Artificial Intelligence for Fault Diagnostics and Predictive Maintenance of Industrial Assets

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Improving health monitoring and early damage detection in industrial fleets

Diagnostics

System health characterisation
Fault detection and classification

Prognostics

Prediction of system health state development and remaining useful life

Decision support

Supporting informed maintenance decision making

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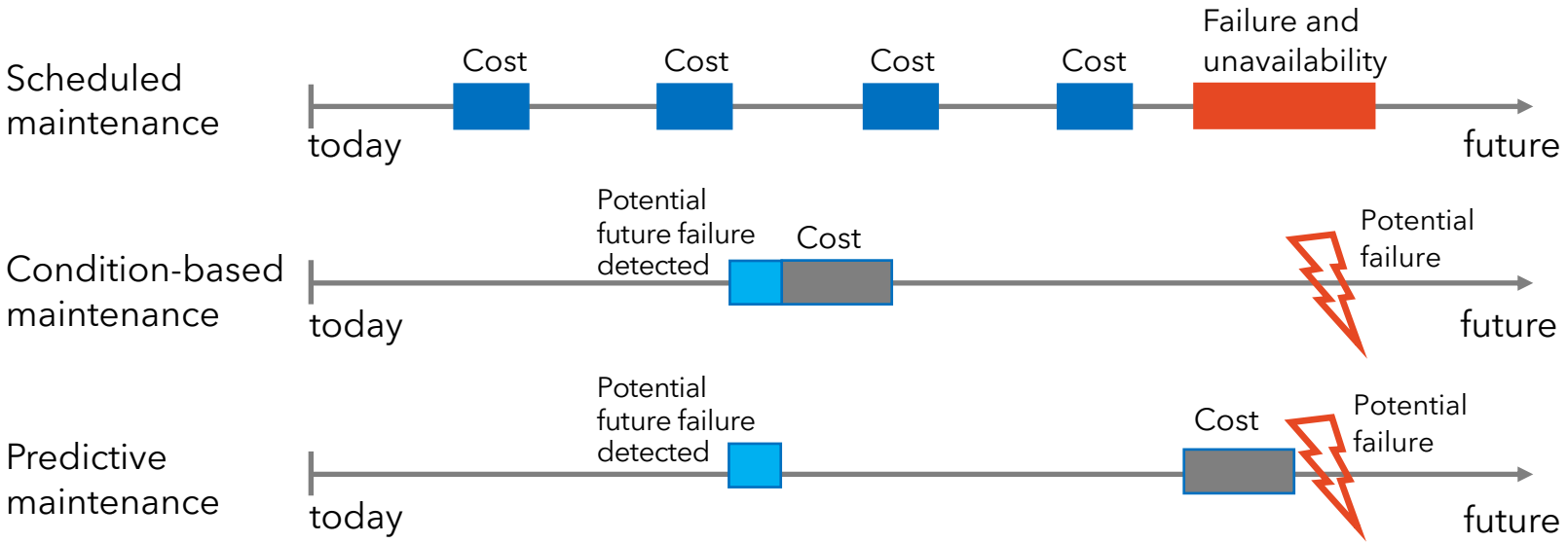
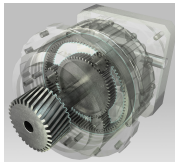
Predictive Maintenance



From physics-based to data-driven and hybrid modelling

Component ⊂ Part ⊂ Subsystem ⊂ Machine ⊂ Fleet

Bearing



Gearbox

Drivetrain

Wind turbine

Wind farm

Physical modelling, domain knowledge, rule-based monitoring

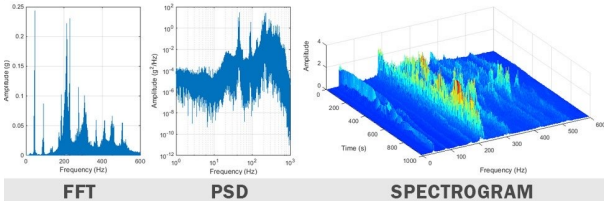
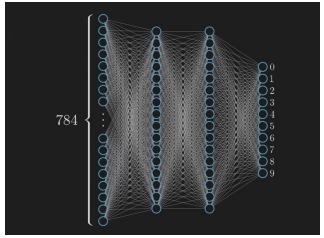


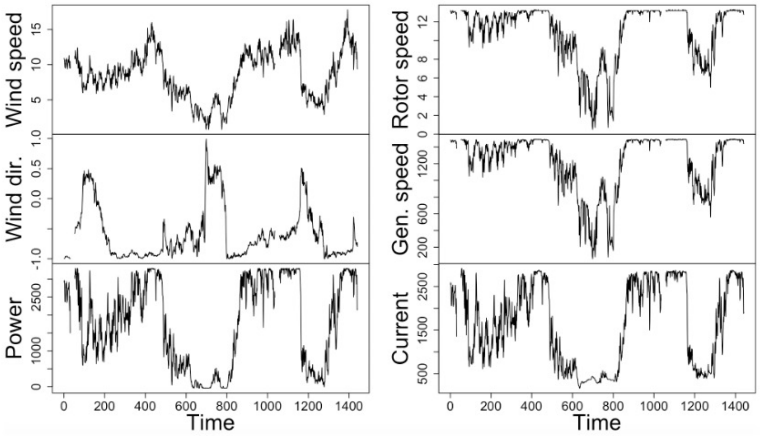
Image: Endaq

Hybrid models

Deep learning and AI

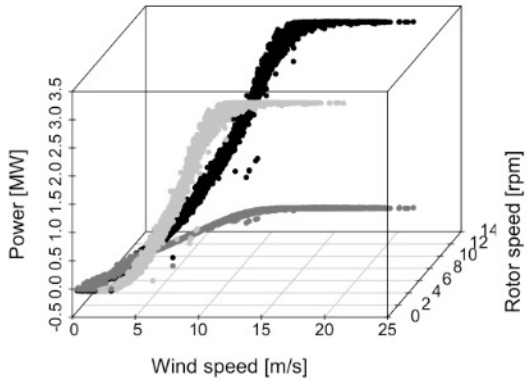


Does my machine operate normally under its various operating conditions?



Input variables	Target variables
Wind speed [m/s]	Active power [kW]
Wind direction [rad]	Rotor speed [rpm]
	Generator speed [rpm]
	Current [A]

- Data-driven AI models of normal operation behaviour
- Automated detection of faults and performance deficits



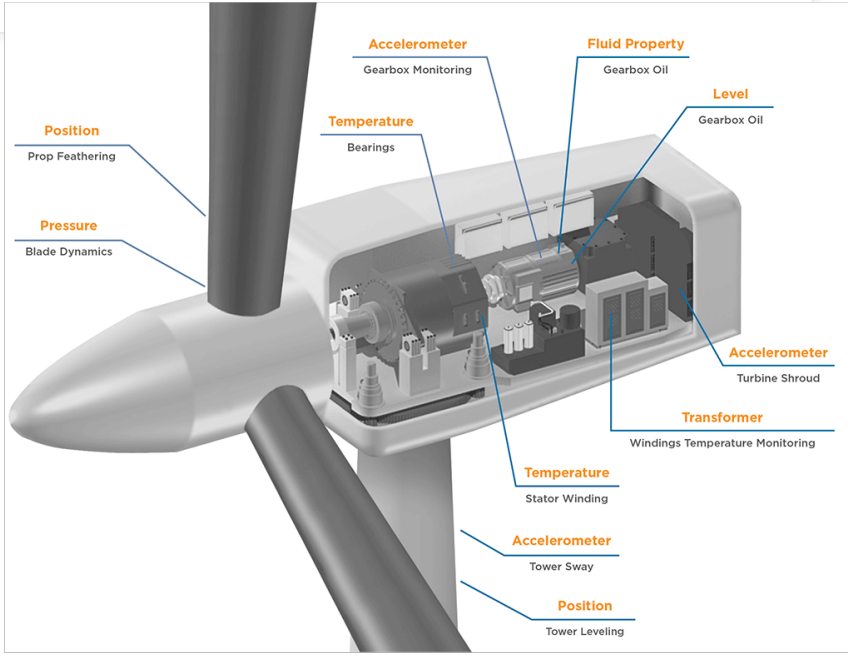
$$P \sim v_{\text{wind}}$$

$$P \sim v_{\text{wind}} + \alpha_{\text{wind}}$$

$$P \sim v_{\text{wind}} + \alpha_{\text{wind}} + T_{\text{air}}$$

Data-driven early fault detection and diagnosis in wind turbine drive trains

- New data-driven method for unsupervised fault detection in wind turbine gearboxes [Meyer 2022]
- Multi-task normal behaviour models simplify condition monitoring and can achieve higher accuracies then prior-art single-target models [Meyer, 2021a]
- Multi-task normal behaviour models can detect faults at least as fast as and in some cases even faster than the prior art approaches. They can achieve the same level of detection stability. [Meyer, 2021b]
- We demonstrated data-driven fault detection in several active wind farms [Maron et al., 2022]

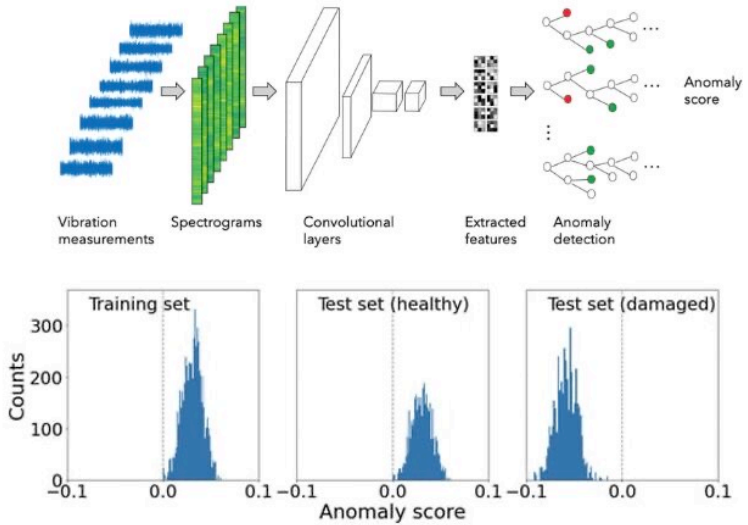


Source: TE Connectivity

Data-driven early fault detection and diagnosis in wind turbine drive trains

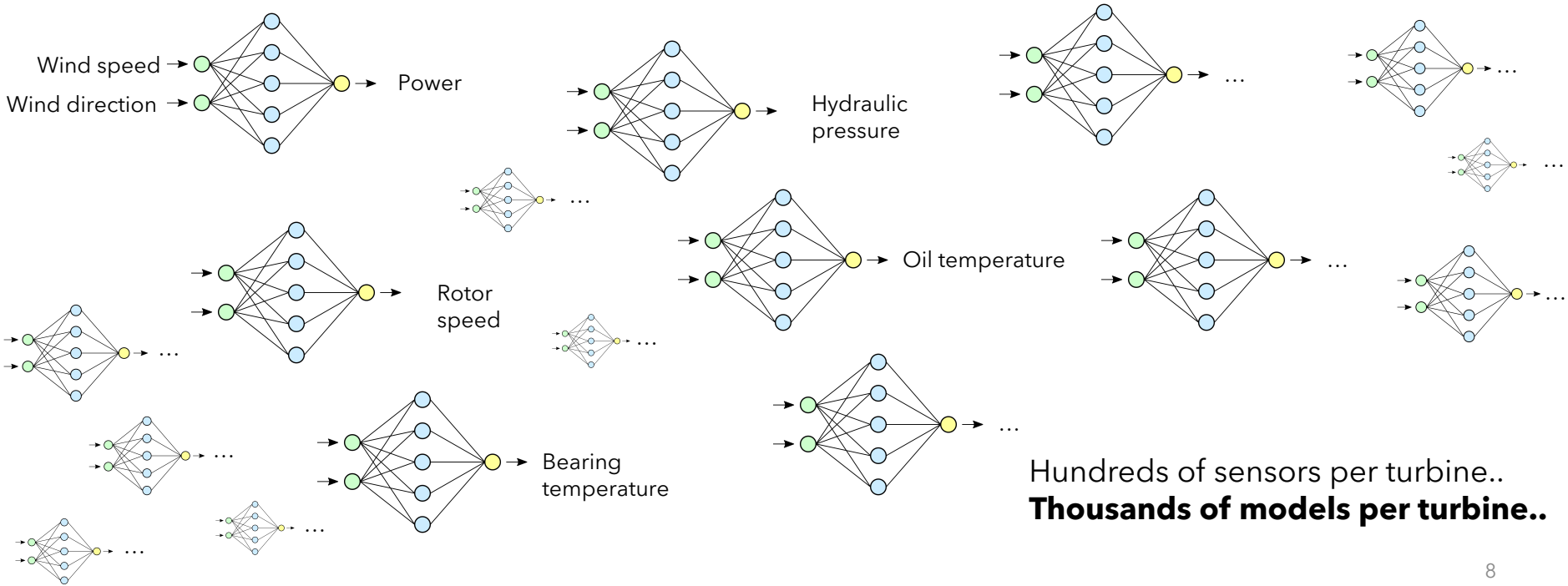
Method for unsupervised fault detection without feature definitions in wind turbine gearboxes:

- Vibration-based fault detection without the usual upfront definition of spectral features. CNN identifies and extracts the most relevant features from the half spectrum instead, thus saving time and effort.
- A spectral model of the normal gearbox behaviour is learnt from past measurements and can successfully discriminate damaged from healthy gearbox components.
- The entire half spectrum is monitored instead of the usual focus on individual frequencies and harmonics.



Meyer, A., 2022, Vibration Fault Diagnosis in Wind Turbines based on Automated Feature Learning, Energies, 15(4), doi: 10.3390/en15041514.

Single-task modelling for wind turbine condition monitoring



Hundreds of sensors per turbine..
Thousands of models per turbine..

Meyer, A., 2021, Multi-target normal behaviour models for wind farm condition monitoring, Applied Energy, doi: 10.1016/j.apenergy.2021.117342

Multi-task learning of normal operation behaviour can achieve and exceed the accuracy of single-task models

Multi-task models

$P, \omega_R, \omega_G, I \sim v_{wind} + \alpha_{wind}$

Model	Global RMSE	Power	Rotor speed	Generator speed	Current
Decision tree	0.13	0.13	0.10	0.10	0.18
Random forest	0.13	0.13	0.10	0.10	0.17
KNN	0.13	0.13	0.11	0.10	0.18
MLP	0.14	0.15	0.11	0.11	0.19
CNN	0.15	0.16	0.12	0.11	0.20
LSTM	0.14	0.13	0.11	0.11	0.18

Single-task models

$P \sim v_{wind} + \alpha_{wind}$

Model	RMSE
Decision tree	0.13
Random forest	0.13
KNN	0.13
MLP	0.14
CNN	0.16
LSTM	0.13

Multi-task normal operation models match the accuracies of their single-task counterparts and can even surpass them

Meyer, A., 2021, Multi-target normal behaviour models for wind farm condition monitoring, Applied Energy, doi: 10.1016/j.apenergy.2021.117342

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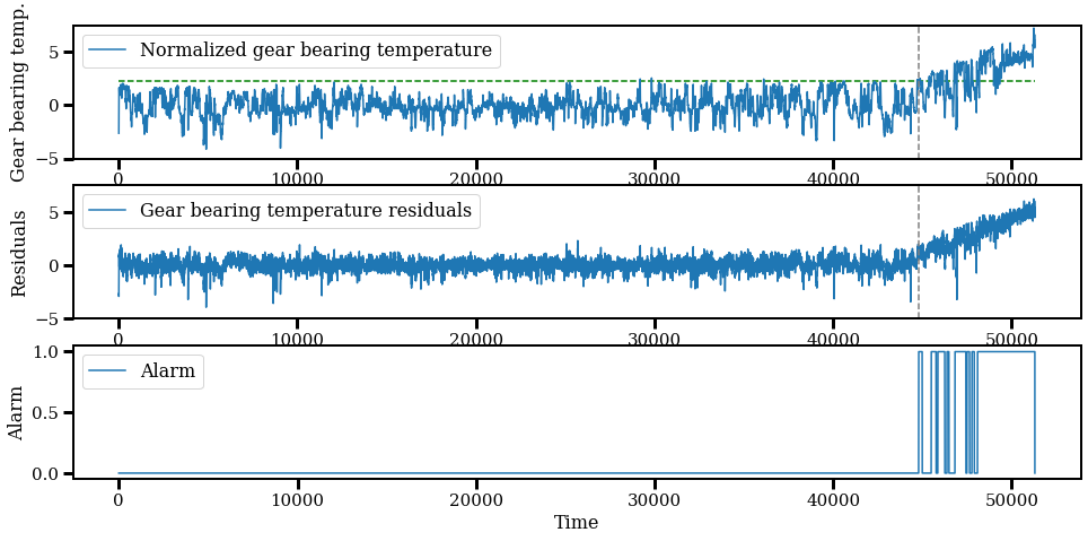
Fault diagnostics in gearboxes based on multi-task learning



Gear bearing fault detection

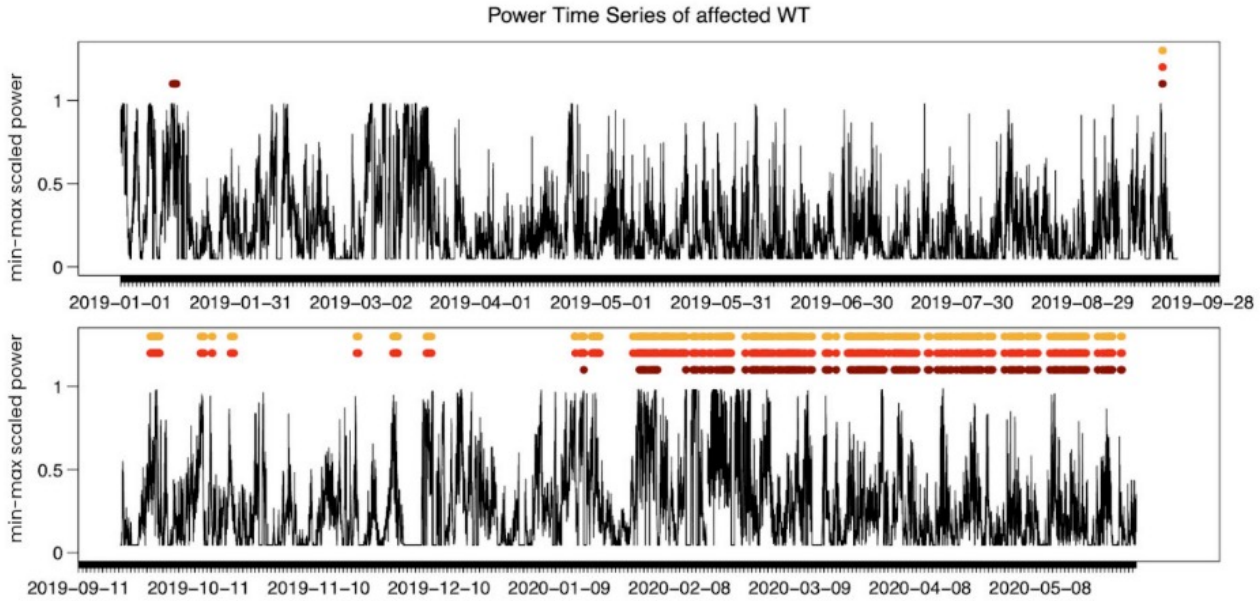
Gear bearing temperature

- Adding 50 trends with random onset times
- Measure detection delay and detection stability
- Two different alarm criteria

$$T_{gear}, T_{oil}, T_{tr} \sim v_{wind} + \alpha_{wind} + T_{air}$$

Meyer, A., 2021, Early fault detection with multi-target neural networks, Lecture Notes in Computer Science, Vol. 12953, Springer, doi: 10.1007/978-3-030-86970-0_30

Application in wind farms



Normalized Power

Anomalies:

Generator Journal Temperature

Generator Temperature 1

Generator Temperature 2

Maron, J., D. Anagnostos, B. Brodbeck, A. Meyer (2022): Artificial intelligence-based condition monitoring and predictive maintenance framework for wind turbines, Journal of Physics Conference Series, doi: 10.1088/1742-6596/2151/1/012007.

winji TRUE POWER

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Innosuisse – Schweizerische Agentur für Innovationsförderung

Thank you!

Prof. Dr. Angela Meyer | SNSF Practice to Science

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