Wind farm optimization using ZX TM nacelle-based LiDARs

Case study: Wind farm performance optimisation in India

Campaign details

Objective:	Optimise wind turbines using ZX TM Nacelle Mounted LiDARs
Wind turbine:	Siemens Gamesa G97 (2MW Rotor 97m)
Number of WTGs with LiDAR campaign:	9
Turbine commissioning year:	2015
Campaign outcome:	Average yaw misalignment (YM) detected for all turbines measured during the campaign was -6.5°, in total identifying potential gains of more than €28,000 annually across the analysed WTGs.

Campaign objectives

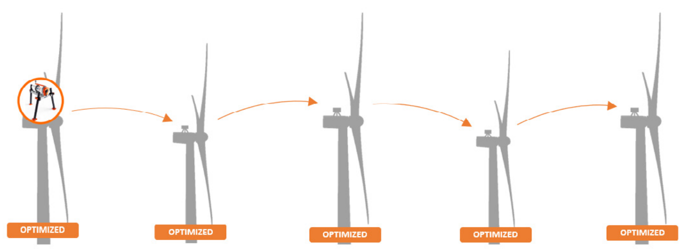
1) Ranking the performance of the WTG's from best to worst using the available data from wind farm
2) Yaw Misalignment (YM)
3) Turbulence Intensity (TI)
4) Quick Power Curve (PC) verification
5) Nacelle Transfer Function (NTF) verification

Performance ranking using SCADA data

A comprehensive analysis of data for the wind farm was conducted to assess the power performance of 45x Siemens Gamesa G97 and 1x Siemens Gamesa G114 turbines. The worst performing WTGs were identified and ranked based on power performance, taking into account downtime, status data, and effects from micro siting, which were then used to perform the LiDAR campaigns.

ZX TM LiDAR Measurement principle and set-up

The ZX TM nacelle-mounted LiDAR is temporarily mounted on top of the nacelle, together with a data collection and communication unit in the nacelle. The LiDAR measures the horizontal wind speed and direction at hub height in front of the turbine at several measurement ranges, between 10m to 550m. Nacelle-based LiDARs are a fast and cost-effective way to evaluate and optimise wind turbine performance.



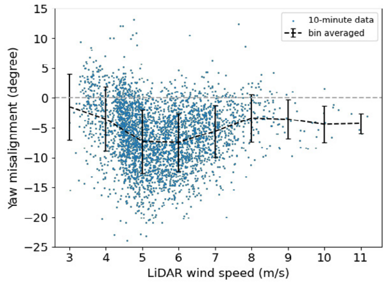
Yaw misalignment

Yaw misalignment is measured as the difference of the incoming wind direction relative to the nacelle direction. The average relative wind direction and wind speed (at hub height) are computed every 10 minutes for measurement ranges in front of the turbine. These measurements are validated or discarded based on standard or more advanced criteria, such as cut-in & rated wind speed, data quality, wind flow complexity, etc.

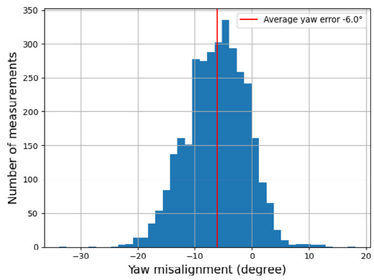
Results:

Average yaw misalignment detected for all turbines measured during the campaign was 6.5°, with one turbine exhibiting a 10° misalignment. Average AEP gain across measured turbines was 1.5% per turbine, and up to 3.3% for worst affected turbine. Average calculated savings of €3,150 per year per turbine, with up to €6,300 per year for worst affected turbine.
Below are the YM results from one WTG, showing an average YM of -6°.

ZXTM LiDAR Campaigns	Wind farm
Number of WTGs analysed	9
Average YM	-6.52°
Max average YM	-10.25°
Min average YM	-3.56°



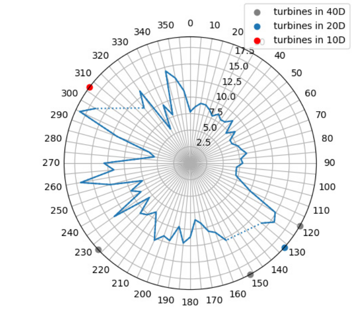
Yaw misalignment on wind speed ranges (with binned average and error bars representing standard deviation).



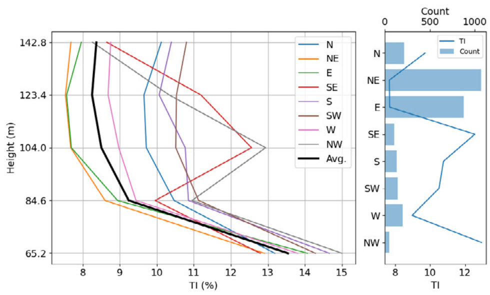
Yaw misalignment distribution with average

Turbulence Intensity 360 profile

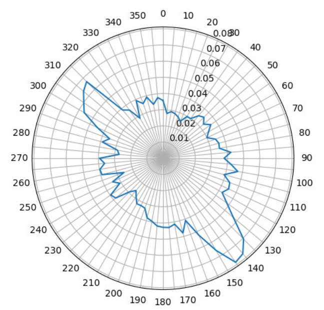
Turbulence intensity (TI) is a ratio of standard deviation of the incoming wind speed to the mean wind speed, representing the intensity of wind speed fluctuations. TI is correlated with the rugosity of the surrounding terrain and obstacles such as buildings and neighbouring turbines. TI is an important measurement when analysing wind turbine performance and behaviour. It is highly correlated with the power output and has significant impacts on the mechanical fatigue and loads of the wind turbine components. The ZXTM can uniquely measure TI at several heights above ground, allowing to understand the TI height profile.



TI 360 profile (binned average).



TI height profile across different directions.



Normalized Mean Fit Residual distribution (NMFR rose), another indicator of complexity of incoming wind flow.

Quick Power curve & Nacelle transfer function verification

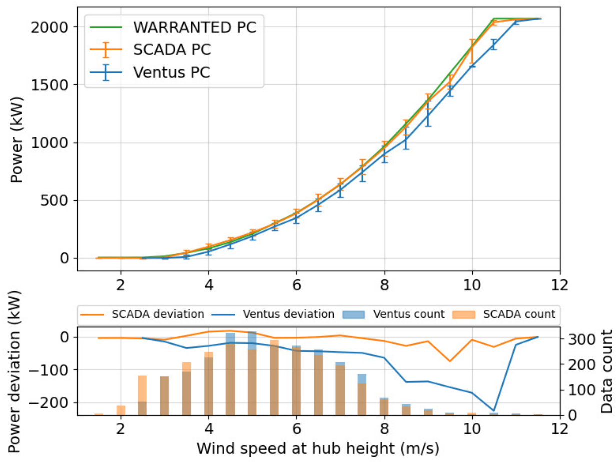
The power curve (PC) and nacelle transfer function (NTF) were analysed using both the SCADA wind speeds and LiDAR wind speeds to identify areas of underperformance, as well as how effective the wind turbine anemometer is at measuring wind speed. The data was filtered to remove WTG downtime as well as sectors with neighbouring turbines.
Below are overall results and recommendations for one WTG.

Results:

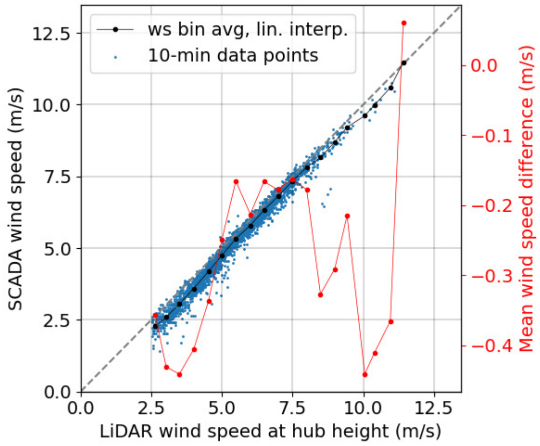
- Average yaw misalignment (YM) of 6°
- Variation of YM by wind speed, between -1° and -7°
- SCADA PC overestimates the actual Ventus PC measured by the ZX TM
- Ventus PC underproduction found at wind speeds 8.5-10.5 m/s
- NTF shows undermeasurement of wind speeds by SCADA system, on average by -0.27 m/s and up to -0.45 m/s in low wind speed region

Recommendation:

- Perform yaw offset correction and investigate variation in YM across wind speed
- Investigate the nacelle transfer function (NTF)
- the differences observed at the SCADA and Ventus PCs are caused by the wind speed measurement (i.e. anemometer and/or NTF)
- delayed WTG cut-in due to SCADA underestimation of the actual wind speed
- Investigate the power curve underperformance and perform power curve analysis post corrections



Power curve performance from SCADA data, Ventus / ZX TM data, with error bars representing interquartile ranges (0.15, 0.85), relative to warranted power curve. Power deviation is average power minus warranted power.



Nacelle transfer function (SCADA vs ZX TM LIDAR wind speed) shows undermeasurement of SCADA wind speeds.