Impact of frequency control supply by wind turbines on balancing costs

Malte Jansen, Markus Speckmann, André Baier
Fraunhofer IWES, Kassel, Germany
Koenigstor 59, 34119 Kassel, Tel.: +49 561 7294 465, Fax: +49 561 7294 260
Email: malte.jansen@iwes.fraunhofer.de

Summary

The introduction of an optional market premium in the revision of the German Renewable Energies Act (EEG) gives renewable energy sources (RES) the possibility to participate in control reserve markets. Though the reform of the EEG has set the legislative framework for the integration of wind farms into the existing market structures, which led to the successful integration in power exchange markets, wind farms have not yet participated in control reserve markets in Germany due to unfavorable market conditions and unresolved problems with the market regulations.

The following study is assessing the economic impact of wind turbines participating in control reserve markets under different parameters. The assessment determines the maximum cost saving potential of wind turbines participating in secondary and tertiary control reserve markets. Results show that under current market conditions cost saving potentials can be achieved within the given scenarios. This will lead to decreasing balancing costs.

In the first part (chapter 4 & 5) of the study it is explained how the offers from wind farms can be calculated. In order to bid on control reserve markets the wind park operator has to calculate an offer, which is based on a defined security level for the forecast. Therefore the operator will use probabilistic forecasts to calculate the offerable amount of control reserve. In the second part (chapter 6) these offers are entered into existing control reserve dispatch lists. The economic impact is evaluated as the difference between two scenarios. One that will serve as the reference scenario without wind turbine participation and one that includes the bids from wind farms. By this means different parameters are examined. This includes the variation of the security level, changes in the block length of control reserve products, bidding for positive and negative products and differences in the mechanism to proof the provision of energy from control reserves for intermittent producers. Results show that cost saving potentials can reach up to 21 % in tertiary control reserve market and up to 24 % on secondary control reserve market.

Keywords: wind integration, control reserve, wind farms, tertiary control, secondary control, available active power, probabilistic forecast

1. Introduction

By 2011 the share of electricity from renewable energy sources (RES) in Germany has reached 20 % [1] and has therefore noticeable effects on the secure operation of the transmission system. With the increasing share of RES in the grid, difficulties with the system's stability may occur. In this context RES have to deliver ancillary services such as control reserve. Not only controllable RES are able to provide those services, but also intermittent production like wind turbines and photovoltaics. The introduction of an "optional market premium" in the revision of the German Renewable Energies Law Act (EEG) gives RES a possibility to participate on control reserve markets [2].

Though the revision of the EEG has set the legislative framework for the integration of wind farms into the existing market structures, which led to the successful integration in power exchange markets, wind farms have not yet participated in control reserve markets in Germany. The lack of proper regulations for intermittent power producers hinders the entry of wind power in such markets. By now regulations are designed for the participation of conventional power plants in control reserve markets. In particular the mechanism to proof the supply of control reserve and the placement of bids prevent the wind turbine operators from the participation in such markets.

In the next chapter the data that was used is described, followed by a description of the model itself. Afterwards it is explained in detail, how wind farms can offer regulating power and how these offers influence the costs for regulating power. Finally the results of the assessment will be shown.

2. Data

The assessment of the impact of wind turbine participation on control reserve markets is based on historical data.

2.1 Market Data

The assessment is performed under the assumption that wind farms participate on regular energy markets with a perfect price forecast. This is the first approach to evaluate the economic value of wind turbines in control reserve markets. In this assessment it is assumed that energy from wind turbines is traded on the EPEX Spot Market.

Control reserve capacity prices are linked to power exchange prices. A wind farm operator that offers e.g. positive control reserve instead of selling the energy on the market will suffer from economical disadvantages. This means that energy which could not be sold on the market needs to be compensated financially by the income from control reserve participation.

Due to the fact that the whole assessment is based on the German energy system, market data from the EPEX Spot for the day-ahead and intraday products [3] is used. Data is available from January 2007 to December 2012.

Balance responsible parties are charged for deviations from the production to the announced schedule with the imbalance settlement price for each time period [4].

2.2 Wind Farm Data

The wind farm data was used from sources at Fraunhofer IWES. Several data sets were used. Day-ahead forecasts for several wind farms are available from January 2009 to February 2011, intraday forecasts from January 2010 to December 2010. The time series for the power feed-in of a set of wind farms is available for the time from January 2009 to February 2011. All data is available normalized for several wind farms and is merged and upscaled in order to represent the whole German capacity of wind turbines.

2.3 Control Reserve Data

For the calculation of the economic impact, control reserve data was used. For the investigation of the two considered markets “secondary reserve” and “tertiary reserve” [5] two sets of market data are necessary. Each set contains merit-order lists and dispatch time series for the respective control reserve type.

Market data (merit-order lists) for both types are available at regelleistung.net [6]. The dispatch of minute reserve is available at the homepages of the Transmission System Operators (TSOs) [7]. Access to dispatch of secondary control is granted on demand by one of the TSOs [8].

2.4 Time frame

As a result of the limited data availability the time period is reduced to July 2010 to December 2010. These six months represent the modeling period.

3. Model

The model to assess the economic impact of wind turbines participation on control reserve markets is divided into two parts:

In the first part the offer for the control reserve market from wind the farm operators’ point of view is calculated. The underlying assumption is that the whole wind turbine capacity in Germany is treated as one single wind farm which is operated together. The calculation of the bids from the wind farms is shown in chapter 5.

The second part assesses the economic impact on the system. The bids created in the first part are placed on the control reserve market by the wind farm operator. These bids are compared to each position in the merit-order list that is valid at the moment for the chosen type of reserve. A more detailed description can be found in chapter 6.

The assessment is performed on secondary control markets as well as on minute reserve control markets. Wind farms would not be able to participate in markets with longer tendering periods due to the forecast uncertainties. In order to assess cost saving potentials in the secondary control reserve market an adjustment was necessary. In contradiction with current market regulations secondary control in this model is tendered daily instead of a weekly tendering. This is done in order to enable wind turbines to offer on secondary control markets.The participation of wind turbines would reduce the costs of the most costly control reserve market in Germany.

The assessment includes the variation of input parameters. The most important requirement, when systems security is considered, is the security level of the offer of control reserve power. Defining security levels will be subject to further considerations when it comes to the integration of intermittent producers into control reserve markets. For the assessment security levels from 95 % to 99.99 % are examined. A security level of 95 % means that with a probability of 95 % the power output is equal or higher than the offer.

The second parameter considered is the length of the products that are tendered in the control reserve markets. The secondary reserve products are tendered weekly with a lead time of five days for high tariffs (8 a.m. to 8 p.m.) and low tariffs (8 p.m. to 8 a.m.) [9]. The length for a block is twelve hours. Tertiary reserve products are tendered daily. The product length is four hours [10]. The Model will assume daily day-ahead tendering for product lengths of 1, 4 and 24 hours for secondary and minute reserve. Another assessment evaluates the influence the proof method (see chapter 4).

The assessment will be performed within the legislative framework of the German Renewable Energies Act (EEG) with exception of the above-mentioned assumptions.

4. Verification of control reserve provision for wind farms

The proof method for the provision of control reserve can have an influence on the control reserve offer bids. That is why it will be assessed how the wind turbine participation on control reserve markets under the current regulations would perform in comparison to a mechanism that has been developed at IWES.

Now the verification is done by calculating the difference between the scheduled power production and the real power production, as it can be seen in Figure 1. This difference has to match the control reserve power. This method applied to wind farms means that the wind farm operator has to deliver a day-ahead schedule and is enforced to keep it, which can only be reached by down-regulating wind turbines or balancing the wind farm with storage. Both solutions are neither economic nor ecologic [11].

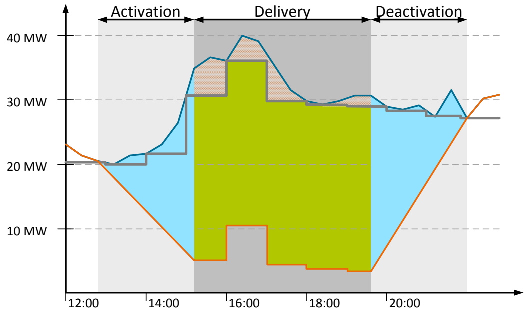

Figure 1: Current concept for proving the provision of frequency control (schematic)

This leads to the conclusion that this proof method, as it is described above, is not favorable for intermittent producers and will eventually prevent wind farms from entering the market. The current proof method is also applied and implemented in the TWENTIES project [12]. The economic advantages of the new proof method is considered in this study.

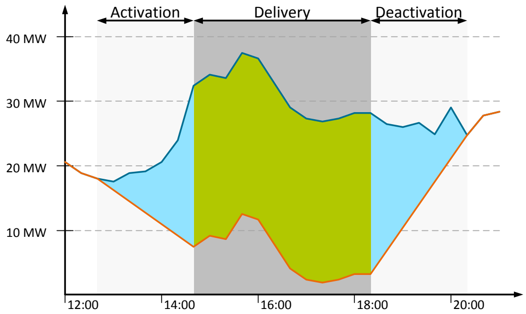

Figure 2: New concept for proving the provision of frequency control (schematic) [13]

Instead of applying the existing proof method to wind farms a new proof method has been developed by Speckmann et al. [13] which can be seen in Figure 2. The proof is performed by comparing the available active power (blue line) with the real power production. Available active power is the power that would have been produced if the wind farm would not have been down-regulated.

This concept overcomes the disadvantages that come along with the application of the current method to wind farms.

5. Control reserve offer from wind farms

In order to place an offer the wind farm operator will have to calculate the amount of capacity that can be produced at a certain time with a certain security level. This implies the usage of probabilistic forecasts. In this study a statistical approach for the estimation of the different security levels is used. The n-dimensional Gaussian kernel density estimation [14] is used for the probabilistic forecast which allows including pre-errors into the calculation. The inclusion of pre-errors means that errors between forecast and feed-in that have already been identified are used for the improvement of the method. By this measure the quality of the forecast at the different security levels can be improved. This is only valid for intraday forecast. Due to the large lead-time of day-ahead forecasts pre-errors cannot be considered.

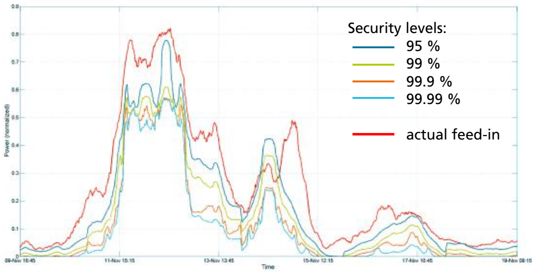

Figure 3: Illustration of probabilistic wind power forecasts (day-ahead) for different security levels and of the real power production of a wind farm

In Figure 2 the forecasts for different security levels can be seen. A security level of 99% means that with a probability of 99% the real power production is equal or higher than the forecast. In times with high wind power predictions the power that cannot be offered due to forecast uncertainty is relatively low compared to times with low wind power predictions. It can also be seen in Figure 3 that lower security levels may endanger system stability as the forecasted values for the 95 % and 99 % security level is higher than the actual feed-in which means that in case of a control power call at that time the required power can not be provided.

Offering control reserve will be more efficient in times with high wind power forecasts. One additional aspect is that energy exchange prices in times with high wind production are most likely lower than in the average. This loss can be compensated from revenues in the control reserve markets. Nevertheless it is likely that a dependency of the energy markets with the control reserve markets could take place, which would lead to decreasing costs of control reserve provision.

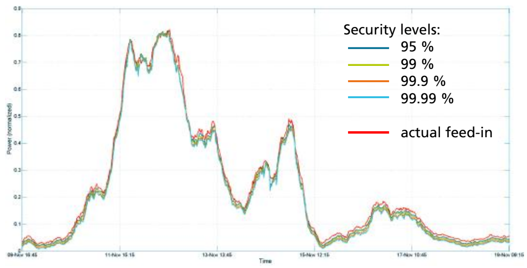

Figure 4: Illustration of probabilistic wind power forecasts (one hour intraday) for different security levels and of the real power production of a wind farm

In Contrast to the determination of forecast values at different security levels under day-ahead conditions the calculation of intraday forecast values can include pre-errors. As seen in Figure 4 the loss of energy for the forecasts at the different security levels is significantly lower than for the day-ahead forecast.

Capacity prices will depend on the predicted power feed-in at certain security levels. The decision taken by the wind farm operator on whether to bid on energy exchange markets or control reserve markets will depend on this. His minimum prices for the capacity will depend on the amount of energy he needs to down-regulate in order to provide control reserve as well as on the proof method for the provision of control reserve from wind farms.

The energy prices will depend on the costs of changing the production schedule. In the case of the German Renewable Energies Act (EEG) this would mean that the down-regulation (negative control reserve) of a wind turbine would cost the operator the income from the market premium and the trades in the energy market. Upward-regulation (positive control reserve) could then consequently lead to negative energy prices due to the fact that the additional energy is refunded with the market premium.

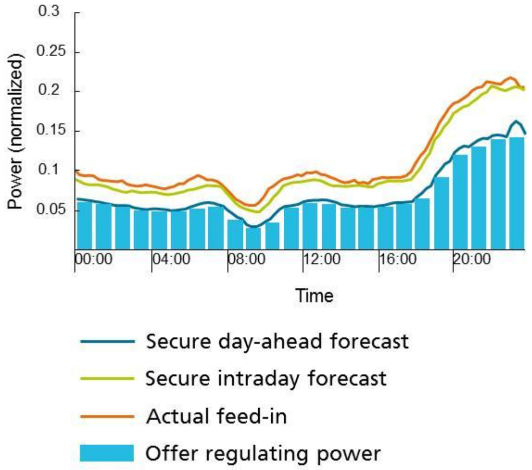

Figure 5: Schematic proceeding for offering Regulating Power

In Figure 5 the proceeding for trading energy and the offer of control reserve is shown:

1. Calculating secure day-ahead capacity
2. Placing control reserve bids
3. Selling residual energy on day-ahead markets
4. Calculating secure intraday capacity
5. Selling residual energy on intraday markets
6. Dispatch

The offers by the wind farm could vary depending on the input parameters. Different security levels and the product length have an impact on the amount of energy that could be offered into the markets.

The difference between the balance control and available active power proof mechanism does not change the amount of control reserve, which can be offered, but has an impact of the prices in the offer. Offers under the balance control mechanism will be less cost efficient than under the available active power mechanism for the same amount of control reserve power.

Wind farms also distinguish between bids for negative and positive control reserve. Therefore offering solely for positive or negative reserve markets is implemented as well as symmetric bidding. This reflects all possible bidding strategies of the wind farm operators.

6. Economic Impact

6.1 Replacing bids in the merit-order lists

After the calculation of the offers by the wind farm operator the bids are compared to existing merit-order lists that are valid for the particular hours. Control reserve units are tendered based on the capacity prices, applying the pay-as-bid principle. Within the tendering process bids with increasing capacity prices are accepted until the tendered amount is reached.

Based on this proceeding the original bids in the merit-order list are compared with the offer from the wind farm. Bids in the merit-order list are replaced, beginning with the highest capacity price, but only if the capacity price from the offer of the wind farm is lower than the capacity price in the merit-order lists. This will be repeated either until the capacity price of the offer of a wind farm is higher than the price in the merit-order list or the amount that could be offered by the wind farms is used up, or all bids in the merit-order list are already replaced by bids from the wind farms. This procedure is performed for every single set of offer that was provided by the wind farm operator.

Merit-order lists are adjusted to the different product lengths. This is done by the dividing the original capacity prices of each merit-order list according to the new product length.

Replaced bids are based on opportunity costs caused by the loss of income in the energy markets. These offers are entered into the merit-order lists in order to determine the maximum saving potential of wind turbines participating in control reserve markets.

However wind farm operators are bidding in these markets because they try to maximize their profits from operation. Another approach is based on market data of the control reserve market. Bids in the merit-order lists are not replaced by the capacity and energy price of the offer from the wind farms but prices from the bid that was replaced at last. This procedure is shown in Figure 6. These are also the minimum and maximum scenarios which will be evaluated alter on.

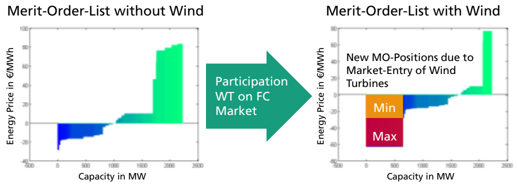

Figure 6: Replacing bids in merit-order lists

6.2 Calculating cost difference

Each of these modified merit-order lists are compared to the ones that have not been changed. The comparison includes the changes in capacity costs and in energy costs. A dispatch calculation was performed in order to calculate the energy costs. Both changes in the costs are summed up and compared to the scenario where wind turbines are not providing control reserves.

7. Results

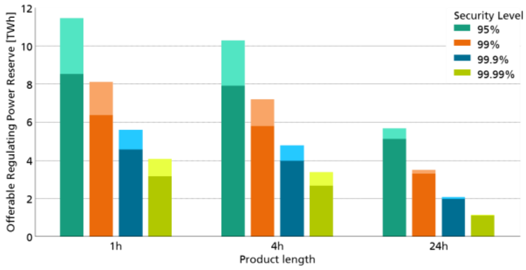

Figure 7: Offerable control reserve (lighter colors: theoretical potential; darker colors: potential with restrictions from the tendered amounts)

The offerable amount of control reserve from wind farms depends on the product length and security level. The theoretical potential at a security level of 99.99 % and a product length of one hour is 4.1 TWh. With a product length of four hours the potential would be 3.3 TWh and with a product length of 24 hours the potential would be 1.1 TWh. The theoretical potential is not restricted by the amount that is tendered by TSO. If this restriction is included then the potentials would be 3.1 TWh (1 hour), 2.7 TWh (4 hours) and 1.1 TWh (24 hours). The wind farm operator is free to offer this energy potential to positive and negative control reserve markets.

The Evaluation of the economic impact shows that cost reductions are realized mainly within the capacity costs. Possible cost increases by the dispatch costs do almost not influence the result. For the tertiary control reserve there was no cost change realized in the considered time frame which is due to the fact that reserve energy from wind turbines was not dispatched, due to their high energy price. For the secondary control reserve the cost change was less than 1 % of change in capacity cost.

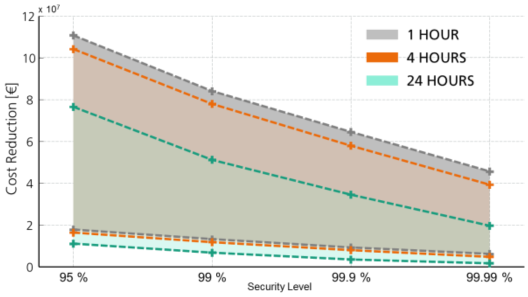

Figure 8: Economic Impact under different security levels and product lengths for secondary control reserve

In Figure 8 the results for secondary control reserve can be seen. The economic impact of the wind turbine participation on tertiary control reserve is significantly lower than on secondary control market. This is not only due to the smaller market size but as well to the lower prices in the tertiary control reserve market. By comparing the original dispatch costs with the scenarios relevant cost reductions can be identified. Under the 99.99 % scenarios maximum cost reductions of up to 21 % for minute reserve markets and up to 24 % for the secondary reserve markets could be achieved. For the secondary control reserve the cost saving potential for hourly products (at 99.99 % security level) then be from 6.001.717 € to 45.344.864 €.

Finally the influence of the proof mechanism can be seen in Figure 9. The underlying amount of control reserve power that was offered in both cases is the same. However the prices are different, so that in the case of available active power more bids from wind turbines would be able to enter into the merit-order lists.

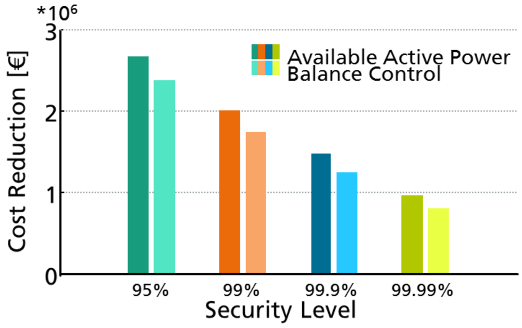

Figure 9: Difference between Balance Control and Available Active Power

The influence of the proof mechanism on the cost saving potential is increasing from lower to higher security levels. The cost saving potential of the new proof mechanism at a security level of 95 % is 12.1 % higher than with the balance control mechanism. At a security level of 99.99 % the cost saving potential is 20.2 % higher than under the balance control mechanism.

8. Conclusion

It has been shown how wind farms could participate in control reserve markets, that it is economically feasible for the operators and that it would generate overall benefits that reduce procurement costs. Additionally the participation of wind turbines would increase the competition in these markets. Due to the fact that wind farms can offer control reserve economically it is possible to generate additional revenue for the wind farm operators.

Wind turbines are currently not participating in control reserve markets. The proof for the delivery of services and unspecified regulations for intermittent producers prevent the market entry of wind turbines. Despite this fact wind turbines could generate cost reductions by up to 24 % (under the 99.99 % Scenario)

Wind turbines would be able to economically substitute fossil fuel fired power plants that would solely be run for the provision control reserve. This could lead to a reduction of the capacity for must-run units. Changes in the framework conditions could therefore lead to greater economic improvements and ease the market penetration of renewable energies.

In the ongoing research it will be evaluated how imbalance settlement prices will change for the balance responsible parties, if wind farms participate in control reserve markets. The model can be used to create offers for single wind farms. As soon as additional data is available the calculations will be re-done on a larger period of time. Additionally the approach will be applied to photovoltaics as well.

Acknowledgement

The work presented in this paper has been funded by the European Commission in the project “TWENTIES”.

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