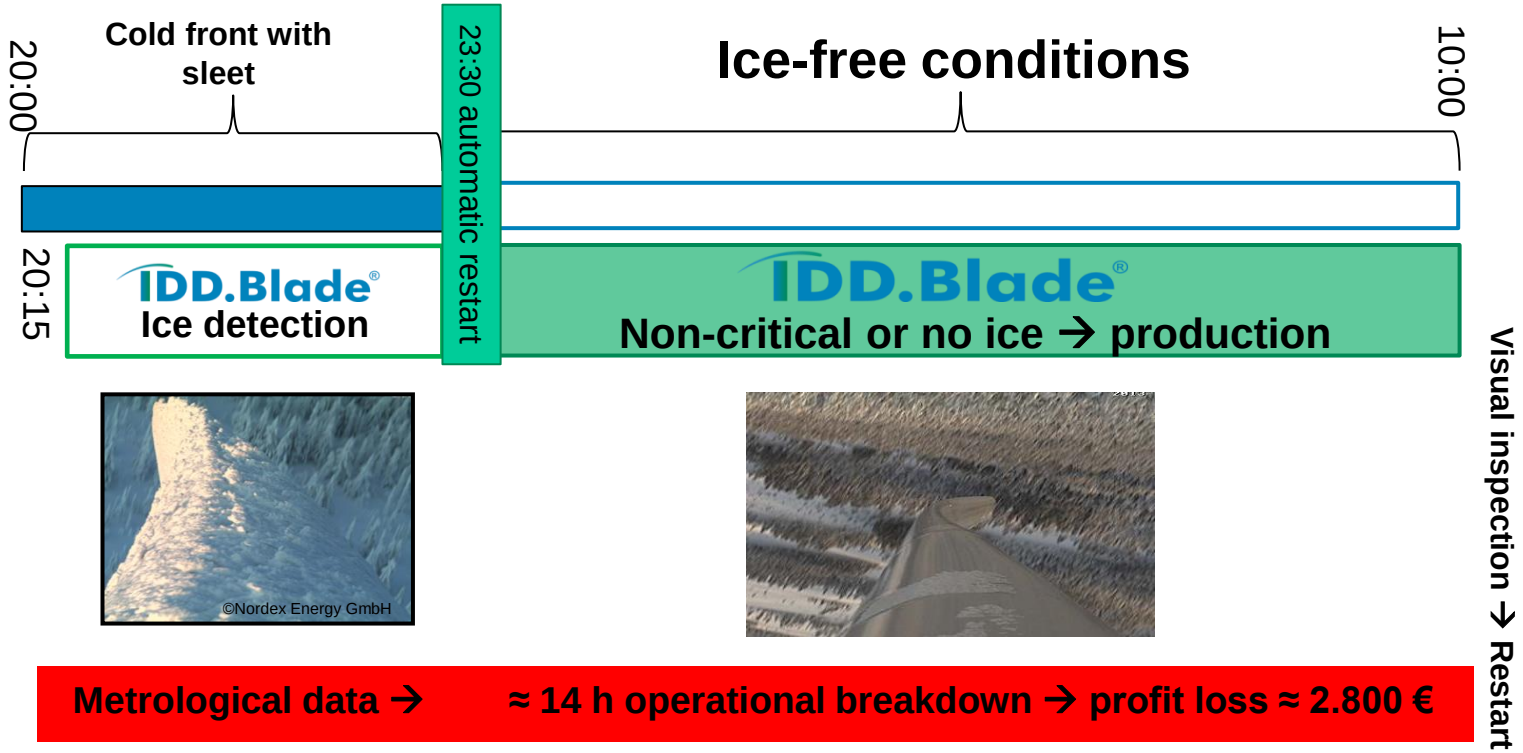
Location: region in Hesse
Period: 13 – 14 Feb. 2015

**Shutdown**
**in critical ice conditions**

**Power production**
**in non-critical ice conditions**



# Return on investment – Cost efficiency at typical German sites




**Metrological data → ≈ 14 h operational breakdown → profit loss ≈ 2.800 €**

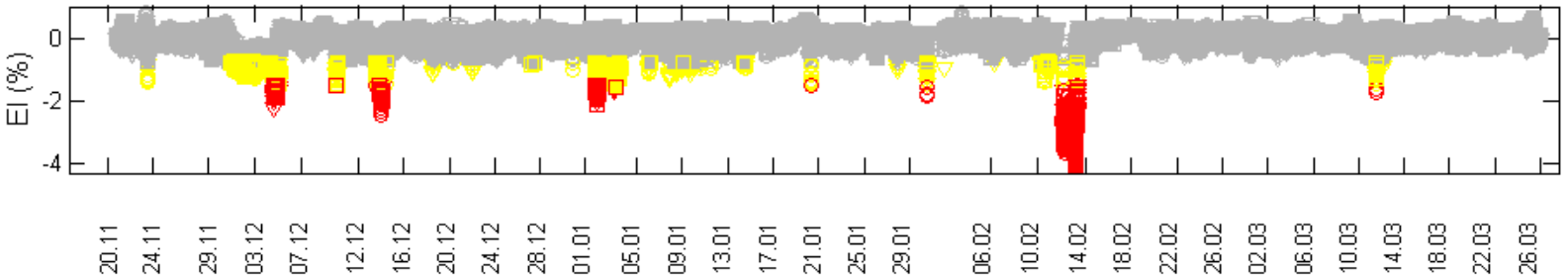
# Return on investment – Cost efficiency at typical German sites

## Monitoring example IDD.Blade®

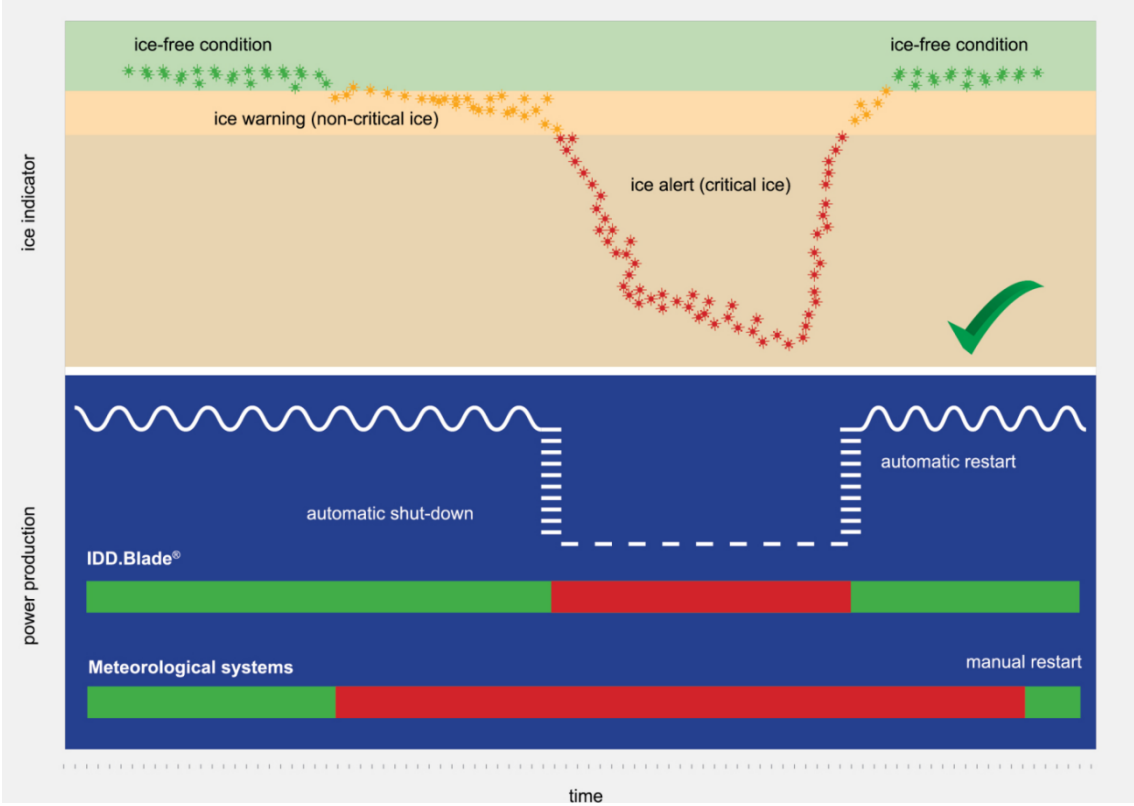
***Winter season 2014/15 in the region of northern Hesse***

| | | | |
|---|---|---|---|
| Temperature below 4°C | | ≈ 50 days | |
| Warning | (non-critical ice) | ≈ 21 days | |
| ***Alarm*** | ***(critical ice)*** | ***≈ 6 days*** | ***possibility of dangerous ice throw*** |

**Ice indicator**



- Exact ice indicator
- Clear signaling
- Automatic restart
- Reduced downtime
- Higher Yield



# Thank you for your attention !

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