Technical University of Denmark

North Sea Offshore Wind Power Variability in 2020 and 2030

Cutululis, Nicolaos Antonio; Litong-Palima, Marisciel; Sørensen, Poul Ejnar

Published in:
Proceedings of 11th International Workshop on Large-Scale Integration of Wind Power into Power Systems

Publication date:
2012

North Sea Offshore Wind Power Variability in 2020 and 2030

Nicolaos A. Cutululis, Marisciel Litong-Palima, Poul Sørensen
Department of Wind Energy
Technical University of Denmark
Frederiksborgvej 399, Risø Campus, Roskilde
niac@dtu.dk

***Abstract*— Wind power is currently the most promising renewable technology and is expected to contribute significantly to achieving the "20-20-20" target set by EU - 20% reduction of greenhouse gases and 20% share of renewables by 2020. The development potential of wind power, especially offshore, is huge. The experience with large offshore wind farms so far has clearly shown that the offshore wind power is significantly more variable than the on-shore wind power, first of all because offshore wind power is more concentrated geographically than existing on-shore wind power. The focus is on time scales of interest for power system operation, thus ranging from minutes to hours. The simulations are based on the offshore wind power development plans developed in the TWENTIES project and includes details such as installed capacity and coordinates for each wind farm existing or planned to be installed in North Europe, by 2020 and 2030. For each target, a base case and a high scenario is simulated. The offshore wind power variability is quantified in terms of ramp rates.**

Wind Power, Variability, Offshore, Ramp rates

I. Introduction

Wind power is currently the most promising renewable technology. It is expected to contribute massively to achieving the "20-20-20" set by EU - 20% reduction of greenhouse gases and 20% share of renewables by 2020.

In North Europe, most of the future wind power is expected to be offshore. The experience so far with large offshore wind farms has shown that the geographical concentration of wind power can lead to increased variability.

The TWENTIES project (www.twenties-project.eu) aims at "demonstrating by early 2014 through real life, large scale demonstrations, the benefits and impacts of several critical technologies required to improve the pan-European transmission network, thus giving Europe a capability of responding to the increasing share of renewable in its energy mix by 2020 and beyond while keeping its present level of reliability performance" [1]. The project is structured in three task forces. One of them, task force 2, is investigating what should network operators implement to allow for offshore wind development. This task force comprises two high level demonstrations. One of the demonstrations in Twenties is the Storm Management demonstration. The objective of this demonstration is: "The occurrence of storms will raise new challenges when it comes to secure operation of the whole European electric system with future large scale offshore wind power. With the present control schemes, storms will lead to sudden wind plant shut downs, which in turn is a threat to the whole system security, unless standby reserves are ready to take over power demands under very short notice. The challenge that this demonstration is addressing is to balance the wind power variability, operating the transmission grid securely during such storm conditions. The more specific objectives of the demonstration are to:

- Demonstrate secure power system control during storm passage, using hydro power plants in Norway to balance storm shut down of Horns Rev 2 wind farm in Denmark.
- Use existing forecast portfolio available to the TSO to monitor and plan the down regulation of large scale offshore wind power during storm passages.
- Provide more flexible wind turbine and wind farm control during storms." [1].

The demonstration is performed on a single offshore wind farm. In order to quantify the offshore wind power variability by 2020 and 2030, simulations are used.

The paper presents the first results of the analysis of the offshore wind power variability, in 2020 and 2030, in North Europe. The next section presents CorWind, the simulation model used for obtaining the wind power time series. Section III presents the wind power development scenarios considered in the simulations, followed by the results of the simulations. Finally, a conclusion section ends this paper.

II. CorWind

The analyses presented in this report are based on simulations with the CorWind power time series simulation

The works and developments required for the elaboration of this paper/article have been carried out partially within TWENTIES project (www.twenties-project.eu) which belongs to the Seventh Framework Program funded by European Commission under project no. ENER/FP7EN/249812/"TWENTIES".

model developed at DTU Wind Energy [1]. CorWind can simulate wind power time series over a large area such as a power system region and in time scales where the wind turbines can be represented by simple steady state power curves, i.e. typically greater than a few seconds. CorWind can be used e.g. for comparison of the impact of the site selection of future wind farms on the system reserves requirements.

The CorWind is an extension of the linear and purely stochastic PARKSIMU model [3], which simulates stochastic wind speed time series for individual wind turbines in a wind farm, with fluctuations of each time series according to specified power spectral densities and with correlations between the different wind turbine time series according to specified coherence functions. The coherence functions depend on frequency and space, ensuring that the correlation between two wind speed time series will decrease with increasing distance between the points. Moreover, the slow wind speed fluctuations are more correlated than the fast fluctuations. Finally, the stochastic PARKSIMU model includes the phase shift between correlated waves in downstream points, ensuring that correlated wind speed variations will be delayed in time as they travel through the wind farm. These model properties ensure that the summed power from multiple wind turbines will have realistic fluctuations, which has been validated using measured time series of simultaneous wind speeds and power from individual wind turbines in two large wind farms in Denmark [4].

The CorWind extension of PARKSIMU is intended to allow simulations over a large areas and long time periods. The linear approach applied in PARKSIMU assumes constant mean wind speeds and constant mean wind directions during a simulation period, which limits the geographical area as well as the simulation period significantly – typically to the area of a single wind farm and to max 2 hours periods. CorWind uses reanalysis data from a climate model to provide the mean wind flow over a large region, and then adds a stochastic contribution using an adapted version of the PARKSIMU approach that allows the mean flow to vary in time and space.

The meteorological data come from a climate simulation using the Weather Research and Forecasting (WRF) model and the dynamical downscaling technique developed by Hahmann et al [4], but using Newtonian relaxation terms toward the large-scale analysis (also known as grid or analysis nudging). Initial and boundary conditions and the gridded fields used in the nudging are taken from the NCEP reanalysis [5] at 2.5° × 2.5° resolution. The sea surface temperatures are obtained from the dataset of Reynolds et al [6] at 0.25° horizontal resolution and temporal resolution of 1 day. The simulation covers the period from 1 January 1999 to 31 December 2010 with hourly outputs. The model is run on an outer grid of spatial resolution of 45 km and a nested grid of 15km, respectively. The data from the inner domain, which covers most of Northern Europe, is used in this study.

III. SIMULATIONS SCENARIOS

The analysis aimed at quantifying the variability of offshore wind power in 2020 and 2030. For that, the simulations used the wind power development scenarios from the TWENTIES project [5]. The database created includes the coordinates of the wind farms. The total number of wind farms considered is 379 for 2030. The MW installed capacities, per considered power system areas, are given in TABLE I.

TABLE I. OFFSHORE WIND POWER IN 2020 AND 2030

Power System Areas	2020 in MW		2030 in MW	
	Base	High	Base	High
UCTE	21,421	27,675	52,590	69,454
Nordel	4,924	7,019	15,009	20,512
UK+IR	15,130	21,500	37,920	52,090
Total	**41,475**	**5,6194**	**105,519**	**142,056**

Simulating such a large number of wind farms, over a large area, is not computationally feasible if one considers all individual wind turbines. Instead, an aggregation at wind farm level was used. As mentioned previously, CorWind uses a steady-state model of the wind turbine, i.e. power curve, to which the storm control dynamic was added. For the simulations, an aggregated wind power curve, presented in Fig, was used. The methodology of obtaining this aggregated wind power curve is described in [6].

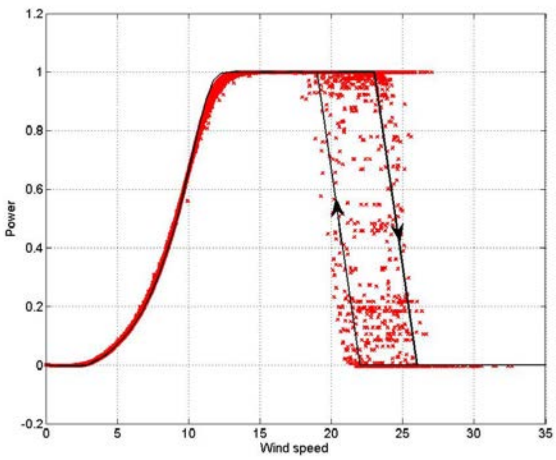

Figure 1. Aggregated wind farm power curve, including wind speed hysterezis

Six different years of mesoscale hourly wind speed data were used. The years are 2008-2011 and 2001/2005. Further, for the stochastic part, for each year of mesoscale wind speed, five random seeds were used, leading to a total of 30 annual wind power time series. The time step is 5 minutes.

The definition of ramp rates involves a statistical period time T_{per}, which reflects the time scale of interest. The time scales of interest will depend on the power system size, load behavior and specific requirements to response times of reserves in the system. In order to study the wind variability, the analysis is performed with fifteen minutes period time.

The definition of ramp rates applied in this paper is quite similar to the definition of load following applied in [7]. The intention is to quantify the changes in mean values from one period T_{per} to another, which specifies the ramp rate requirement that the wind power variability causes to other power plants.

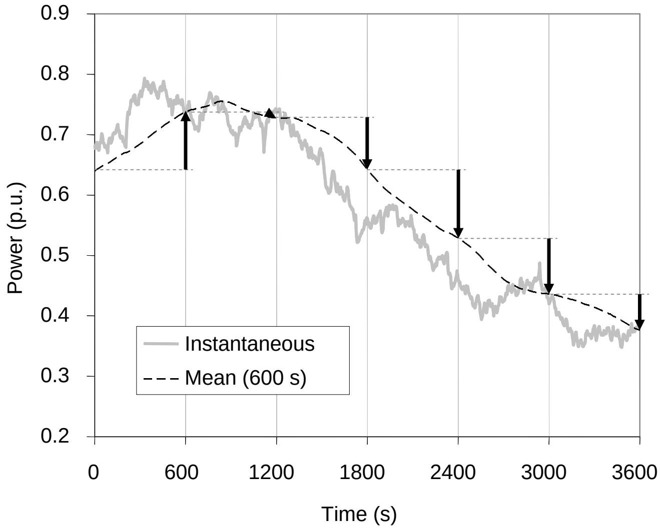

Figure 2. Definition of ramp rated for period time Tper = 10 min. The ramp rates are indicated with arrows.

The definition of ramp rates is illustrated for period time T_{per} = 600 s in Figure 2.

IV. RESULTS

In the power system operation, maintaining the system frequency is a critical task. Frequency deviations occur when there is an imbalance in the system. The imbalance can be either due to over production (over frequency) or due to under production. The latter is considered to be more critical, since it requires that extra power is produced by other generators in the system.

Wind power variability is, in this context, of interest, since it will require other generation in the system to ramp up and maintain the balance between production and consumption. Frequency reserves can be shared among different Transmission System Operators (TSO), so it makes sense to quantify the offshore wind power variability over large power system areas, i.e. UCTE and Nordic synchronous systems. On top of that, the wind power variability is quantified for UK and Ireland. The fifteen minutes time period chosen coincides with the activation time of the Frequency Restoration Reserves, as defined by ENTSO-E [11].

Statistics of the wind power ramp rates, for each of the considered power system areas, are presented in Figure 3. In all cases, the wind power ramping increases significantly in 2030. The area smoothening is more visible in the case of the UCTE synchronous area, where the difference in the wind power variability between 2020 and 2030 is less pronounced than in the other cases.

Still, the most interesting point of the duration curves is around 100 %, where the highest requirement to the ramp rates of other power plants is quantified. The wind power positive ramp rates can be limited directly by the ramp limiter in wind farm controllers [12].

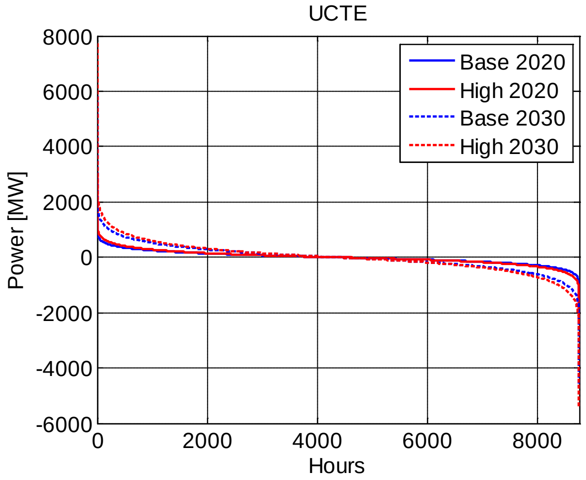

Figure 3. Wind power variability duration curve for UCTE

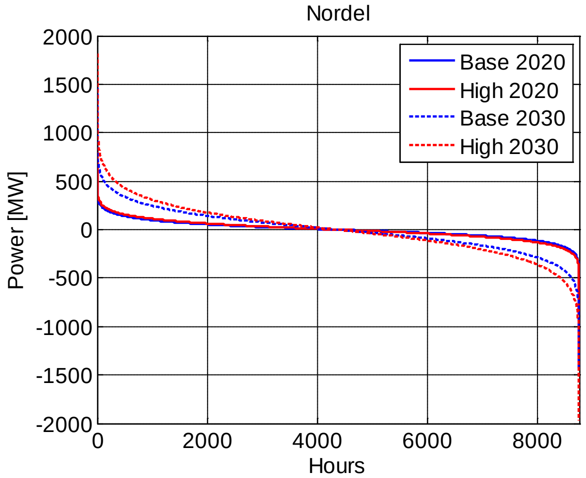

Figure 4. Wind power variability duration curve for Nordel

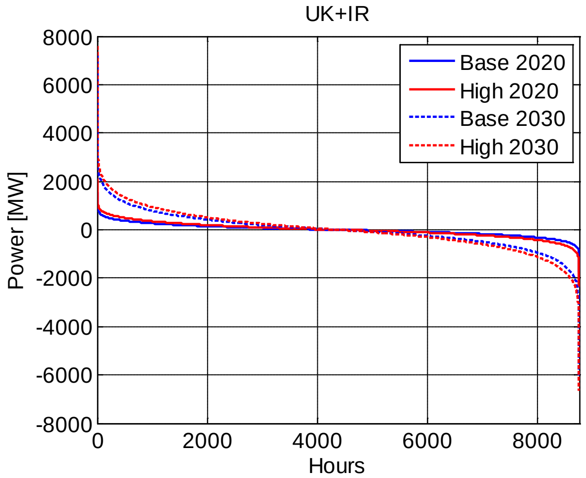

Figure 5. Wind power variability duration curve for UK+Ireland

For that reason, the 99 % percentile of the duration curves for all power system areas are shown in Figure 6.

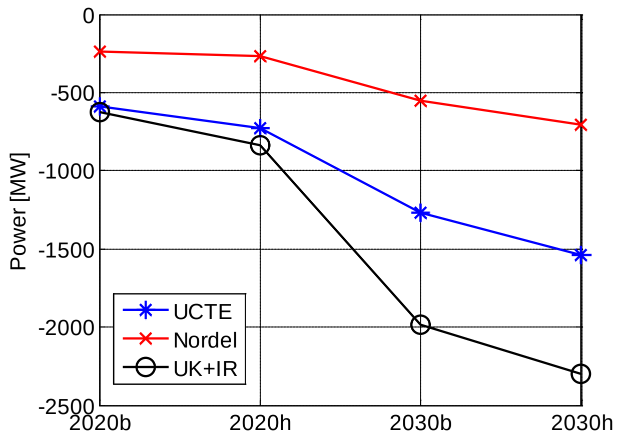

Figure 6. 99% percentiles of wind power ramping

TABLE II. 99% PERCENTILES OF WIND POWER RAMPING

Power system area	2020		2030	
	Baseline	High	Baseline	High
UCTE	-586	-726	-1270	-1542
Nordic	-239	-264	-549	-709
UK+IR	-625	-836	-1985	-2302

The numerical values of the 99% are given in TABLE II. For Nordel, the impact is rather low, since the increase in the ramping rates, while significant numerically, is still rather small when taking into consideration the dimensioning fault of 1200 MW [13]. Similar is in the case of UCTE, where the 99% percentile in the high 2030 scenario ramping rate is significant, but still not close to the 3000 MW dimensioning fault [14].

TABLE III. 99% NORMALIZED WIND POWER RAMP RATES

Power system area	2020		2030	
	Baseline	High	Baseline	High
UCTE	3%	3%	2%	2%
Nordic	5%	4%	4%	3%
UK+IR	4%	4%	5%	4%

When looking at the normalized wind power ramp rates, one ca notice that the 99% percentile, given in TABLE III. , decreases over time. The normalization is done with the installed wind power capacity in each scenario.

V. CONCLUSIONS

The wind power development scenarios for North Europe include significant offshore wind power capacities. Offshore wind power variability can be significant, especially due to the geographical concentration.

North Europe wind power ramp rates were quantified for 2020 and 2030. For each target year, the development scenarios included a baseline and a high one. The simulations were done for six historical year worth of data, each with five different seeds for the stochastic part. The analysis was done for a time period of 15 minutes, relevant for the frequency restoration reserves.

The ramp rates were calculated for large power system areas, i.e. UCTE and Nordel synchronous systems and then UK+Ireland.

The normalized 99% percentile of the wind power ramp rate decreases over time.

REFERENCES

[1] EU FP7 TWENTIES project, www.twenties-project.eu

[2] P. Sørensen, P. Pinson, N.A. Cutululis, H. Madsen, L.E. Jensen, J. Hjerrild, M.H. Donovan, A. Vigueras-Rodríguez. Power fluctuations from large wind farms – final report, Risø Report, Risø-R-1711(EN), August 2009

[3] P. Sørensen, A. D. Hansen, P. A. C. Rosas, ”Wind models for simulation of power fluctuations from wind farms”, J. Wind Eng. Ind. Aerodyn. (2002) (no.90) , 1381-1402

[4] P. Sørensen, N.A. Cutululis, A. Vigueras-Rodriguez, H. Madsen, P. Pinson, L.E. Jensen, J. Hjerrild, M.H. Donovan. Modelling of Power Fluctuations from Large Offshore Wind Farms. Wind Energy (2008) 11, 29-43

[5] N.A. Cutululis, M. Litong-Palima, L. Zeni, A. Gøttig, N. Detlefsen, P. Sørensen, ”Offshore Wind Power Data”, Deliverable 16.1, TWENTIES project, www.twenties-project.eu

[6] N.A. Cutululis, M. Litong-Palima, P. Sørensen, “Offshore wind power production in critical weather conditions”, EWEA Annual event, Copenhagen, 2012.

[7] B. Parson, M. Milligan, B. Zavadil, D. Brooks, B. Kirby, K. Dragoon, J. Caldwell, “Grid Impacts of Wind Power: A summary of recent studies in the United States,” Wind Energy , vol. 7, Apr./Jun. 2004, pp 87-108.

[8] Hahmann, A. N., D. Rostkier-Edelstein, T. T. Warner, Y. Liu, F. Vandenberghe, Y. Liu, R. Babarsky, and S. P. Swerdlin, 2010: A reanalysis system for the generation of mesoscale climatographies. J. Appl. Meteor. Climatol., 49, 954-972.

[9] Kanamitsu, M., W. Ebisuzaki, J. Woollen, S.-K. Yang, J. J. Hnilo, M. Fiorino, and G. L. Potter, 2002: NCEP–DOE AMIP-II Reanalysis (R-2). Bull. Amer. Meteor. Soc., 83, 1631–1643.

[10] Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes, and W. Q. Wang, 2002: An improved in situ and satellite SST analysis for climate. J. Climate, 15, 1609–1625.

[11] ENTSO-E Operational Reserve Ad Hoc Team Report, Final Version, May 2012, https://www.entsoe.eu/fileadmin/user_upload/_library/consultations/Network_Code_OR/2012-06-14_SOC-AhT-OR_Report_final_V9.pdf, accessed October 2012

[12] Kristoffersen JR, The Horns Rev Wind Farm and the Operational Experience with the Wind Farm Main Controller, Copenhagen Offshore Wind, 2005

[13] Kristiansen J., “The Nordic approach to market-based provision of ancillary services”

[14] UCTE Operation Handbook, available on www.ucte.org