Effect of wind flow direction on the loads at wind farm

Romans Kazacoks
Lindsey Amos
Prof William Leithead

Objectives:

- Investigate the effect of wind flow direction on the wind turbine loads (fatigue) within a wind farm.
- Two layouts are considered as depicted in Figure 1.
- Wind flow direction ($\in [0:10:90]$) as shown in Figure 2

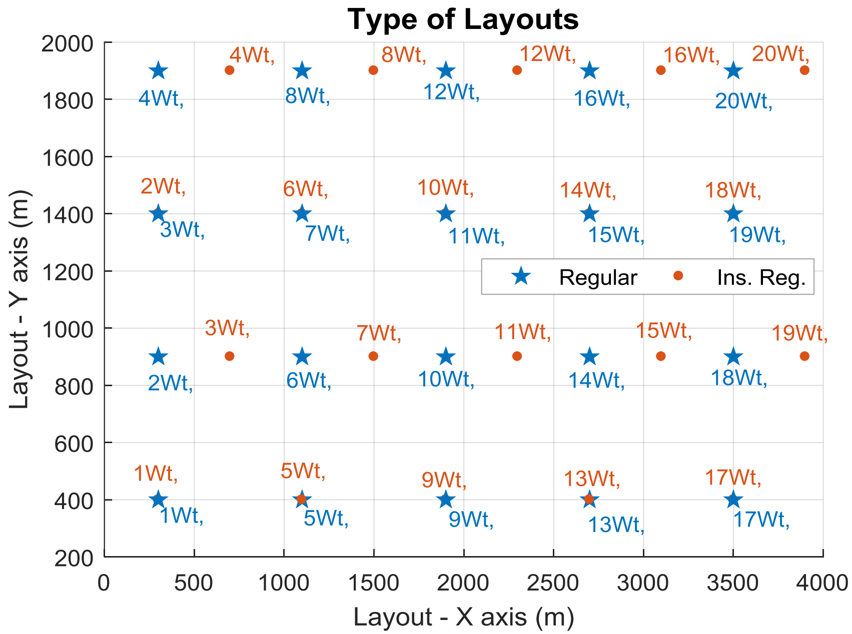


Figure 1: Two layouts of this study (Regular- blue star, Installed regular - red dot).

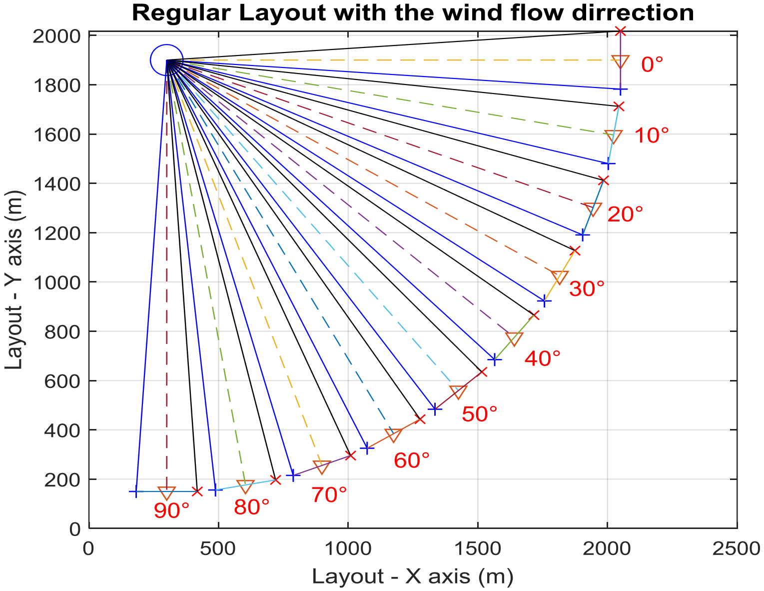


Figure 2: Wind low direction.

Strathfarm simulation tool:

StrathFarm is the University of Strathclyde's wind farm modelling tool:

- Models wakes and wake interactions.
- Models the turbines in sufficient detail that tower, blade and drive train loads are sufficiently accurate to estimate the impact of turbine and farm controllers on loads.
- Includes commercial standard turbine controllers.
- Includes a wind farm controller.
- Provides very fast simulation of large wind farms; run in real time with 100 turbines.
- Full flexibility of choice of farm layout, choice of turbines & controllers and wind conditions, direction, mean wind speed and turbulence intensity.

Validation of StrathFarm:

Comparison between 5MW Supergen model in StrathFarm (Red line) and 5MW Supergen model in DNV-GL Bladed (Black line) .

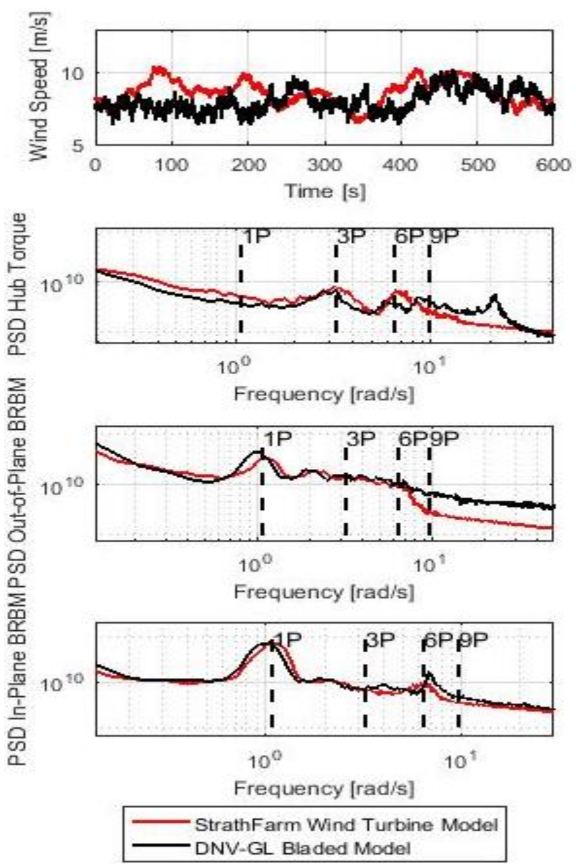


Figure 3: corresponds to a mean wind speed of 8 m/s

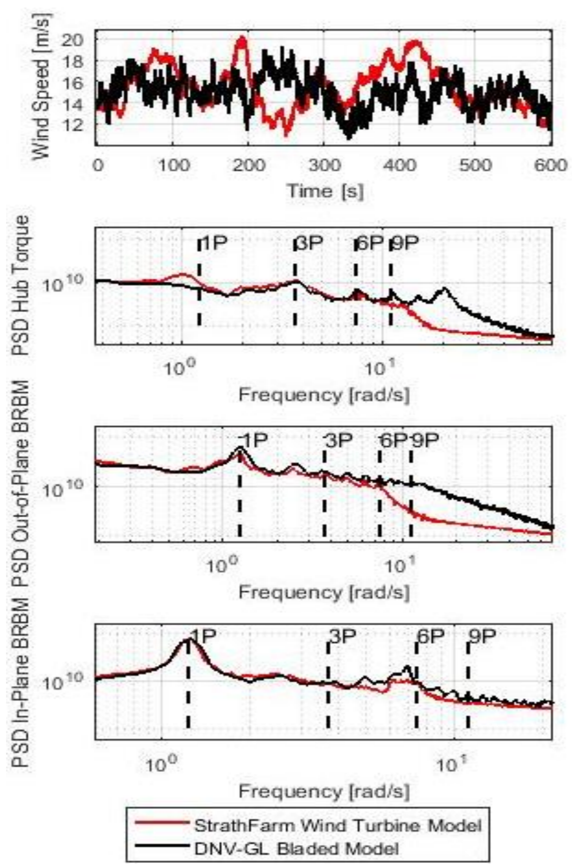


Figure 4: corresponds to a mean wind speed of 15 m/s

wind field time series

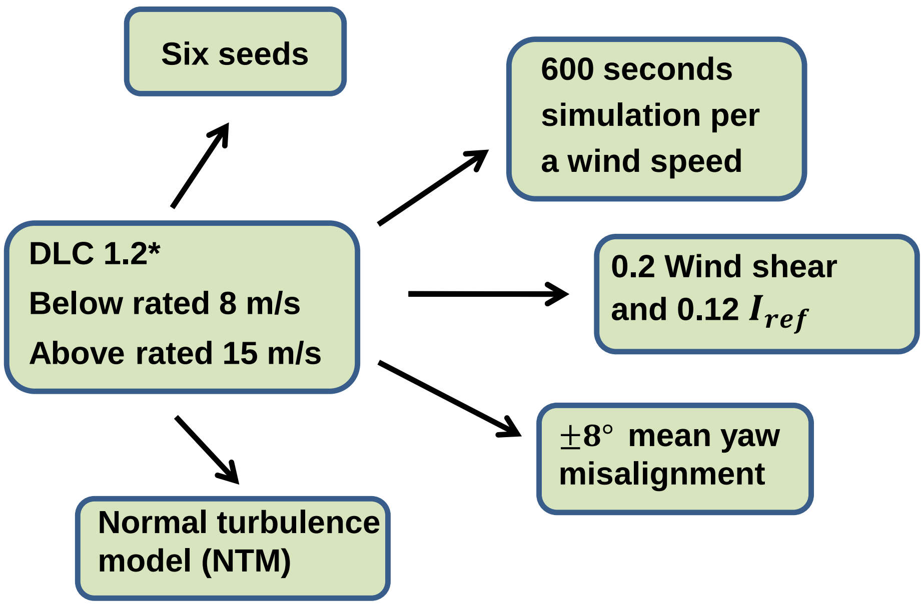
PSD of output hub torque

PSD of out-of-plane bending moment

PSD of in-plane bending moment

* PSD – Power spectral density

Procedure for estimation of fatigue loads:



- **DLC** 1.2: design load case – wind turbine is in power production range and connected to the electrical load at normal turbulence model (**NTM)**.
- This study uses **20%** power of curtailment for all machines within the wind farm

- The damage equivalent loads (DELs) represent the fatigue loads in this study

$$L_{DEL} = \left(\frac{\sum_{ip} \left(\sum_i^k n_i \, L_i^m \right)}{t_{sim} \, f} \right)^{\frac{1}{m}}$$

Where, $\boldsymbol{n_i}$ is number of cycles, $\boldsymbol{L_i}$ is load range at bin, $\boldsymbol{m}$ is Wöhler coefficient, $\boldsymbol{t_{sim}}$ is simulation time and f is the reference frequency

- Wöhler coefficient **4 – steel**
- Wöhler coefficient **10 – composite**

Results for regular layout:

Each figure includes four different conditions as shown below:

- Below rated wind speed (8 m/s) with turbulence (0.12 Iref.) and no curtailment.
- Below rated wind speed (8 m/s) with turbulence (0.12 Iref.) and 0.2 curtailment.
- Above rated wind speed (15m/s) with turbulence (0.12 Iref.) and no curtailment.
- Above rated wind speed (15m/s) with turbulence (0.12 Iref.) and 0.2 curtailment.

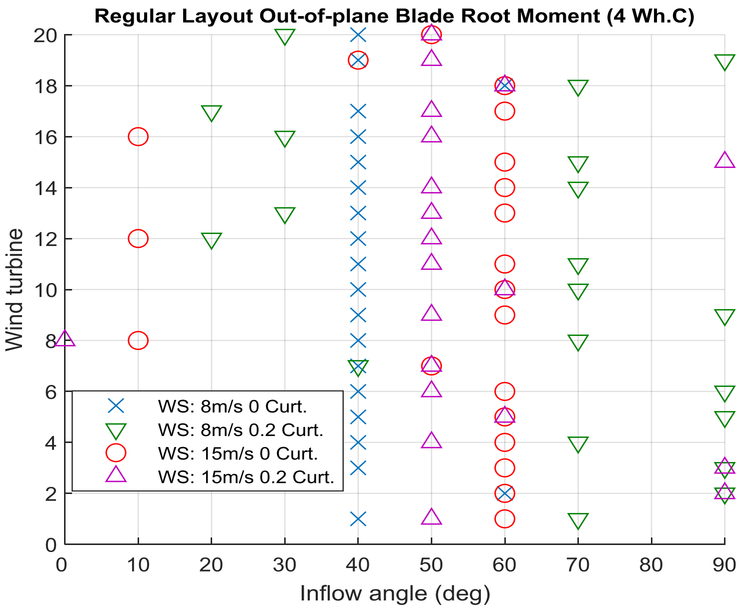


Figure 5: Out-of-plane blade root DELs at Wöhler coefficient 4 for the regular layout.

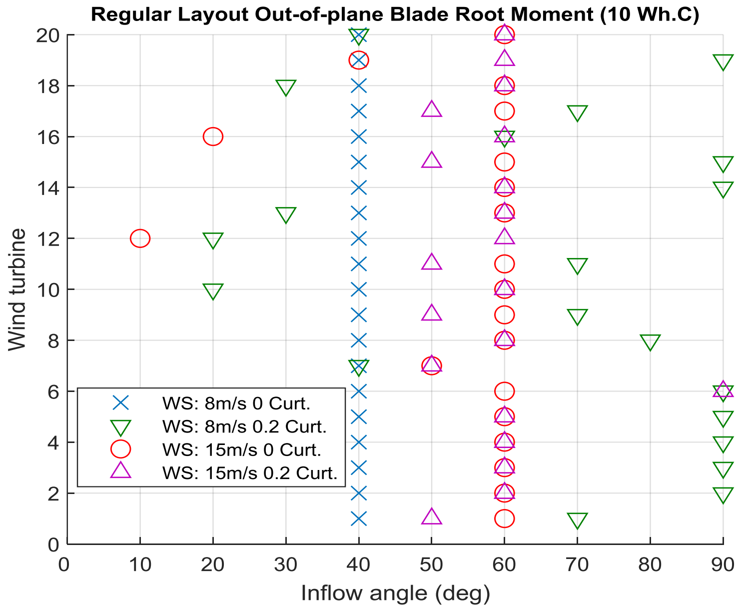


Figure 6: Out-of-plane blade root DELs at Wöhler coefficient 10 for the regular layout.

Results for installed regular layout:

Each figure includes four different conditions as shown below:

- Below rated wind speed (8 m/s) with turbulence (0.12 Iref.) and no curtailment.
- Below rated wind speed (8 m/s) with turbulence (0.12 Iref.) and 0.2 curtailment.
- Above rated wind speed (15m/s) with turbulence (0.12 Iref.) and no curtailment.
- Above rated wind speed (15m/s) with turbulence (0.12 Iref.) and 0.2 curtailment.

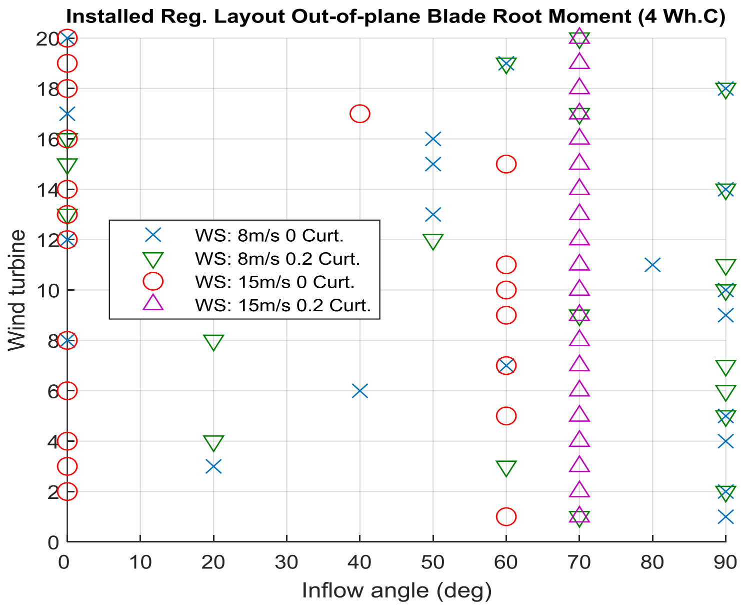


Figure 7: Out-of-plane blade root DELs at Wöhler coefficient 4 for the installed regular layout.

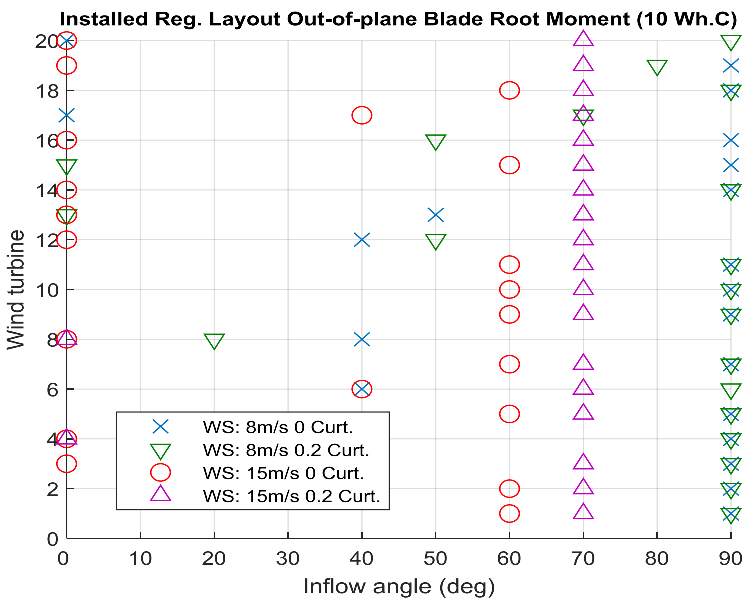


Figure 8: Out-of-plane blade root DELs at Wöhler coefficient 4 the installed regular layout.

Power efficiency:

The effect of wind flow direction on the power efficiency of a wind farm for the regular and installed regular layouts.

$$Eff_{power} = \frac{energy\ of\ whole\ wind\ farm}{(energy\ of\ one\ isolated\ turbine) * (number\ of\ Wts\ in\ farm)}$$

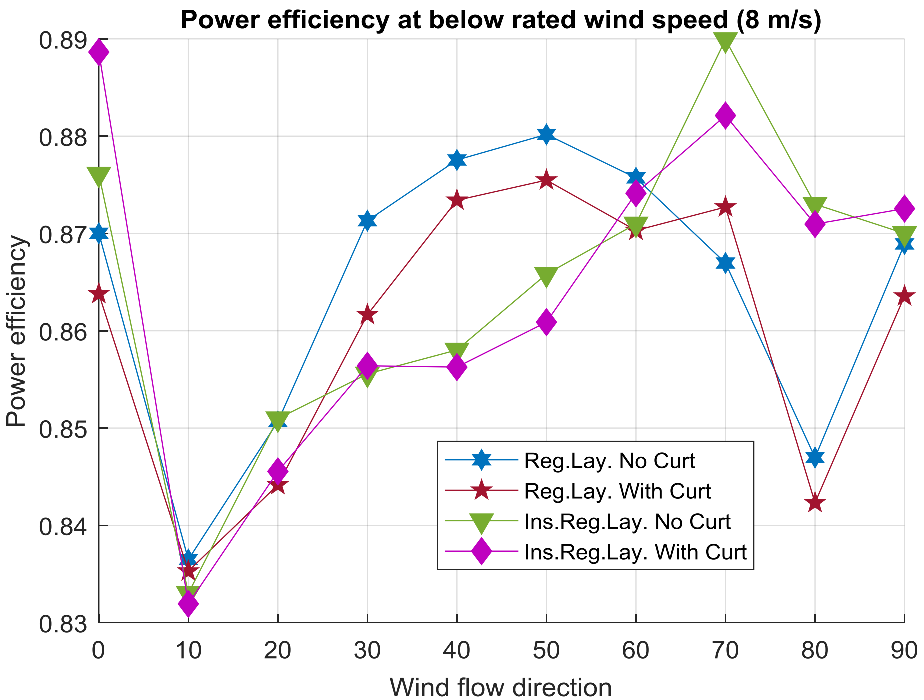


Figure 9: Changes power efficiency as a function different wind flow angle (0:10:90°) for the three layouts

Conclusion:

<u>Key findings:</u>

- Highest power efficiency and fatigue loads occur at same wind flow angles.
- Majority of the highest fatigue loads occur in the range 40 to 70 degrees.
- Power efficiency gets higher with larger spacing among the wind turbines in the layout.
- Uncertainty in results still high with 6 runs of 1250 seconds.

<u>Future work:</u>

- Longer simulation times required to reduce uncertainty
- Validation of results required, particularly by direct comparison to actual performance of a real wind farm.

University of
Strathclyde
Glasgow