Quality of synthetic winds by testing of similarity to measured data by spectral modelling and statistics of increments

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Abstract

For analyses of fatigue loading of wind turbines and their control schemes via numerical simulations detailed information on the 3D wind field are necessary. Schemes for the generation of respective synthetic sets had been developed and are in use. There is a need for the validation of these schemes in view of the realistic representation of statistical characteristics of the real wind field. This comprises – besides the correct reflection of the spectral properties of the field - the reflection of non-Gaussian properties of the series. In this paper we report on the analysis of synthetic data from a full-field, turbulent wind simulator by comparison with highly time resolved measured wind data sets.

1 Introduction

In order to have proper wind turbine design and performance analysis, it is important to have an accurate representation of the incoming wind field. To ease the analysis, tools for the generation of synthetic 3D wind fields have been developed, The TurbSim procedure [1],[2] forms a kind of standard and is widely used for structural analysis and the development of control strategies (see e.g. [3]). This program can be operated in a basic mode, using as input but the spectral information and a mode respecting the intermittent characteristics of the wind flow by superimposing coherent events (see [2] and section below)

For more information on the confidence to be put into results gained by the use of the TurbSim synthetic wind, we analyze measured sets and the respective synthetic data sets in view of the similarity of the spectral characteristics and the statistics of wind speed increments (relevance to load assessment) of measured and synthetic sets for both modes of the TurbSim operation

2 Data base

Measured sets are given here by the data as offered by the server of the National Renewable Energy Laboratory (NREL) Wind turbine test center [4] Data used refer to tower based measurements by sonic anemometers at 100 m height above ground with a rate of 20Hz. Analyses are performed for time section representing a length of 10min each.

3 Measured spectra and spectral models

As the TurbSim code is in its basic version uses information on the spectral and cross-spectral characteristics to generate equivalent data sets, the first test concerns the ability of the spectral model applied to reflect measured data characteristics. As TurbSim can incorporate various spectral model, this test is done here as example for the Mann model (see [5] and [6] for a critical appraisal of this model). Fig.1a gives model spectra for the longitudinal, lateral and vertical wind components (u, v and w respectively).

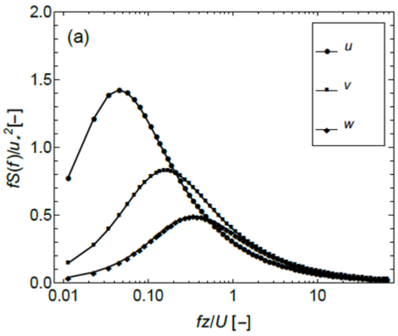


Fig. 1a: Spectra of the u,w and v wind speed components according to the Mann model.

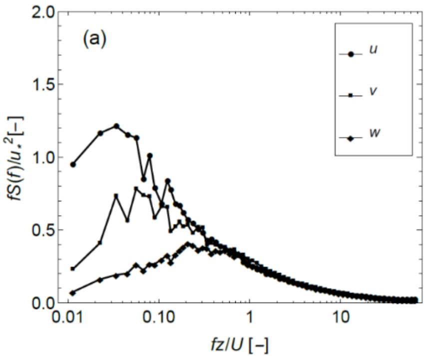


Fig.1b: Example for empirical spectra for the wind speed components.

4 Spectra of synthetic winds

Applying the spectral analysis to a 10min data set generated with the basic TurbSim procedure according to the Mann-model results in spectra as given in fig.2. These results are in line with the expected spectra.

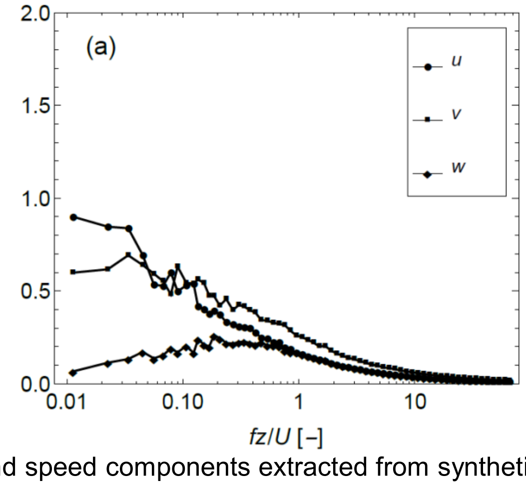


Fig. 2: Spectra of the wind speed components extracted from synthetic wind generated by basic TurbSim without inclusion of coherent events.

Larger differences appear, when the program mode with superimposed coherent events is used as can be remarked in fig. 3. Several distinct peaks occur in the mid to high frequency part of the spectra.

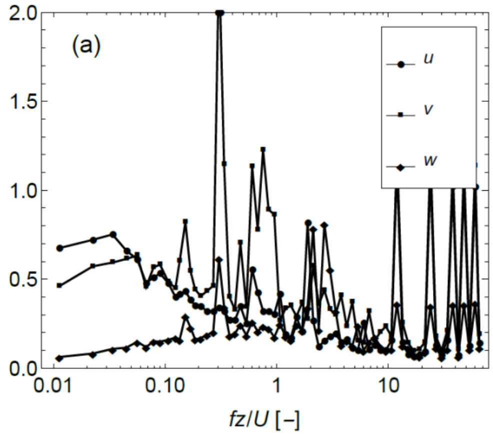
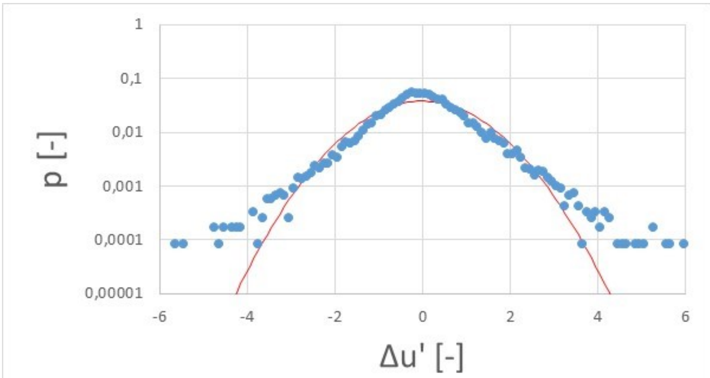


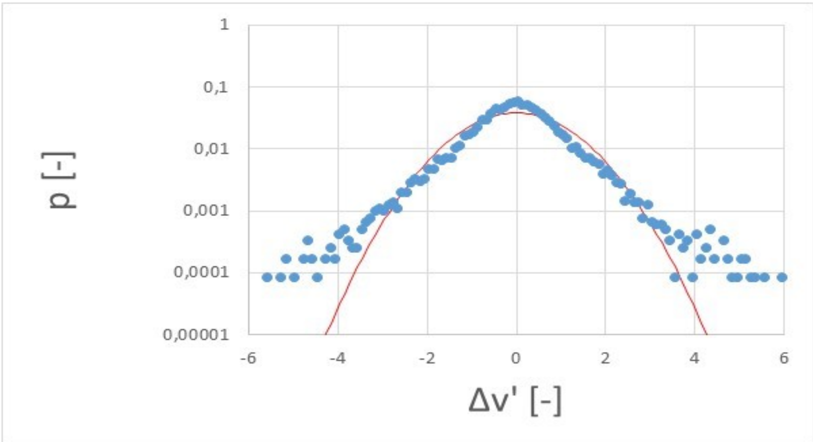
Fig. 3: Spectra of the wind speed components extracted from synthetic winds generated with inclusion of coherent events.

5 Statistics of increments of in measured data

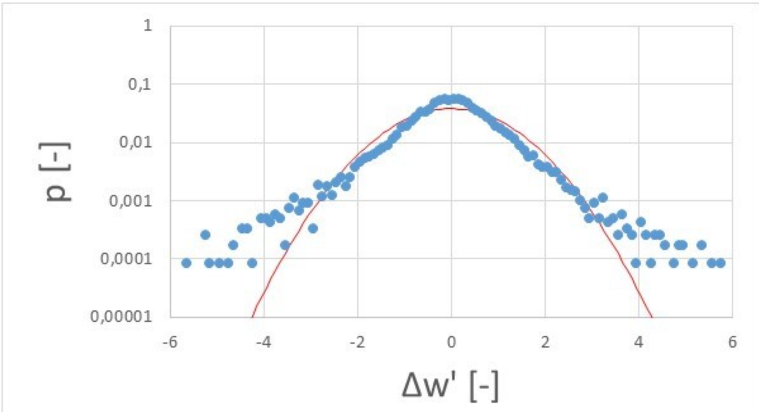
From basic research into turbulence, it is known that the turbulent data are not the outcome of a purely Gaussian process. The increments of the time series $\Delta x = (x(t+\Delta t)-x(t))$ are not expected to follow a Gaussian distribution (see e.g. [8]). This holds for the wind speed time series under inspection, demonstrated here for $\Delta t = 0.05s$ according to the maximum temporal resolution. Fig. 4-6 give the probability density (PDF) of the increments in measured u,v and w series.



a)



b)

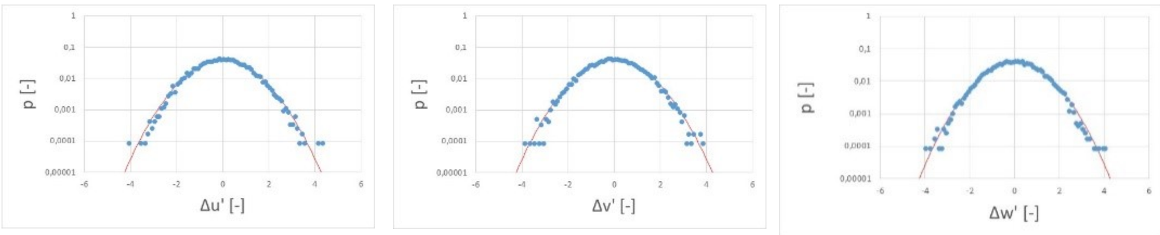


c)

Fig. 4 a-c: Probability density (PDF) of u (a), v (b) and w (c) components of measured 20Hz wind time series (points). The data (‘) are normalized here with the respective standard deviation. The red line refers to the PDF of a Gaussian distribution with unit standard deviation.

6 Statistics of increments in TurbSim synthetic data sets

The characteristics of the increments as presented form a remarkable challenge for the procedure to generate of synthetic data sets. As the initial method for the generation of random sets is based on the addition of trigonometric series.- representing the contribution of different frequencies -with random phase setting, purely Gaussian outcome is expected. Fig 5 – resulting from the analysis of an respective outcome proves this.

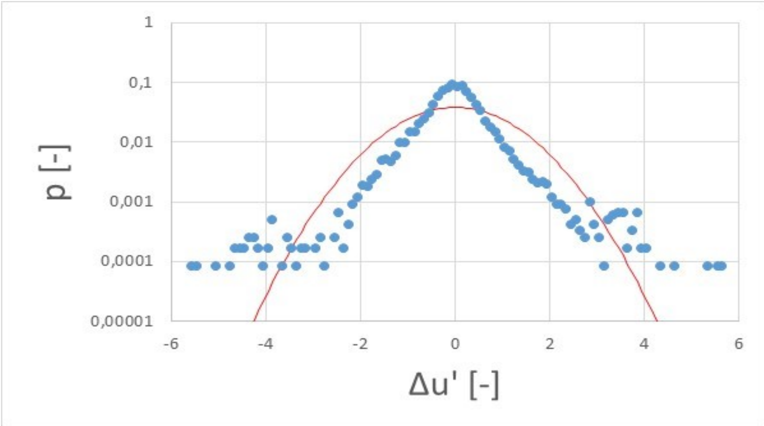


a) b) c)

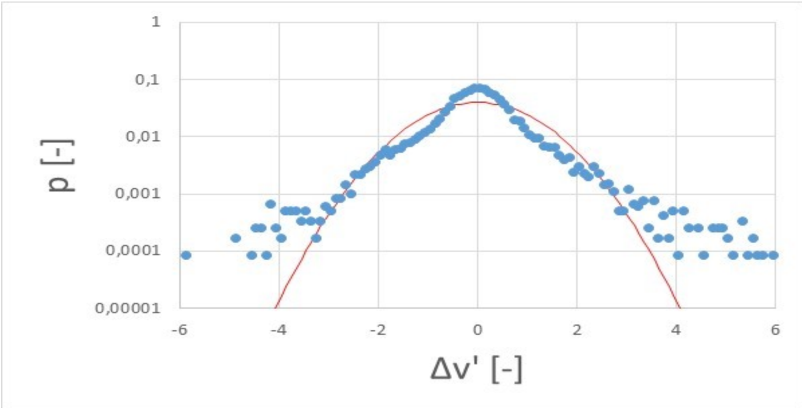
Fig. 5 a-c. Same presentation as fig.4, but presenting the probability densities (PDF) of u (a),v (b) and w (c) components of simulated time series. This simulation refers to the output of a basic Fourier scheme.

To overcome this limitation TurbSim is able to an overlay of time sections exhibiting now Gaussian characteristics to the normal data set - the ‘coherent events’ [2]. These data may originate e.g. from computational fluid dynamics modelling for large eddy simulation LES that exhibit non Gaussian properties. The drawback to the spectral content of the resulting set was shown above. In addition. Its turbulence intensity and standard deviation of the increments may require an adaption to reflect the target value.

The analysis of the outcome of TurbSim in the mode respecting coherent events is given in fig.6.



a)



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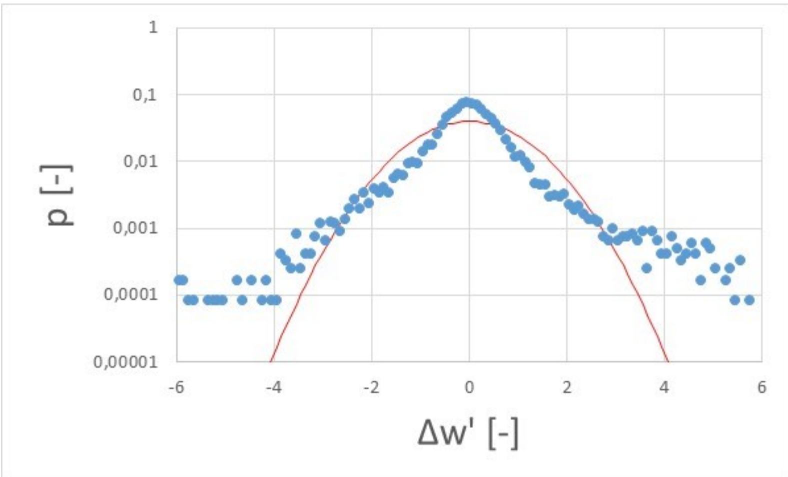

c)

Fig. 6 a-c: Same presentation as fig.4 but referring to the analysis of the increments in the components of synthetic wind generated negotiating coherent events.

It is obvious that this set contains a non-Gaussian characteristic, which qualitatively resemble the PDF of the respective measured data. In the details however, there are remarkable differences. These differences depend on the setting of the scheme for the overlay. Fig.7 gives the increment PDF for the outcome when using a different scaling of the coherent events.

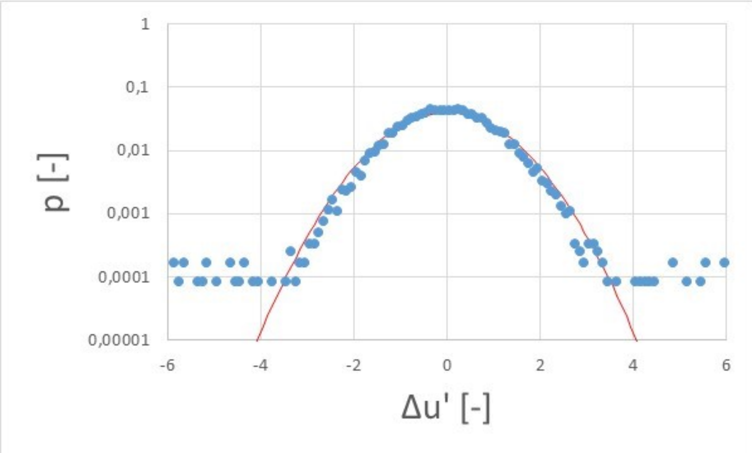

Fig. 6. Same presentation as fig.6 but referring to the analysis of the increments in the u component of synthetic wind generated with different setting for negotiating coherent events.

This calls for further development in giving guidelines for setting the parameters of the overlay of the coherent events (amplitude, number and length …of coherent events negotiated).

6 Conclusions

In view of the application of the synthetic wind field data as input to turbine load assessment it is obvious that - besides the realistic spectral modelling - the inclusion of coherent events in the generation scheme is essential for a realistic modelling. However, further research is necessary to adopt the scheme for the inclusion of coherent events for increased match of modelled and empirical characteristics,

7 References

[1] Nwtc information portal (turbsim) https://nwtc.nrel.gov/turbsim accessed 25-February- 2016

[2] Nwtc information portal (fast) https://nwtc.nrel.gov/fast accessed 25-February-2016 [5] Jonkman B J and Kilcher L 2012 Turbsim user's guide: Version 1.06.00 Technical Report NREL/TP-xxx-xxxx National Renewable Energy Laboratory

[3] T. Bakka, H. R. Karimi and N. A. Duffie, "Gain Scheduling for Output H∞ Control of Offshore Wind Turbine", Proceedings of the 22nd International Offshore and Polar Engineering Conference, page 496-501, 2012.

[4] https://nwtc.nrel.gov/MetData (visitet 20.09.2016)

[5] Chougule A, Mann J, Kelly M, Sun J, Lenschow D H and Patton E G 2012 J. Turbul. 13(36) 1–13 (Preprint DOI:10.1080/14685248.2012.711524)

[6] Chougule A, Mann J, Segalini A and Dellwik E 2015 Wind Energy 18 469–481 (Preprint DOI: 10.1002/we.1709)

[7] BÖttcher F, Barth S and Peinke J 2007 Stoch. Environ. Res. Ris. Assess 21 299–308