Wind energy : On the statistics of gusts and their propagation through a wind farm

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1 Introduction

From wind turbines to gusts : The design of wind turbine structures is determined by the nature of the wind field, and thus, knowledge of turbulent wind and its impact on loads is required. For pitch regulated turbines, the loads can be reduced by optimization of the regulation system after turbulence characteristics. Part of the turbulence, gusts are a relevant parameter to study the fatigue loading. According to the IEC 61400-1[5] standard, one of the design requirement for wind turbine is to resist to different extreme gusts. In order to perform loads simulation, an estimate of the mean gust shape[4] is needed.

Prospect of the study : The main objective was to study the propagation of gusts through the row of turbines available at ECN test farm. This kind of analysis has never been performed before, and thus several steps were needed before arriving to the propagation results. This work required to clearly state the definition of gust and compute several methods of gusts detection in harmony with the different conventions suggested by the literature. After this step, a database of gusts has been established. From this database, comparisons between experimental mean gust shape and theoretical gust shape have been performed. Then, specific gusts have been selected and their propagation studied.

2 ECN test farm

The Energy Research Center of the Netherlands is a dynamic environment for wind energy research, holding a strategic position between universities and industries. The Wind Energy unit has opened in 2003 an onshore test site for prototype wind turbines called ECN Wind turbine Test site Wieringermeer (EWTW). A row of five Nordex N80 wind turbines are equipped with more than 30 sensors for experimental research and a 108m high meteorological mast has been built at proximity. The turbines are labelled from 5 to 9, and the mast is labelled MM3. Figure 1 shows the disposition of the turbines on the test site. The data measured are validated and stored as "raw data". An extensive validation and statistical treatment of these data is then peformed and they are stored in a database. For my internship, I chose to manipulate the raw data with the use of the program $\mathcal{R}$, whereas SQL statements were used for the database. The results presented in my report come only from programs that I have personnally written, during the period of time assigned for the internship, separated in 200 $\mathcal{R}$ scripts, representing 10 thousand lines of code, with 15 Gb of results produced from the 100 Gb of "raw data".

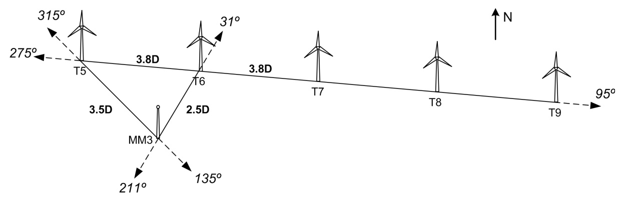

FIG. 1 – Disposition of the studied turbines and meteorological mast at ECN test site

3 Gust definition

Gust definition : It is generally accepted that gusts and turbulence are observed over time intervals between 1s and 10 minutes. The most simple definition corresponding to gust is the following : *a Gust is a short-term wind speed variation within a turbulent wind field.* From this, a canonical example is drawn, the so-called "Mexican-hat" gust. Nevertheless, our analysis on the mean gust shape will provide us with different shapes. When the acceleration of the wind is important, leading to high wind speed in a short time, we qualify the gust as a *Front.* Confusion is often often made with longer events called *Squall.* Eventually, attention is centered on positive gusts but fast *Negative gust* can also imply sharp increase of loads.

Gust detection : Once the definition of gust is clear, it is needed to detect gusts from the meteorological data. Three methods were found in the literature : The *Peak-peak procedure*[2], the *Velocity increment method*[3], the *Peak over threshold method*[1]. Standardization of all notations and all definitions are presented in my report. I also suggested another method of detection, the *Correlation method*, which appeared to produced powerful results.

4 The mean gust shape

Theoretical definition : From the work of G.Cr. Larsen[4] and the the general method of Middleton, the mean gust shape for an extreme between levels A and

$A + dA$, is theoretically given by :

$$\frac{\tilde{u}(\tau)}{\sigma} = \frac{A}{\sigma} r(\tau) - \frac{\sigma}{A}\left(r(\tau) - \frac{\ddot{r}(\tau)}{\ddot{r}(0)}\right) \quad (1)$$

Where, σ is the 10 minute standard deviation of the wind speed around the maxima, $\tilde{u}$ the fluctuating wind speed such that $\tilde{u}(t) = u(\ddot{)} - \bar{U}$, and $r(\tau)$ is the normalized autocorrelation function is expressed with Bessel function.

Experimental results : For each experimental gust, datasets of 10s before and after the maximum of the gust are stored. The average gust shape is obtained by averaging along all the datasets for each time value. On figure 2 it can be seen that good correlation with the theory is found for each amplitudes. Nevertheless, my study revealed that different theoretical spectrum should be used for different wind speed. Moreover, I suggested another protocol for the analysis on the mean gust shape that takes into account the whole structure of the gust and not only a fixed time interval around a maximum. This resulted in gust shapes that had a better physical intepretation.

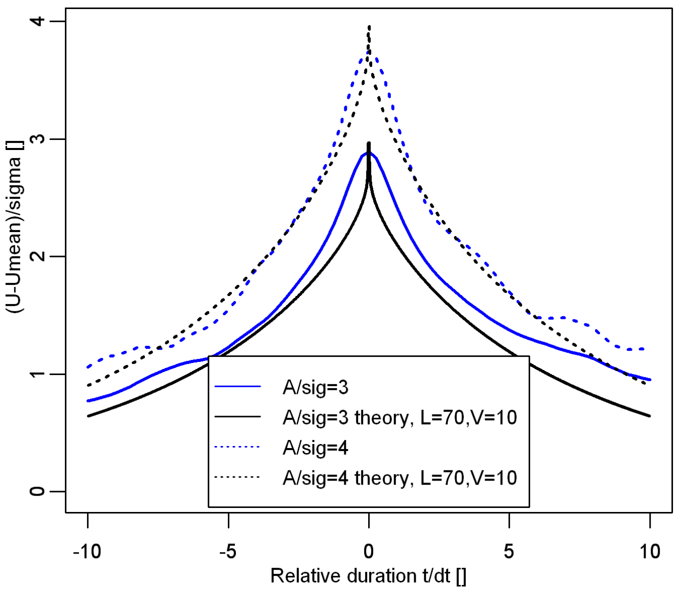

FIG. 2 – Mean gust shape - Comparison of theoretical results and experimental results for a bin of wind speed around 10m/s, and for two different amplitudes $A = 3\sigma$ and $A = 4\sigma$

Gust vertical profiles : I noticed that the gust can be expected to travel faster at higher height, as the average wind speed profile follows a logarithmic law. Nevertheless, the amplitude of the gust is not following the vertical logarithmic law as its amplitude is in average, maximum at the height where it was detected and then attenuates with height. Even though the focus of this study was not on wind direction change, it has also been seen that in average all gusts come with a direction change.

5 Gust propagation through a row of turbine

Based on a correlation method, I proved that in a good approximation, the gust can be expected to travel at the average wind speed. Given this result, it has been possible to look into the raw data to describe the propagation of gusts. By extrapolating the results obtained for several directions, I tried to interpret them in terms of longitudinal, lateral and vertical spread. The results were fitted with decreasing exponential, which seem to be the best fitting function. The empirical function suggested is of the form :$\hat{P}\left(\Delta X = \delta x, \Delta Y = \delta y\right) = e^{-\frac{\delta x}{l_x}}\, e^{-\frac{|\delta y|}{l_y}}$. It provides the probability of detecting a gust at a position downstream the location where the gust was detected. Some trends have been noticed that require further investigation. For instance it has been noticed that the gusts of narrow lateral spread seem to last longer than the ones with a large lateral spread.

6 Conclusions

A row of onshore turbines, characterized by flat terrain, has been studied. The gusts parameters are site-specific, so that, comparison with other locations is required to complete this work. Nevertheless, one can be satisfied with the preliminary results provided by this study. Indeed, the propagation of gusts has never been studied before and its knowledge can be used to optimize the production of power by introducing a communication between all the pitch controllers of a wind park. The upcoming of new generation offshore 2/3 blades stall regulated turbines can be expected in the following years as this technology can significantly reduce the operation and maintenance cost. It would then require careful analyses on stress and constrains due to gusts and vertical shears they can imply.

Literature Cited

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