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Inflow angles in complex terrain: is it possible to accurately predict them in a wind farm site?

Dr. C. Meissner, WindSim AS, Norway
A. Fontaine and V. Vandale, Pacific Hydro, Australia

Abstract

Wind turbines are certified for inflow angles usually within ±8° as required by the IEC 61400-1 standard. It is critical that turbine locations comply with this requirement to ensure that the turbines will be affected by reasonable wear and tear during their expected lifetime (20-25 years).

Inflow angles can be measured on-site with sonic anemometers, but these on-site measurements are limited to the mast locations on which the anemometers are installed, and significant difference may exist between the inflow angle at the mast location(s) and the inflow angle at the turbine locations. Current computational fluid dynamics (CFD) models such as WindSim allow predicting the inflow angles at chosen turbine locations within a wind farm site, based on wind data and terrain information.

The objective of this study was to determine the accuracy of the inflow angle predictions by comparing the inflow angle measurements carried out on the mast with a sonic anemometer at a mast location with the inflow angle predictions at this mast obtained with the WindSim CFD model.

Good level of predictions seem to be achievable in complex terrains with no dense vegetation, but predictions become unreliable when dense vegetation such as forest are found on site or nearby, as the effect of such vegetation on the wind flow is harder to model. Thermal effects might need to be considered in this case.

Further studies are recommended to better estimate the reliability of WindSim inflow angle predictions at wind farm locations.

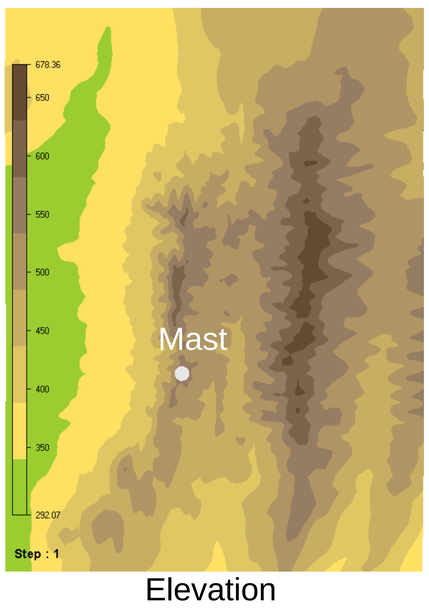
Methods

Compare on-site inflow angle measurements with WindSim inflow angle predictions at the mast location at two different wind farm sites, using 30° directional sectors.

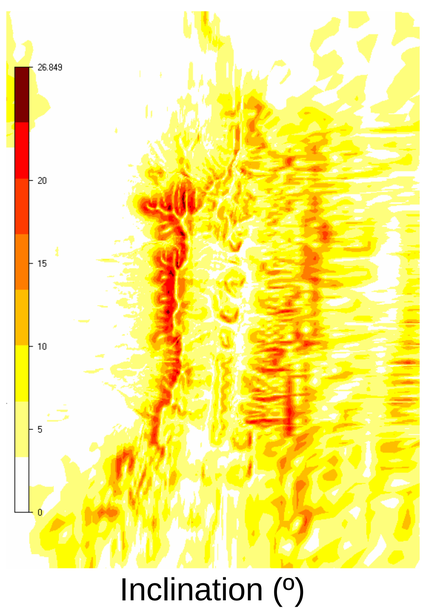
• on-site measurements performed with an ultrasonic anemometer installed at the top of the mast

• WindSim CFD inflow angle predictions based on terrain information, height contours, roughness data

• comparison of measured and predicted inflow angles at each mast location based on 30° directional sectors



Elevation



Inclination (º)


Ultrasonic anemometer

Site 1

• 70m mast installed in complex terrain

• top-mounted WindMaster Ultrasonic anemometer installed at 68.5m above ground level

• 16 months of measured inflow angle data available (Sept 2009 – Dec 2010)

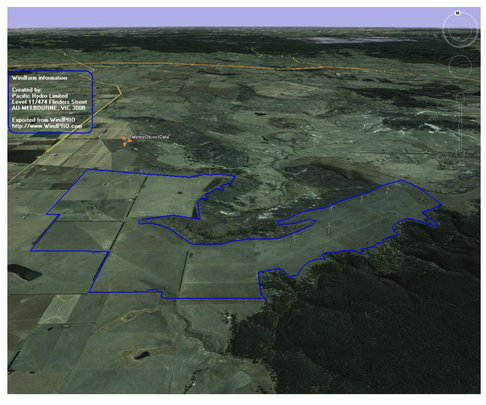
Site 2

• 80m mast installed to the north of the wind farm site

• forest to the SE of the site

• 40° side-mounted WindMaster ultrasonic anemometer installed at 78.3m above ground level

• 8 months of measured inflow angle data available (May to Dec 2010)



Definitions

Inflow angle: angle off the horizontal plane at which the mean wind flow comes into the rotor. High inflow angles are generally found in complex terrains with steep slopes.

Computational Fluid Dynamics (CFD): A field of study concerned with the use of high-speed digital computers to numerically solve the complete nonlinear partial differential equations governing viscous fluid flows.

WindSim: CFD-based wind farm software that solves non-linear transport equations for mass, momentum and temperature to predict the site wind field conditions, wind resource and the wind farm energy yield.

Objectives

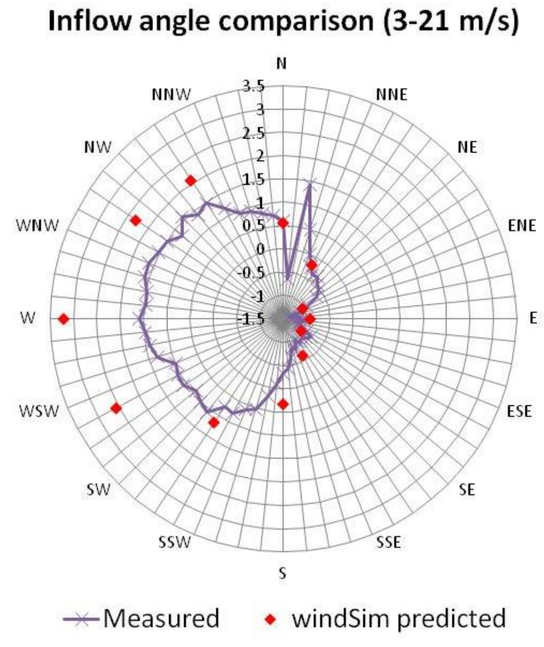
Determine the accuracy of inflow angle predictions using the WindSim CFD model

Predict the inflow angle at the turbine locations if the prediction accuracy is acceptable.

Verify the turbine suitability at a proposed wind farm site with regards to the inflow angle

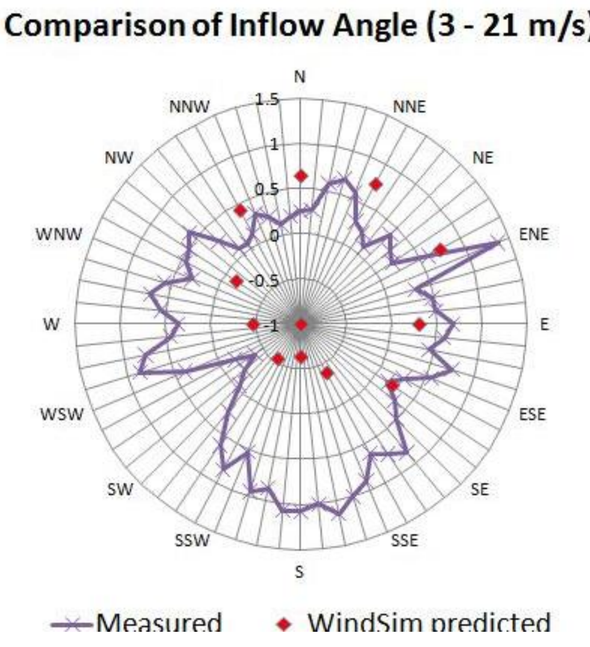
Results

Site 1



• 95% inflow angle data availability
• Inflow angle predictions at 71m
• Good predictions for winds coming from the N, E and S
• Overprediction of the inflow angle for westerly winds

Site 2



• 97% inflow angle data availability
• Inflow angle predictions at 77m
•Good predictions for winds coming from the N and E
• Underprediction of the inflow angle for westerly and southerly winds

Conclusions

• On-site inflow angle measurements don't seem to be reliable for low and high wind speeds: the measured values become erratic.

• Difficulty to predict wind flow and site conditions when there is dense vegetation (e.g. forest) on- or near the site. This might be due to non-neutral atmospheric conditions . WindSim was run with neutral atmospheric conditions.

• A year of on-site measurements is recommended to avoid seasonal bias in measurements. Further analysis should be carried out at the site 2 when more measured data will be available.

• Relatively good predictions are obtained in complex terrain when there is no dense vegetation around the wind farm.

• Additional analysis should be carried out to conclude on the reliability and accuracy of the inflow angle predictions obtained with the WindSim model when forest and/or non-neutral atmospheric conditions are found on the site.