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Multi-scale correlations between synchronized power and wind measurements: a way to characterize turbulent effect in a scale invariant way.

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Abstract

From earlier studies, we learn that wind speed and the aggregate power output are intermittent and multifractal over a wide range of scales [1]. Here, we consider the relation between velocity and power output with synchronous wind turbine database. The database is a wind turbine with gear box technology situated in Denmark with a 37.6 Hz sampling frequency. The wind-power relationship, at smaller scales, is of random nature. It is important to be able to model such relation. Here, we use several methods to grasp such relation and to characterize it in a multi-scale way: Fourier analysis, co-spectral analysis and Empirical mode decomposition. We employ in particular methods for quantify scaling properties in a multi-scale way and to look for multi-scale correlations

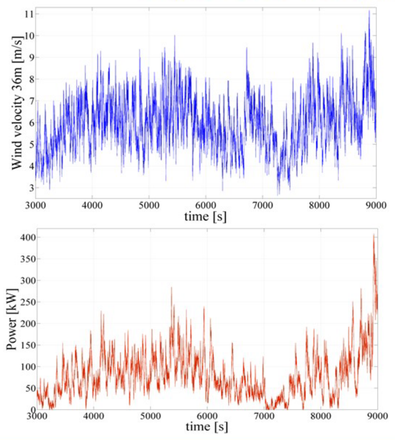
Objectives

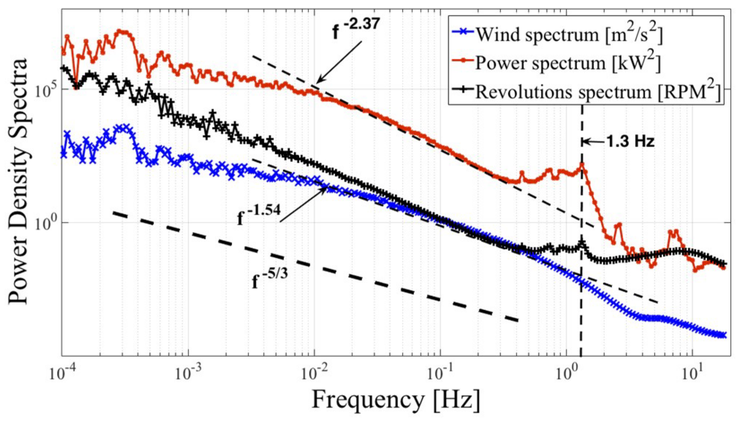
We aim to put a light into local correlations between the wind input and power output of a wind turbine. The local correlations will put some light on complex dynamics in a multi-scale way presented in generating wind power.

Methods

Spectral Analysis

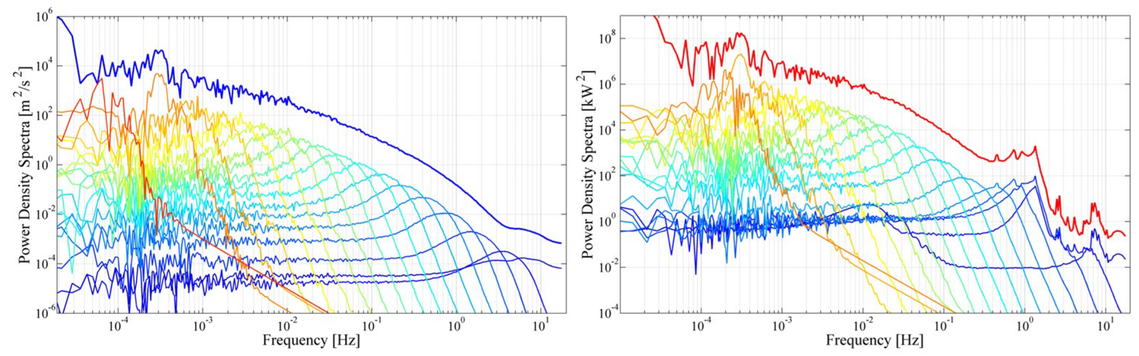
For an homogeneous and isotropic turbulence, Kolmogorov and Obukhov (1941) assumed that the power spectral density of the velocity will be a power law of slope -5/3 in a certain frequencies range. This power law behavior in a turbulent flow represents the multi-scale and invariant kinetic energy transfer.





Empirical Mode Decomposition

The EMD method [2] decomposes nonlinear, non-stationary time series into a sum of different time series called mode, each one being narrow-banded and having a characteristic frequency [3]. The sum of every mode recreates the original time series. It is very suitable for non-linear and non-stationary time series analysis. The Hilbert-based methodology is very local in both physical and spectral space.



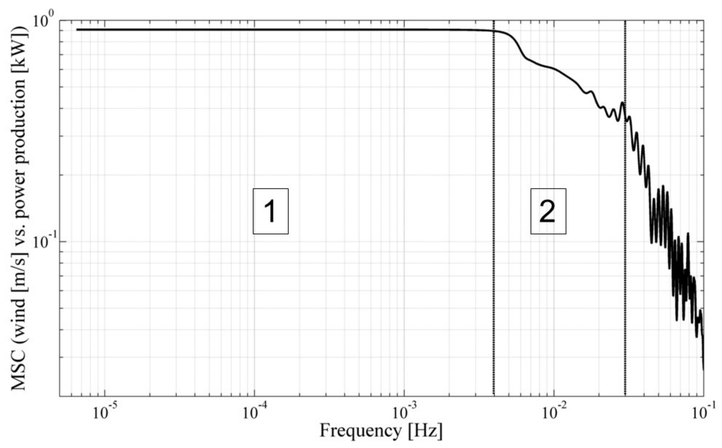
MSC & TDIC Correlation

Magnitude square coherence (MSC).

The MSC spectrum returns real values between 0 and 1 to indicate how well two time series *x(t)* and *y(t)* match one with another. This function is defined as :

$$\gamma_{xy}^2(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)} \leq 1 \quad (1)$$

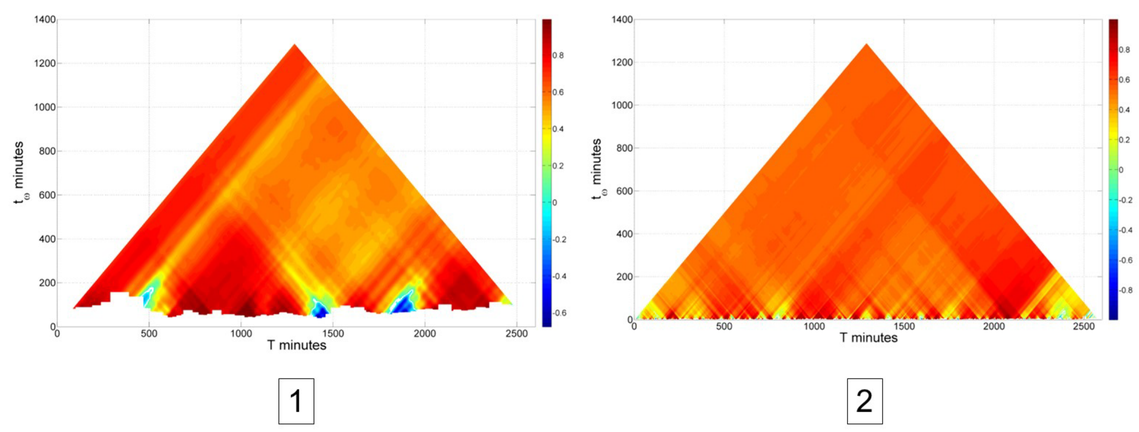
In which P_{xy} is the cross-power spectral density of *x(t)* and *y(t)* and, P_{xx} and P_{yy} the related power spectral densities. It satisfies for all *f*, $0 \leq \gamma^2 \leq 1$.



Time-dependent intrinsic correlation (TDIC).

Here we use this recent method [4] to estimate cross correlations between nonlinear and non-stationary data time series. We estimate the cross correlation coefficient in a multi-scale framework, by using a sliding window based on the local characteristic scale given by the data itself. The color bar indicates positively correlated (+1) in red meanwhile a negatively correlated (-1) is shown in blue.

The efficiency of this approach has been shown in [4] and applied recently in Huang and Schmitt [5].



Conclusions

Spectrum Analysis : We find in the wind spectrum a slope close to -5/3 for a frequency range of $0.01 \leq f \leq 0.5$. This power law is not found for the production spectrum. In recent works, we have observed that the Direct Drive wind turbines presented the 5/3 power law on both spectra [6]. We can make the hypothesis that the -2.37 power law could be caused by the gear box. The peak frequency presented in the spectra (1.3 Hz) could correspond to the rotor frequency.
Correlation Analysis : The MSC shows a high correlation at a value around 0.9 in the lowest frequencies (time scale between 6 min. to 43 hours). TDIC triangle shows in this case, local anti-correlation zones. After this time scale, we observe no correlation, however we can observe these global lost as a multiplication of local zero correlations in the lower window of the TDIC triangle. Further works will be focus on the understanding of those zones and the possible existence of patterns in order to get access to the nonlinear interactions between the incoming wind and the wind power production.

References

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