Wind Turbine Condition Monitoring and Reliability

Dr Donatella Zappalá

WindEurope Conference 2019 - SUPERGEN Wind Hub Showcase Session
3rd April 2019

Durham University

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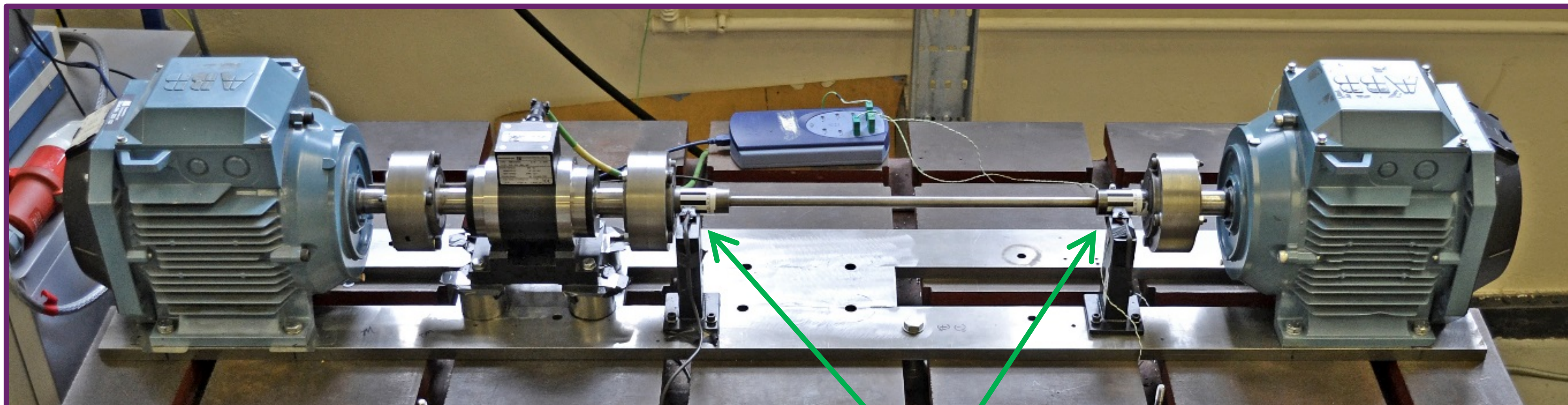
Outline

- 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)

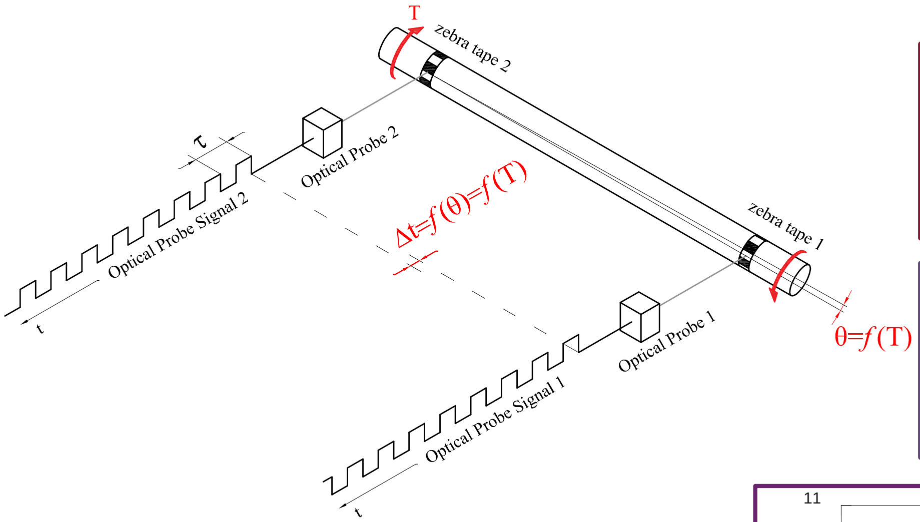
Barcodes and Optical Probes

Grid-connected Induction Generator

[1] Zappalá et al., 2018, *Meas. Sci. Technol.* 29(6): 065207

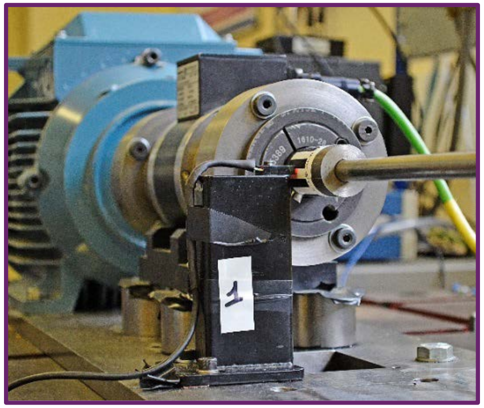
[2] Zappalá et al., In Press, *The Journal of Engineering*

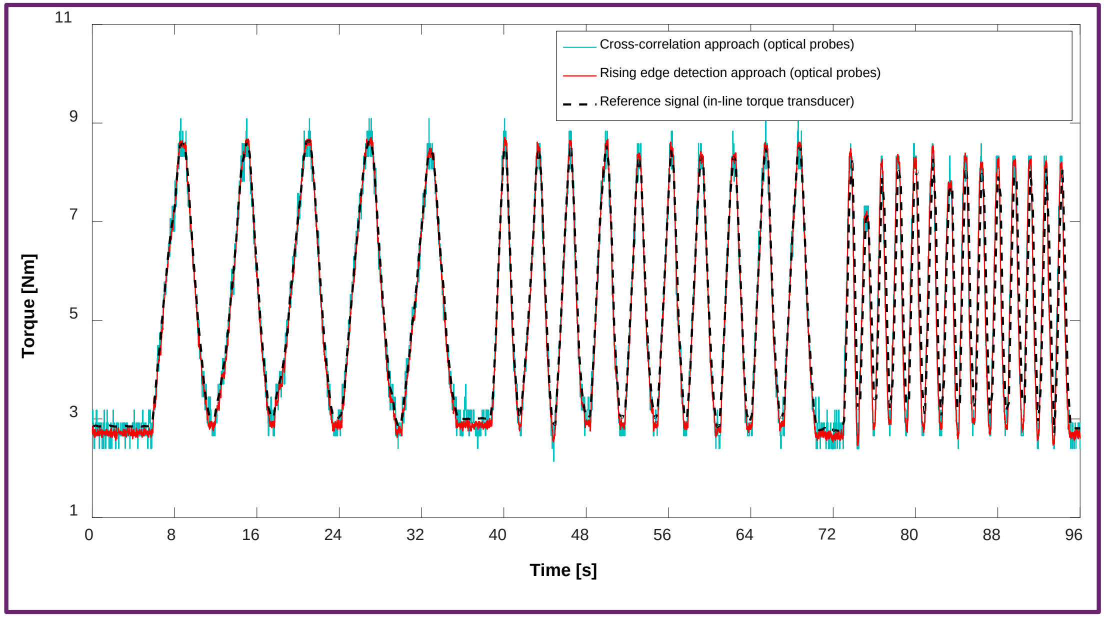
Optical Torque Measurement



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





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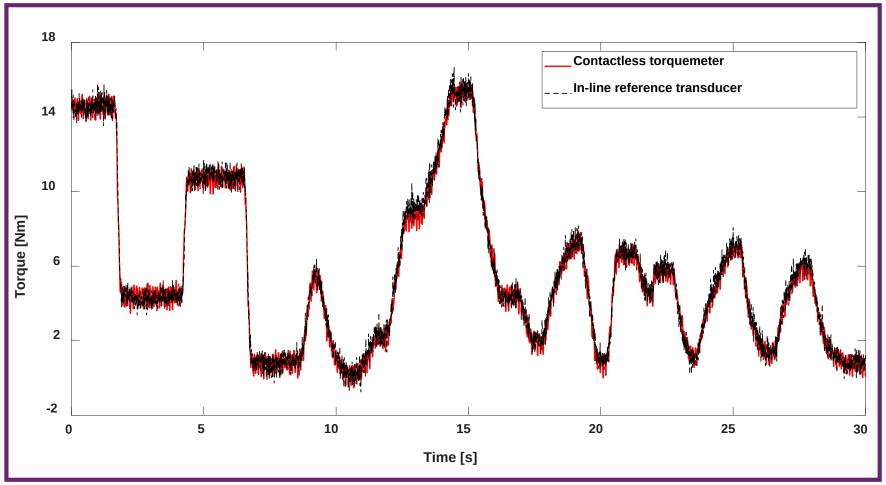
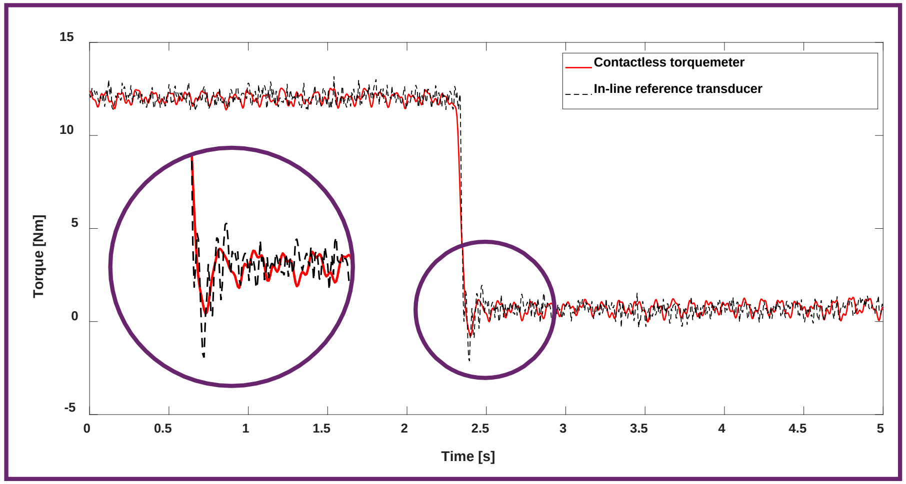
Wind Turbine Dynamic Transient Loads

- 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

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Wind Turbine Generator Condition Monitoring

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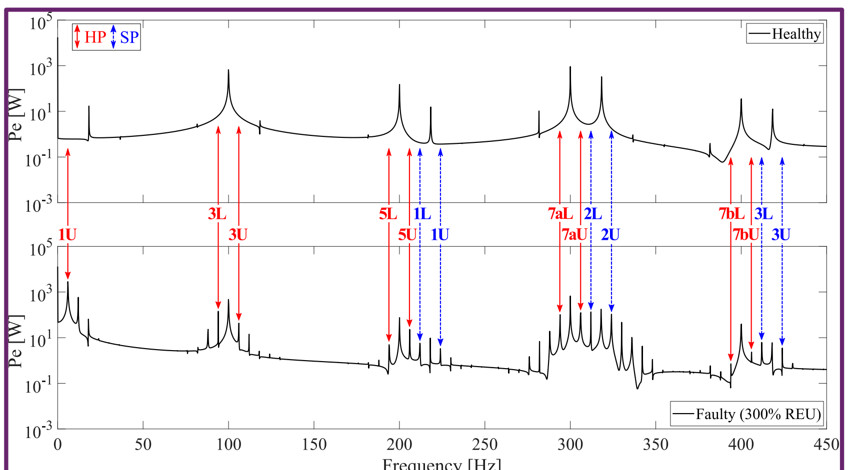
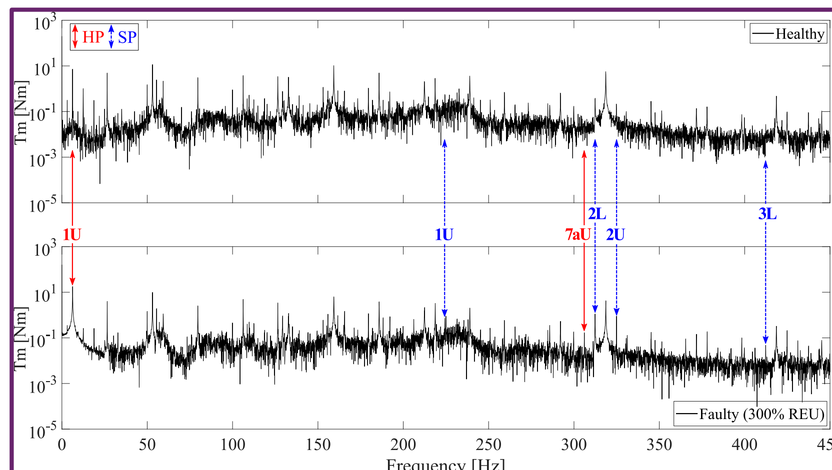
Electrical & Mechanical Diagnostic Indicators

MANCHESTER 1824
The University of Manchester

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





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Zappalá et al., 2019, *Renewable Energy* 131: 14 – 24

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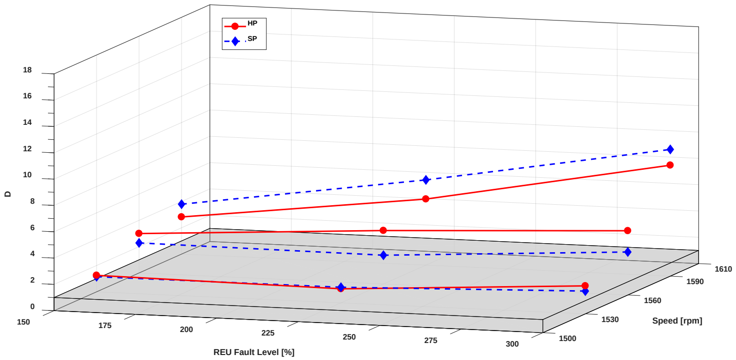
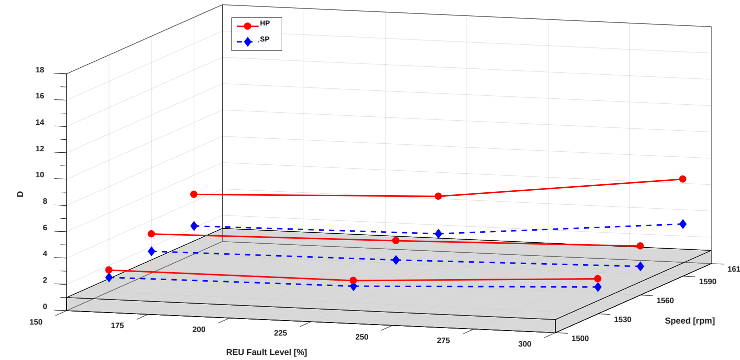
Fault Detection

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

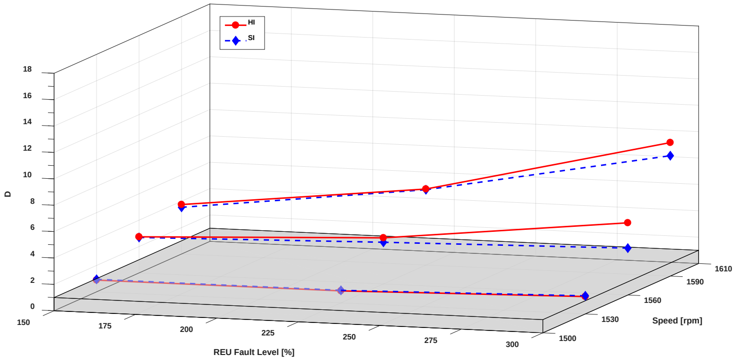
Normalised Detectability $D = \frac{\sum_i F_i^2}{\sum_i H_i^2}$



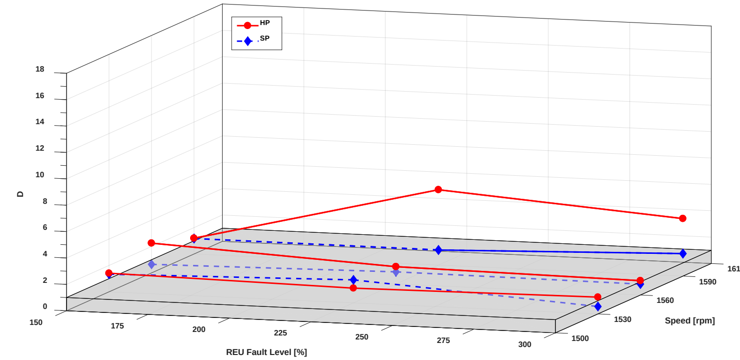
Power, P_e



Mechanical Torque, T_m

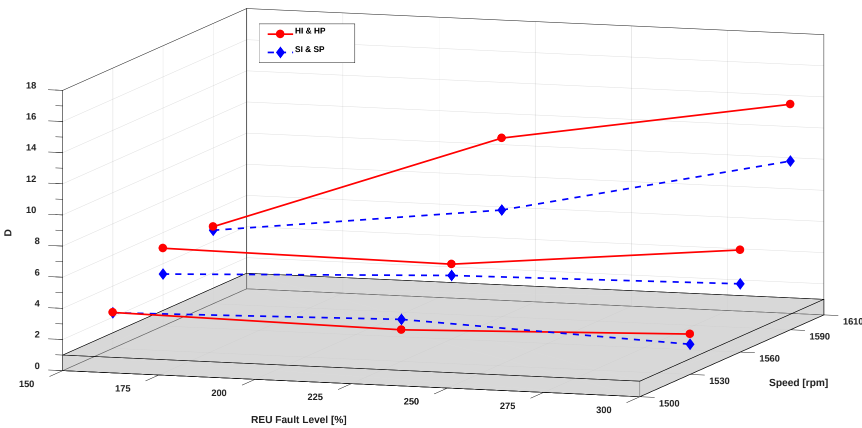


Current, I_s

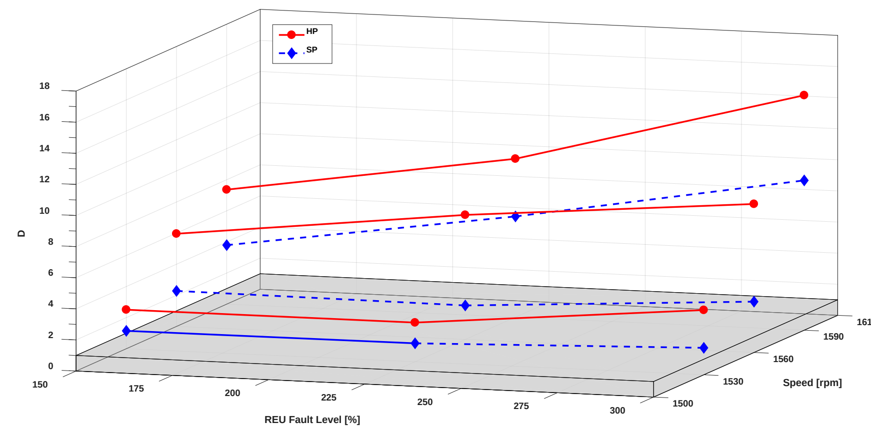


Vibration, A_v

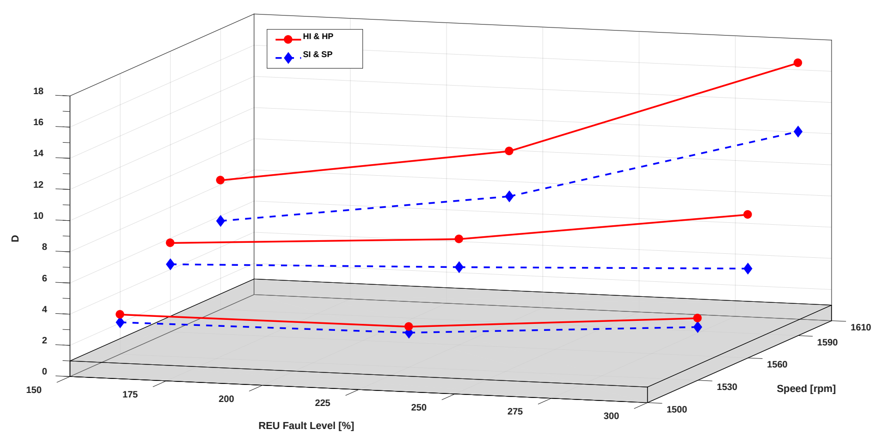
Fault Detectability by Data Fusion



Current & Vibration

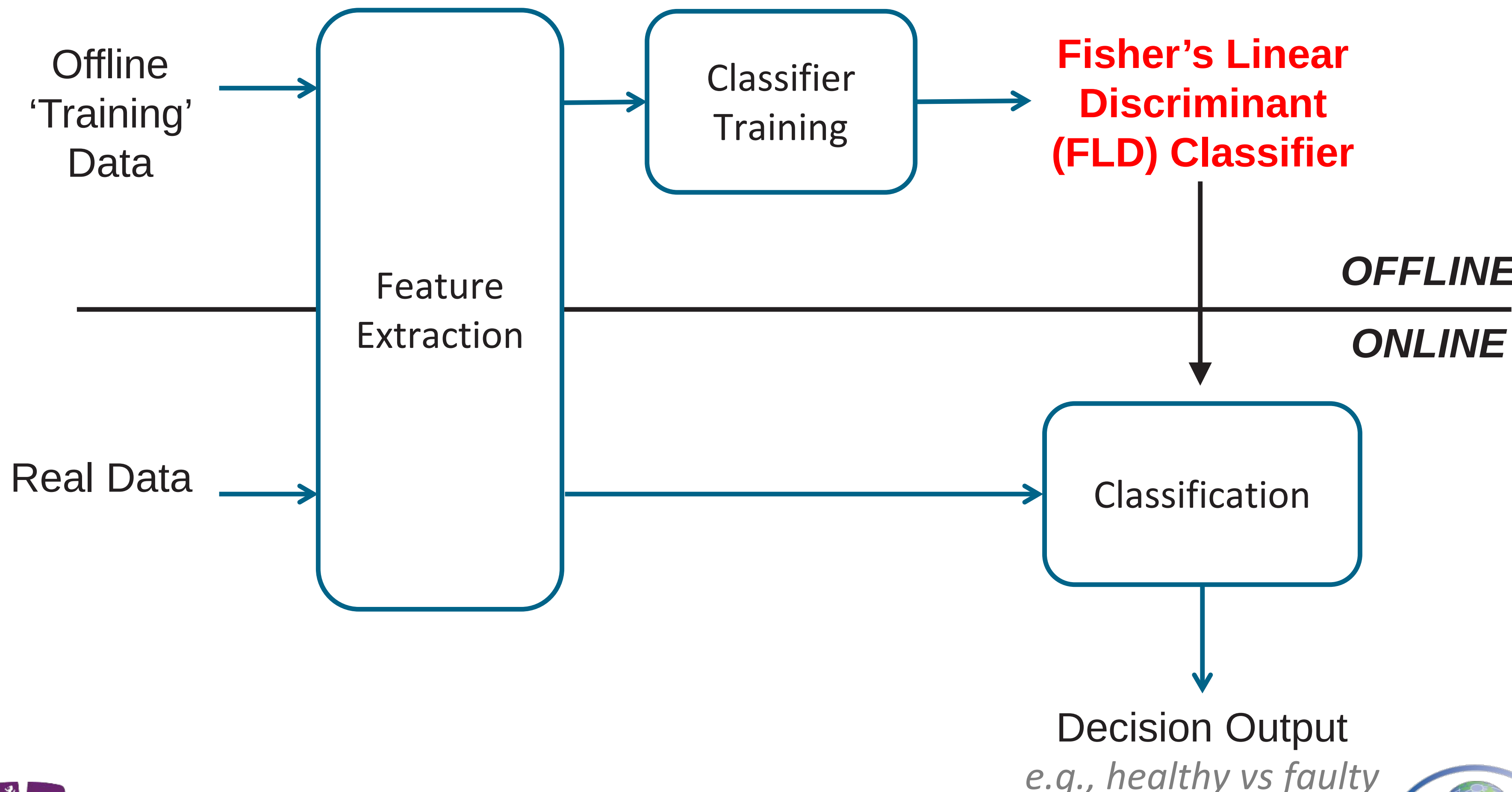


Power & Speed



Current & Mechanical Torque

Automated Rotor Fault Detection



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Brigham et al., *IET PEMD 2018 Conference, Liverpool, UK*

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Experimental Datasets

Data collected from the Durham Wind Turbine Condition Monitoring Test Rig

<table>
<tr><th></th><th>Dataset</th><th>Speed (rpm)</th><th>Fault Level</th></tr>
<tr><td>FLD training</td><td><code>TrainSet</code></td><td>1520</td><td>none (healthy)
21% rotor asymmetry</td></tr>
<tr><td>Feature extraction parameter tuning</td><td><code>DevSet</code></td><td>1525
1540
1553
1585
1600
variable (7.5m/s mean, 6% turbulence intensity)</td><td rowspan="2">none (healthy)
21% rotor asymmetry
43% rotor asymmetry</td></tr>
<tr><td>Fault detection system testing</td><td><code>EvalSet</code></td><td>1530
1555
1565
1590
variable (15m/s mean, 20% turbulence intensity)</td></tr>
</table>

Varied parameters:

- time window length (1 to seconds)
- Number of bandpass filters (1 to 25)
- Frequency range of bandpass filters (5Hz, 7Hz, 9Hz)

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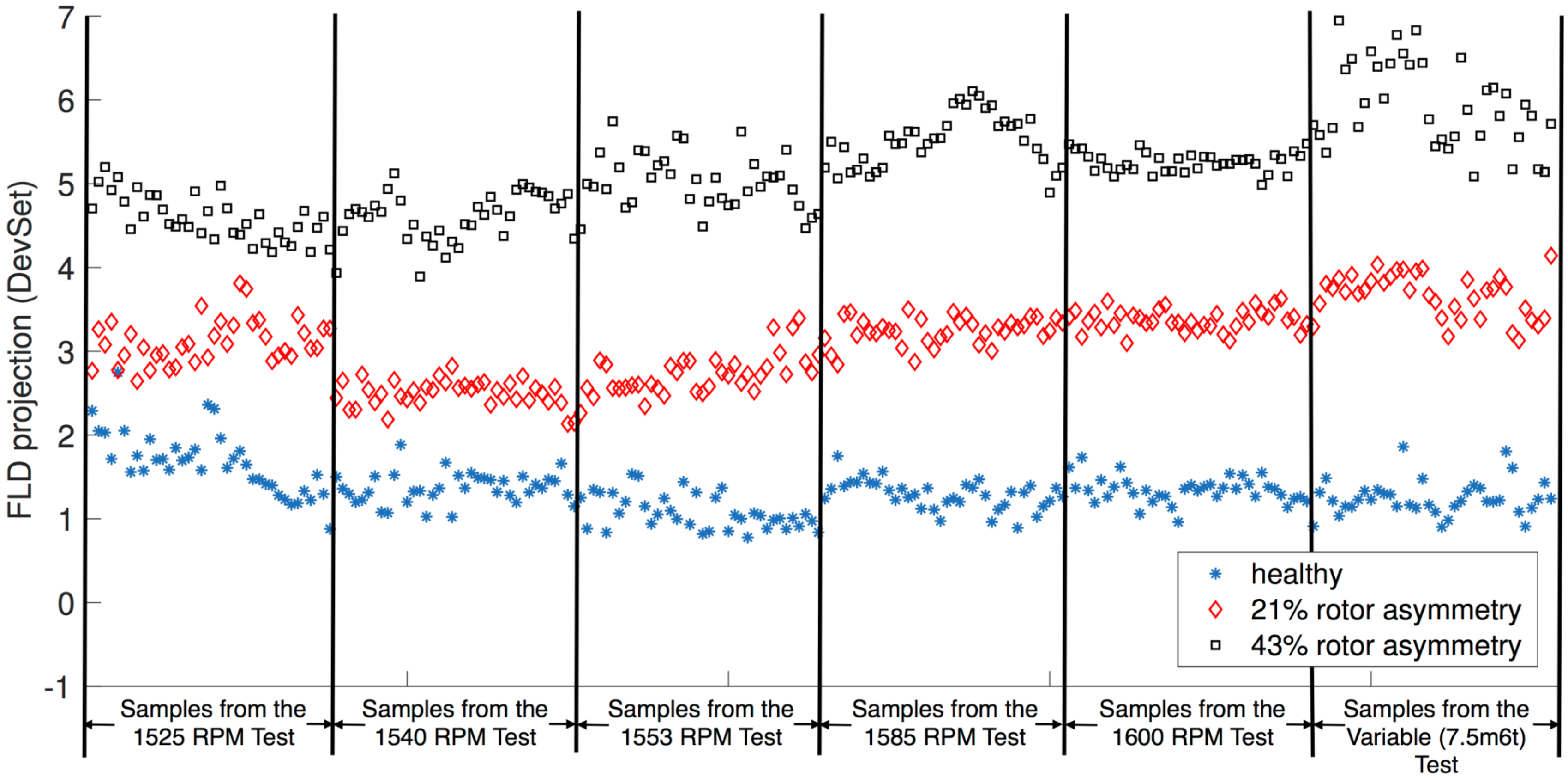
FLD Projection (DevSet)

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



- 98.8% Accuracy
- 1.2% False Positive Rate (FPR)

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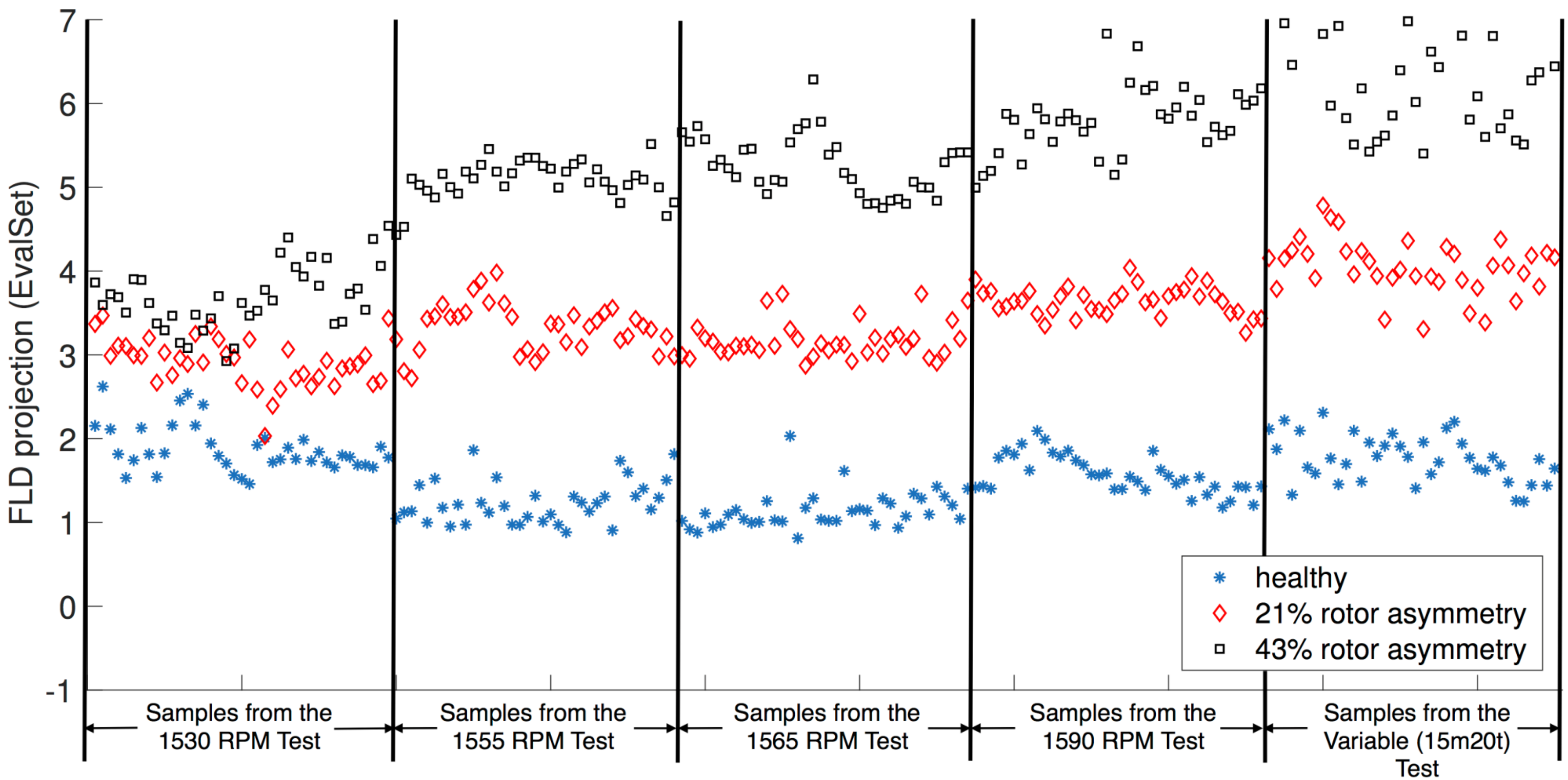
FLD Projection (EvalSet)

Using 'best' parameters from DevSet testing



- 97.4% Accuracy
- 3.6% False Positive Rate (FPR)

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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**

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[1] Smith et al., 2017, IET Power Electronics 10(11): 1268 – 1278
[2] Smith et al., In Press, The Journal of Engineering

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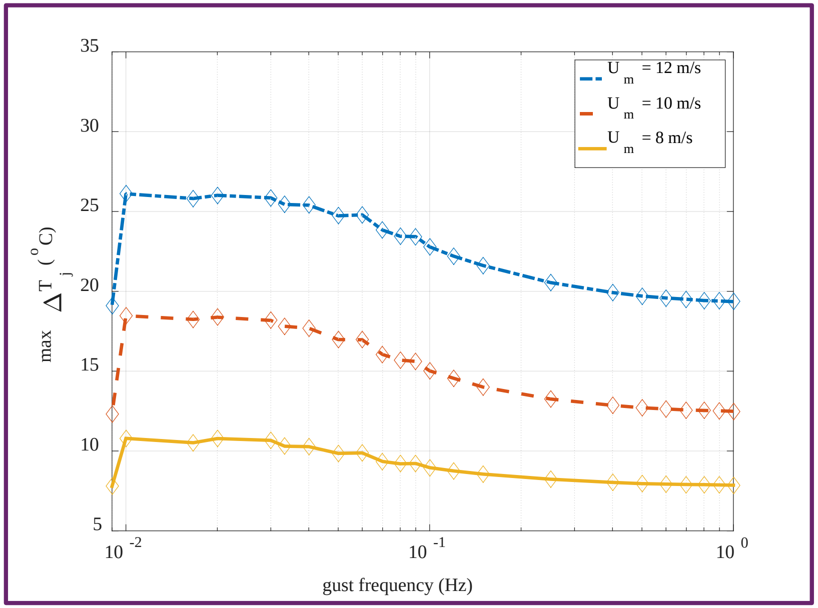
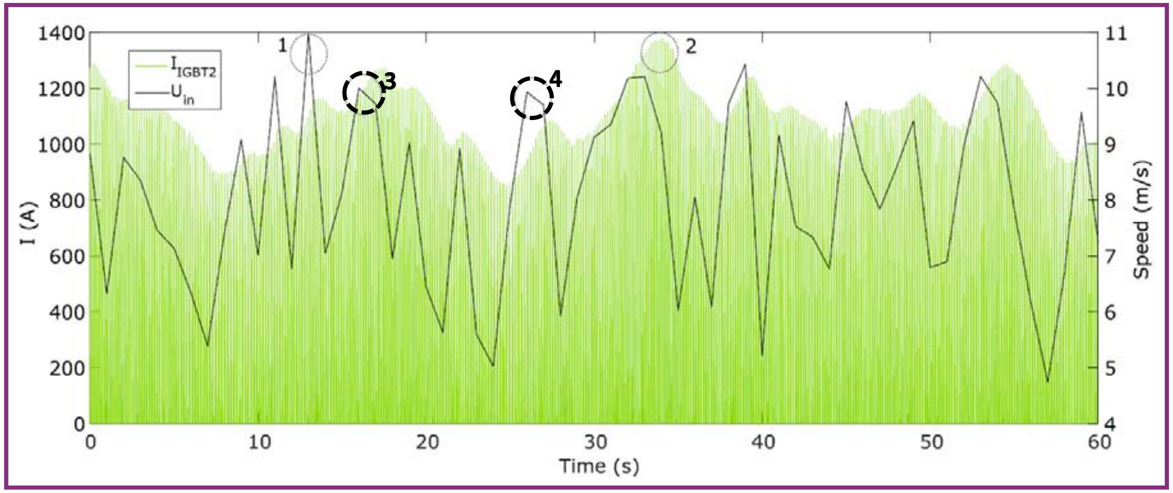
Modelling

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

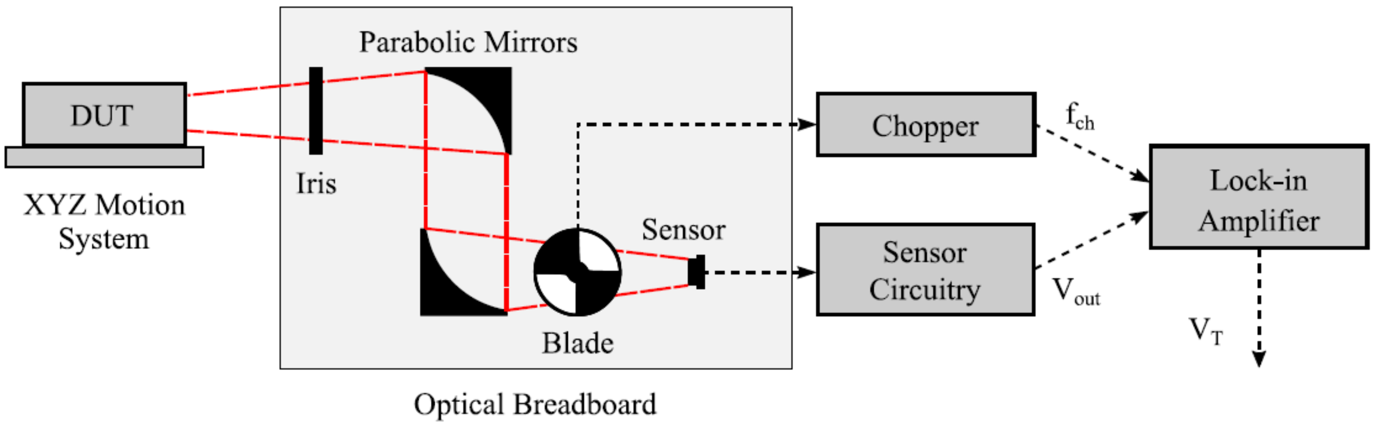
Power electronic device thermal response depends on incoming wind and drive train dynamics, not just electrical design/control

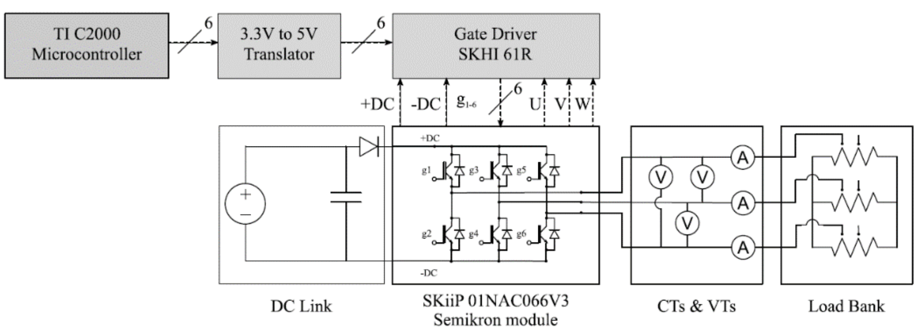


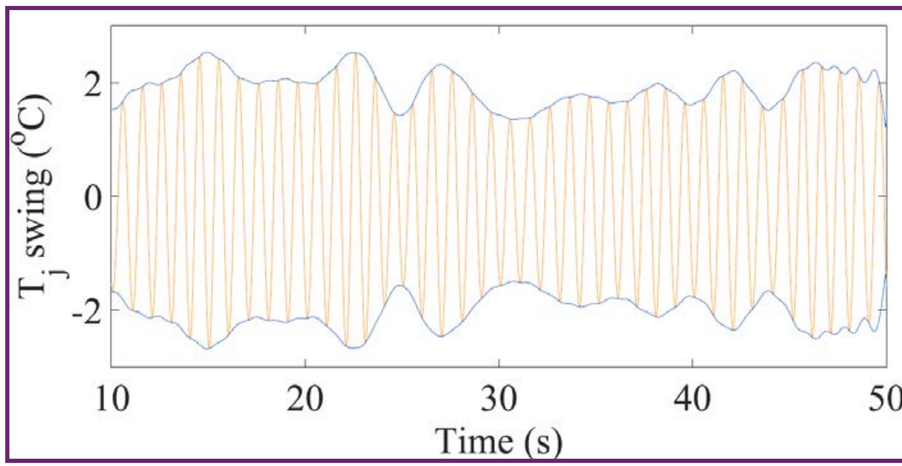


IR Thermal Measurement

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

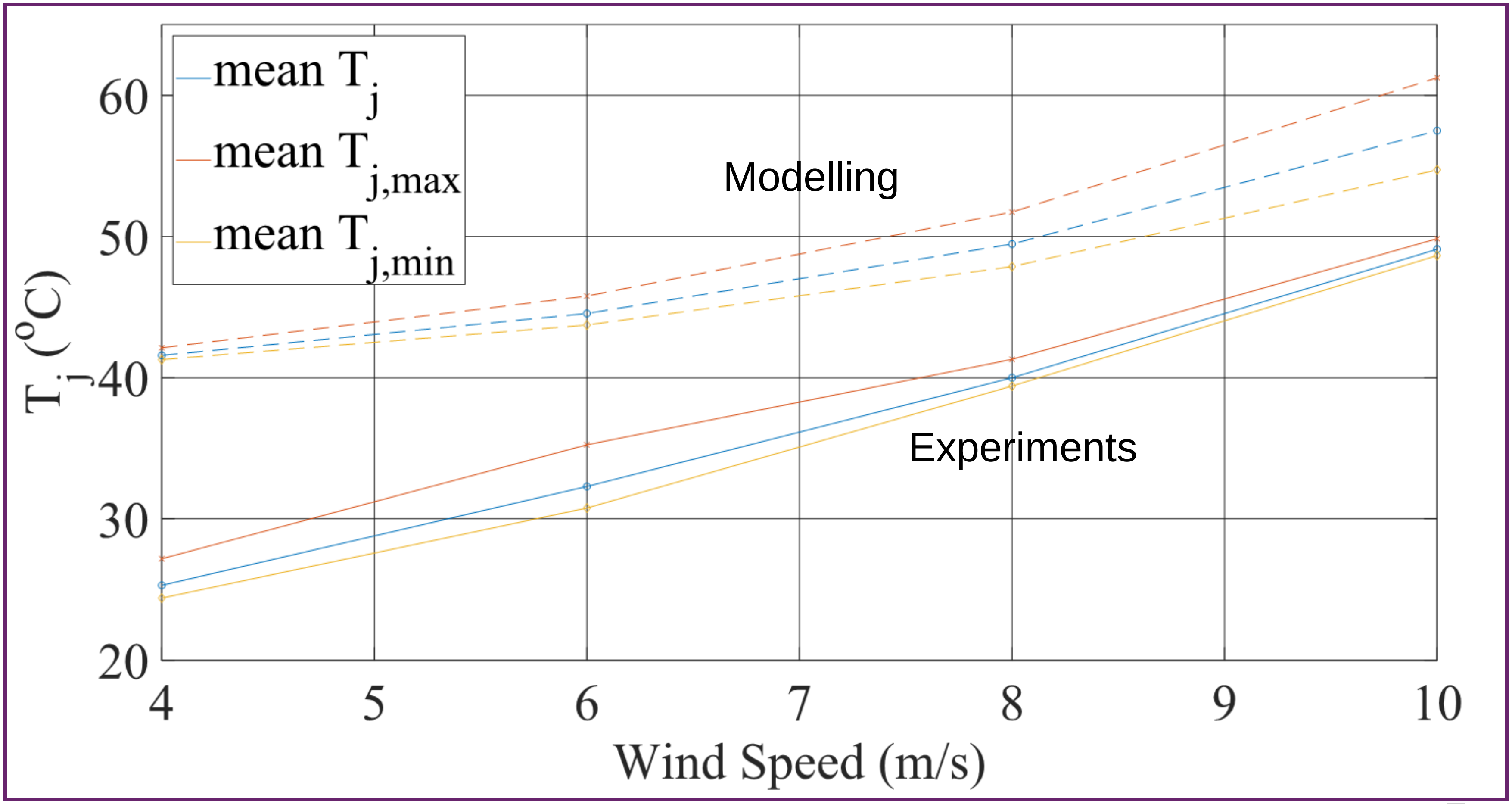






Power converter emulation test rig

Modelling vs. Experiment



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Thank you for your attention.
Any questions?

Dr Donatella Zappalá
donatella.zappala@durham.ac.uk

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