Characterization of wind power fluctuations from frequency measurement data

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Introduction

- Generation based on renewable energy sources has become a main component of the generation mix of most European countries. Wind power is particular relevant in Ireland, where the monthly wind capacity factor is about 50% and the maximum wind penetration can reach almost 70% of the total demand.

- The stochastic behavior of the production of wind power plants has an impact on the system frequency in terms of:
  Variability Uncertainty Asynchronism

While large frequency variations are due to energy imbalances, it is not possible a priori to know which parameters affect frequency fluctuations. In this study, we assume that the main parameters are only the level of wind power generation and the level of load demand.

Our **Objective** of this work is to determine how variability, uncertainty and asynchronism affect the stochastic properties of the frequency.

Methodology

- Acquisition of measurement is lead by a Frequency Disturbance Recorder (FDR), sample time is 0.1s

- Trends of the variability and magnitude of wind are based on EirGrid public data.

- Different lengths of time series are considered, and results and conclusion are based on the different sets analysed.

Analysis on short datasets Due to the reduced time frame, different load demand and wind generation levels can be identified. We consider the four scenarios resulting from the combinations of the following wind and load conditions:

1) Low Load (LL) the time frame between 3am-4am;
2) High Load (HL) the time frame between 11am-12pm;
3) Low Wind (LW) the wind generation when < 250 MW;
4) HighWind(HW)the wind generation when > 500MW

To understand which probability density function fits best the frequency distribution of the considered scenarios, we tested four common distributions, (Normal, Weibull, Rayleigh and Exponential) and we evaluated results through qualitative and qualitative assessment like graphical analysis and statistical criterion such as Bayesian Information Criterion (BIC).

Analysis on long datasets The definition of a SDE for the frequency can be done only for large data sets. This is a consequence of the need to satisfy the stationary conditions.

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Results

Available measures and statistical properties lead to assume that there might be a correlation between wind power production and frequency variations: the higher the wind power production, the higher the standard deviation of the frequency.

Test	Frequency Variance $[Hz]^2$ LL-LW	Wind Generation Average [MW] LL-LW	Frequency Variance $[Hz]^2$ LL-HW	Wind Generation Average [MW] LL-HW
1	0.00017518	64	0.00037423	919
2	0.00043609	112	0.00070981	1097
3	0.00042059	106	0.00200000	743
Test	**Frequency Variance $[Hz]^2$ HL-LW**	**Wind Generation Average [MW] HL-LW**	**Frequency Variance $[Hz]^2$ HL-HW**	**Wind Generation Average [MW] HL-HW**
1	0.00025114	45	0.00073492	602
2	0.00036818	163	0.00069135	1208
3	0.00079450	26	0.00110000	1140

Tab. 1 Frequency variance and wind generation for some experiments on the four different scenario.
It is possible to appreciate the difference of values looking at the different condition of wind.

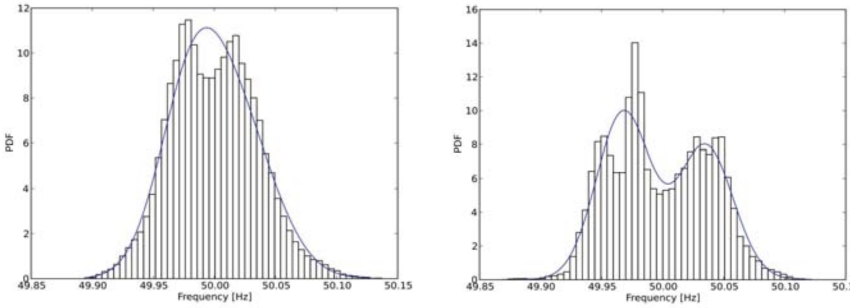
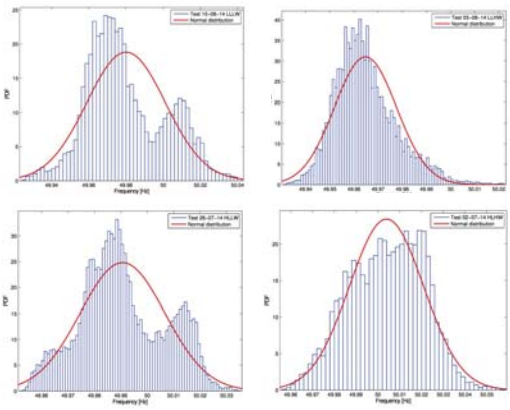


Fig. 1 Frequency distribution during a windy and a non-windy days. The bimodal behaviour of the frequency is certainly due to the droop of primary frequency regulation that prevents the system to operate exactly at 50 Hz after a power variation.

Fig. 2 Frequency distributions for *short periods* with high/low wind variability, do not show clear patterns, and no common path is apparent for the four scenarios either.

The graphical analysis shows that the normal distribution appears the one which better describe frequency variations.

Scenario	Normal	Weibull	Rayleigh	Exponentia
LL-LW	-184000	-177462	303753	353661
LL-HW	-170022	-163098	303744	353649
HL-LW	-199280	-196014	303765	353670
HL-HW	-157809	-155246	303770	353678



Tab.2 BIC values for the four test, minimum BIC values of the parameter have been obtained for the Normal distribution

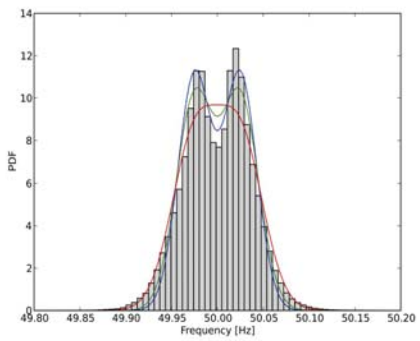


Fig. 3 Taking large datasets for the definition of SDE, the shape of the related histogram shows two peaks and suggests that the frequency stationary distribution is bimodal.

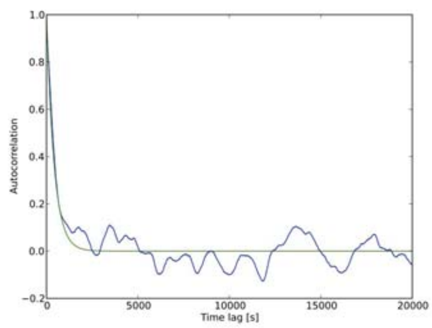


Fig. 4 The autocorrelation of the frequency values, which depicts the measured autocorrelation and the idel autocorrelation obtained by the ideal Ornstein-Uhlenbeck process.

Conclusions

Conclusions that can be drawn depend on the time frame.

- In the short term, available data suggest that the frequency likely follows a Normal distribution and is affected by the wind power generation variability.

- In long term, the frequency is likely stationary and can be described by a bimodal distribution.

- On the long term, the Ornstein-Uhlenbeck process provides a reasonable approximation of the dynamic behaviour of the frequency.