Wind turbine control strategies for mitigating tower fatigue loads using wind roses or wake detection

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PhD Motivation

- Tower Fatigue Damage – potential structural failure
- Controller objective – reduce or mitigate tower load
- Simple Inputs

Aim

- Increase information to controller strategy

to improve controller adaptability and predictability

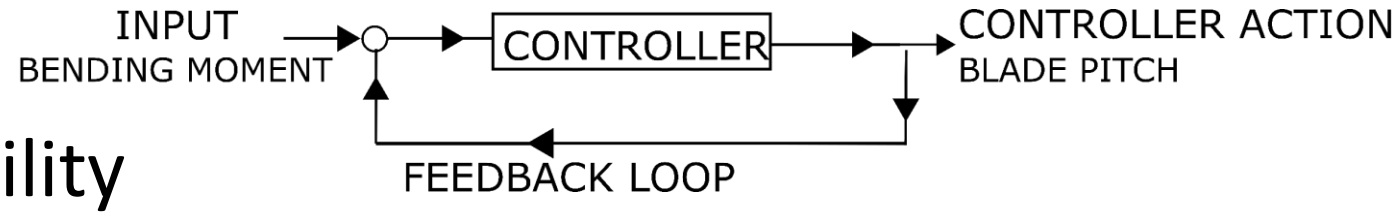


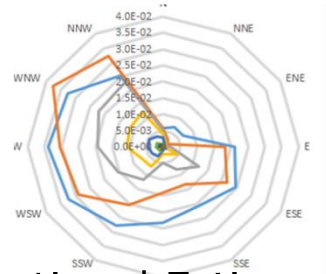
Figure 1– Simple Controller

PhD Overview

SHORT TERM INPUT

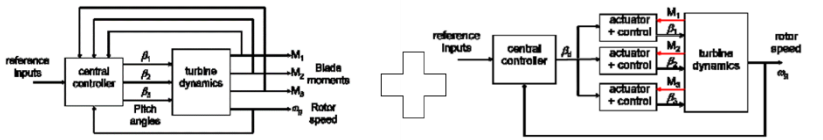
Wake Detection

LONG TERM INPUT



Directional Fatigue Damage

HYBRID BLADE CONTROLLER



IPC IBC

INTERFACE

CONTROLLER

CONTROLLER ACTION
BLADE PITCH

FEEDBACK LOOP

Figure 2– Schematic of PhD

SHORT TERM INPUT

Wake Detection

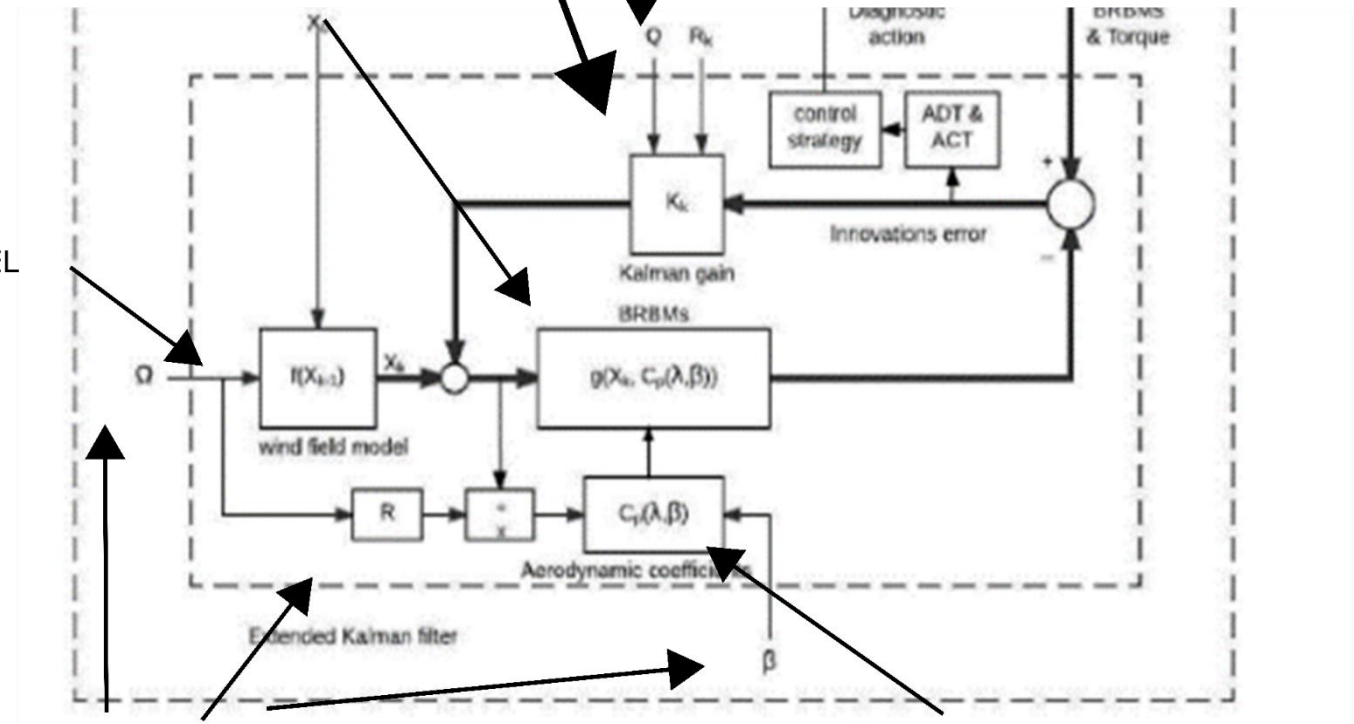
Short term – Wake Detection – Anomaly Detector

KALMAN GAIN

KALMAN FILTER TUNING PARAMETERS

BENDING MOMENTS
(Simulation or Measurement)

WIND FIELD MODEL
[GALA SANTOS]



WIND TURBINE PARAMETERS
(Simulation)

COEFFICIENTS
(Simulation of Calculation)

Figure 3– Annotated Schematic of Anomaly detector

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Hur, S., L. Recalde-Camacho, and W. E. Leithead. "Detection and compensation of anomalous conditions in a wind turbine." *Energy* 124 (2017): 74-86.

Short term – Wake Detection - Extended Kalman Filter

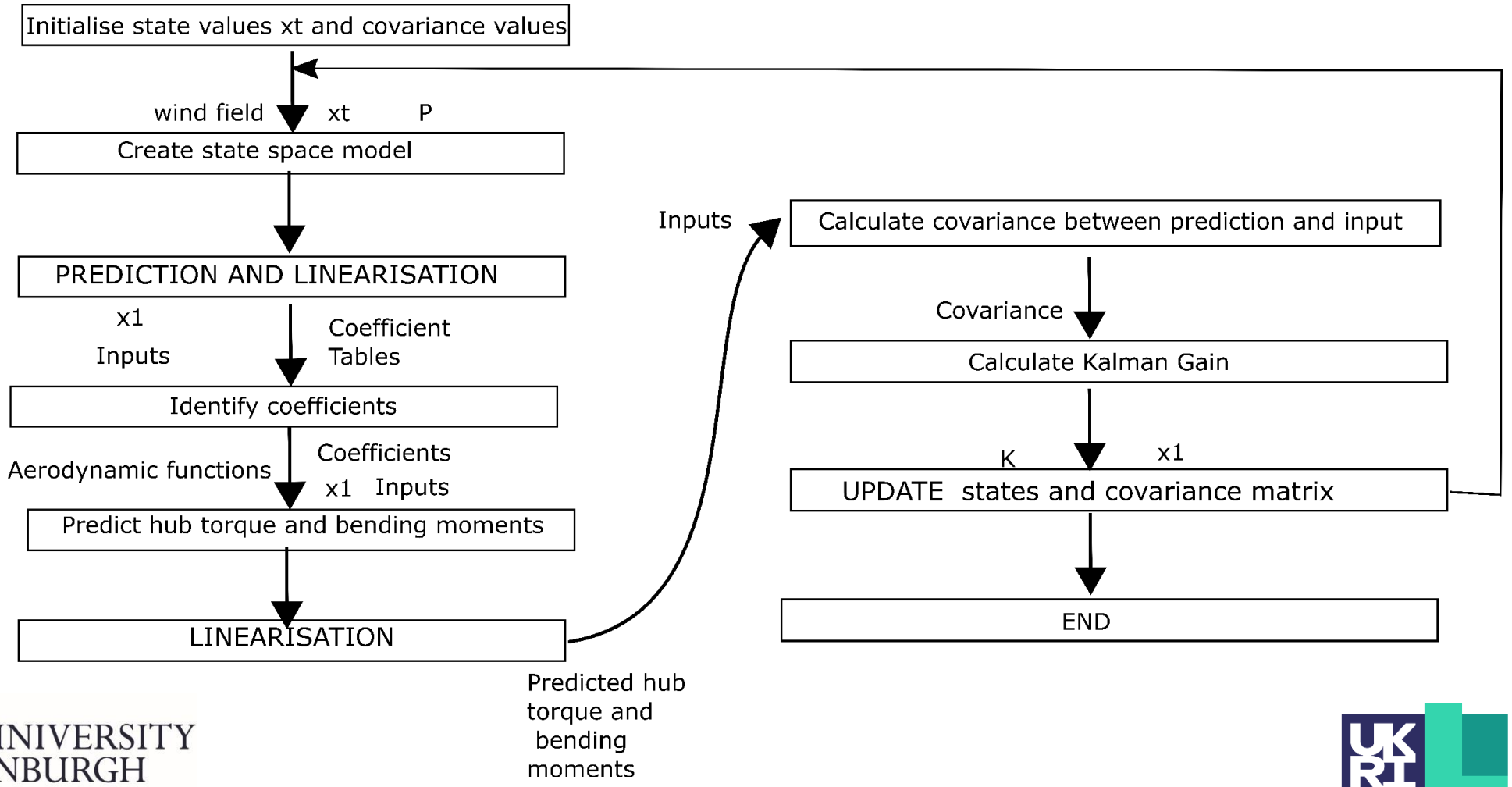


Figure 4–Schematic of Extended Kalman Filter

Short term – Wake Detection – Extended Kalman Filter Below Rated Results

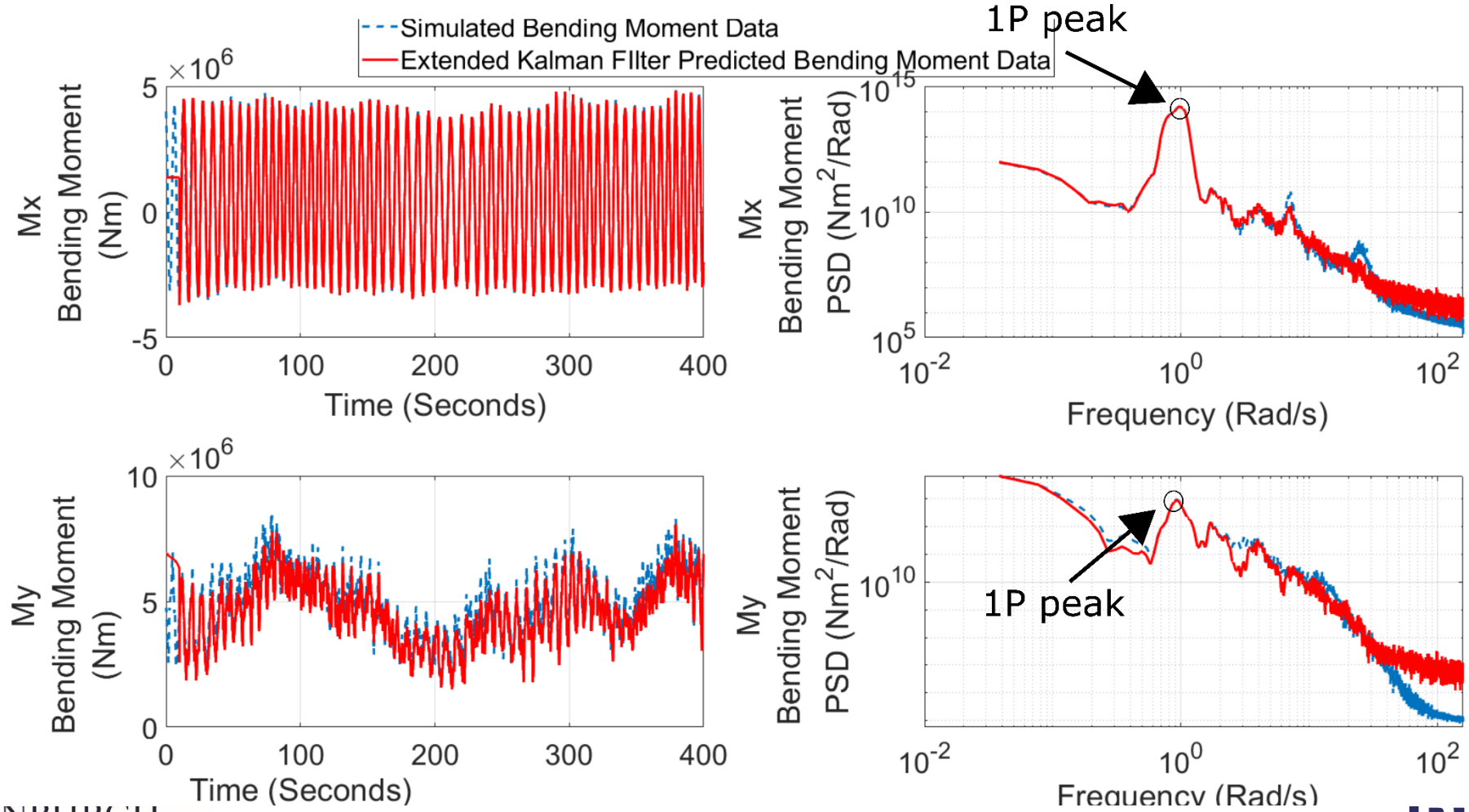


Figure 5– Time domain and frequency domain results for in plane Mx and out of plane My bending moments for Extended Kalman Filter for 8 m/s

Short term – Wake Detection – Extended Kalman Filter Above Rated Results

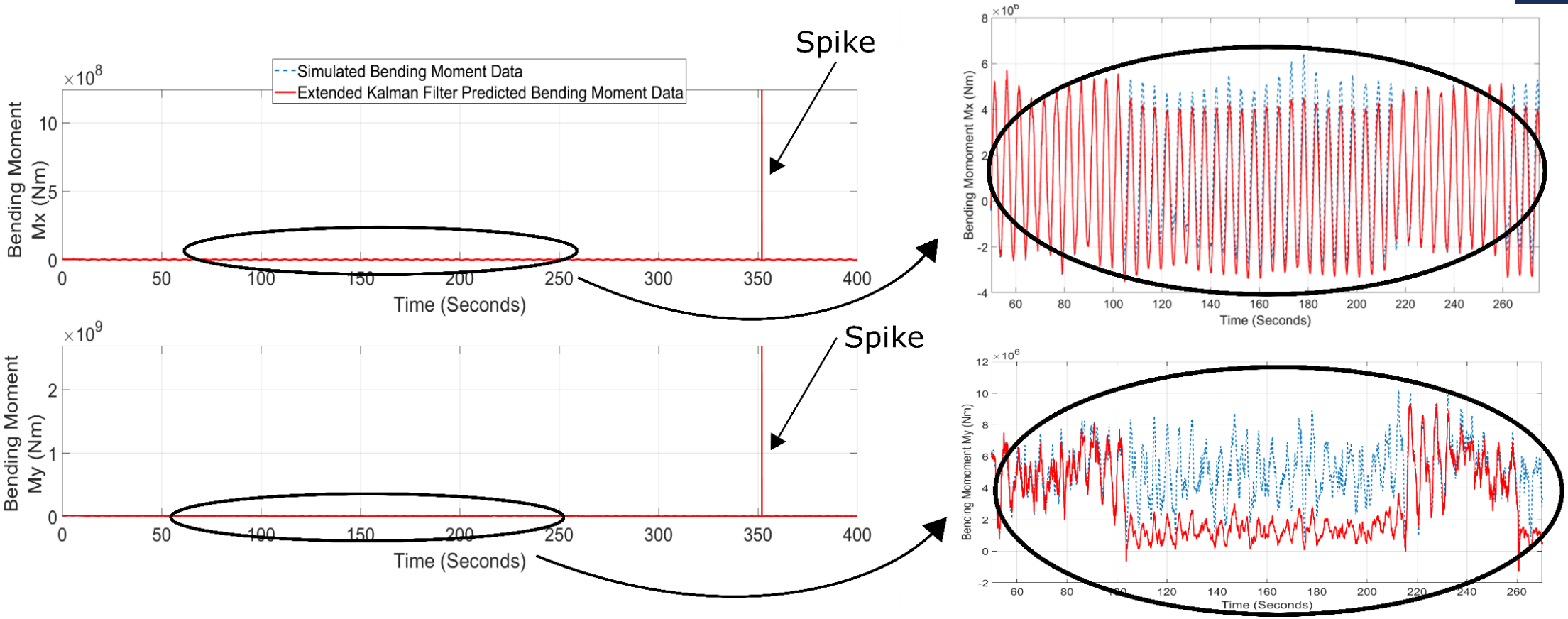


Figure 6– Time domain results for in plane Mx and out of plane My bending moments for Extended Kalman Filter for 16 m/s

Short term – Wake Detection – Extended Kalman Filter Above Rated Results

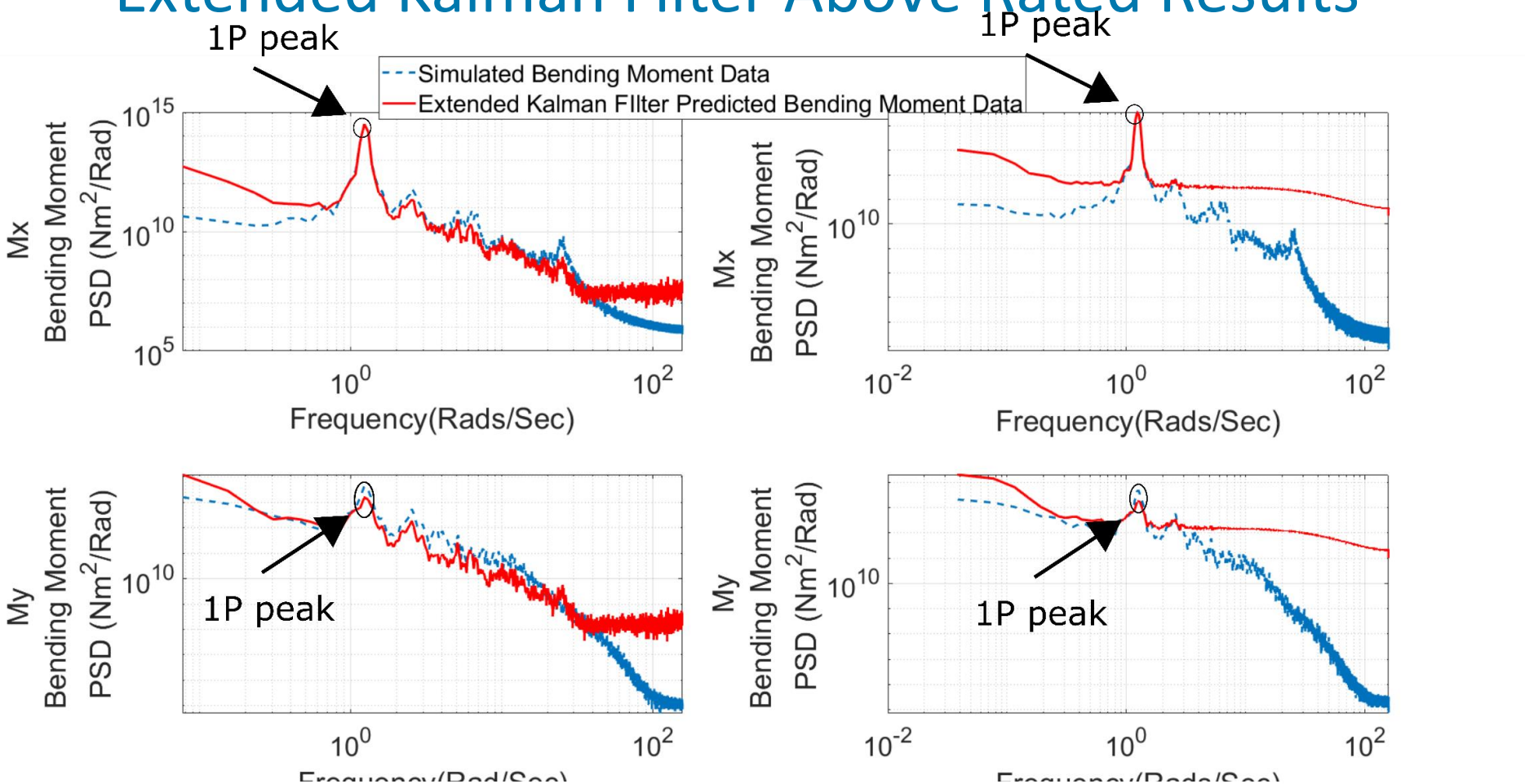


Figure 7– Frequency domain results for in plane Mx and out of plane My bending moments for Extended Kalman Filter for 16 m/s up to 351.92 seconds (left) and 400 seconds (right)

Short term – Wake Detection

Related to horizontal wind variation across rotor

$$U = \bar{U} + (U_{a1}(t) + a_1)\sin\psi + (U_{b1}(t) + b_1)\cos\psi \quad (1)$$

State predicted by kalman filter

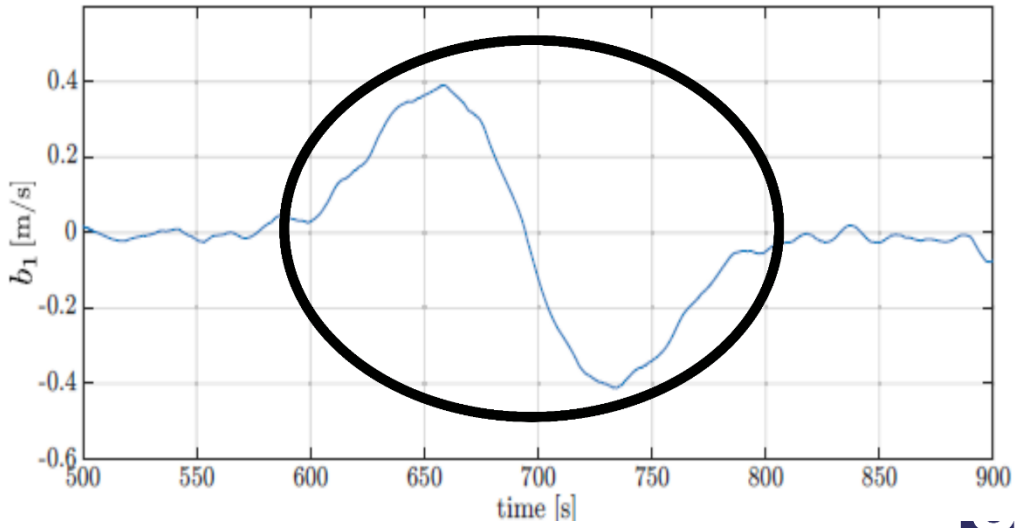
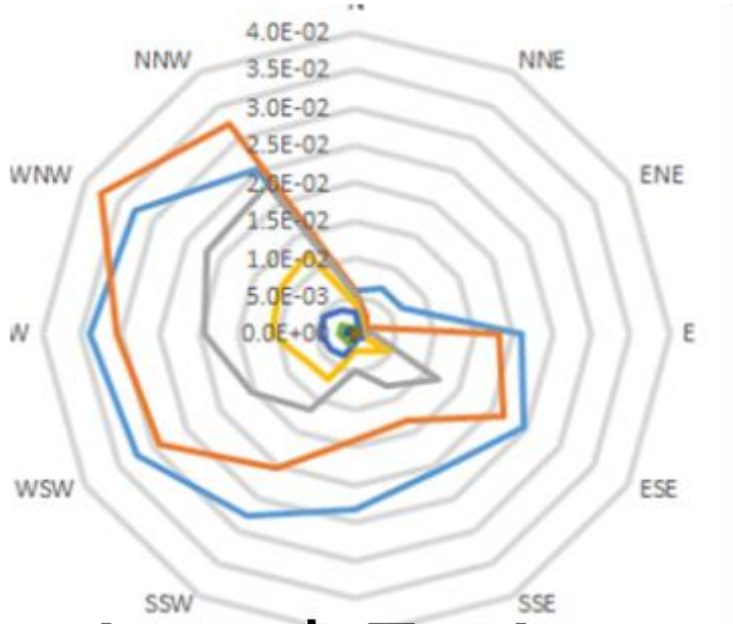


Figure 8 – Extended Kalman Filter Predicted state b1 [Zorzi]

LONG TERM INPUT



Directional Fatigue Damage

Long Term – Fatigue Damage -Closed Form Solution

Figure 9 – Example finite element model of wind turbine tower used for finite element analysis [Amiri]

Tower Position

Mean Wind Speed

Mean Wind Direction

Tower Position

$$D_{TOT}(\theta) = \int_{\tau}\int_{v} p(v,\tau) D_{v,\tau}(\theta)\, dv\, d\tau \qquad (2)$$

WIND ROSE PROBABILITY

FATIGUE DAMAGE

Long Term –Fatigue Damage

Case Study Overview

- Mx and My time series for 4m/s to 24m/s in 2m/s steps
  - 2.3 MW Aeroelastic Wind Turbine model *[Amiri et al]*
- 7 wind roses
  - Wind Farm SCADA data

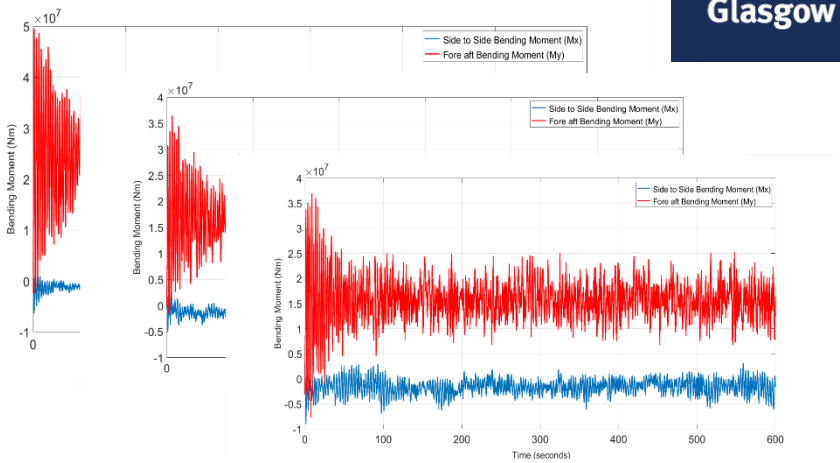


Figure 10– Examples of Case Study Bending Moment Data

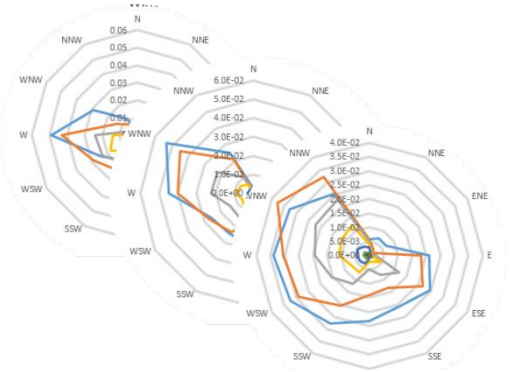


Figure 11– Examples of Case Study Wind Roses

Amiri AK, Kazacoks R, Mcmillan D, Feuchtwang J, Leithead W. Farm-wide assessment of wind turbine lifetime extension using detailed tower model and actual operational history. Journal of Physics: Conference Series, WindEurope Conference and Exhibition 2019 2019; 1222. doi: 10.1088/1742-6596/1222/1/012034

Long Term – Fatigue Damage –Closed Form Solution – Directional Damage

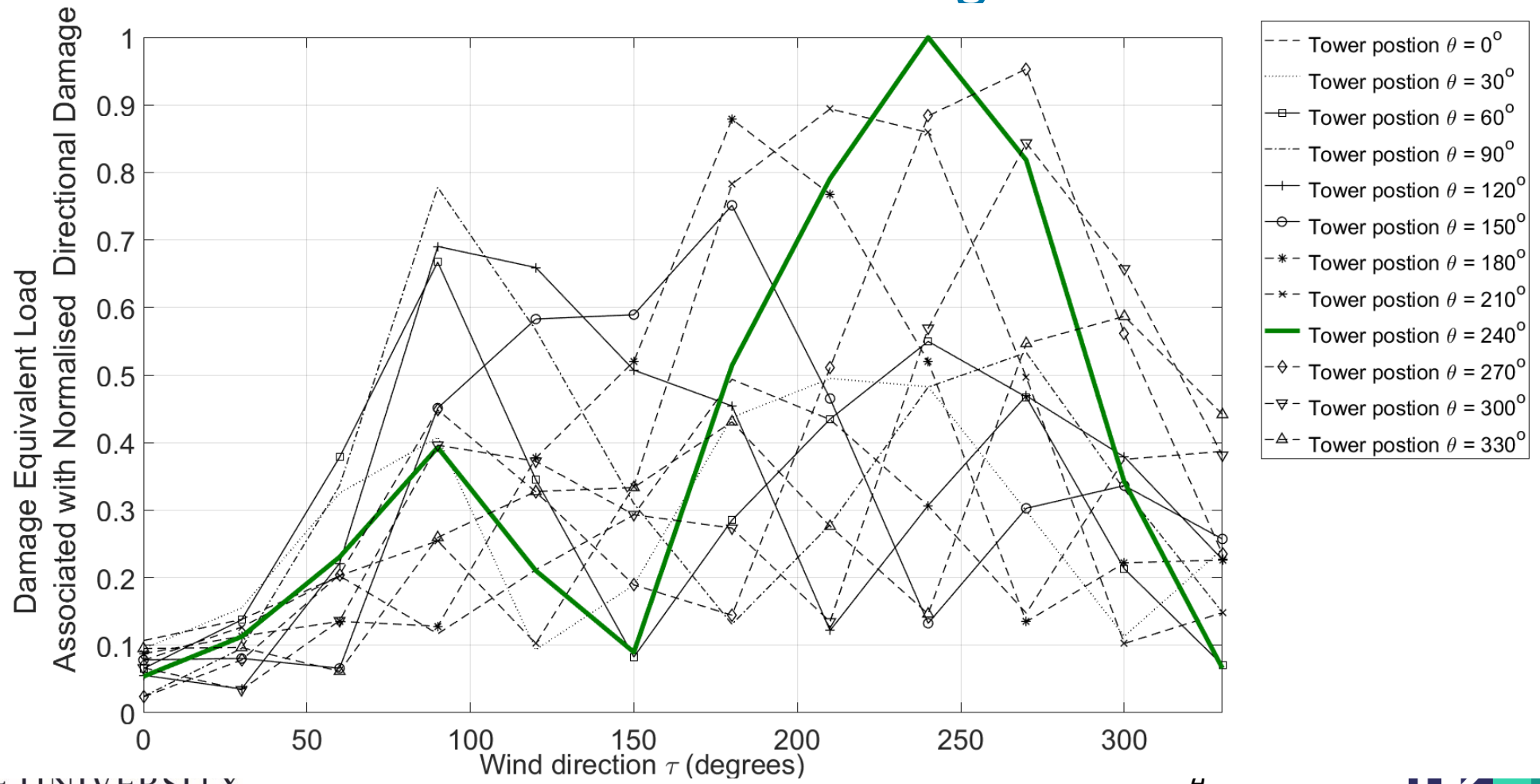


Figure 12–Normalised fatigue damage equivalent load for tower position θ and wind direction τ for wind turbine 1

Lifetime Extension Potential

Maximum
Damage Equivalent Load
on point on Tower

Wohler's
Coefficient

$$LTE\ \ potential = \ \ 1 - D_{ratio} = 1 - \left(\frac{DEL_{\max}}{DEL_{direct}} \right)^{m}$$

(3)

Worst Case Scenario -
Maximum
Uni-directional
Damage Equivalent Load

Uni-directional Damage and Wind Rose Probability

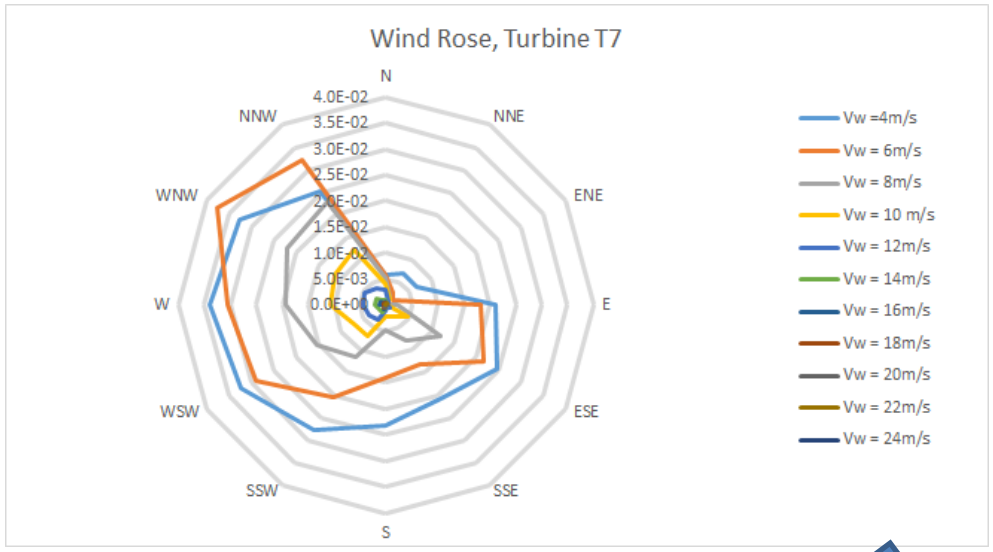


Figure 13 – Wind rose 7

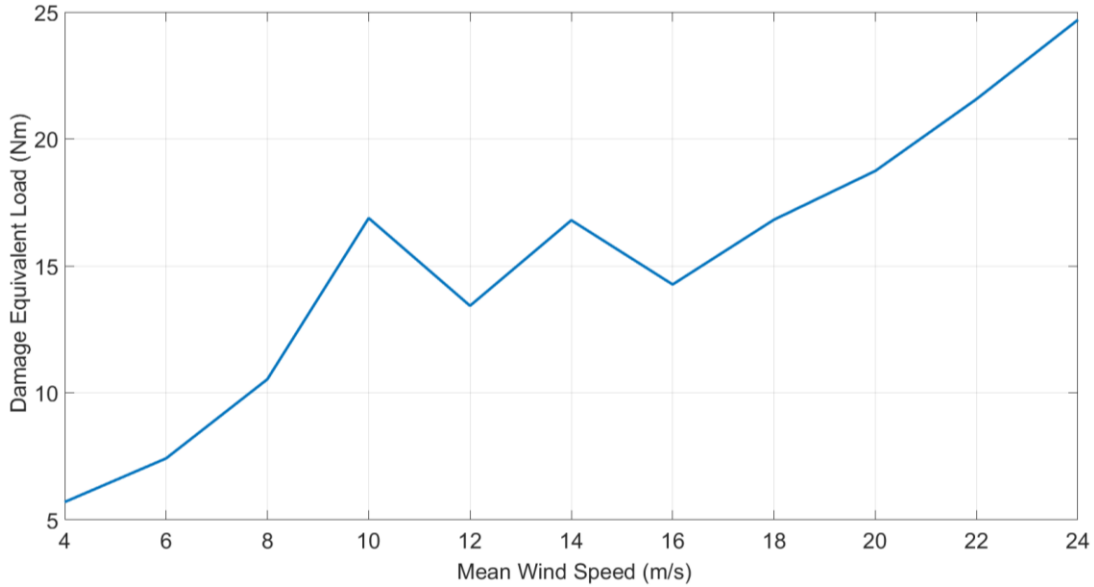


Figure 14 – Unidirectional Damage Equivalent Load

$$D_{Tot}(\theta_{fixed}) = \int_{v} p(v)\, D_{v}(\theta_{fixed})\, dv \qquad (4)$$

Weibull Distribution

Damage Equivalent Load Damage Ratio

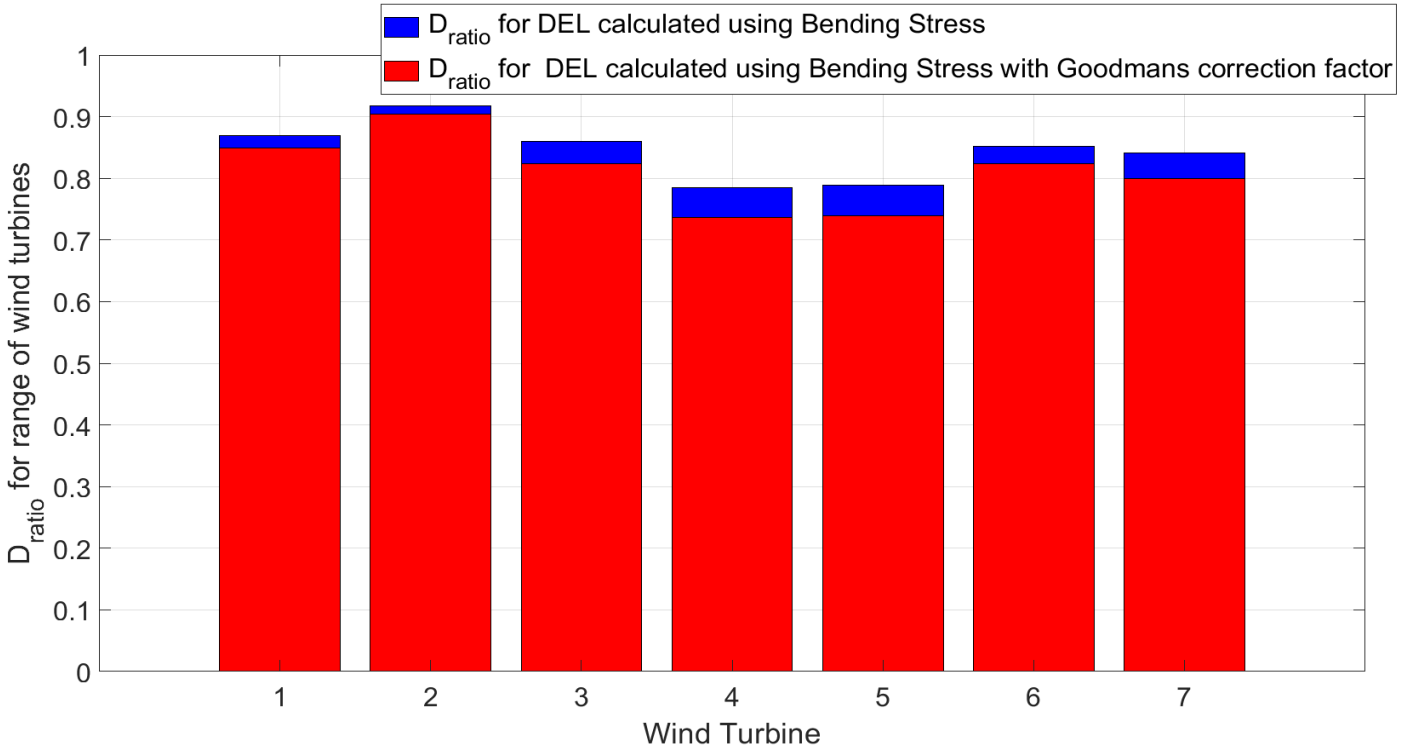


Figure 14– Damage equivalent load ratio with and without Goodman's correction

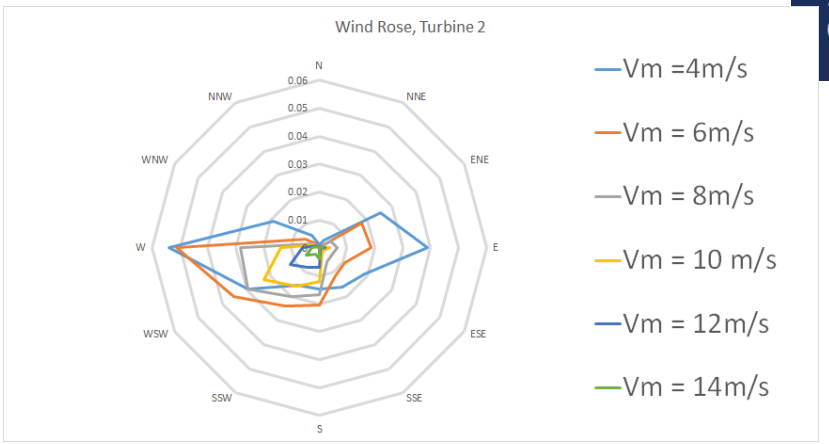


Figure 15– Wind Rose 2

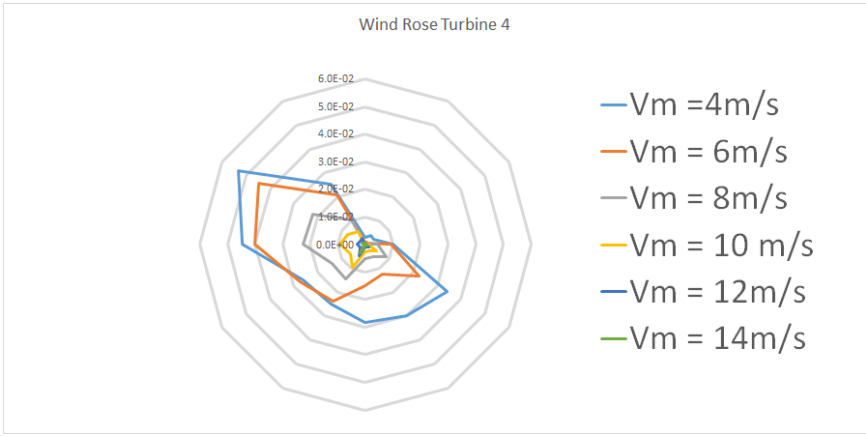


Figure 16– Wind Rose 4

Lifetime Extension Potential and Validation

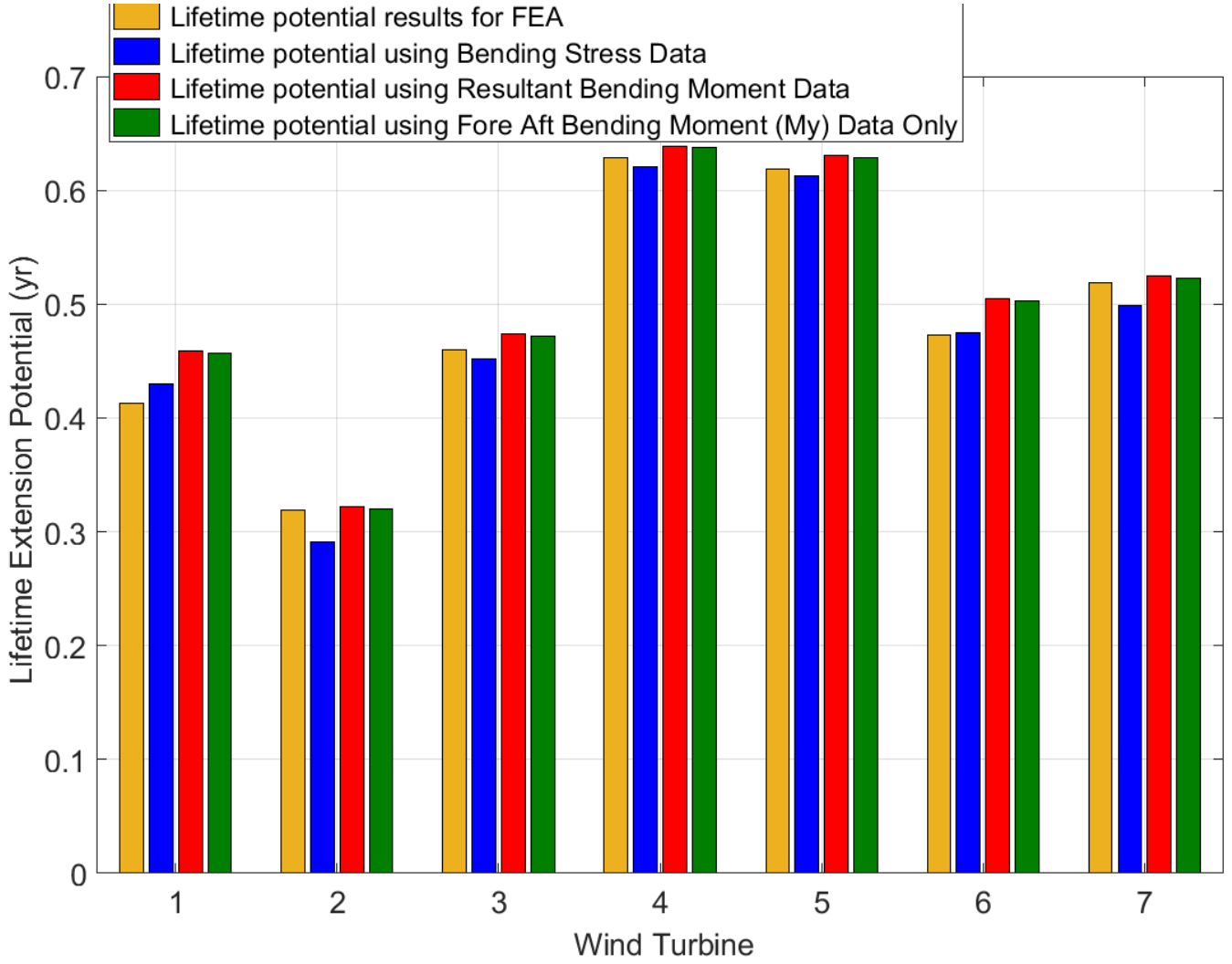


Figure 17– Lifetime Extension For Range of wind turbines

Lifetime Extension Potential for life of wind turbine

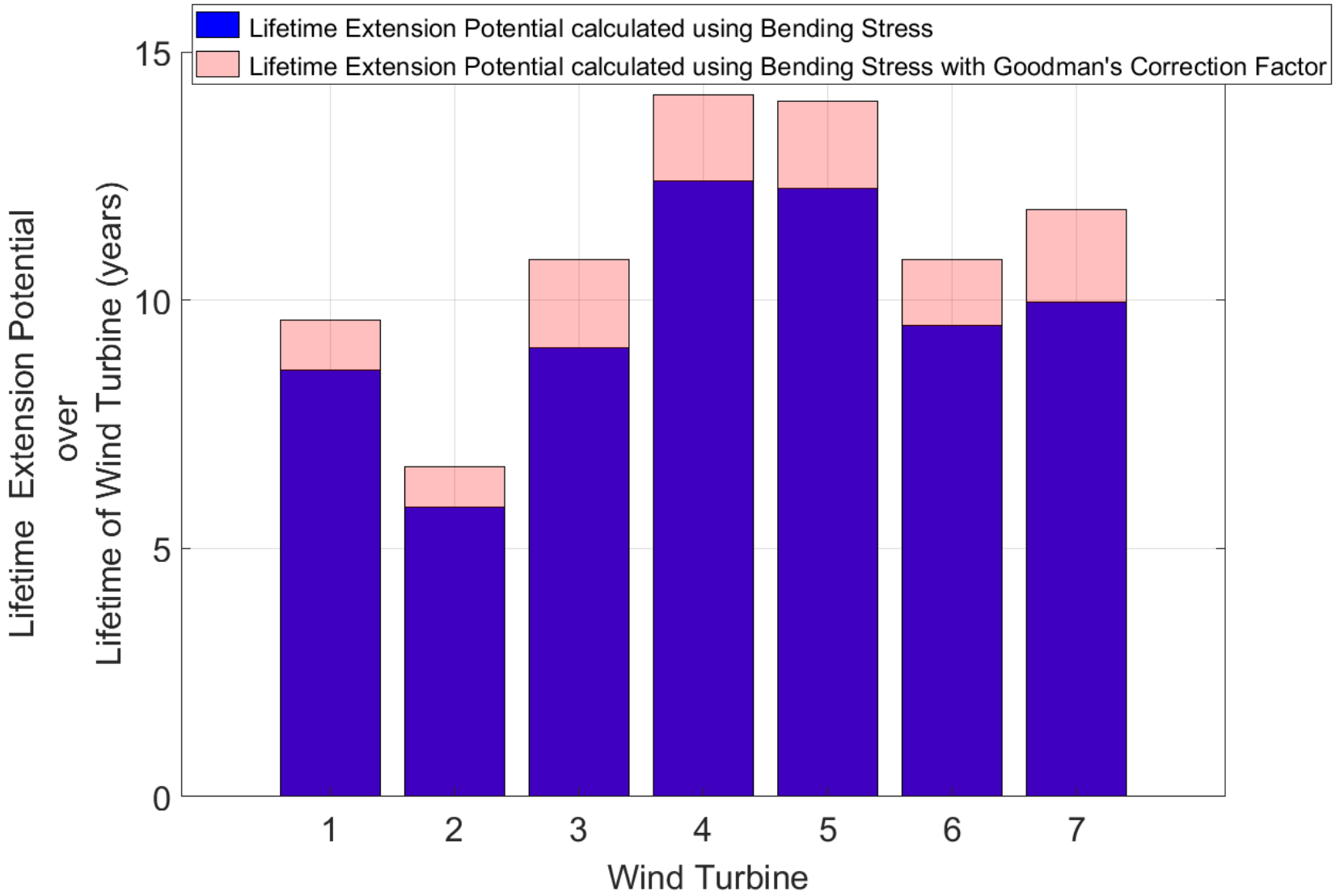


Figure 18– Lifetime Extension Potential For life of Wind Turbine

Conclusion and Next Steps

- Successful tuning of EKF for below rated case
- Development of closed form solution to identify tower fatigue life due to wind directionality
- Lifetime extension potential assessment using closed form solution validated closed finite element modelling results.

Wind & Marine Energy Systems CDT

University of Strathclyde Glasgow

Thank you for the attention, any questions?

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