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Combining hydro-generation and wind energy Biddings and operation on electricity spot markets

Jorge Márquez Angarita, Julio Garcia Usaola *
Universidad Carlos III de Madrid, Department of Power Engineering, Avenida de la Universidad, 30, 28911 Leganés, Madrid, Spain

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Abstract

Wind generation is growing rapidly in all the world, especially in Europe. The power produced by this kind of generation is difficult to predict and the predictions are not very accurate. In most systems these imbalances are costly. These penalties reduce the revenue for the wind generation company (WGENCOs). An option to solve this problem would be to work together with another agent. In this paper, a combined strategy for bidding and operating in a power exchange is presented. It considers the combination of a WGENCO and a hydro-generation company (HGENCO). The mathematical formulation for the optimal bids and for the optimal operation is presented, as well as results from realistic cases.

Keywords: Wind energy; Combined operation; Combined bids; Power exchange

1. Introduction

The great amount of non-dispatchable wind energy connected to the grid has led the regulatory authorities in Spain to promote the integration of this kind of energy in the electricity market. The rules that these producers must follow are the same of any other generator. This means that a wind generation company must make a schedule for the day ahead market, and that penalties must be paid if this schedule is not followed.

This paper presents two methods to minimize these penalties, taking into account the stochastic nature of the primary source of this energy, the wind. The first method is based on a statistical analysis of the expected production probability, in order to minimize the risk of the prediction for the day ahead.

The second one employs a hydro-plant (HGENCO), in order to minimize the penalty for incurring in imbalance.

In both cases, it is assumed that the company (WGENCO and HGENCO) is a price-taker.

1.1. Participation in the pool

The study presented here has been designed for a pool market, where bids must be made once a day and corrected in intraday markets. Bilateral contracts are not considered.

Two different hypotheses are studied. The first one considers a single daily auction, i.e., bids can be presented only once a day (1A). The second one considers several daily auctions (SA). An illustration of both cases is presented in Figs. 1 and 2.

In the example the following values will be used: $tdi = 14$ h, $tdf = 38$ h for single daily auction (1A) and $tdi = 4$ h and $tdf = 8$ h for several auctions (SA, 6 auctions per day in this case).

1.2. Penalties for imbalance

According to the Spanish regulation [1], those agents incurring in imbalances must pay the cost of this imbalance. This value is going to be expressed in this paper as a penalty proportional to the market price of energy. This approach is valid if this percentage is estimated somehow in advance.

In order to calculate the expected penalty it is necessary to forecast the day ahead energy prices [2–4]. In this paper a perfect price forecasting will be assumed.

1.3. Wind power prediction

In order to decrease the amount of the penalty for imbalance it is necessary to use a short term wind power prediction tool [5,6]. The simplest prediction tool is persistence. This method

* Corresponding author. Tel.: +34 916 249404; fax: +34 916 249430.
E-mail address: jusaola@ing.uc3m.es (J.G. Usaola).

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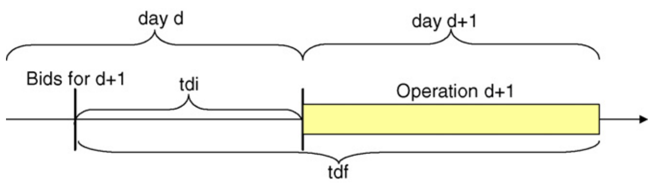

Fig. 1. Single daily auction session (1A).

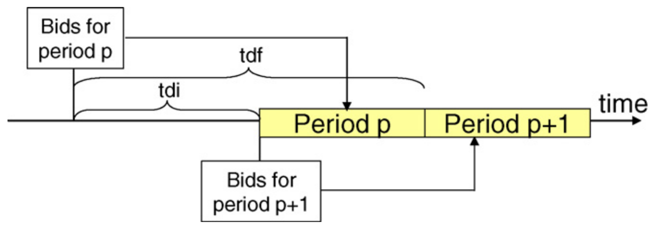

Fig. 2. Several day auction sessions (SA).

assumes that the production in the future is the same as the present one. Persistence is usually used as a reference that must be improved by any practical prediction tool.

In this paper, predictions will be made with higher accuracy, following the results obtained by the program SIPREÓLICO [7]. This program takes wind speed and direction predictions from the Numerical Weather Prediction program HIRLAM, as well as real time power measurements, and provides hourly predictions up to 42 h in advance. SIPREÓLICO has been developed by Universidad Carlos III de Madrid for Red Eléctrica de España, the Spanish TSO, where it has been running since 2002. The accuracy of SIPREÓLICO has been checked with other prediction tools, and it is similar to the present state-of-the-art [8].

In the following section, the equations for minimizing the imbalance cost of the WGENCO and maximizing the revenue of a HGENCO are presented. Section 3 presents the equations for the combined operation optimization problem. The results for a realistic case are shown in Section 4. Finally the conclusions are exposed.

2. Independent scheduling

In this section, the optimal power to be declared in the bid will be found. The WGENCO will try to find the minimum expected power imbalance cost and the HGENCO will try to find the maximum expected revenue.

2.1. Wind optimization problem

The revenue of a WGENCO is the difference between the revenues for the energy sold and the penalty paid for the incurred imbalance [9]. For the sake of simplicity, the operational costs of the wind generation are supposed to be negligible, although this is not realistic. The penalties paid are a fraction of the daily marginal prices. The formulation of the problem consists in minimizing the expected penalty for deviations (WEP), by choosing the best value of wind power to bid in each period t, pws_t.

Min WEP

$$\mathrm{WEP}=\sum_{t=1}^{t=T}\left\{\sum_{i=1}^{i=N}\{\lambda_t\cdot\psi\cdot|\mathrm{pwr}_i-\mathrm{pws}_t|\cdot\rho(\mathrm{pwr}_i|\mathrm{pwr}_0,t\mathrm{di}+t)\}\right\} \tag{1}$$

$$\text{if } \mathrm{pwr}_i>\mathrm{pws}_t,\quad \psi=\psi_{\mathrm{up}}$$
$$\text{if } \mathrm{pwr}_i<\mathrm{pws}_t,\quad \psi=\psi_{\mathrm{down}}$$

The probability density function ρ of Eq. (1) must be known. There are different methods to estimate it and in this paper it has been found from historical records of wind farm power production. The solution of this problem provides the optimum amount of power to be presented as a bid to the day ahead market for every hour $\{\mathrm{pws}_1, \mathrm{pws}_2, \ldots, \mathrm{pws}_T\}$. Only a wind farm is considered, but this farm might also be a combination of wind farms that present a joint bid, as in the example shown later.

2.2. Hydro-optimization problem

This model is based on [10,11], but instead of limiting the water volume at the end of the period, the future price of water is used. The unit performance curve (UPC) is a highly nonlinear function, and it is approximated by a non-concave piecewise linear approximation. The effect of the head variation of the reservoir is neglected. This approximation is valid for large reservoirs and short term hydro-scheduling.

The problem consists in the choice of the scheduled hydro-power for each hour t and hydro-unit i $\mathrm{phs}_{i,t}$ for the maximization of the revenue of the hydro-GENCO, but taking into account the expected price of the water.

Max HEP

$$\mathrm{HEP}=\sum_{t=1}^{t=T}\left\{\sum_{i=1}^{i=I}\{\lambda_t\cdot \mathrm{phs}_{i,t}-\mathrm{su}_i\cdot y_{i,t}+x_{i,\mathrm{TF}}\cdot Q_i\}\right\} \tag{2}$$

$$\mathrm{phs}_{i,t}=p_{0,i}+\sum_{l=1}^{l=L}\rho_{i,l}\cdot u_{i,t,l},\quad \forall i\in I,\ \forall t\in T \tag{3}$$

$$x_{i,t}=x_{i,t-1}+W_{i,t}+M\sum_{j=1}^{j=I}\{u_{t-\tau ij,j}+s_{t-\tau ij,j}\} -M\{u_{i,t}+s_{i,t}\},\quad \forall i\in I,\ \forall t\in T,\ \forall j\in R \tag{4}$$

$$\begin{aligned} x_{i,t}&\geq X_{\min,i},\quad \forall i\in I,\ \forall t\in T\\ x_{i,t}&\leq X_{\max,i},\quad \forall i\in I,\ \forall t\in T \end{aligned} \tag{5}$$

$$u_{i,t,l}\leq U_{i,l},\quad \forall i\in I,\ \forall t\in T,\ \forall l\in L \tag{6}$$

The solution of this problem gives the power generated by each unit in the river basin. The data for this system have been taken from [10].

In this problem, Eq. (3) gives the hydro-generation characteristic which is a non-concave piecewise linear approximation. The output power of each hydro-plant has been divided into L blocks. The characteristic in each block is linear.