Effects of turbulence, wind shear, wind veer, and atmospheric stability on power performance: a case study in Brazil.

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1. Introduction

The power curve is estimated using the average wind speed at hub height as suggested by International Electrotechnical Commission (IEC) [1]. However, other meteorological parameters such as wind shear, turbulence intensity, wind veer and atmospheric stability can also affect the power curve measurement [2–5]. Recently, this topic has been discussed in the wind industry in order to reduce the uncertainties on the certified power curve [6]. New power curve models that include turbulence and wind shear have been proposed [4,7,8]. Although preview studies have shown the influence of turbulence and wind shear on wind turbines, the results are specific to each local condition, and new experiments are necessary at different sites.

2. Approach

The present work aims to investigate the influence of turbulence intensity, wind shear, wind veer and atmospheric stability on turbines power performance. The Pedra do Sal experiment, located on the northeast coast of Brazi,l is used as a case study.

3. Main body of abstract

3.1 Site Description

The Pedra do Sal experiment is located on a flat coastal area in the northeast of Brazil where local winds are influenced by sea breeze and trade winds [9,10]. The surface is covered by sand and open shrub, but the fetch is typically marine as 92.7% of wind blows from the ocean, which has a dynamic roughness surface [11,12]. See Figure 01.

Figure 01 – Pedra do Sal Wind Farm with 20 wind turbines and the 100m met mast.

The experiment consists of one 100 m meteorological tower with five instrumented levels, and one Lidar Wind Profiler, model Windcube8, with a range from 40 m to 500 m. (Figure 02). The measurements were carried inside the 18MW Pedra do Sal Wind Farm, where 20 turbines of 0.9MW are aligned with local shoreline. Each turbine has 55 m of hub height and a rotor diameter (D) of 44 m [13].

The turbines close to the tower presented different power curve setup along the campaign and could not be considered in this study [14]. Thus, wind turbines W06, W04 and W03 were selected in this study, which are located at 306m (7D), 583m (13.3D) and 733m (16.7D) away from the tower respectively (Figure 02).

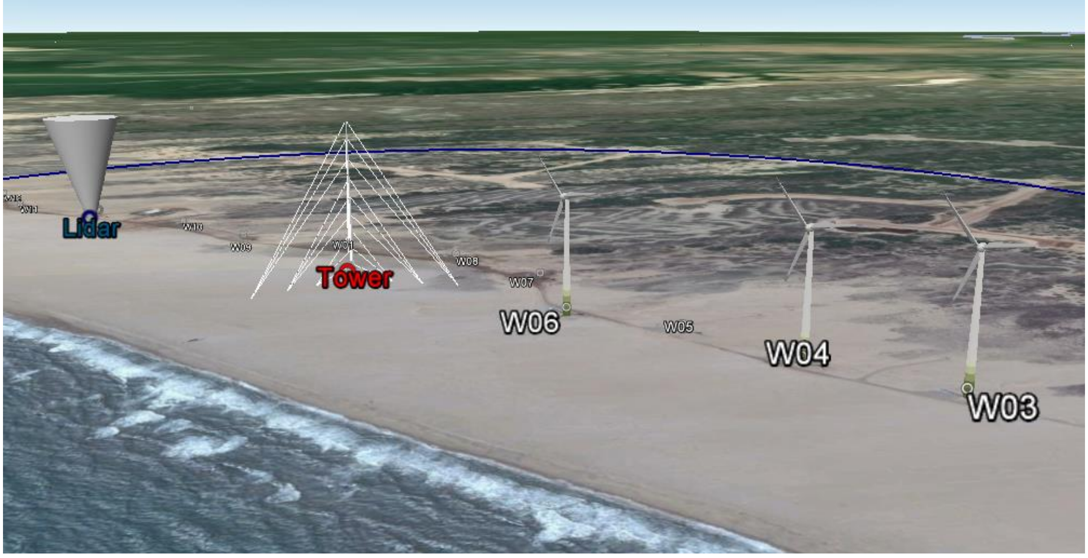


Figure 02 – Layout of 100m Met mast, Lidar Wind Profiler and Wind Turbines W03, W04 and W06.

3.2 Methodology

Complete dataset of all meteorological parameters and turbines power output are selected from November 2013 to May 2014, which totalized seven months of 10-min average data. This study uses only part of those measurements to calculate: turbulence intensity (TI), wind shear (α), wind veer (θ) and atmospheric stability (L). The cup anemometer at 60m is used to calculate turbulence intensity, which is the ratio of standard deviation and average wind speed. The wind shear is based on shear coefficient from power law [1], and uses cup anemometers at 40m and 80m heights as the rotor disk is within 77m and 33m. The wind veer is calculated by wind direction difference from 40m to 80m using wind lidar data, which have better data available than wind vanes on the tower. The atmospheric stability is based on Obukhov length (L), that considers turbulent fluxes in the surface layer [15]. The sonic 3D at 100m is used to measure the high frequency wind speed and sonic temperature at 20Hz. The sonic data are processed using EddyPro software, which calculates friction velocity and heat flux based on eddy covariance method [16]. The atmospheric stability is normalized at z=10m (z/L). Each parameter was divided into three parts according to their distribution, where the lower limit refers to quantile 25% and the upper limit refers to quantile 75%. See Table 01.

Parameter	Lower Limit	Interquartile	Upper Limit
Quantile(q)	q < 25%	25% < q < 75%	q > 75%
Turbulence Intensity (TI)	**TI01** < 5%	5% < **TI02** < 7%	**TI03** > 7%
Wind Shear (α)	**α01** < 0.011	0.011 < **α02** < 0.048	**α03** > 0.048
Wind Veer (θ)	**θ01** < 0.4°	0 < **θ02** < 1.5°	**θ03** > 1.5°
Atmospheric Stability (zL)	**zL01** < -0.09	-0.09 < **zL02** < 0	**zL03** > 0

Table 01 – Limits of each meteorological parameter refers to quantile 25% and 75%.

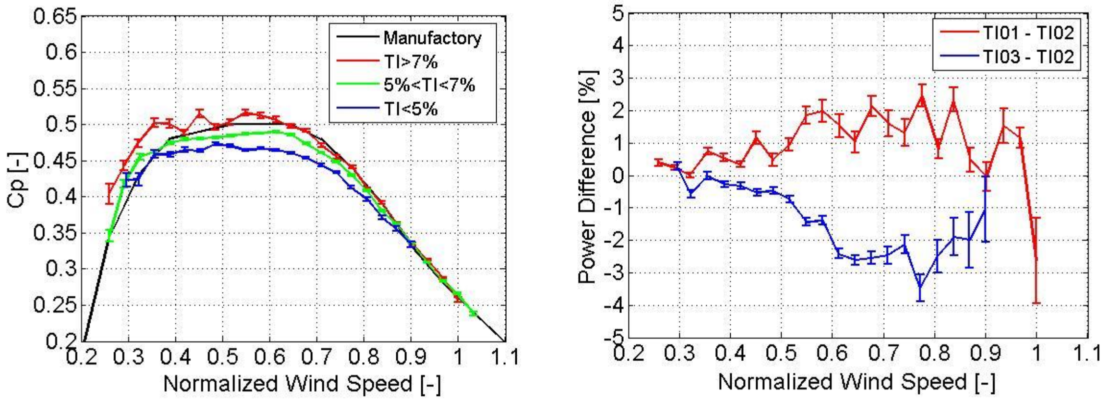
The wind power output data needs to be filtered in order to remove data related to maintenance and wakes effects. Four filters are applied on power output data. The first filter discards data affected by wakes, within the wind sector from 100° to 345°. The second filter is used, when wind speed at 55m is higher than 2.5m/s and power output is lower than 1kW. The third filter eliminates bad data related to turbine's shut down, which takes some minutes to stop completely the rotation of turbine engine. Then, this filter discards 2-hours before and 2-hours after the period that turbine is completely off. The last filter, excludes graphically bad data from nacelle wind speed vs. power output chart, because the data are significant distant from power curve. This situation is not often, but it is probably related to measurements or telecommunication of wind farm SCADA system, as the problem usually occurs to all wind turbines at same time.

The power coefficient (Cp) is calculated according to IEC [1] and two corrections are applied on wind speed. First, wind speed measured at 60m is extrapolated to hub height at 55m using power law with an averaged shear coefficient of 0.055. Second, it is applied to normalization of wind speed with air density at standard value of 1.225 kg.m^{-3}, which allows to compare with standard manufactory curve.

3.3 Results

The experiment totalized 30,528 data point of 10-min average in 7 months, however 12,780 values were removed by filters (48%). Power output of three wind turbines (W03, W04 and W06) were averaged and compared with each meteorological parameter used in this study. The power difference are based on rated output power of wind turbine (0.9MW).

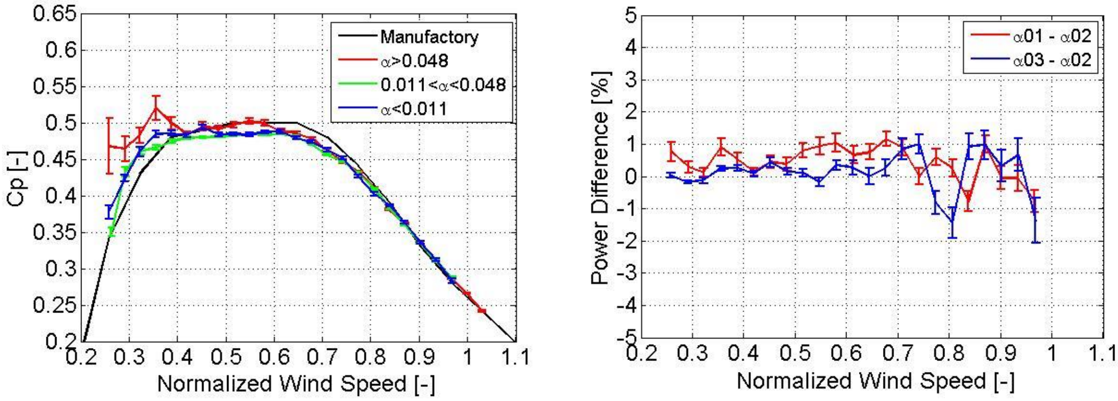
Figure 03a shows power coefficient (Cp) at different turbulence intensity, and it is observed that high turbulence intensity (TI>7%) can increase Cp up to 0.52, while low turbulence intensity (TI<5%) can reduce it to 0.46. Results show that turbulence intensity influences significantly the performance of wind turbines and can be +2.4% of rated output power at TI>7%, or -3.5% at TI<5%, when compare with TI02, see Figure 03b.



(a) (b)

Figure 03 – Power Coefficient (a) and Power output difference (b) at different turbulence intensity conditions.

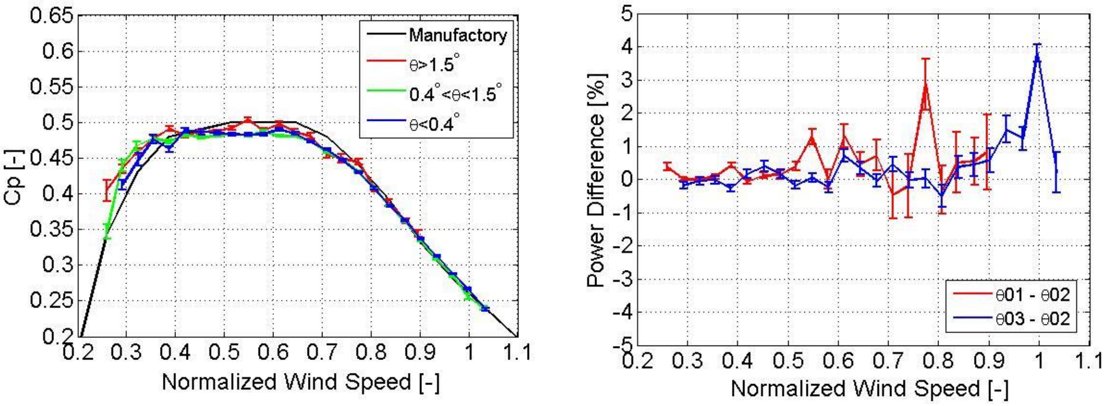
Figure 04a and 4b show Cp and power output difference at different wind shear condition respectively. It is observed that wind shear does not influence significantly the power output with deviation lower than 1.3% of rated output power.



(a) (b)

Figure 04 – Power Coefficient (a) and Power output difference (b) at different wind shear conditions.

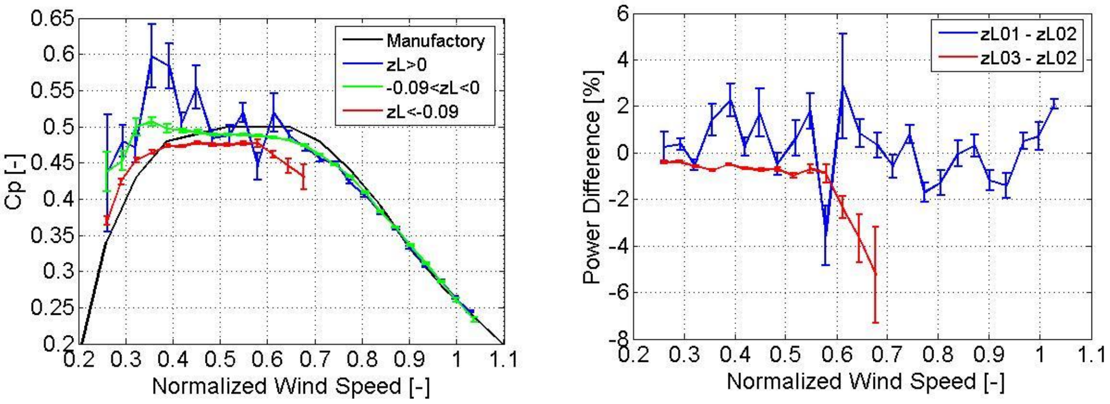
Figure 05a and 5b show Cp and power output difference at different wind veer condition respectively. It is also observed that wind veer does not influence significantly the power output with deviation lower than 1.5% of rated output power, except two bins that show deviation up to +3.8%.



(a) (b)

Figure 05 – Power Coefficient (a) and Power output difference (b) at different wind veer conditions.

Figure 06a and 6b show Cp and power output difference at different atmospheric stability respectively. At unstable condition (zL03), the power output is always lower than zL02, and has a significant difference (-5.2%) at strong winds. At stable condition (zL01), the rated output power difference can vary by ±2%, and it is usually higher than zL02.



(a) (b)

Figure 06 – Power Coefficient (a) and Power output difference (b) at different atmospheric stability conditions.

4. Conclusion

Turbulence intensity, wind shear, wind veer and atmospheric stability were used to investigate the effects on power performance of three wind turbines in the northeast coast of Brazil. Turbulence intensity is the parameter that most influence the turbine power performance in this site. Other parameters did not show significant difference on turbine power performance as wind shear, wind veer and atmospheric stability have low variability caused by sea breeze and trade winds.

5. Learning objectives

- Understand the effects of turbulence, wind shear and atmospheric stability on power performance in order to reduce uncertainties in resource assessment, power curve measurement, wind forecasting and wake losses.
- Understand the coastal meteorological conditions in Brazil caused by sea breeze and trade winds.

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