METHOD FOR THE PROVISION OF NEGATIVE TERTIARY RESERVE BY WIND FARMS

André Baier, Markus Speckmann

Fraunhofer IWES, Kassel, Germany

Nowadays wind farms do not provide frequency control in Germany. Because of the increasing wind energy generation, wind farms will have to provide this ancillary service in the future. Even though the provision of frequency control by wind farms has become a big research field, no work has yet been done concerning the proof of the provision. Thus in this paper a new concept is presented how wind farms can prove the provision of frequency control. Moreover a method for calculating the available amount of frequency control power based on probabilistic forecasts is described. An economic analysis is conducted for three different wind farms and a virtual power plant, consisting of these wind farms, participating at the market for negative tertiary control power in Germany.

frequency control, wind farms, probabilistic forecast, tertiary control, available active power

1. Introduction

Because of the increasing installation of renewable energy sources, the energy system in Germany is changing towards a more decentralized and intermittent power production. Consequently in the future renewable energies will have to take over the provision of ancillary services which is nowadays mainly done by conventional power plants. Frequency control is one important ancillary service. As it is described in many studies [1] wind farms will have to provide frequency control in the future. A lot of work has already been done in this research field. Two research fields are the calculation of the amount of needed frequency control [1], [2] and developing measures to handle the decreasing of inertia due to the extension of wind energy [3], [4]. Another research field is the development of control strategies for the provision of frequency control by wind farms [5], [6]. Until now no work has been down concerning the proof of frequency control provision by wind farms. Therefore a concept is presented here (chapter II). Another field of study which received little attention yet is calculating the amount of available frequency control power. Herein we describe a method based on probabilistic forecasts (chapter III). Closing an economic analysis is made for the German negative tertiary control market for three different wind farms and a virtual power plant consisting of theses wind farms (chapter IV).

2. Proof of frequency Control provision with wind farms

State of the Art

Nowadays the proof of frequency control provision is done by comparing the planned power production with the real power production. Usually the transmission system operator (TSO) gets the planned power production at the previous day [7]. If the TSO calls frequency control power, the difference between the planned power production and the real power production must equal the amount of frequency control power. This method is suited for controllable power plants, like coal power plants or biogas plants since they can follow a planned power production made at the previous day.

For wind farms there are only two possibilities to keep a planned power production. One is reducing their planned power production thus increasing the probability of reaching it. This possibility is illustrated in Fig. 1. On the y-axis the normalized power of a wind farm is outlined. The graphs in fig.1 illustrate different security levels. The topmost graph resembles a security level of 90%, the lowest graph resembles a security level of 99.9%. Security level of 90% means that the probability is 90% that the real power production is above that 90% graph. The graphs display probabilistic day-ahead forecasts. The area in the background equals the real power production.

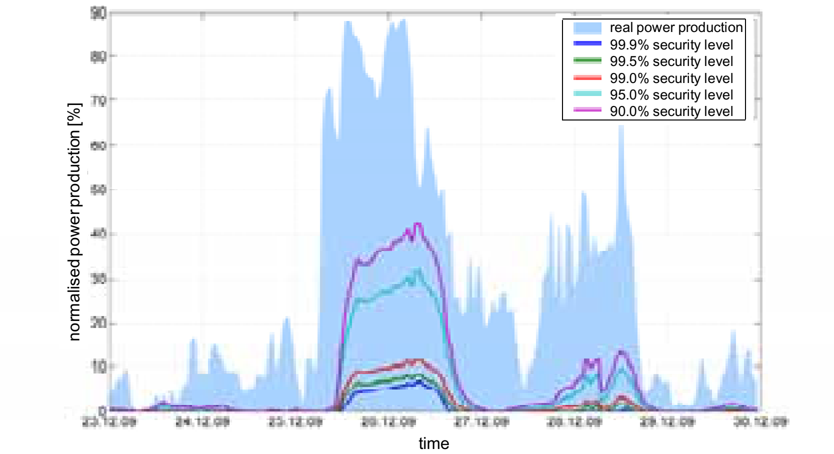

Fig. 1. Illustration of probabilistic wind power forecasts (day-ahead) for different security levels and of the real power production of a wind farm [8]

As it can be seen, already for a low security level of 90% a great amount of energy is lost. Therefore this solution is neither economic nor ecologic.

The second possibility of keeping a planned power production is the combination of a wind farm with storage. This was done in [9]. Here the participation of a virtual power plant consisting of a wind farm, a pumped storage plant and a biogas plant at the negative tertiary control market was investigated. The pumped storage plant was used to balance the forecast error of the wind farm. The result was that the participation of the wind farm has almost no effect on the amount of tertiary control offered by the virtual power plant. This is due to the fact that the amount of power of the pumped storage plant, needed for balancing the forecast error of the wind farms, equals the amount of tertiary control, which can be provided by the wind farm. It can be expected that the results are different if the virtual power plant consists of more than one wind farm localized in different regions. This would lead to a better wind forecast and thus to a lower amount of power from the pumped storage plant needed for balancing the forecast error. Nevertheless the disadvantage of optimizing subsystems remains leading to an unnecessary high amount of storage. This is due to the fact that sometimes the pumped storage plant of the virtual power plant will operate in a different direction than the frequency control in the control area. This is always the case, if the forecast error of the wind farm is in a different direction than the call for frequency control in the control area.

New Concept for Proving the Provision of Frequency Control by Wind Farms

Since both possibilities of keeping a planned power production with wind farms explained in the chapter before have disadvantages this leads to the following conclusion. Wind farms do not provide frequency control or the verification of the provision is changed for wind farms.

In [8] we developed a new proof, which is illustrated in Fig. 2. This concept has neither the disadvantage of loosing wind power nor the disadvantage of optimizing subsystems leading to an increased amount of storage.

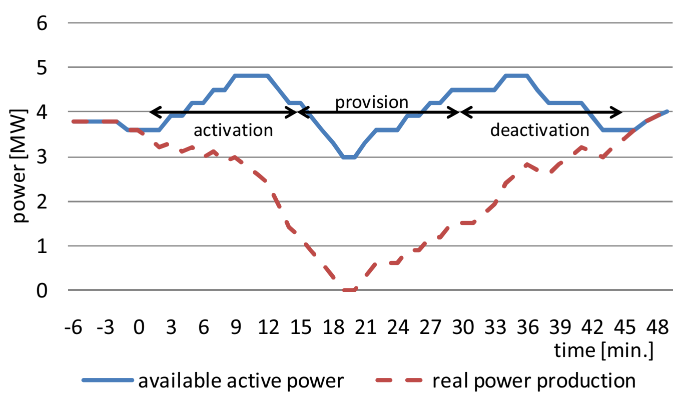

Fig. 2. Illustration of the new concept for proving the provision of frequency control, by comparing the available active power (upper graph) with the real power production (lower graph) [8]

The proof is done by comparing the available active power (upper graph) with the real power production (lower graph). The available active power equals the power production of the wind farm if the power was not reduced. Fig.2 illustrates the example of providing tertiary control with the wind farm. In the first 15 minutes the tertiary control is activated (activation). Than the provision of tertiary control is hold constant for 15 minutes (provision) and afterwards the tertiary control is deactivated within 15 minutes (deactivation).

Determining the available active power brings some difficulties. Current methods [13] do not consider shadowing effects, thus leading to an overestimation of the available active power.

The available active power can also be used for other purposes. For example for the operation of the transmission or distribution network. Another field of application is short term forecasting of wind power production, because an input data for the short term forecast is the current power production.

3. Calculating an offer for the provision of frequency control

In general wind power possesses volatile characteristics. Therefore an offer for wind farms to be placed at the negative tertiary reserve market should be based on meaningful wind power forecasts. The use of ordinary point wind power predictions is not advisable in this context because of forecast errors. A failure to fulfill the contracted capacity could be fined and moreover contradicts the meaning of frequency control power. To manage this risk of failure we propose a method to determine an offer based on probabilistic wind power forecasts. Ordinary wind power point forecasts are only able to estimate the amount of wind power which could be expected for the future point in time. In contrast probabilistic wind power forecasts estimate the probability distribution of the wind power feed-in for a future point in time. More precise the probability distribution of the random variable X_t at the point at time t. This probability distribution could then be used to determine the probability of occurrence $P(X_t \leq x)$ of any wind power feed-in x. An example for the forecasted probability distribution for wind power feed-in is displayed in Fig. 3.

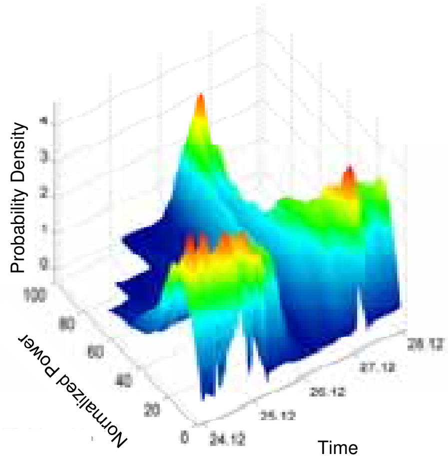

Fig. 3. Example for a forecasted probability distribution for wind power feed-in for a certain period of time. Each time step represents a probability distribution function.

For an offer of negative frequency control it is important to know the amount of wind power which could be expected with a certain level of security S. This amount is the wind power x for the security level $S = 1 - P(X_t \leq x) = P(X_t > x)$. Thus the offered negative frequency control is the $(1 - S)$ - quantile of the forecasted probability distribution for the time step t. In other words the wind power for which the probability to fail to deliver the offered wind power is $(1 - S)$.

Example Negative Tertiary Control Power

The german tertiary control power market is a day ahead market in a four hour time resulution. An offer therfore has to be uniform for one four hour block. Thus the maximal possible offer is the four hour minima of the quantile forecast with the securety level S or the probability $(1 - S)$. An illustration of an offer is given in Fig. 4. An example for an actual offer is displayed in Fig. 5.

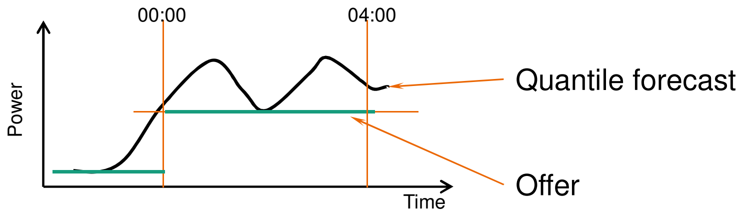

Fig. 4. Illustration of the determination of an offer for negative tertiary control power using the (S-1)-quantile of a probabilistic forecast.

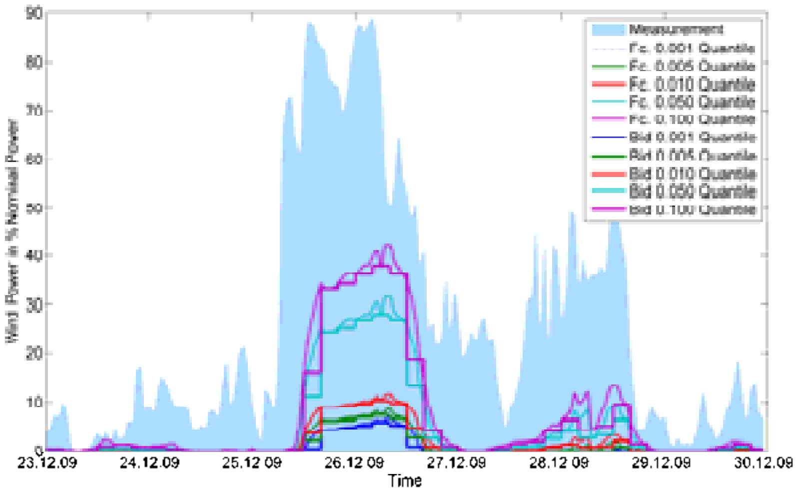

Fig. 5. The (1-S)-quantile forecast for security levels of 99.9%, 99.5% 99.0%, 95% and 90% and the corresponding offers.

This calculation of offers is done for the whole year 2009 for three wind farms wf north, wf middle and wf south. These wind farms are located in the north, middle and south of the 50Hertz Transmission zone. Additionally offers for a virtual power plant (vpp) consisting of the three wind farms are analyzed. The probabilistic forecast for the vpp for each time step $P(X_{vpp,t} \leq x)$ is the combination of the three single probabilistic forecasts under the assumption that these wind farms are stochastically independent. Under this assumption the probabilistic distribution function (pdf) of $X_{vpp,t}$ is the convolution of the single pdf of the three wind farms. More general:

$$X_{vpp,t} = \sum_{i=1}^{n} X_{i,t} \quad : \quad f_{vpp,t}(x) = (f_{1,t} * \ldots * f_{n,t})(x) \quad t \in [t_{Start}, t_{End}].$$

The result of the analysis for the vpp and the sum of the three different wind farms for 2009 is given in Fig. 6. Here the proportion of the offered negative tertiary control power of the overall production is displayed.

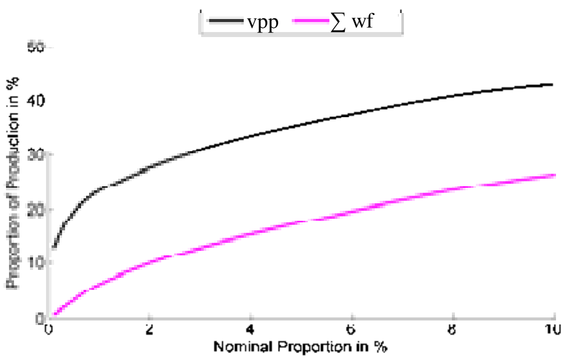

Fig. 6. Proportion of the offered negative tertiary control power of the overall production for 2009 against the probability to fail of delivering (1-S).

One obvious result of the analysis is a huge improvement of the available negative tertiary control power for the vpp in comparison to the sum of the three different wind farms. This behavior can be observed over all probabilities to fail from 0.1% to 10% or in terms of security level from 99.9% to 90%. Where the sum of single offers can't offer any noticeable amount of negative tertiary control power for the security level of 99.9%

the vpp is able to deliver around 13% of the overall production in 2009. For a security level of 90% the sum of the single offers is 27% and for the vpp 43% of the overall production.

The results show a great influence of spacial balancing effects to the predictability of the volatile wind power. Thus, the offers for negative tertiary control power increase for the vpp in comparison to the sum of the single offers for the same security level.

4. Economic analysis

With the results from chapter IV an economic analysis was conducted. For the three different wind farms and the virtual power plant the profit was calculated, if they had participated at the German market for negative tertiary control power in 2009. At this market the six four hour intervals of the next day or the following days in case of weekends or public holidays are traded at every working day at ten o´clock in the morning [10].

The analysis was conducted for different security levels of the offer. Since the tertiary control market is a pay as bid market, the calculation were done for three different prices per kilowatt. The low price equals the lowest price in the particular four hour interval. The medium price equals the average price and the high price the highest price in the four hour interval. The prices can be downloaded on the internet platform of the TSO (www.regelleistung.net).

The profit at the negative tertiary control power market equals the income resulting from the price per kilowatt minus the penalty for not providing frequency control power. On the one hand, the income rises with lower security levels, since more tertiary control can be offered. On the other hand, the penalty increases with lower security levels, since the occurrence of times in which the wind farms or the virtual power plant cannot provide the offered tertiary control rises. The income is calculated by multiplying the price per kW of the particular four hour interval with the offered tertiary control. The penalty is calculated by multiplying three with the EPEX spot price (Day-Ahead market) at the particular hour in which the wind farms or the virtual power plant could not have provided the offered amount of tertiary control with the difference between the offered tertiary control and the available tertiary control of the wind farm [14]. Moreover the wind farm or virtual power plant doesn´t get a price for kW for the not available tertiary control.

Prices per kWh were not considered since negative tertiary control is rarely called in Germany [15]. Moreover it can be expected that wind farms will have a high price per kWh compared to controllable power plants like coal power station, which can save fuel cost in case of a call for negative tertiary call. Consequently they will be among the last plants on the merit order list of the TSO and thus deployed rarely.

In the economic analysis it was not considered if the wind farms were paid according to the Renewable Energy Law (EEG), if they participated at the spot markets or if they conduct other possibilities of direct marketing.

For every wind farm and for the virtual power plant 18 scenarios were calculated since six different security levels and three different price levels were considered.

Fig. 7 illustrates the results for the highest price per kW, for six different security levels and for each wind farm and the virtual power plant.

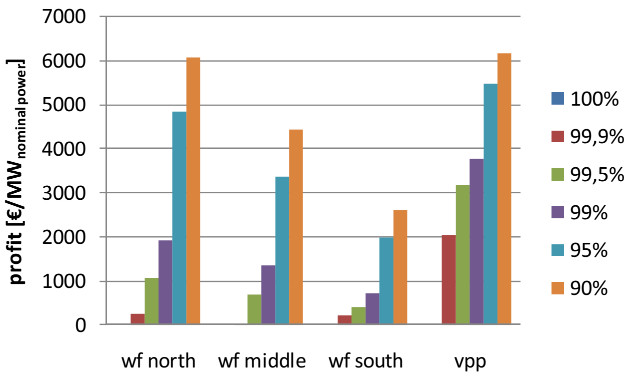

Fig. 7. Results of the economic analysis showing the profit of the different wind farms and the virtual power plant for the highest price per kW at the negative tertiary control market in 2009 [8]

For all wind farms and the virtual power plant the profit increases with lower security levels. This means that the increase in income from a high security level to the next lower security level is always bigger than the increase of the penalty. This is not the case for the scenarios with the lowest price per kW for all wind farms and the virtual power plant. This is due to the fact, that the increase of the penalty from a security level of 95% to a security level of 90% is bigger than the increase of the income.

Since the wind farm north has got the highest full load hours, its results are the best, compared to the other wind farms. The virtual power plant has got the best results. This is because of balancing effects between the wind farms, which can only be used if they are combined in a virtual power plant. If for example all wind farms shall provide four MW of negative tertiary control, but the power production of wind farm south is only three MW, wind farm north can take over the provision of the missing MW, if its available active power is bigger than five MW.

It must be mentioned that in the year 2009 the prices per kW were very high at the negative tertiary control market, compared to the following year [11]. Thus the results cannot be transferred to 2010 or to the current situation on the negative tertiary control power market.

A comparison between the profit at the negative tertiary control power market and the income according to the EEG is made. This is done for the virtual power plant. Assuming a payment of 9,41 Cent/kWh [12] the virtual power plants gets circa 131000 €/MW and year. For a security level of 90% (99%) and the highest price per kW the profit is 6148 €/MW (3775 €/MW) respectively 4,7 % (2,9%) of the EEG income. For the lowest price per kW and a security level of 90% (99%) the profit is 1323 €/MW (1209 €/MW) respectively 1% (0,9%) of the EEG income. The results show, that the attractiveness of the negative tertiary control power market for a wind farm operator depends strongly on the security level and the price per kW.

5. Other aspects

There are also other aspects which have to be considered concerning the provision of frequency control by wind farms.

One is the legal framework. The actual EEG [12] forbids the provision of frequency control for power plants within the fixed price payment of the EEG. Since most wind farms take this payment the potential for frequency control decreases dramatically due to this regulation.

Moreover the regulation framework of the network operators have to be adopted [16]. This concerns the procedure of the prequalification and the data transfer between the TSO and the wind farm operator.

An interview with a manufacturer of wind mills showed, that the provision of frequency control does not affect the manufacturer's guarantee [8].

6. Conclusion

A new concept for proofing the provision of frequency control with wind farms was presented and its advantages compared to the actual method were discussed. This concept is based on the determination of the available active power. Moreover a method for calculating an offer for negative tertiary control based on probabilistic forecast was described. This method was applied to three different wind farms and the combination of these wind farms in a virtual power plant for the year 2009. Here the proportion of the overall production differs from about 0% to 43% depending on the security level with great advantages for the virtual power plant. The results of an economic analysis for the different wind farms and the virtual power plant were presented. The profit differs from nearly 0 €/MW to 6149 €/MW depending strongly on the security level and the price per kW. The combination of the wind farms in a virtual power plants leads to higher profits, due to balancing effects. Due to the extension of wind power it can be expected that this research field will gain more interest in the following years.

In a future project with the participation of the Fraunhofer IWES a method for a more exact determination of the available active power considering shadowing effects will be developed.

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9. Biographies

André Baier finished his studies of Mathematics in 2006 and received his Master degree in Renewable Energies and Energy Efficiency in 2009. He gained his professional experiences at the Institute of Air Handling and Refrigeration (ILK) and the German Aerospace Center (DLR). He is now research engineer of R&D Division Energy Economy and Grid Operation at the Fraunhofer IWES in Kassel. Mr. Baier’s current main R&D interests are the development of probabilistic energy forecasts and the management of virtual power plants consisting of renewable energy generators.

Markus Speckmann received the energy system technology engineer degree in 2007 from the Clausthal University of Technology. Between 2007 and 2008 he worked for the Fraunhofer ISE in Fribourg where he also wrote his diploma thesis about organic solar cells. He is now research engineer of R&D Division Energy Economy and Grid Operation at the Fraunhofer IWES in Kassel. His main topic is the integration of renewable energies in the balancing market.