Wind farm strategic investment considering forecast errors penalties in a nodal prices market

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Abstract
To maintain its development, renewable energy (RES) needs to be profitable selling its production directly on the market, such as the day-ahead market [1]. However, works on operational or investment strategies do not account for the penalties induced when the energy delivered does not match the amount contracted (some use empirical data [2,3]). The aim of this work is therefore to determine investment strategies for RES plants considering penalties coming from forecast errors, generating the penalties endogenously (rather than using empirical data), the results are shown for a simple case study with real French wind production data.

Objectives
We aim to determine investment strategies for RES plants, taking into account the impact of the new plants on the market price, and the impact of forecast errors coming from these plant’s production on penalties (we consider that the penalties charged correspond to the real-time price). This work is carried out using local marginal prices (both for day-ahead and real-time operations) to account for network constraints.

Model
To determine the investment, we solve an optimization problem, which has the following structure:

Upper-level problem : minimization of the global cost
- Capacity invested : determines power forecast and observed using normalized wind power data
- Respectively: Day-ahead and Real-time local market price

Lower level problem : Day-ahead market clearing

Lower level problem : Real-time market clearing

Main (upper-level) problem: minimization of the global cost for the wind producer composed of:
- the investment cost.
- the revenue from the day-ahead market clearing.
- and the revenue (or penalty) coming from the real-time market clearing (considering a zero-production cost).

This problem’s constraints include:
- the fact that the energy bid on the day-ahead market is the forecasted production,
- the actual production is entirely injected in the system.
- We consider that the imbalances come from forecast errors only, and that
- the considered generator is the only source of error (other generators are conventional units).
- Finally, bounds are given for the investment capacity.

This problem is dependent on the market prices, which are determined through market clearings in the lower level problems. Considering that reserve should only balance errors from the wind producers, the two lower level problems are independent.

Day-ahead market clearing (first lower-level problem): It minimizes the cost of buying production to satisfy the demand. The offer-demand equilibrium constraint’s dual variable gives the market price which is used to calculate the revenue in the upper level problem. This problem also enforce the power flow and voltage angle constraints, as well as the limits of production for the conventional units.

Real-time market clearing (second lower-level problem): It minimizes the cost of buying reserve production. Reserve means only intervene here (we consider that day-ahead conventional units are not responsive enough). They counterbalance locally (i.e. the power flow on the grid remains those planned with the day-ahead market clearing) imbalances (under or overproduction) coming from wind power forecast errors only (i.e. the conventional generators do not introduce imbalances).

Method
To solve this optimization problem, we transform the lower-level problems into constraints of the upper-level problem using their Karush Kuhn Tucker conditions. We are able to linearize the objective function using the strong duality theorem, and the non-linear constraints adding constraints using the following relation:

\[ \alpha \geq 0, \beta \geq 0, \alpha \beta = 0 \]

Case study
We consider a simple three node system:

<table>
<thead>
<tr>
<th>Node</th>
<th>Demand (MW)</th>
<th>Generator type</th>
<th>Cost (€/MWh)</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Coal</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>Gas</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>Nuclear</td>
<td>7</td>
<td>20</td>
</tr>
</tbody>
</table>

Normal wind production forecast and error

The wind power data set we consider has a normalized forecast error’s bias of 0.6% (i.e. actual overall production is overestimated for the sites considered). All the lines’ susceptance value is 9.412 p.u. The lines’ maximal capacity is 25 MW. The investment cost is 900k€/MW adjusted to the February-March 2008 period considered for the wind production and considering a 20-year amortization. We consider a 20 MW reserve unit on each node.

Results
We compare the optimal investment decision and benefit (net profit left when the different costs have been subtracted from the revenue) obtained taking into account real-time penalties for different marginal cost of reserve:

<table>
<thead>
<tr>
<th>Without penalties</th>
<th>Reserve cost (€/MWh)</th>
<th>Investment at each node (MW)</th>
<th>Benefit (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15.5/0/5.1</td>
<td>66 964</td>
<td></td>
</tr>
<tr>
<td>With penalties</td>
<td>10</td>
<td>15.4/0/4.9</td>
<td>42401</td>
</tr>
<tr>
<td>With penalties</td>
<td>40</td>
<td>0/0/0</td>
<td>0</td>
</tr>
</tbody>
</table>

Conventional (red) and wind power (green) contracted on the day-ahead market

Conventional (red) and wind power (green) contracted on the real-time market

Conclusions
The penalties weight down the producer’s revenue. Combined to the investment cost, the investments are not beneficial.

In this work the reserve cost has been used as a parameter of the problem but further work could emphasize on scenarios for future cost of reserve.

The opportunities to benefit from imbalances coming from other players in the system is also of interest, as we only have considered the errors coming from the investor.

References
1. Wind power investment within a market environment, Applied Energy
2. Assessment of wind power predictability as a decision factor in the investment phase of wind farms, Applied Energy

Acknowledgement

EWEA 2014, Barcelona, Spain: Europe’s Premier Wind Energy Event