POWER RESERVE PROVISION WITH WIND FARMS

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1. Abstract

Considering the relation between system frequency and power equilibrium, the technical characteristics of primary and secondary power reserve and the fact that traditional schemes regarding ancillary services are not directly transferable to wind power, a new concept is developed addressing how wind power could provide power reserve, both positive and negative, in a stable and reliable way.

The main challenge is to overcome the natural fluctuating characteristic of wind power through a process which provides the structure and the needed data flow allowing wind energy to contribute with both, positive and negative power reserve, within a reliable framework regarding power availability and stability, as happens nowadays with conventional generation.

This paper presents a methodology [5] which makes use of the advantages of centralized and decentralized control systems, providing a two layers architecture (TSOs and dispatch centres) as well as giving the dispatch centres their own autonomy based on their own monitored and calculated data. It also decreases the complexity of the control and decision making process with regard to the power reserve provision, considering that a large volume of wind farms is expected to be able to participate in the power reserve provision markets.

2. Introduction and objectives of the present methodology

The integration of large shares of fluctuating generation into the existing energy transmission and distribution systems requires a new strategy for the operational management of wind farms which should be equivalent (but not equal) to the strategies followed by the conventional generation power management. Some basic facts should be considered before addressing the objectives of the developed methodology and algorithm. The considered facts are described as following:

1. Considering the technologies available nowadays, wind power has the capability to be forecasted with a 98% level of accuracy in a time frame of 8 hours ahead [1] [2].
2. The “lower interval” from each forecast has to be considered as the reference forecasted power.
3. Wind farms should be prequalified in order to be able to provide ancillary services as happens nowadays with conventional generators.
4. Due to the needed time response, an automatic algorithm is needed to monitor and control the different steps until the power reserve is provided by the selected wind farms. This algorithm may consider the interaction between the TSO, the wind farm operator and the wind farms SCADA system.

Finally, the objectives of the developed methodology are described as following:

1. Increase the power quality at low costs of those electrical systems which may have a strong penetration of wind power.
2. Allow a control of the grid in a more flexible and intelligent way, keeping the current security levels of the system requested by the TSOs.
3. Provide a secure and stable environment for all market participants to allow complex interactions between independent actors.
4. Promote the aggregation of wind farms into wind farm clusters [3] [4] in order to support the coordination between TSOs, dispatch centres, wind power producers and energy markets.
5. Promote the “multi layer control structure”[1] as the next step for large scale integration of wind power in order to allow wind farm clusters to be monitored and controlled in real time according to the TSO needs.
6. Provide a communication structure to coordinate the bidirectional data flow and to participate in the dynamics of the power market.
7. Encourage the needed changes in the current procedures in order to allow wind power to be integrated in a flexible and secure way into the ancillary services market.

[1] TSO and DSO

3. Methodology for providing power reserve with wind power

This process is based on an 8 hours procedure where economical variables are considered as well as the stability of the offered power reserve, at wind farm level, is being monitored and evaluated according to the TSOs requirements. A schematic description is depicted in Figure 1.

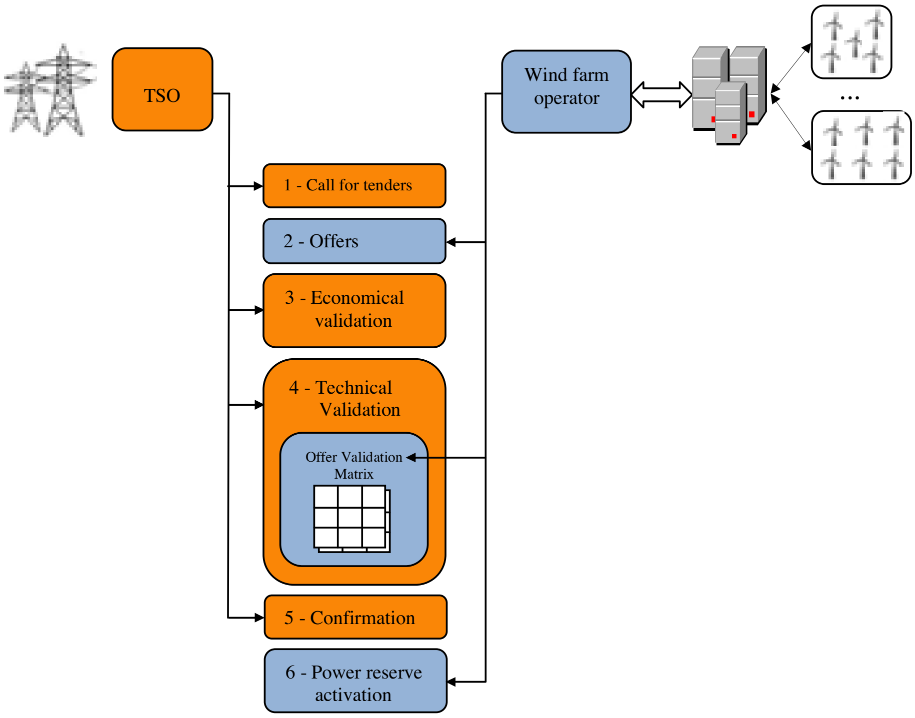

Figure 1 - Proposed methodology

Call for tenders: the needed power reserve volumes are published by the TSO one month in advance as it is described in Figure 2.

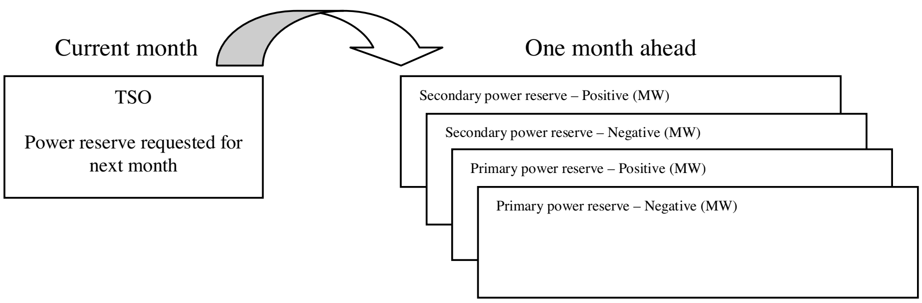

Figure 2 – Month ahead power reserve request

Tendering process: based on the requested power reserve volumes by the TSO, a "tendering process" would be opened every hour, 8 hours before the "Power Reserve Activation Time" (PRAT), as it is depicted in Figure 3. During these 8 hours tenders are posted, economically evaluated and finally their availability and stability is validated.

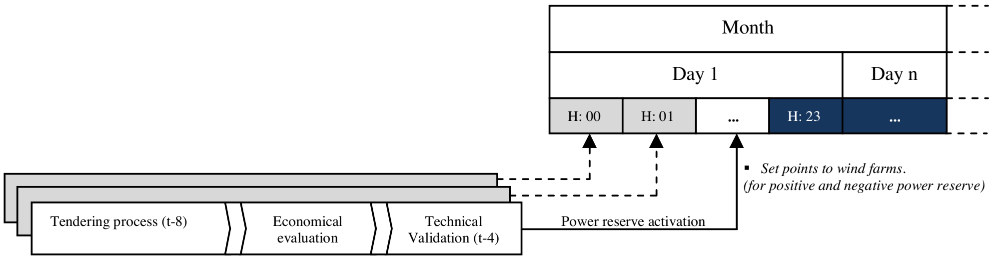

Figure 4 – Reserve power tendering process

Economical evaluation: once the tendering process is closed, an economical evaluation of each offer is performed. This is a market oriented process where the economical variables of each offer are being considered allowing the TSOs to optimize and reduce costs concerning power reserve provision. Those successfully evaluated economical offers are going to be technically verified during the last four hours before the power reserve activation takes place.

Validation process: the objective is to evaluate the relation between "offered power" and "available power" during the last four hours before the power reserve activation takes place. This "offer stability" validation process considers an offer to be unstable when the offered power volume is bigger than the one reported by the Lower Interval (LI) from the wind power forecast for a given wind farm.

The "Validation Process" is performed through the "Offer Validation Matrix", described in Table 1. Every hour the required updated information should be loaded by the wind farm operator or the dispatch centre. In order to evaluate the offer stability, two factors were developed during this PhD ("Hour Stability Factor" and "Offer Stability Factor") considering as input data for them the information available in the "Offer Validation Matrix". Based on these two factors all offers are monitored in an hourly basis as well as in a global concern regarding the whole offer and the power availability at the activation time.

Offer Validation Matrix						
Company	Wind farm	t-4	t-3	t-2	t-1	osf
Name	Offer type Install capacity Offered power Price (€)	f(P) LI (f(P)) --- hsf(t-4)	f(P) LI (f(P)) --- hsf(t-3)	f(P) LI (f(P)) --- hsf(t-2)	f(P) LI (f(P)) --- hsf(t-1)	

Table 2 – Offer validation matrix with a time frame horizon of four hours

f(P):	Forecasted active power for offered time frame
LI (f(P)):	Forecasted Lower Interval (LI) for offered time frame
hsf:	Hour Stability Factor
osf	Offer Stability Factor

Additionally to the already described schema, a weight factor was attached to each one of the four hours before the PRAT (see Table 3). The aim of this factor is to give a degree of relevance to each hour considering that potential fluctuations may occur during these hours and depending on when they occur, they could be more or less relevant with regard to the stability of the offer. This weight factor combined with the "hour stability factor" is being referred in Equation 2 by the "offer stability factor" calculation, which evaluates each offer as a whole based on the hourly evaluation described in Equation 1.

Time frame	t-4	t-3	t-2	t-1
Weigh factor (w)	0,25	0,50	0,75	1

Table 4 – Weigh factor

The two developed factors are explained as following:

- **H**our **S**tability **F**actor (hsf): evaluates the offer stability by each of the four hours previous to the power reserve activation. This factor indicates by each hour how stable the offer was keeping as a reference the offer time frame. It is based on the forecasted active power and on its Lower Interval (LI). As it is described in Equation 1 the "hsf" could have two possible values: 0 or 1, meaning with 0 that for a given hour the offer was not stable enough and with 1 that the offer was sufficient stable.

  The needed conditions for the "hsf" to report an offer to be stable are included into Equation 1 and described as following:

  1. For a given hour the Lower Interval from a wind power forecast should be lower than the forecasted power (as it always should be under normal conditions).
  2. The Lower Interval should be above 20% of the offered power reserve.

$$\overbrace{f(P) - LI(f(P)) > 0}^{1} \wedge \overbrace{LI(f(P)) - 20\%(offer)}^{2} > offer \qquad hsf = 1$$
$$else \qquad hsf = 0$$

Equation 1 – Calculation of the "hsf"

- **O**ffer **S**tability **F**actor (osf): evaluates the complete offer based on the "hsf" results of each hour previous to the power reserve activation time and the hours weigh factor. As it is described in Equation 2 each offer would be evaluated at wind farm level considering its stability during the past four hours.

$$osf = hsf(t-4) * w(t-4) + hsf(t-3) * w(t-3) +$$
$$hsf(t-2) * w(t-2) + hsf(t-1) * w(t-1)$$

Equation 2 – Calculation of the "offer stability factor"

  With regard to the result of Equation 2, an offer is considered stable enough if its final value is bigger than "2", representing that at least during the last 3 hours before the activation time of the offered power reserve from a given wind farm, the offer was always available.

4. Potential power reserve provision with wind power in Germany during 2009

The aim of this analysis is to calculate for which percentage of the year primary and secondary power reserve could have been provided by wind power, considering the developed methodology [5] presented in this paper.

The considered time series from 2009 are described in Figure 5. A better description of the available information can be observed in Figure 6, where October 2009 is represented.

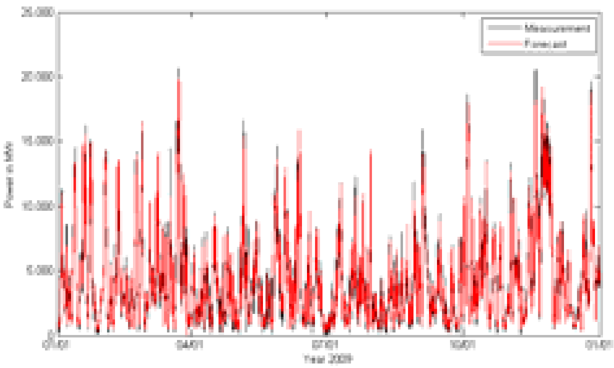

Figure 5 – Wind power production and forecast in Germany, 2009

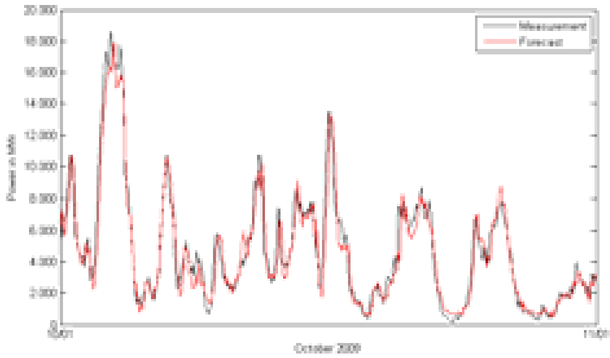

Figure 6 – Wind power production and forecast in Germany, October 2009

Based on the information represented in Figure 5 and deeply described in Figure 6, Lower Intervals (LIs) from the wind power forecast were calculated considering different reliability factors (see Figure 7 and Figure 8). The reliability factors used for the lower intervals calculation are 90%, 95%, 99% and 100%.

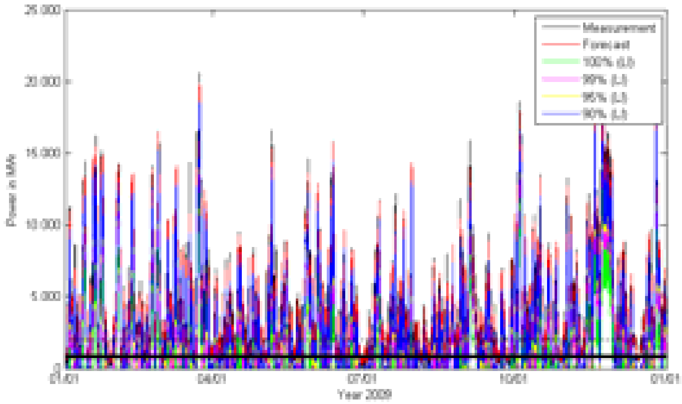

Figure 7 – LI calculation for wind power forecast in Germany during 2009

An example and a better description of the available information from the calculated Lower Intervals is included in Figure 8 and Figure 9. The black line represents the current needed primary power reserve volume (800 MW) and the black dotted line represents the secondary power reserve volume (2000 MW).

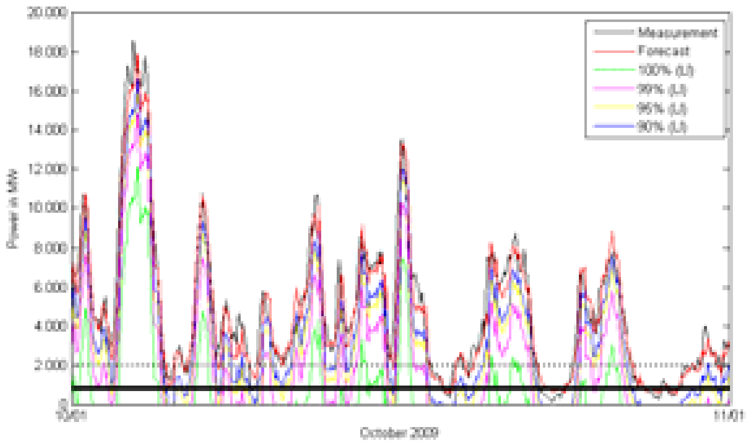

Figure 8 – LI calculation for wind power forecast in Germany, October 2009

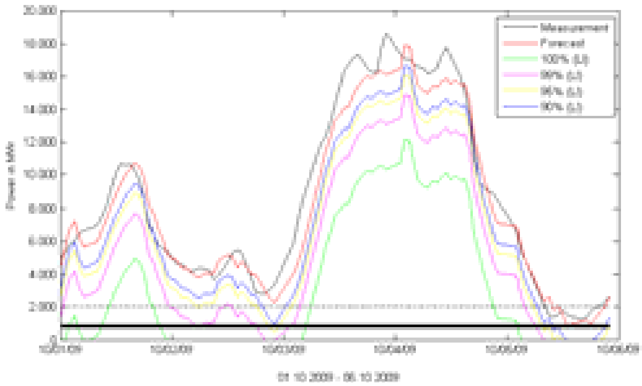

Figure 9 – LI calculation for wind power forecast in Germany, 01.10.2009 – 06.10.2009

The developed methodology was applied to the German wind power production time series in 2009. Based on the lower intervals from the wind power forecast it was calculated for which % of the year primary and secondary power reserve provision could have been provided by wind power. Lower intervals with reliability factors of 90, 95, 99 and 100% were calculated. The results can be observed in Table 5, Table 6 and Table 7. For both, primary and secondary power reserve, the relevant reliability factors are 95 and 99% (more realistic ones if the natural characteristics of wind power are considered).

In Table 5 it can be observed that primary power reserve provision (800 MW) could have been provided by wind power with a 99% of certainty during 3656 hours (41,74%) in 2009.

Primary power reserve (800 MW)	
Reliability	Potential power reserve provision during 2009
100 %	19,58 %
99 %	41,74 %
95 %	57 %
90 %	66,22 %

Table 5 – Potential primary power reserve provision with wind power in Germany

Secondary power reserve provision results can be observed in Table 6. These results show that wind power could have provided with a 99% of certainty 2000 MW of power reserve during 2580 hours (29,46%) in 2009.

Secondary power reserve (2000 MW)	
Reliability	Potential power reserve provision during 2009
100 %	13,95 %
99 %	29,46 %
95 %	41,97 %
90 %	47,98 %

Table 6 – Potential secondary power reserve provision with wind power in Germany

Finally, Table 7 shows the calculation results from both, primary and secondary power reserve, together. It can be observed that both kinds of power reserves could have been provided by wind power with a 99% of certainty during 2096 hours (23,93%) in 2009.

Primary and Secondary power reserve (2800 MW)	
Reliability	Potential power reserve provision during 2009
100 %	11,49 %
99 %	23,93 %
95 %	33,38 %
90 %	39,08 %

Table 7 – Potential primary and secondary power reserve provision with wind power

5. Conclusions

The planned construction of numerous wind farms of the magnitude of conventional power plants calls for a new strategy in their operational management. In terms of the monitoring, connection and control conditions, wind farms should be equivalent to conventional power stations. Particularly related to the ancillary services provision, it is proved that wind farms could take over the tasks currently carried out by conventional generators.

As it has being described during this paper, wind power can not only be decreased but also be increased within a time frame of seconds. Widespread use of this method of operation can result in a significant frequency-supportive power reserve provided by wind farms.

The contribution of wind energy into power reserve market leads to new market rules, legal and regulatory frameworks. Furthermore, in order to achieve its wide application and participation throughout Europe, these new rules and frameworks will need to be highly compatible and partly even harmonized in the European Internal Electricity Market (IEM).

This new context, characterized by complex regulations, an increasing number of actors and the services that they require, asks for more intelligent control systems that can manage both the electrical and financial operation of the grid and new interactions between grid participants.

Many different visions have been proposed for future power systems. Each of these visions depends on equipment, regulations, legal structures, environmental factors and many more, all with specific control needs.

The consensus no longer exists with regard to the question how a future power grid should be controlled, or what should be intermediate steps towards that direction. A new research area is currently forming on the border between electrical power engineering, industrial automation, control engineering, energy economics, communications technology and intelligent systems. The first large research projects in this area have already been launched. Some countries like Denmark or Spain, have already implemented the proposed “two layers” concept (TSO and dispatch centres), showing that wind power is controllable and predictable enough to allow larger penetration levels, according the world wide trends.

The necessity of the wide use of renewable generation is nowadays self evident. However, it is not the need of ancillary services provision based on renewable energies. Large wind farm clusters will be centrally controlled in order to coordinate and adjust the operation of many individual wind farms distributed in the field.

Developing an innovative concept to provide power reserve with wind power requires also testing the technical capabilities of real wind farms. In some cases, the already implemented technologies at wind farm level are not fully being used and the capability of wind farms to be controlled is already there.

Several scientific tests were carried out based on control strategies for active power control considering the structure of wind farm clusters developed by Fraunhofer IWES as well as the need of sharing data between TSO control systems and dispatch centres [4] [5].

During several R&D projects, control strategies for wind farm clusters management were implemented and evaluated. Wind farms located in Germany and Portugal were proposed as real test fields being online monitored and controlled by the Wind Farm Cluster Management (WCMS).

Concerning the performed tests, the obtained results are described as following:

- Wind farms have showed the capability of reacting to a given control command.
- Controllability of wind farm clusters was successfully tested.
- Power oscillations were registered. They should be deeper analyzed in order to be minimized.

Deviation between the set point target and the real power production in 90% of the measurements was not more than 1%. The biggest deviation was 3,5% from the given control command. This shows high controllability levels of wind power during the execution of a set point [5].

Existing barriers, available technologies and design parameters have been considered for the development of an innovative methodology in order to allow wind power to provide primary and secondary power reserve in a secure and flexible way.

For an effective management of the wind power input into the electricity supply systems, wind power forecasts are essential, therefore the main algorithm includes the use of wind power forecast and the lower boundary of its confidence interval. At the same time, it is also considered the interaction between the TSO, the wind power generation companies and the SCADA system of each wind farm.

The structures included into the developed algorithm are “Offer Validation Matrix”, “Hour Stability Factor” and “Offer Stability Factor”.

Finally, it was studied the concrete capability of wind power to provide primary and secondary power reserve during one year. The analysis was performed based on the German wind power production time series from 2009. The results of the validation process can be described as following:

- The innovative developed methodology allows increasing the power quality at low costs from those electrical systems which may have a strong penetration of wind power.
- The structure of wind farm clusters is recommended in order to reduce limitations due to potential unavailability of single units by grouping wind farms into clusters.
- Wind farms should be prequalified in order to be able to provide ancillary services as happens nowadays with conventional generators.
- Due to the needed time response, an automatic algorithm is needed to monitor and control the different steps until the power reserve is finally provided by the selected wind farms.

For the year 2009 it was calculated for how long and with which certainty level primary and secondary power reserve could have being provided by wind power. Results have shown that wind power could have contributed to primary power reserve[1] during 41,74% of the year with a 99% of certainty. It can also be observed that secondary power reserve[2] could have been provided by wind power during 29,46% of the year with a certainty level of 99%.

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Thanks to the commitment of all involved sectors, wind energy is demonstrating once more that it is ready to face a new challenge in the renewables energies history. It is not only fulfilling the market demand with new modern multi mega-watt wind turbines (on and off-shore), it is also capable to face the challenge of progressively replace conventional generation bringing at the same time security to the system through its already demonstrated controllable characteristics.

This is it self a step forward in the direction of the 100% renewable energies scenario which was also presented by Fraunhofer IWES.

6. References

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