Making wind turbines smart – accessing and evaluating operational data of a research wind turbine

Michael Pagitsch, Georg Jacobs, Dennis Bosse

Valencia, 2017-11-09
Contents

- From “Industrie 4.0” towards “Smart Wind Energy”
- Operational data – the SCADA system
- Benefits of evaluation of SCADA data
“Industrie 4.0” and smart wind energy

4th industrial revolution

• Caused by introduction of Internet of Things and Services into the manufacturing environment

• Global networks with Cyber-Physical Systems of machinery, warehouses and production facilities

• Technical integration of CPS in product development, production, and logistics

• Research and development activities need to be accompanied by appropriate industrial policy decisions
Examples for smart services: Smart farming services – today

Source: Claas
Examples for smart services: Smart farming services – tomorrow
Examples for smart services: Smart energy services – today

Loose customer connectivity due to undifferentiated supply

Source: BTC
Examples for smart services: Smart energy services – tomorrow

![Diagram showing the interaction between consumer, energy suppliers, and further service providers.]

- **Consumer & Prosumer**
  - Consumption: flexibility, customer requirements
  - Tariff offers, price signals
  - Value-added services

- **Serviceplatform: App-Store related to transition of energy**
  - Predictions, customer requirements, customer acceptance
  - Tariff offers for high flexibility
  - Basic services

- **Energy suppliers**
- **Further service providers**

- **Close customer connectivity due to attractive, tailor made supply**

---

Source: BTC

---

SMARTSERVICELMEN2015
“Industrie 4.0” and smart wind energy

“Smart wind turbine”

- **Smart maintenance**: Combination of maintenance activities across wind farms
- **Communicating smart grids**: Quick and “optimized” response to requests from grid operators
- **Online state information**: Detailed real-time state analysis and display in web-based dashboards
- **Intelligent wind farms**: Wind farm controllers operate based on grid requirements and optimal utilization of individual WTGs
- **Predictive maintenance**: Intelligent scheduling of maintenance activities (prior to damages)
## Examples of smart services

<table>
<thead>
<tr>
<th>Level</th>
<th>Addressee</th>
<th>Manufacturer</th>
<th>Service</th>
<th>Operator</th>
<th>Local resident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbine</td>
<td>Wind turbine</td>
<td>• Intended load spectrum</td>
<td>• State of maintenance</td>
<td>• Production of energy</td>
<td>• Shutdown function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Remaining lifespan</td>
<td>• Remaining lifespan</td>
<td>• Remaining lifespan</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Service report</td>
<td>• Service report</td>
<td>• Service report</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Documentation of life cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind farm</td>
<td>Wind farm</td>
<td>• Load-reducing strategy of operation</td>
<td>• Identification of malfunctions</td>
<td>• Identification of potentials for yield increases</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wind forecast</td>
<td>• Maintenance plan</td>
<td>• LCOE forecast</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power system</td>
<td>Power system</td>
<td></td>
<td></td>
<td>• Operational management optimized for maximum yield and minimum load</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Security of supply</td>
<td></td>
</tr>
</tbody>
</table>

Michael Pagitsch, Georg Jacobs, Dennis Bosse
Valencia | 2017-11-09
Contents

- From “Industrie 4.0” towards “Smart Wind Energy”

- Operational data – the SCADA system

- Benefits of evaluation of SCADA data
Main elements of a SCADA system

- Field data interfaces (RTUs, PLCs)
  - Sensors, actuators

- Communications system
  - Equipment for data transfer
  - TCP/IP networks, field bus systems

- Central host computer / server
  - Data processing unit
  - Human machine interface

- Operator workstations and software components
  - Collection of standard and/or custom software
Smart wind: The path towards full deployment of SCADA data

WT DATA

Time-variant data
• SCADA, SHM, CMS
• Data from additional sensors

Documentation
• Type & location of WT
• Schedule & journal of maintenance

DATA INFRASTRUCTURE

• Aggregation & distribution
• Storage (data security & integrity)
• WT onboard analytics

DATA ANALYSIS

Data-based analysis
• Machine learning algorithms (Neuronal networks)
• Knowledge discovery and data mining (KDD)
• Statistical methods

Model-based analysis
• Observer-based condition monitoring
• Functional models
• Operational models
• Fatigue / wear / remaining lifespan
The CWD's research turbine – “FVA-Nacelle”

- 4 MW Direct-drive
- 5 DOF wind loading unit
- FVA-Nacelle: 2.75 MW research turbine
The CWD’s research turbine – “FVA-Nacelle” in Hardware-in-the-Loop-operation

Input-variables:
\( v_{\text{Wind}} \), TI, angular deviation

Windfield simulation

Wind loads

1 DOF

5 DOF

Wind loads

Electrical grid

Pitch angles, rot. speed

SCADA system

1 DOF

5 DOF
Overview of available signals and their origin

- T
- OpState
- Rot. Speed
- Torque (calc.)
- Wind/Pitch/Yaw
- u, i

Converter System

Ctrl
Accessing SCADA data in a "standard" WT

**Data source**
- FVA-Nacelle
  - WT-Ctrl
  - HiL-Ctrl

**Onboard processing**
- Raspberry Pi
  - Data pre-processing (calculation of statistics and derived quantities)
  - Protocol Buffers
    - Message queue
    - Data
  - Data processing
    - Python
  - Web frontend
    - Apache
    - D3.js

**Server-side processing**
- CWD server infrastructure
  - Message queue
  - MySQL
  - Data processing
  - Web frontend
Contents

- From “Industrie 4.0” towards “Smart Wind Energy”
- Operational data – the SCADA system
- Benefits of evaluation of SCADA data
Possible deployment of SCADA data

Snapshot of the WTG’s current state

- SCADA-based condition monitoring
- Detection of “intended state” of WTG
- Comparison of current and intended state for selected quantities

<table>
<thead>
<tr>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS error: 0.023</td>
</tr>
</tbody>
</table>
Snapshot of the WTG’s current state

- SCADA-based condition monitoring
- Detection of “intended state” of WTG
- Comparison of current and intended state for selected quantities

Possible deployment of SCADA data

<table>
<thead>
<tr>
<th>Bearing temperature – neural network prediction vs measured values [°C]</th>
</tr>
</thead>
</table>

- Prediction
- Measured value
Possible deployment of SCADA data

Snapshot of the WTG’s current state

- SCADA-based condition monitoring
- Detection of “intended state” of WTG
- Comparison of current and intended state for selected quantities

Error detection and optimization of wind farms

- E.g. based on a comparison of power curves
  - Across wind farms
  - Comparison between intended and actual power curve
- Long-term monitoring allows for detection of anomalies
- Early detection and correction for higher energy output
Possible deployment of SCADA data

Snapshot of the WTG’s current state

- SCADA-based condition monitoring
- Detection of “intended state” of WTG
- Comparison of current and intended state for selected quantities

Error detection and optimization of wind farms

- E.g. based on a comparison of power curves
  - Across wind farms
  - Comparison between intended and actual power curve
- Long-term monitoring allows for detection of anomalies
- Early detection and correction for higher energy output
Possible deployment of SCADA data

Snapshot of the WTG’s current state

- SCADA-based condition monitoring
- Detection of “intended state” of WTG
- Comparison of current and intended state for selected quantities

Error detection and optimization of wind farms

- E.g. based on a comparison of power curves
  - Across wind farms
  - Comparison between intended and actual power curve
- Long-term monitoring allows for detection of anomalies
- Early detection and correction for higher energy output
"Smart wind energy"

- Industrie 4.0
- Smart services
  - Smart farming services
  - Smart energy services

The SCADA system

- Introduction of CWD's research turbine
- Available data and how to access them

Deployment of SCADA data

- SCADA-based condition monitoring
- Detection of malfunctions
Thank you for your attention.