Wind offering in energy and reserve markets

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1. Introduction

The continuous introduction of wind power in power systems is changing the behaviour of electricity market participants. Currently, have been proposed multiple methodologies for optimizing the strategic behaviour of wind power producers (WPP) in the energy market, accounting for expected costs in the balancing market [1]–[3]. On the other hand, wind power generators are now able to provide ancillary services [4]. Thus, new business models may emerge, stimulating the willing of wind power producers to participate and take advantage of reserve markets to increase their profit, as detailed in [5], [6].

This paper contributes with a stochastic methodology that maximizes the expected revenue of the WPPs in the day-ahead energy market and in the reserve market, while accounting with expected costs for failing to provide the energy and reserve products in the balancing market. A proportional strategy for splitting the available power into energy and reserve is assumed. The results shows that allowing a change on the proportionality of energy and reserve between day-ahead and balancing market, improves the expected revenues of the WPP, as well as, reduces the time coupling effect of wind power.

2. Problem description

The development of a methodology for wind power participation in energy and reserve markets at the day-ahead market, while accounting with expected costs in the balancing market is proposed and illustrated in Figure 1. The energy and reserve markets assume different characteristics, so different considerations are taken. On the one hand, wind energy bids submitted in the day-ahead market should account for potential imbalance situations and their asymmetric penalties. On the other hand, bids submitted in the reserve market should take into account the possibility to fail in providing the service.

Nevertheless, this model allows WPPs to submit bids into the energy and reserve market at day-ahead stage, following a proportional strategy for the split of the available power into energy and reserve (a share parameter is obtained by the split between energy and reserve). The bids submitted in the day-ahead market assume an expected energy market price, while the reserve market accounts with the capacity reserve price.

On the balancing stage, expected costs for energy and reserve deviations are considered. On one hand, expected costs for energy surplus or deficit of the WPP are considered. In contrast, reserve costs are only accounted for deficit of reserve, since the reserve surplus is not detrimental to the system. Additionally, this models assumes that share parameter (split between energy and reserve) at the balancing stage can assume different value of the day-ahead market decision. Thus, WPPs have the opportunity to reduce some energy or reserve deviations, thereby, increasing its expected revenue.

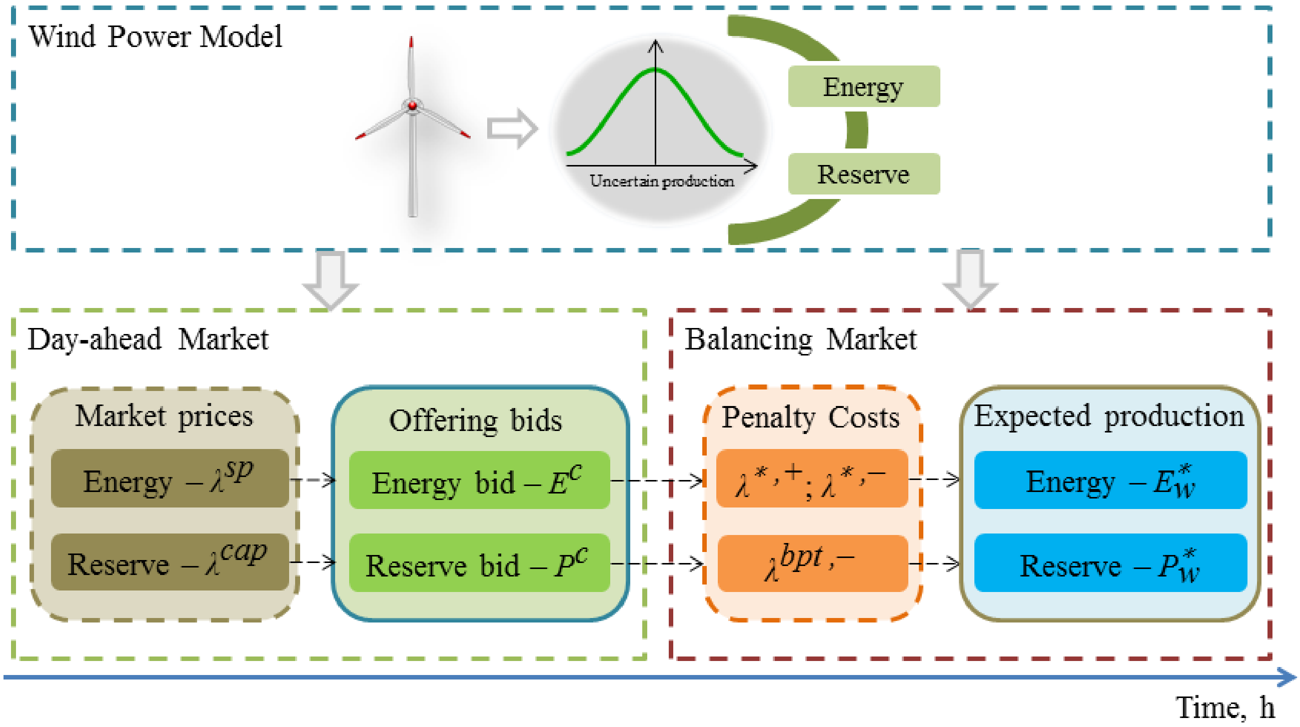

Figure 1: Wind power participation model in the energy and reserve market).

3. Wind offering methodology

A two-stage stochastic approach is used to optimize the revenue R for a given WPP, and is expressed as

$$Maximize\ R = \lambda^{sp}E^c + \lambda^{cap}P^c - \sum_{w\in\Omega}\pi_w\left[T_w^* + W_w^* - \lambda^{sp}\left(E_w^* - E^c\right) - \lambda^{cap}\left(P_w^* - P^c\right)\right] \quad (1)$$

where λ^{sp} is the spot price, E^c is the amount of energy offered at day-ahead market, λ^{cap} is the capacity price for primary reserve allocation, P^c is the reserve contracted (offered) in the day-ahead market, T_w^* is the regulation costs from the regulation market, W_w^* is the penalty cost for wind power plant failing to provide the scheduled reserve, (E_w^*- E^c) is the energy balance between the delivered energy E_w^* and the energy offered, and (P_w^*- P^c) is reserve power imbalance between the deployed level of reserve P_w^* in real-time and the reserve offered.

Additionally, it is assumed that the WPP acts as a price-taker. Thus, the production of the WPP is independent of market prices and penalties. Then, the regulation costs from the regulation market can be defined as

$$T_w^* = \begin{cases} \lambda^{*,+}\left(E_w^* - E^c\right), & E_w^* - E^c \geq 0 \\ -\lambda^{*,-}\left(E_w^* - E^c\right), & E_w^* - E^c < 0 \end{cases} \quad (2)$$

The variables $\lambda^{*,+}$ and $\lambda^{*,-}$ are the regulation unit costs for positive and negative deviations

$$\lambda^{*,+} = \lambda^{sp} - \lambda^{c,+}$$
$$\lambda^{*,-} = \lambda^{c,-} - \lambda^{sp} \quad (3)$$

where $\lambda^{c,+}$ is the unit down-regulation price for being long, while $\lambda^{c,-}$ is the up-regulation price for being short.

In addition, a two-price settlement rule (as in NordPool) is assumed [1].

The penalty costs for reserve imbalance is given by

$$W_w^* = \begin{cases} \lambda^{bpt,+}\left(P_w^* - P^c\right), & P_w^* - P^c \geq 0 \\ -\lambda^{bpt,-}\left(P_w^* - P^c\right), & P_w^* - P^c < 0 \end{cases} \quad (4)$$

where $\lambda^{bpt,+}$ is a unit penalty when wind producer generates more power than the contracted (surplus), and $\lambda^{bpt,-}$ is the unit penalty cost when the WPP generate less than contracted. These are given by

$$\lambda^{bpt,+} = \lambda^{cap} - \lambda^{pt,+}$$
$$\lambda^{bpt,-} = \lambda^{pt,-} - \lambda^{cap} \quad (5)$$

hence $\lambda^{pt,+}=0$ since (extra) positive reserve is not detrimental to the system's reliability. $\lambda^{pt,-}$ is the penalty for negative reserve imbalance, weighted by the probability that reserve is needed.

The objective function is subject to the following constraints regarding the proportional strategy split of energy and reserve. The proportional wind offering strategy is used to define the share of energy E^c and reserve P^c to be submitted in the market [6], [7],

$$E^c = \alpha^c Q \quad (6)$$

$$P^c = (1-\alpha^c)Q \quad (7)$$

$$1 \leq Q \leq E^{max} \quad (8)$$

where Q is the total power bid and α^c the strategy parameter controlling the share of energy and reserve bids at day-ahead stage, which varies between 0 and 1.

Under some support schemes, the WPPs are required to participate in the day-ahead market, thereby, the bounds of the total power bid Q reflects the minimum power bid to participate in the market (1 MW in most of electricity markets) and the installed capacity of the WPP.

Equations (7) and (8) concerns the wind offering strategy under the balancing power market

$$E_w^* = \alpha_w^* E_w^{obs} \quad (9)$$

$$P_w^* = (1-\alpha_w^*) E_w^{obs} \quad \forall w \in \Omega \quad (10)$$

where E_w^{obs} donates the eventually observed wind power production, composed by energy E_w^* and reserve P_w^* share actually available. α_w^* is the strategy parameter for the splitting in real-time operation.

4. Evaluation of offering strategy

A wind power plant with 15 MW of installed power is considered. The wind total bid offer is subjected to a minimum amount of power to participate in the markets. Currently, electricity markets settle 1 MW as the minimum power for the bidding process. A set of 100 wind power scenarios presented in [8], has been considered for evaluating the proposed methodology. It is assumed that all the scenarios are equiprobable.

The evaluation of the proposed strategy is performed according with a set of prices and penalty costs combination allowing us to test the behaviour of the strategy for different assumptions, such as $\alpha_w^* = \alpha^c$ and allowing that α_w^* can be free (i.e., α_w^* can be equal or different of α^c).

The prices for energy and reserve, and the unit penalty costs for up and down deviations in our base case are presented in Table 1.

Table 1 - Prices and penalty costs in energy and reserve market for base case.

Energy	Price (€/MWh)	Reserve	Price (€/MW)
λ^{sp}	20-40	λ^{cap}	25
$\lambda^{c,+}$	17	$\lambda^{bpt,+}$	0
$\lambda^{c,-}$	32	$\lambda^{pt,-}$	30

Different combinations of prices and penalty costs for energy and reserve can occur in the market. Figure 2 illustrate the behaviour of the stochastic approach with standard share parameter relationship between day-ahead and balancing market, as well as the approach assuming that share parameter can change from day-ahead to the balancing market. The variation of the spot price results in different combinations of prices and penalty costs. From Figure 2, one can observe that allowing share parameter to change in balancing market get at least the same revenue than with the strategy with fixed share parameter.

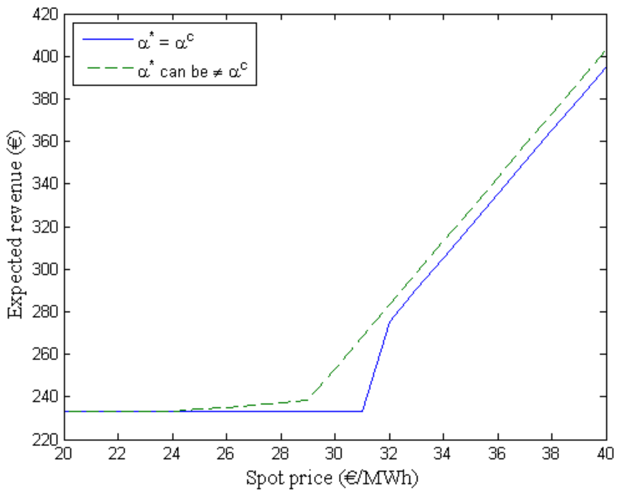

Figure 2**:** Expected revenue for both approaches under variation of the spot price.

The energy and reserve bids in day-ahead market taking into account a variation of the spot price is illustrated in Figure 3. The different behavior of the energy and reserve bids in the day-ahead market strongly depends on the relationship between prices and penalty costs, i.e. (λ^{sp} and λ^{cap} as prices at day-ahead market; and $\lambda^{*,-}$, $\lambda^{*,+}$ and $\lambda^{bpt,-}$ as penalty costs in the balancing market). At the beginning of the spot price range, both strategies assume to offer in the reserve market, since the capacity price is higher than the spot price, as well as, the penalty costs on reserve are lower than in energy. The change on behavior of both strategies occurs when the spot price is higher than capacity price and energy and reserve penalty costs are similar. At this state, the approach with flexible share parameter on balancing changes, starting offering only energy. The same behavior is only achieved for the approach with fixed share parameter, when energy price and penalty costs are higher and lower than capacity price and reserve penalty cost, respectively.

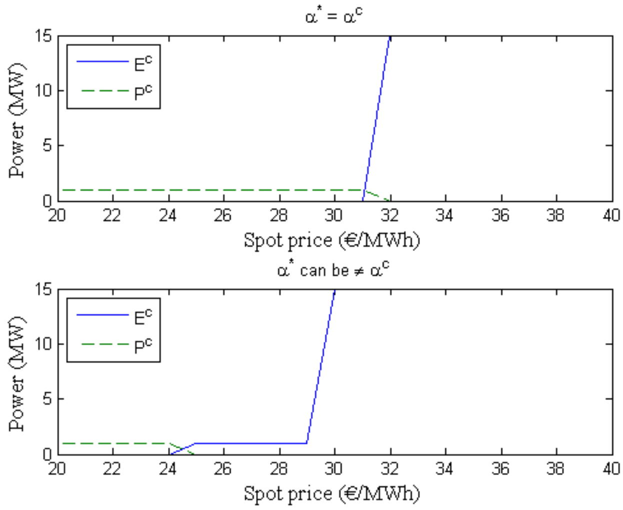

Figure 3**:** Energy and reserve bids at day-ahead stage considering both approaches under variation of the spot price.

Moreover, it is noteworthy that proportional offering approach has a straightforward behavior in which only submits bids to one of the markets. I.e. the strategy assumes a risk neutral behavior, as expected, by submitting all availability to energy or reserve.

5. Conclusions

With the introduction of new business models where the WPPs can provide energy and reserve bids in the day-ahead market while accounting with expected cost in the balancing market, new strategic bidding for WPPs is crucial to increase their profit.

This work shows the benefits that the WPPs may achieve by participating in energy and reserve market with different behaviour of the share between energy and reserve in day-ahead and balancing market. On average, the opportunity to change the energy and reserve share in the balancing market can improve the revenue of the WPPs about 2.43 %.

6. Learning objectives

- The new design of methodologies for strategic bidding of wind power producers in day-ahead and balancing market may increase the profit of wind power producers;
- New behaviour and market opportunities for wind power producers may influence future market design and mechanisms. Wind power participation in reserve markets may lead to a change of the current market mechanisms for ancillary services;
- Market operators may develop market mechanisms to support wind power integration, however, ensuring system reliability.

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