Utilizing wind-turbine failure and operating data for root-cause analysis

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Outline

- Fraunhofer IWES
- Motivation
- Approaches for utilizing field data for root-cause analysis
- Example case: power-converter failures in wind turbines
- Selected analysis methods and results
- Summary
Short profile of Fraunhofer IWES Northwest

Managing Director: Prof. Dr.-Ing. Andreas Reuter

Research spectrum: Wind energy from material development to grid connection

Operational budget 2015: 15 Million €

Staff: 150 employees

Locations: Bremerhaven, Oldenburg, Bremen, Hannover; Germany

Previous investments in the establishment of the institute: 60 Million €

Research Alliance
Wind Energy

Strategic Alliance with ForWind and the German Aerospace Center DLR
Motivation: Reliability is key

- Failures in wind turbines cause considerable downtime and repair costs → reliability is among the key factors for a further cost-of-energy reduction

- Crucial: to make use of experience and data gained on existing turbine fleets

- Potential benefit of systematic field-data analysis:
  - Reveal main sources of unreliability and maintenance cost
  - Support the identification of failure root-causes and mechanisms

Basis for effective countermeasures in the existing fleets as well as for new developments

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Failures in wind turbines cause considerable downtime and repair costs → reliability is among the key factors for a further cost-of-energy reduction.
Utilizing wind-turbine failure and operating data for root-cause analysis: approaches, guiding questions

- Analysis of weak points and cost drivers
  → On which components should the root-cause analysis concentrate?

- Comparison of failure rates (among turbines / components of different manufacturers, between sites, in view of differences in design…)

- Examination of the failure observations with respect to temporal or spatial patterns

- Combined analysis of failure data and operating (10min SCADA) data → Is there a relation between the operating history / conditions of a turbine and its failure behaviour?

- If component age known: ‘classical‘ Weibull analysis
  → early-failure, random-failure or wearout-failure behavior prevailing?
Data and examples from: Innovation Cluster for enhanced power-converter reliability in wind turbines

→ Background: power converters are among the main sources of wind-turbine failure
→ Project duration: 2014 – 2017
→ Coordination: Fraunhofer IWES
→ Subjects:
  → Field-experience based root-cause analysis and reliability improvement
  → Condition monitoring of electronic components
  → Dynamic interaction of electrical and mechanical drivetrain components
  → Fault-tolerant generator / converter systems
→ Budget: 4 Million Euro
→ Further information: www.power4re.de/en

→ Consortium:
  three research institutes
  16 companies
Root-cause analysis approach

This presentation

Evaluation of field failure and operating data

Field measurements

Post mortem analysis

Root-cause analysis workshops

Catalogue of countermeasures
Data basis

- Converter failure data from >4000 operating years of wind turbines of different types, ages, sites
- Operating histories of these turbines (10min-averaged SCADA data)

Data processing

- Based on description and used spare parts, failures are assigned to component categories

IGBT modules incl. driver boards, DC-link capacitors, busbars
Weak point analysis:
Average failure rates of converter components

<table>
<thead>
<tr>
<th>Component</th>
<th>DFIG</th>
<th>EESG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase module</td>
<td>0.21</td>
<td>0.08</td>
</tr>
<tr>
<td>Control board</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Crowbar</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Cooling system</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Semiconductor fuse</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>Main circuit breaker</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>Grid-coupling system</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>Other</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>Converter (total)</td>
<td>0.53</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Data basis:
- DFIG: 925 operating years
- EESG: 344 operating years

For further details, please see
Cost-driver identification: Distributions of converter repair cost

Main focus of subsequent analyses on category ‘phase module’ (i.e. IGBT modules incl. driver boards, DC-link capacitors, busbars)
Spatial distribution of failures

- Background: considerable deviation between converter failure rates in turbines of identical type (here: 0…9 phase-module failures within one wind farm)

- For wind parks with known collection-grid topology:
  Assessment of the spatial distribution of failures in the wind farm → pattern?

- Example:

- Correlation with:
  - Main wind direction?
  - Position within the collection grid?
  - Converter type!
Seasonal variation of converter failures

- Diagrams: Phase-module failure rates (normalized values) of wind turbines in Europe (top) and India (bottom)
- Europe: minimum in August coincides with lowest average wind speed
- India: highest failure rates during June – September (Monsoon period: strong wind, high humidity)
- Results suggest influence of wind speed (+ possibly humidity) on converter failure
Combined analysis of failure and operating data

Guiding question: Are there systematic differences in the operating histories of turbines with high and turbines with low converter failure rates?

Data basis here: 48 wind turbines with fully rated converter, failure data from a period of 3.5 years

Methodology adopted from Gray and Watson (2010)

Boxplots:
- Turbines without converter failures
- Turbines with few converter failures
- Turbines with frequent converter failures

Conclusions (for WT type in this example):
- ‘Work horses’ more prone to conv. failure
- Start-stop cycles: no effect on converter
- Operation above \( P_{\text{rated critical}} \)
Advanced reliability assessment: Weibull analysis

Failure rate $\lambda(t) \quad \leftarrow \quad$ Powerful tool, but requires knowledge of component age at failure

$\leftarrow \quad$ Weibull distribution: suitable to represent the failure behaviour of technical systems in all phases of the “bathtub curve“

$\leftarrow \quad F(t) = 1 - \exp \left[ - \left( \frac{t}{a} \right)^b \right]$

with scale parameter $a$, shape parameter $b$ (both $> 0$)

$\leftarrow \quad$ Bathtub curve’

$b<1$

Early failures due to material defects, design blunders, assembly errors,

$b=1$

Random failures

$b>1$

End-of-life failures due to ageing, wearout, fatigue

Decreasing failure rate

Constant failure rate

Time $t$

Increasing failure rate
Summary

- Systematic field-data evaluation can provide valuable information to direct and support root-cause analysis, directed measurements and damage analysis on failed components are important complements.

- Methods have proven useful for root-cause analysis on both electrical and mechanical components.

- Presented approaches are based on failure rates → applicable also in the (practically prevailing) cases in which component-age information is missing.

- Field data available today is extremely diverse in format, structure, depth and nomenclature → standardizing and automating field-data collection is crucial to allow efficient analyses and to tap the full potential.
Acknowledgments

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THANK YOU FOR YOUR ATTENTION

Any questions?
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