Economic assessment of the participation of wind generation in the Spanish secondary market

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***Abstract*— The aim of this paper is to analyse the profitability of wind technology to participate in the Spanish system frequency regulation, specifically in the secondary reserve. This participation is based on existing market rules.**

Firstly, a revision of the bibliography about the relevant technical possibilities of this technology is done. Then, a simulation study based on real data is made in order to evaluate the maximum possible profits. Later, a specific offer strategy is proposed and the profit is estimated based on statistical modelling and checked by simulating its performance using actual and forecast productions of a wind portfolio. This study brings into focus the critical role of the penalties because of not being able to fulfil the acquired regulation commitments. A more sophisticated strategy is proposed and simulated.

It is concluded that under the current generation structure and regulatory framework in the Spanish system, expectation of benefits, although positive, is not very high. However, secondary regulation by wind generators might facility higher penetration levels of this technology. In the long term, without or greatly decreased wind generation subsidies and higher needs and prices of regulation reserves, regulation-related profits might become a sizeable fraction of total profits of wind generators.

***Index Terms*— Wind power, ancillary services, frequency control, monitoring system.**

I. Nomenclature

B_{Total}	Total band offered by the wind producer (MW)
B_{Up}	Upper band offered by the wind producer (MW)
B_{Down}	Down band offered by the wind producer (MW)
R_{Up}	Relation between the upper band and the total band
R_{Down}	Relation between the upper band and the total band
P_{DM}	Daily market price (€/MWh)
P_{IDM}	Intra-daily market price (€/MWh)
P_{Band}	Price of the secondary regulation band (€/MW)
P_{Up}	Price of effective up energy used by secondary regulation (€/MWh)
P_{Down}	Price used to remunerate wind power under the feed in premium scheme (€/MWh)
P_{Wind}	Price of wind power energy submitted to the grid (€/MWh).
$Profit$	Hourly profit of wind energy (€/h)
α	Relation between the intra daily market price and the daily market price.
β	Relation between the effective up energy price and the daily market price
γ	Relation between the effective down energy price and the daily market price.
U_{Up}	Percentage of utilization of the up regulation energy (%)
U_{Down}	Percentage of utilization of the down regulation energy (%)
C	Cost of the energy production (€/MWh)
$Q_{failure}$	Failure volume (MWh) of requested secondary regulation energy
Q_{real}	Real volume (MWh) of energy that a wind power agent provides.
$Q_{desviation}$	Difference between the real volume of energy and the volume that the wind power agent compromised (MWh).
$P_{desviation}$	Desviation price (€/MWh).
I_{compl}	Income for compensating reactive power (€/h).

According to the Spanish market rules all variables are hourly.

II. Introduction

Controlling frequency has always been an essential role in order to guarantee the secure and reliable operation of a power system. Active power control is designed to reestablish the necessary equilibrium between generation and demand in order to keep the frequency of the power system within admissible bands, and is mainly provided by generators.

Active power control includes primary, secondary (AGC) and tertiary regulation operating within different time scopes. Generators incur in an extra cost for providing frequency control that should be recovered through regulated or market–based tariffs. Within the Spanish system, primary regulation is considered a mandatory non-remunerated service, while

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secondary and tertiary regulations are driven by market-based mechanisms. Secondary regulation in Spain is provisioned by band and energy markets. The band market defines the power resources for the AGC and the secondary energy used by the AGC is paid according to a price defined by the so-called tertiary reserve market.

Wind power has experienced a wide development throughout the world due to technological advances in wind turbines and favorable policy incentives. Spain is the fourth largest country in wind power installed capacity, 19149 MW of installed capacity at the end of year 2009 [12]. The Spanish Ministry of Industry, Tourism and Commerce considers as a probable scenario 29000 MW of installed wind power capacity for the year 2016 [13]. The wind production has reached 16000 MW and during some hours it represents a 50% of the total generation [14]

Within this worldwide and national framework, wind power poses increasing challenges to the planning and operation of power systems. Transmission System Operators (TSO) have often been cautious regarding massive penetration of wind energy into the grid arguing that wind power does not provide frequency and voltage control. However, nowadays technology developments enable the design of operation and control strategies of wind turbines to provide such grid services [8], [9], [10], [11].

On the other hand, the provision of secondary up band by the wind producer reduces it energy program. This reduction means a cost because the wind energy is a use-or-lose energy. Therefore, remuneration of the secondary service should be enough to compensate that loss of production.

Participation in the secondary regulation has both technical and economic interest. From the technical viewpoint, a higher wind penetration can be facilitated. From the economic standpoint, wind generators can make a profit by providing regulation that surpasses the losses by not selling the maximum possible amount of energy, as shown in Section V.

Most of the literature on wind power integration into electricity markets have looked into ways to hedge uncertain wind energy bids into energy markets [1-3], forecast wind production [20], value capacity credits [4], forecast reserve requirements [5], or proposing ways of joint operation with other technologies [6, 7], among other issues.

These works assume that the wind generator is technically passive, i.e., the decisions are limited to the optimal amount of power to contract in the different markets assuming an uncontrollable physical generation. On the other hand, this paper focuses in the possibilities that an active control of the generated wind power and the associated reserve margin offer as bids are presented in the energy and reserve markets. Study is done for the Spanish system, although we believe that the obtained results are of a much wider interest.

The paper is organized as follows. Section III. reviews the primary, secondary and tertiary regulation loops of frequency control and its regulation in the Spanish system. An overview of wind power Spanish regulation is provided in section IV. The suggested methodology to participate in the secondary band market is illustrated in section V. Simulation of economic results, by using real data of the market prices and the utilization of the up or down energy for the years 2004-2008, is presented in section VI. Finally, conclusions are drawn in section VIII.

III. Secondary Regulation in Spain

A. *Overview of the Spanish sequence of markets*

Frequency control in Spain conforms with the definitions and recommendations laid out for the UCTE systems, as described in [19]. Active power reserve provision includes primary, secondary and tertiary regulation. In Spain, primary regulation is a non-remunerable mandatory service, while secondary and tertiary regulations are managed by market procedures [17].

Generally speaking, Spanish system operation is organized around a sequence of markets [14], [15]. The first market to clear is the daily energy market, in which most of the energy is traded. Its product is energy to sell or buy for each one of the 24 hours of the day ahead. After the daily energy market, the System Operator (SO) performs the technical constraint analysis, modifying the generation dispatch in order to guarantee a secure operation of the power system.

After the technical constraint management procedure, the secondary regulation market is carried out. This market provides for the 24 hours of the next day the up and down band necessary to maintain the scheduled values of the system frequency and the system interchanges.

Afterwards, intra daily markets are six times a day so demand and generation agents may carry out adjustments before the energy is delivered, in order to correct infeasible schedules, forecasts deviations or to apply strategic modifications.

The tertiary reserve market is intended to reestablish the secondary energy in use, so it is only called and cleared if the secondary reserve is exhausted. Finally, deviation management markets are only carried out if the SO predicts a significant deviation of energy between generation and demand for the hours not covered by the intra daily markets. A generating agent participating in the Spanish electricity market faces the issue of sharing its electrical resources among these different markets.

The Spanish market sequence and timetable is depicted in Fig 1.

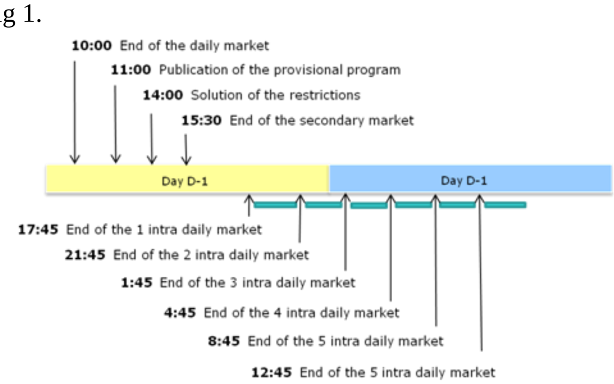

Fig 1: Spanish electricity market sequence and timetable

B. *Overview of secondary regulation market*

The SO is the responsible entity for determining the hourly requirements of secondary band. These hourly requirements are the total band (B_{Total}), split in up and down band according to a predefined ratio B_{up}/B_{down}. Up and down ratios are defined as:

$$R_{Up}=B_{Up}/B_{Total} \quad (1)$$

$$R_{Down}=B_{Down}/B_{Total} \quad (2)$$

Generators offer the up and down band that are willing to provide in case the system requires it. If the secondary regulation offer of a generator is cleared, the remuneration of the service contains a capacity term and an energy term. The capacity term (€) for each hour is obtained from the secondary reserve market clearing price P_{Band} (€/MW) and the total cleared band B_T (MW):

$$B_{Total}P_{Band}=(B_{Up}+B_{Down})\,P_{Band} \quad (3)$$

The effective use of secondary regulation energy is remunerated (or charged) at the substituting tertiary energy. In case the generator has provided upward regulation expressed as a percentage U_{Up} of the total offered band B_{Up}, i.e. $B_{Up}U_{Up}$, it will be remunerated at price P_{Up} €/MWh. On the opposite case, if the generator has been asked to decrease its schedule, the generator will have to pay the non produced energy $B_{Down}U_{Down}$ at a price $P_{Down.}$. In case of neglecting the operational costs, the profit related to this effective use of secondary regulation can be expressed as:

$$B_{Up}U_{Up}P_{Up}-B_{Down}U_{Down}P_{Down} \quad (4)$$

If the generator fails to comply with commitments acquired in the reserve regulation market, it will be penalized. In the Spanish market, the penalty factor is established as 50% of the band price for each hour where the requested band is not provided with the dynamic response criteria:

$$-1.5P_{Band}Q_{failure} \quad (5)$$

IV. Overview of wind power regulation in Spain

Currently in Spain new wind installed power technology is remunerated according to Royal Decree RD661/2007. It considers two different options to be selected by the wind promoter. The first one remunerates the wind energy at a constant regulated price independently of the daily market price. Within the second option the wind generator owner participates by sending an offer to the daily market (possibly the wind energy forecast). Since it is always offered at zero price this energy is almost always cleared, as Spanish regulation does not allow negative prices and wind spillages have been very unusual events. The remuneration in this second option is computed adding a premium to the daily market price. In addition, there is a wind energy price cap at 85 €/MWh and a floor at 71 €/MWh. The cap is only applied so long as the day-ahead price is below it. Fig 2 depicts the remuneration of wind energy according to RD 661/2007.

$P_{Wind}=$

$$\begin{gathered} \text{If } (P_{DM}<42) \text{ then } P_{Wind}=Floor \\ \text{If } (42<P_{DM}<56) \text{ then } P_{Wind}=P_{DM}+Premium \\ \text{If } (P_{DM}>56) \text{ then } P_{Wind}=Cap \\ \text{If } (P_{DM}>85) \text{ then } P_{Wind}=P_{DM} \end{gathered} \quad (6)$$

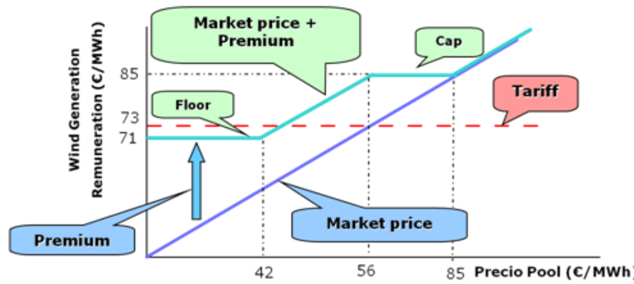

Fig 2: Remuneration of wind energy according to RD 661/2007

In addition, the wind power has other complements (I_{compl}) if it fulfills specific technical requirements and it should pay the deviation costs of their energy program [18]. As a result the final remuneration of the wind power, in case of not adjusting the program in the intra-daily markets is:

$$Profit=Q_{real}P_{Wind}+I_{compl}-Q_{desviation}(P_{DM}-P_{desviation}) \quad (7)$$

V. Methodology

The proposed methodology of the economic assessment of the participation of wind power in the secondary regulation market comprises three steps: (a) computation of perfect information bounds of the potential additional profits if wind power participates in secondary regulation, (b) definition of the bidding strategy and (c) validation of the offering strategy.

A. *Computation of additional profits*

This paper considers that the forecasted wind production for each hour is going to be offered to the daily market. Next a bid is presented to the secondary regulation market. In case that the offered band is accepted the generation schedule must be reduced in the first intra-daily market to allow for the cleared up power band. It should be noted that with this strategy the wind power only reduces its program in case that exists a possible profit of participating in secondary regulation. According to the remuneration rules of the secondary reserve, outlined in subsection III. B. the hourly profit of wind power participating in secondary regulation can be computed as follows (only market incomes have been considered, operational cost can be neglected for this strategy):

$Profits=$

$$\begin{gathered} (Q_{real}-B_{Up})P_{Wind} \\ -Q_{desviation}(P_{DM}-P_{desviation})+I_{compl} \\ +B_{Total}P_{Band} \\ -B_{Up}(P_{IDM}-P_{DM}) \\ +B_{Up}U_{Up}P_{Up}-B_{Down}U_{Down}P_{Down} \end{gathered} \quad (8)$$

Subtracting (7) from (8) the additional profit equation is obtained.

$\Delta Profits=$

$$+B_{Total}P_{Band}$$
$$-B_{Up}P_{Wind}$$
$$-B_{Up}(P_{IDM}-P_{DM})$$
$$+B_{Up}U_{Up}P_{Up}-B_{Down}U_{Down}P_{Down} \quad (9)$$

The meaning of each term in (9) is:

- B_TP_{Band}: capacity term of the secondary regulation, representing the income of the cleared up and down band
- $B_{Up}P_{Wind}$: since the wind generator has reduced its program to allow for the cleared up band, this term represents the loss of profit of the spilled power.
- $B_{Up}(P_{IDM}-P_{DM})$: extra cost due to the adjustment in the first intra daily market. If the hourly daily market price is higher than the intra-daily market price, this term is positive representing an extra profit (the wind generator receives the market price for the selling of energy in the daily market and buys the energy in the intra-daily market at a lower price). On the contrary, if the intra-daily market price is higher, the term is negative meaning a cost.
- $B_{Up}U_{Up}P_{Up}-B_{Down}U_{Down}P_{Down}$: energy term of the secondary regulation representing the income of real use of up and down regulation energy by the TSO.

The sum of the three first items is defined as "band component" and the fourth item as "energy component". The band component could be forecasted the day ahead with high degree of precision using the estimates of P_{Band} and P_{IDM}, but the energy component depends on the requested regulation energy which will depend on the actual electrical system behavior in real time, which is very difficult to estimate the day before.

Since the energy term is very volatile, two bounds of profits are going to be evaluated considering perfect information of all market results: bound 1 and bound 2:

- **Bound 1**: This case evaluates all the hours when the (9) is higher than zero. This bound means a maximum theoretical limit of profits.
- **Bound 2**: Due to the decision to participate on secondary reserve is made the day ahead, the energy component of the hourly profits (the fourth term of the (9)) is unknown and very difficult to anticipate as previously explained. Therefore the bound 1 could be too optimistic. In order to evaluate a realistic bound of profits, (9) is considered only in hours when the band component is positive (otherwise the generator would not run the risk of participating in the secondary regulation market). In this case the energy component is added independent of its sign. This bound reproduces the behavior of the agents and it has been determined with perfect market information.

In both bounds, two regulatory situations are going to be studied. The first one takes into consideration the actual the remuneration of the wind energy according to the RD661/2007 (the energy is paid at daily market marginal price plus a premium, limited by the cap and the floor). However, regulatory uncertainty may result in the elimination of the premium (in fact, the amount of the premium is under revision at present [9]). Thus, the second situation considers that the wind power energy is paid at marginal market price with no premium, with the same conditions that any other conventional technology. That situation could be considered as a future scenario.

B. *Definition of the offering strategy*

All the bids that are presented to the secondary regulation market must have a volume *(MW)* and a price *(€/MW).*

For determining the offering price the following strategy is proposed.

This offer will take advantage of the sequence of the different markets outlined in subsection III. A.

The key element to define the best hourly bid is the additional profits equation. Introducing the ratios of up and down band defined in (1) and (2) in (9) the breakeven price that allows obtaining profits in one hour is computed as:

P_{Band} =

$$+R_{Up}P_{Wind}$$
$$-R_{Up}(P_{DM}-P_{IDM})$$
$$-R_{Up}\,U_{Up}P_{Up}+R_{Down}U_{Down}P_{Down} \quad (10)$$

The optimum hourly price expressed in (10) depends on a number of parameters that are subject to uncertainty. For reducing the uncertainty the following strategy is presented.

At the moment of presenting the bid to the secondary regulation market, the daily price of the market (P_{DM}), P_{Wind} and the ratios (R_{Up},R_{Down}) are already known. However, the rest of the terms in the (10) are unknown and they need to be estimated using the statistical behavior of the market. Using the statistical distributions of the hourly values α (P_{IDM}/P_{DM}), β (P_{Up}/P_{DM}), γ (P_{Down}/P_{DM}) (relation between the intra-daily price, up and down energy price to the daily market price) the prices P_{IDM}, P_{Up} and P_{Down} can be roughly estimated for each daily market price. Table 1 presents the parameters α, β and γ for the year 2005

TABLE 1

		Minimum	Mean	Maximum
γ	P_{Down}/P_{MD}	0	0.5919	4.123
β	P_{Up}/P_{MD}	0	0.995	6.855
α	P_{IDM}/P_{MD}	0.0001	0.987	2.075

The terms U_{Up} and U_{Down} are the best use expectative of the up and down band for the next day. In this study, results will be presented using constant hourly forecasted values equal to the average value for each year. Nevertheless, in the real offer process the agents have more adapted information to the real situation. The profitability of participating in the secondary market could be greater than the results of the study.

The total band offered in this study will be a percentage of the production forecast that the agent has at the moment of presenting the bid to the market. That percentage depends of the technical characteristics of the wind generators and the acceptable risk. In this study it is considered a total band of 10% of production forecast.

C. *Historical simulation*

Once that the offer price has been determined taking into account the uncertainty, it is possible to evaluate the additional profits.

A bid will be accepted in case that the price of the secondary market is higher than the offer price and this means that it is expected to obtain profits. Later, the actual profits depend on the secondary energy used by the secondary regulation.

VI. Results

The methodology presented in the previous section has been applied to the Spanish electricity market where wind generation is playing an important role in the energy markets (day-ahead, and intraday markets). Moreover, secondary reserve is provided by transparent market mechanisms, and therefore, the required information to carry out the assessment is public and available. In particular, the following real hourly historical data has been collected for years 2004-2008, using public information by the Spanish TSO [14] and the market operator [15]:

- Market prices (P_{Band}, P_{Wind}, P_{DM}, P_{IDM}, P_{Up})
- Real deployment of the up and down energy (U_{Up}, U_{Down}) by the TSO during real-time power delivery.
- Ratio between the up band and the total band (R_{Up})

In addition the day-ahead forecasted hourly wind generation, and the real production of a wind power agent has been used for the same years. This information has been collected from real wind farms, and the possibility of carrying out the historical simulation with both hourly time series (the day-ahead forecast and the real production), makes this analysis very realistic and useful for drawing interesting conclusions.

This section is organized as follows. (a) Computation of additional profit bounds (1 and 2) in case that the total band offered is 1 MW, (b) computation of the bounds of total additional profits for a real wind power portfolio, (c) historical simulation of how much of such theoretical hourly bounds of additional profits could be attained following the offering strategy of subsection V. B. , and (d) optimization of the percentage of the power forecast production that will be offered as secondary reserve to maximize the expected profits.

A. Computation of per unit additional profits by MW

This subsection analyses the additional profits that could have been obtained by offering 1 MW of total band in every hour of the studied period. This total band has been split in up-band and down-band according to the historical hourly ratios R_{Up} and R_{Down}. In order to illustrate the proposed methodology, the detailed unitary profit results are presented just for year 2005. Later on, aggregated results for the whole interval 2004-2008 will be shown.

The theoretical bounds 1 and 2 have been computed for each year, considering two different regulatory frameworks: 1) the current scheme of feed-in-premium under the rules of RD661/2007, and 2) the hypothetical case of no wind premiums.

Fig 3 shows the unitary-profit duration curves (€/MW) corresponding to the theoretical bound 1 for year 2005. In these curves, the hourly increased additional profits have been arranged in non-chronologic descending order. It can be seen that no negative values are obtained, as this theoretical bound corresponds to the perfect-information case. Moreover, it could be surprising that additional profits in the scenario without premiums are higher. This can be explained because the wind power must reduce its energy program to provide secondary reserve, and this decrease means an opportunity cost which is higher when the wind power is remunerated according to the RD 661/2007.

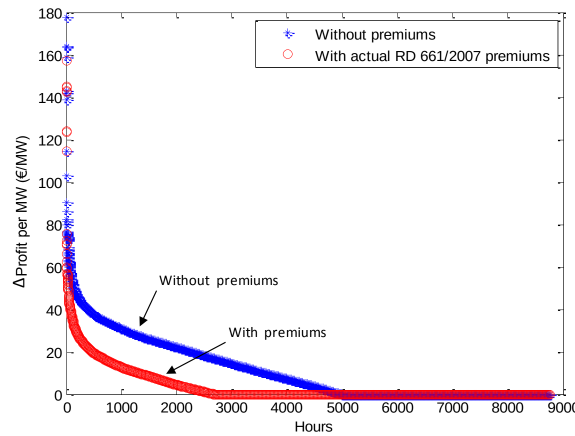

Fig 3: Duration curve of bound 1 of unitary-profits for year 2005

Fig 4 depicts the same curve of the unitary additional profits (€/MW) corresponding to the bound 2 in which the decision of participating in the secondary reserve market is made according just to the sign of the band component. Therefore, the positive or negative term related to the use of such reserve by the SO is unknown in advance. When this possible negative term is higher than the band component, negative profits could arise, as it can be seen in some hours of the figure. The rationale behind this result is the following. When the SO faces an unexpected event of generation increase or load decrease during the real time operation, the SO will decrease the total output by using the available down secondary reserve. When this downward energy use is high, if the wind power agent decided to participate in the secondary reserve market with a very small value of the band component (for instance, because secondary regulation prices were just a little higher than in the daily market), the negative term could be greater resulting in economic losses. This is the risk that wind power agents will have to assume if they want to participate in the secondary regulation market. This result suggest that it would be helpful to include in the bidding problem the characterization of the expected use of the cleared up and down secondary reserve by the SO. Nevertheless, the number of hours with negative profits is very low in comparison with the hours with positive profit.

Another interesting result is that the number of hours with profits greater than cero in Fig 4 is lower than in Fig 3 for both regulatory frameworks. This happens because bound 2 does not consider profits when the band component is negative but the energy component allows obtaining a profit.

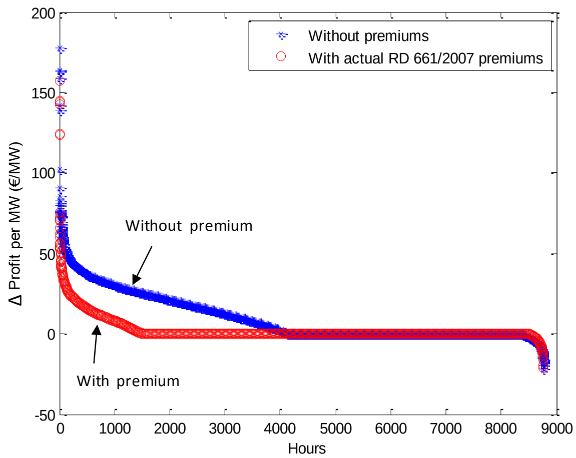

Fig 4: Duration curve of bound 2 of unitary-profits for year 2005

In order to assess the relative importance of the different components of the additional profits, Table 2 shows the percentage of the total profit that represents both the band and the energy components. It also shows the detailed information about the intra-daily purchases of the quantities previously sold in the daily market required to decrease the output power in order to have the upward margin cleared in the secondary reserve auction. Notice that this term is always positive in 2005, meaning that daily market prices were higher than intra-daily market price.

In the case of perfect information (bound 1), it can be observed that the band component is negative for some cases. Negative results occur when the loss of profit for allowing the up band B_{Up} P_{Wind} is higher than the profits due to the band B_T P_{Band}. In these cases the additional profit equation is higher than zero because there is a high degree of utilization of upward energy by the TSO. Nevertheless, it would be very difficult to grasp this profit as it depends on the real operation, which is very difficult to anticipate the day ahead.

TABLE 2

			$B_T P_{Band} - B_{UP} P_{Wind}$	Energy component	Intradaily adjustment
2004	Bound 1	With premium	-50.61%	146.44%	4.16%
		Without premium	59.72%	39.30%	0.98%
	Bound 2	With premium	53.95%	41.47%	4.57%
		Without premium	78.46%	20.58%	0.96%
2005	Bound 1	With premium	-4.68%	98.22%	6.45%
		Without premium	57.11%	40.27%	2.62%
	Bound 2	With premium	54.98%	34.89%	10.14%
		Without premium	74.72%	22.46%	2.81%
2006	Bound 1	With premium	-57.71%	142.10%	15.60%
		Without premium	34.80%	58.25%	6.94%
	Bound 2	With premium	30.27%	33.70%	36.02%
		Without premium	62.57%	28.54%	8.87%
2007	Bound 1	With premium	-95.63%	182.33%	13.29%
		Without premium	48.85%	46.92%	4.22%
	Bound 2	With premium	47.42%	26.31%	26.26%
		Without premium	76.24%	18.79%	4.97%
2008	Bound 1	With premium	-110.49%	196.38%	14.11%
		Without premium	-44.98%	137.00%	14.11%
	Bound 2	With premium	53.51%	17.55%	28.94%
		Without premium	64.92%	23.39%	11.69%

Fig 5 shows the yearly additional unitary profit (k€/MW) for each simulated year (from 2004 to 2008). It is possible to conclude that at present time, i.e. with the current feed-in premium, the additional profits are modest both under perfect (bound 1) and no perfect (bound 2) information. However, if wind power producers were remunerated just as any other conventional technology (no premiums), the revenues coming from participating in the secondary reserve market could be a substantial percentage of their incomes. In addition, in case of high prices of secondary regulation, both bounds of profits are very close to each other. Finally, it is important to highlight that there are additional profits in all the studied years. Therefore, if wind producers were forced to participate in the secondary reserve market, it would not mean necessarily a bad consequence them assuming that future prices behave in a similar way.

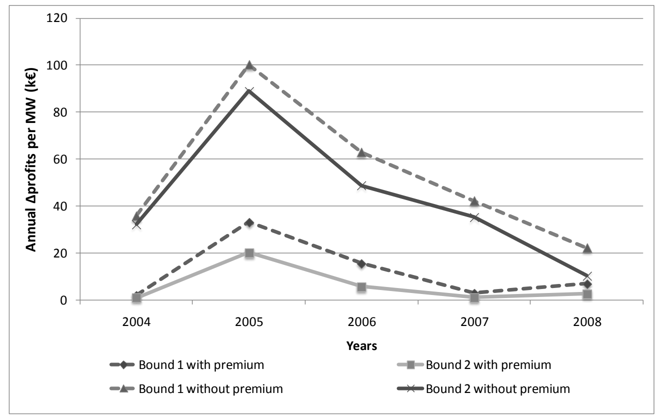

Fig 5: Annual unitary profits in the period 2004-2008 (k€/MW)

B. *Computation of total additional profit of a Wind Power Portfolio*

This subsection analyses the profits that a realistic wind producer would have obtained by participating in the Spanish secondary regulation market during the period 2004-2008evaluating (9). The studied wind portfolio consists of an aggregation of several wind farms with the following characteristics:

- 29 farms
- 1125 wind mills
- 730.58 MW of total installed power

All the farms belong to a regulation zone where there is not installed any other type of generation technology. This means that wind power generators must be able to provide secondary upward and downward reserve by themselves. In order to perform the study, the 2008 hourly data of real production and forecast production (the day before) has been used. The characteristics of this production are:

- Annual production: 1.829 GWh
- Equivalent hours: 2503 h

In the study it is considered that the total band offered to the market is 10% of the production forecast, and the real band regulation is 10% of the real production. The study considers the rule that in order to participate in the market, the offered band must be greater than 5 MW [17]. The total band is split in upward and downward band, according to the hourly SO requirements [14]. Taken into account the last criteria, the average secondary band provided by the wind portfolio is 23.01 MW. Fig 6 shows the economic results obtained in each studied year, where the real wind generation and day-ahead forecast of year 2008 have been applied in all the years in order to make easier the comparison.

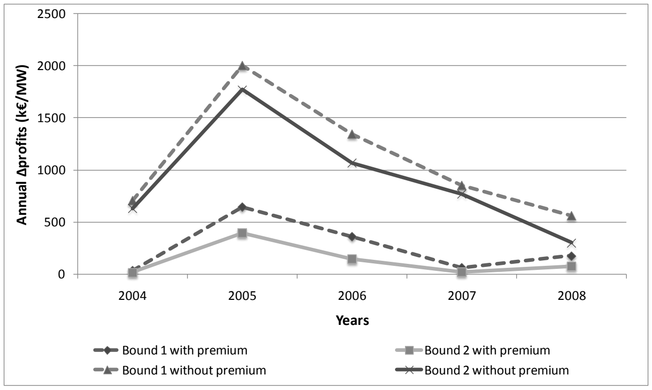

Fig 6: Profits of a wind portfolio of 730.58 MW

It can be observed that Fig 5 is very similar to Fig 6. If the average secondary band (23 MW) is multiplied by the unitary results (Fig 5) it is obtained approximately the values of Fig 6. This means that per-unit values could be applied to any wind power agent. In order to obtain an evaluation of their profits they only should multiply the per-unit results by their average secondary band to have a rough estimation of additional profits, without the need of performing the detailed simulation presented in this paper.

Fig 7 shows the percentage that these additional profits represent with respect to the total portfolio market incomes. Although the percentages are quite small, they represent a substantial value when translated into money, and therefore, the investment cost required to adapt the wind farms for providing AGC regulation, could be economically profitable.

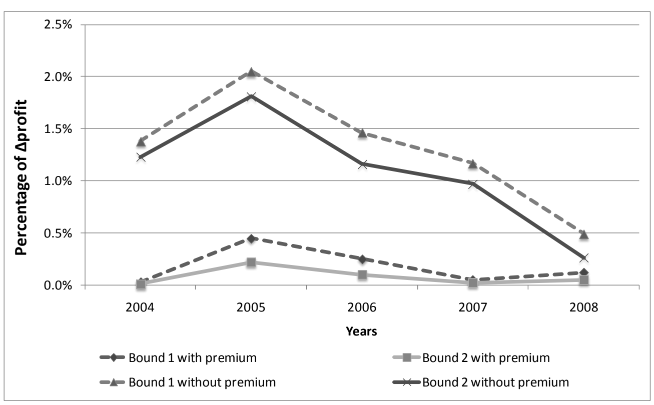

Fig 7: Profits of a wind portfolio (percentage)

The forecast error could lead to a situation in which the wind generator is not able to provide the secondary regulation commitments acquired in the secondary reserve market. For instance, if the wind forecast for a given hour is 50 MWh, the wind producer could sell 5 MW in the secondary reserve market, assuming that after the first intra-daily market the energy program can be adjusted to 45 MWh. However, if real generation decreases to 5 MW, the wind generator could correct its energy program in the remaining intraday markets, but there is no way to correct the secondary band program. Therefore, if the SO ask for such 5 MW of band, the wind farm will not be able to provide more than 0.1 W (a 10% of the real generation in this case), resulting in a severe economic penalty. In order to reduce this source of risk, it is proposed not to participate in the secondary reserve market when the production forecast is lower than a percentage of the installed power.

C. Historical simulation of the offering strategy proposed

In order to evaluate the offering strategy proposed in this paper, an historical simulation is presented for the wind power portfolio offering 10% of the total production as a total band at the price (10). The bid will be accepted in case that the price of the secondary market is higher than the offer price. Fig 8 compares the real additional profit of the agent with the perfect information bounds (1 and 2) computed in subsection V. A. It can be seen how the bound 1 profits are only attained in a range of 30%-40%. However, the more realistic bound 2profit are much more reached (close to 90%) during the whole period. These results validate the design of the offer that has been performed in the study.

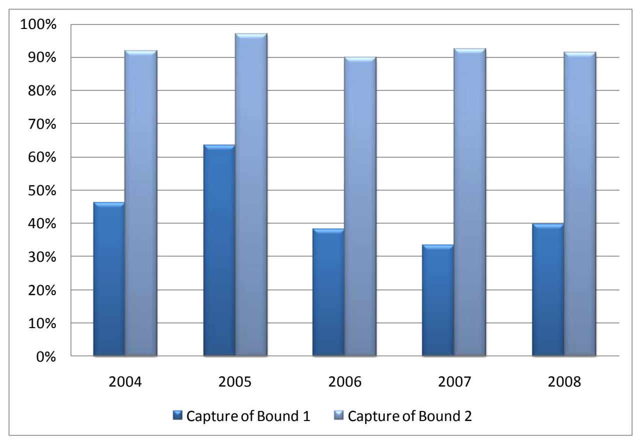

Fig 8: Capture of profits

A more detailed analysis can explain that when the price of the secondary band is high, for example year 2005, the band component has more weigh in the income-share, reducing the variability of the energy component.

It is possible to conclude that the design of the bidding strategy has a good behavior, and it allows capturing more than 90% of the realistic profits under non-perfect information.

VII. Acknowledgements

The authors would like to thank Eloísa Porras, Carlos Elías, and Rafael G. Hombrados for their valuable comments, and for making available the needed data for the example case.

VIII. Conclusions

Wind generators are quickly becoming a mainstream source of electricity. Therefore, it should be expected that their remuneration is also going to become mainstream. In the current regulatory setting this hypothesis implies an active participation in the electricity markets and the likely ending of specific provisions that discharge wind generators from balancing requirements.

On the other hand, wind generators are technically able to provide reserve and balancing services. This paper aims to prove that even in the current Spanish regulatory setting and with the current market prices, exploitation of this technical possibility leads to profitable business opportunities, even if generators use quite simple bidding strategies. As wind penetration increases, wind generators profits from this source as well as the profit for the whole system are expected to increase as well.

Finally, although the study is very much focused in the Spanish case, we feel that the basic logic is applied to most, if not all, electricity markets enjoying high wind penetration

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