Dynamic Network Behavior of Offshore Wind Parks

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***Abstract*-- Today there are around 60 offshore windpark projects planned in the area of the German North Sea with distances to the shoreline ranging from 30 to 200 km. The projects are divided into four clusters. Because of the high number of windparks and HVDC links assumed to be installed in future a good understanding of the dynamic behavior of the electrical system is necessary to guarantee overall system stability. This paper describes the investigation of the dynamic network behavior of offshore windparks and their grid connection with main focus on the system stability of the offshore grid and the overall system. In order to investigate the impact of the wind fluctuation on the onshore power system the maximum wind speed gradient has to be defined. For this the wind speed measurements of the FINO1 platform of the years 2006 are analyzed. Timeframes with very high variations of wind speed in the range of 1.2 m/s per second are identified and a profile with millisecond time steps is interpolated. Using that "worst case" wind profile together with the model of the wind turbine a variable power infeed is created and interpreted in terms of system interaction.**

Index Terms-- Offshore wind power; HVDC; wind speed gradient; system stability

I. INTRODUCTION

In the area of the German North Sea a lot of offshore wind power activity takes place. There are around 58 offshore wind parks (OWP) planned with a total number of more than 4500 wind turbine generators (WTG). The most wind parks will have a distance to the nearest suitable grid connection point of around 120 to 250 kilometer and a water depth of 20 to 50 meters. The first parks to be built are the test site 'Alpha Ventus' and the first commercial one 'BARD Offshore 1', both started construction in 2009. Because of their location the OWP were combined into four clusters. Cluster DolWin, BorWin, SylWin and HelWin (see fig. 1).

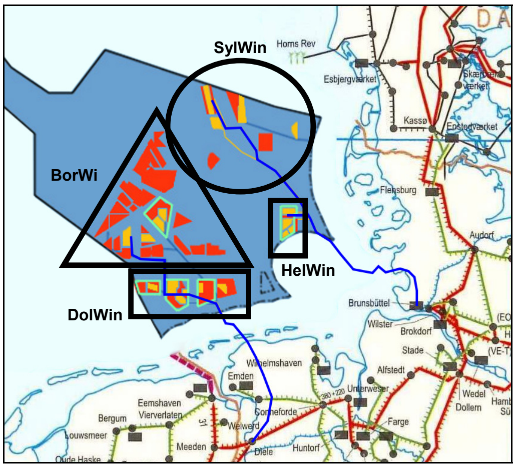

Fig.1: German North Sea area [2,3].

These clusters will be in the most cases connected to the nearest suitable onshore grid connection point via voltage source converter high voltage direct current (VSC HVDC) transmission. The VSC HVDC technology has multiple advantages compared to line commutated current HVDC or AC transmission. The most important advantages especially for offshore use are [5]:

- Inherent startup capability
- Enhanced Stability of power transmission together with long cables
- Decoupling the offshore and the

onshore grid resulting in maximum support of the wind generators during fault condition

- No synchronous compensator in the offshore grid is necessary
- Compact site area
- Lower losses in the transmission cables compared to AC transmission due to the lack of dielectric losses
- Independent active and reactive power control on both converters (within ratings)
- Dynamic control of the AC voltage in the offshore grid

The aim of this paper is to get a good understanding of the variation of the wind turbine generator power infeed caused by variations in wind speed considering the dimension of an offshore wind park. Because of the dynamic behavior of the onshore transmission grid changes of power infeed can lead to oscillations in the whole system and under special circumstances to instabilities of it. The paper describes the correlation between the fast changes in wind speed and the corresponding power infeed profile.

Figure 2 shows a typical layout of an offshore wind park consisting of 80 wind turbine generators and two 3-winding transformers. The distances between the windmills are 1000 meters in each direction. If a wind direction is assumed like it is marked in Figure 2 a sudden change in wind speed would be visible in the power infeed of the different generators but with a delay of:

$$t_d = \frac{1}{2} \bullet \frac{\sqrt{(1000m)^2 + (1000m)^2}}{wind\,speed\,[m/s]}\,[s] \quad (1.1)$$

To find the maximum variation of the power infeed a realistic wind speed profile is needed. For the year 2006 the FINO 1 platform collected nearly 300 million measured values for wind speed and direction in a one second interval [4]. To extract a realistic wind profile with high variation of wind speed the software Matlab was used.

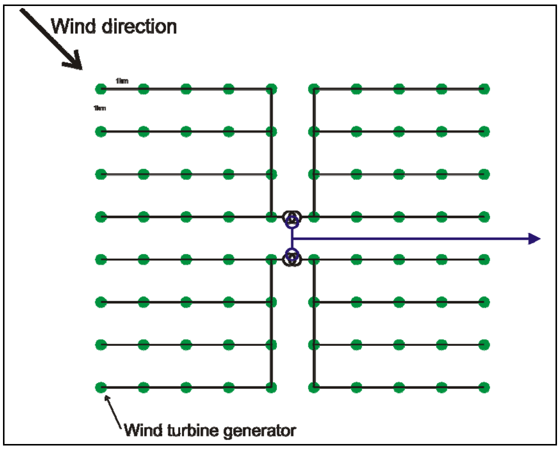

Fig. 2: Typical OWP layout.

All measured values were imported into Matlab and sorted into an array. After that only the wind speed values in a height of 90 meters were extracted. Within these around 24 million values the time with the greatest wind speed gradient was demanded. With the help of an automated script all values were compared with the respective next value to find out the gradient. The mean gradient value of a time frame of 150 second was calculated and compared to a preset value to extract the wanted high wind speed variation time.

Figure 3 shows 1800 seconds of the wind speed measurements in 90 meters height in one second increments of March 6^{th} 2006. At this time high fluctuations occurred. The maximum wind speed was 15.4 m/s and the minimum 4.5 m/s with a mean wind speed of 9.7 m/s. In the year 2006 were periods of time with higher wind speed gradients but with a maximum wind speed near or higher as the switch off value of the wind turbine generators. The limit for mean wind speed of 5 minutes was set to 10 m/s.

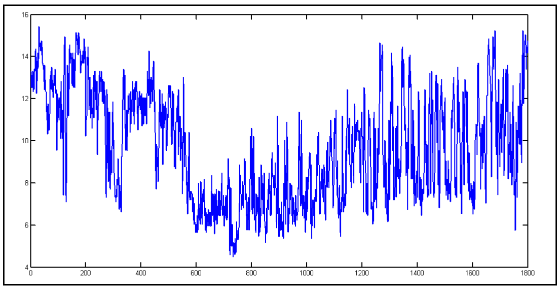

Fig. 3: Wind speed [m/s] in 90 meter height, measured at FINO 1 at the 6th march 2006.

Using the wind speed and the equation 1.1 the delay t_d between the generators is calculated. Each generator of the simulated wind park gets a 5 minute cut out of the profile in figure 3 depending on its position inside the wind park as an input value to calculate the power infeed. As a model of the wind turbine generators a standard double fed induction generator (DFIG) model of the used software PSS™ Netomac is chosen (see figure 4). All simulations were done in stability mode with a time step of one millisecond.

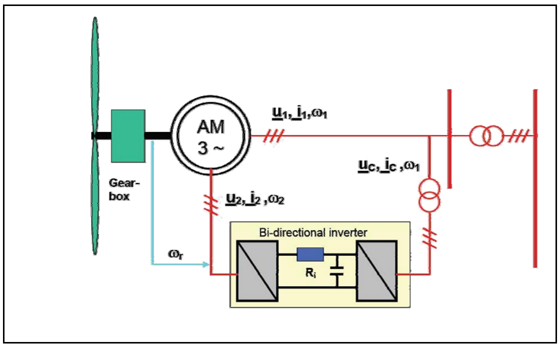

Fig. 4: DFIG wind turbine generator model [1].

II. RESULTS

Because of the 45 degree angle of the wind direction to the rows of wind turbine generators between one and eight generators get the same wind profile and as a result nearly the same power infeed (little differences are possible because of little differences in the voltage values inside the wind park). Figure 5 shows the wind profile and the resulting power infeed of one wind turbine generator.

The maximum infeed is 4.72 megawatt and the minimum is 0.48 megawatt. Within 16 seconds the infeed reduces from 4.7 to 3.2 megawatt (time step around 100 s). Later a decrease from 3.12 to 0.8 megawatt during a time of 60 seconds was calculated (time step around 200 s).

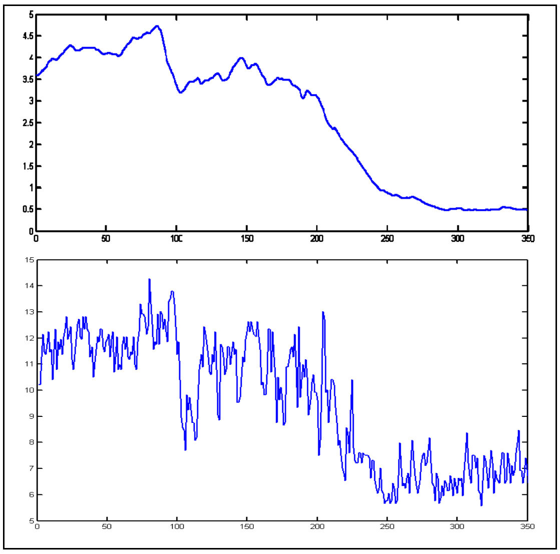

Fig. 5: Power infeed [MW] (top) and wind profile [m/s] (bottom) of one wind turbine generator.

The gradients of one generator seems to be very high but together with the other wind turbine generators of one park a balancing effect smoothes the infeed of one wind park. Figure 6 shows the infeed of different generators in the same wind park. There are great differences in the power infeed of each generator caused by the delay mentioned above. The range is between <1 megawatt and 5 megawatt each at the same time.

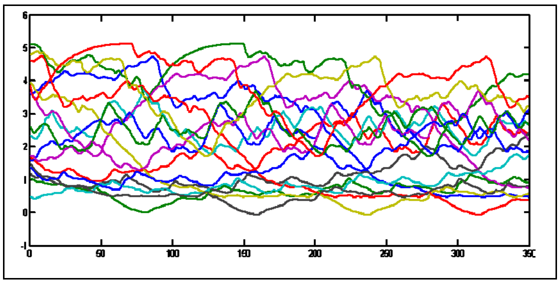

Fig. 6: Power infeed [MW] of 17 wind turbine generators in one wind park.

The superimposed power infeed of all wind turbine generators of one offshore wind park is shown in figure 7.

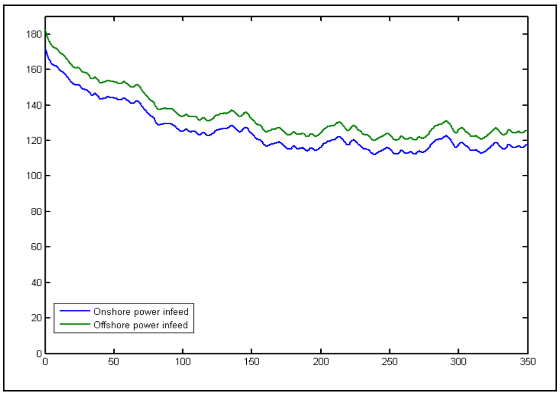

Fig. 7: Power infeed [MW] of one wind park into the offshore HVDC converter and into the onshore grid.

Compared to the wind profile and the infeed of each wind turbine generator the fluctuation is much lower. A decrease of 14 megawatt in 16 seconds seems to be the maximum short term power gradient. That is a mean decrease per wind turbine generator of around 0.18 megawatt. The long term variation is a reduction of 60 megawatt (0.74 megawatt mean value per wind turbine generator) within 190 seconds. The smoothing effect is clearly visible. Figure 8 compares the mean infeed of all wind turbine generators and the infeed of a single generator.

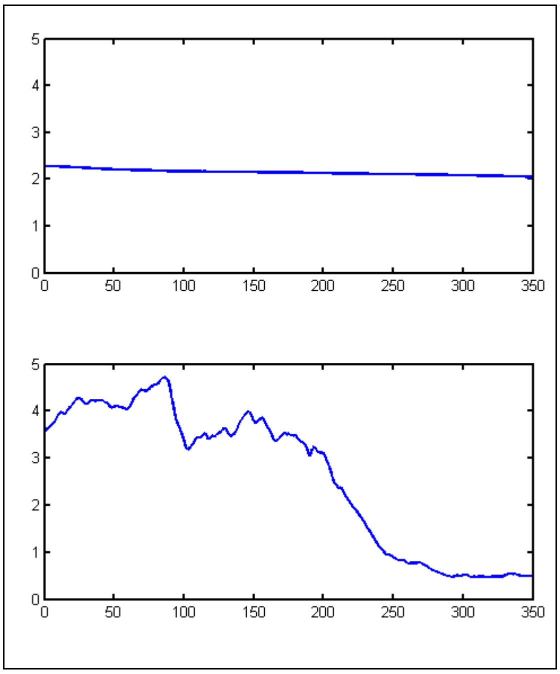

Fig. 8: Power infeed of one (bottom) generator and mean infeed over all wind turbine generators (top) [MW].

The VSC HVDC link has nearly no influence on the variation. Only the transmission and converter losses bring the infeed to a lower level but the curve has the same characteristic.

The voltage variation at the terminals of the 150 kV side of the wind park transformer is very low (see fig. 9).

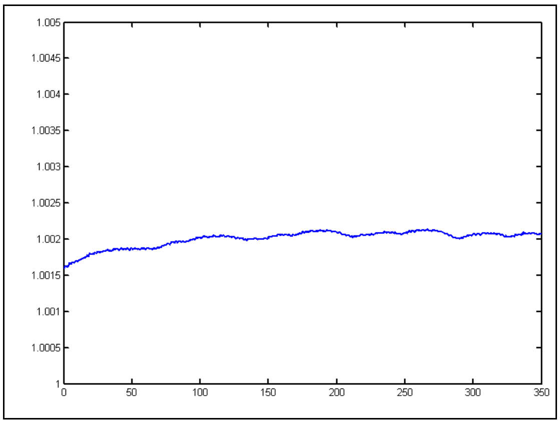

Fig. 9: Voltage [pu] at the 150 kV terminals of the wind park transformer.

III. CONCLUSION

The variation of power infeed for single wind turbine generators depends very strong on the wind profile. Because of the inertia of the wind turbines a smoothing effect can be seen. Nevertheless the variation in the studied high fluctuation wind speed scenario was up to 1.5 megawatt within 16 seconds respectively 6 megawatt per minute for a single wind turbine generator.

Because of the dimension of an offshore wind park the power infeed also varies with the location of the single wind turbine generator within the wind park. The superposition of the infeed of all wind turbine generators provided the combined infeed of the wind park. The short term fluctuation is reduced to a mean value per wind turbine generator of 0.18 megawatt in 16 seconds (0.675 megawatt per minute). The HVDC link has nearly no influence to the characteristic of the infeed. It is anticipated that the combination of many offshore wind parks with different locations within an offshore wind park cluster will further improve the smoothing effect.

In ongoing studies the model of the fluctuating infeed is used to investigate the dynamic interaction between the onshore and the offshore grid under different loading scenarios.

IV. REFERENCES

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V. BIOGRAPHIES

Thomas Ahndorf received in 2004 his diploma in electrical power engineering and automation from the University of Applied Science in Karlsruhe, Germany. After this he started a postgraduate study also at the University of Applied Science in Karlsruhe and received his Master degree in Electrical Engineering in 2006 with distinction. Since 2006 Mr. Ahndorf worked at the Associated Institute of Power Transmission Systems of Technische Universität München as a Ph.D. student. His research is focused on the grid connection of large scale offshore wind power. Mr. Ahndorf is a member of the VDE

Rolf Witzmann received the Dipl.-Ing. (M.S.E.E.) and the Dr.-Ing. (Ph.D.E.E.) degrees from Technische Universität München in 1982 and 1989, respectively. From 1990 to 2004 he was with Siemens AG in Erlangen, Berlin and Frankfurt. For more than 10 years he was Senior Consultant and Director in the Network Analysis and Consulting Division of the Power Transmission and Distribution Group. His fields of activity were stability of large interconnected power systems, HVDC-transmission, FACTS (Flexible AC Transmission Systems) and power quality. After this he was active in research and development being responsible for the R&D project in High-Temperature-Superconductivity. From 2002 he was head of technology department of the Medium Voltage Division of the Power Transmission and Distribution Group. In December 2004 Rolf Witzmann was appointed professor of Technische Universität München, Associated Institute of Power Transmission Systems. His main fields of activity are system stability, decentralized generation of renewable energy and the impact on the transmission and distribution systems.