Wind Turbine Condition Monitoring and Reliability

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Outline

• Optical, Contactless Torque Measurement System
• Wind Turbine Generator Condition Monitoring
• Reliability of Wind Turbine Power Converters
Optical, Contactless Torque Measurement System

- Speed-controlled Induction Motor
- Torque Transducer (reference)
- Barcodes and Optical Probes
- Grid-connected Induction Generator

Optical Torque Measurement

Torsional measurement provides useful loading information but a non-invasive, cost-effective solution is needed.

Time shifts between pulses analysed over time using either edge analysis or cross-correlation approaches.

![Optical Torque Measurement Diagram]

![Torque vs Time Plot]

- Cross-correlation approach (optical probes)
- Rising edge detection approach (optical probes)
- Reference signal (in-line torque transducer)
Wind Turbine Dynamic Transient Loads

- Long-term mechanical torque measurements for fully understanding WT dynamics and for CM purposes
- Direct measurement of the shaft dynamic behaviour under transient conditions, the most critical for the WT drive train components

Turbulent torque oscillations

Drastic shaft torque reduction

Average RMSE = 0.53 Nm
Electrical & Mechanical Diagnostic Indicators

- Comprehensive model and experimental study of generator rotor electrical unbalance (REU) at varying load and fault levels
- Significant increase in the magnitude of slip-dependent side-bands of a wide range of both supply frequency and slotting harmonics under faulty REU conditions

Fault Detection

Influence of REU severity and generator load on the fault recognition capability

Normalised Detectability \( D = \frac{\sum_i F_i^2}{\sum_i H_i^2} \)

- Power, \( P_e \)
- Mechanical Torque, \( T_m \)
- Current, \( I_s \)
- Vibration, \( A_v \)
Fault Detectability by Data Fusion

Current & Vibration

Power & Speed

Current & Mechanical Torque
Automated Rotor Fault Detection

Offline ‘Training’ Data  \[\rightarrow\] Feature Extraction  \[\rightarrow\] Classifier Training  \[\rightarrow\] Fisher’s Linear Discriminant (FLD) Classifier  \[\rightarrow\] OFFLINE

Real Data  \[\rightarrow\] Classification  \[\rightarrow\] ONLINE

Decision Output  
\[\text{e.g., healthy vs faulty}\]
# Experimental Datasets

Data collected from the Durham Wind Turbine Condition Monitoring Test Rig

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Speed (rpm)</th>
<th>Fault Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>TrainSet</td>
<td>1520</td>
<td>none (healthy) 21% rotor asymmetry</td>
</tr>
<tr>
<td>DevSet</td>
<td>1525, 1540, 1553, 1585, 1600 (variable (7.5m/s mean, 6% turbulence intensity))</td>
<td>none (healthy) 21% rotor asymmetry 43% rotor asymmetry</td>
</tr>
<tr>
<td>EvalSet</td>
<td>1530, 1555, 1565, 1590 (variable (15m/s mean, 20% turbulence intensity))</td>
<td></td>
</tr>
</tbody>
</table>

Varied parameters:
- time window length (1 to seconds)
- Number of bandpass filters (1 to 25)
- Frequency range of bandpass filters (5Hz, 7Hz, 9Hz)
FLD Projection (DevSet)

‘Best’ DevSet parameters:
- 7 second time window
- 20 bandpass filters
- 7Hz frequency range

- 98.8% Accuracy
- 1.2% False Positive Rate (FPR)
FLD Projection (EvalSet)

Using ‘best’ parameters from DevSet testing

- 97.4% Accuracy
- 3.6% False Positive Rate (FPR)
Wind Turbine Power Converter
Reliability: Models and Test Rig

1. Which wind speed operating conditions cause the greatest thermal loading to power modules and how does this correspond to damage?

2. Is manufacturer thermal data valid for lifetime estimation under complex wind turbine loading conditions?

Simulate wind turbine drive train and wind speed profiles
Simulate power module thermal loading profiles
Experimentally validate model and explore assumptions

Modelling

What drives unreliability in wind turbine power converters?

The lower the frequency of wind speed variation, the higher the temperature swing, the greater the damage

Power electronic device thermal response depends on incoming wind and drive train dynamics, not just electrical design/control

![Graph showing temperature swing vs. gust frequency](image-url)
IR Thermal Measurement

Infra-red sensor and high-frequency chopper allow fast, low-noise temperature measurement on power module IGBTs and diodes

Power converter emulation test rig
Modelling vs. Experiment

![Graph showing the comparison between model predictions and experimental data for Tj. The graph plots mean Tj, mean Tj,max, and mean Tj,min against wind speed (m/s). The model predictions are shown as solid lines, and the experimental data are shown as dashed lines.]}
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Thank you for your attention. Any questions?

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