Stochastic Joint Optimization of Wind Generation and Pumped-Storage Units in an Electricity Market

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Overview

Renewables, Problems, Solution

- Increasing concern over the environmental impact
- Renewable energy sources become an important portion of generation mix.
- Renewables participate in electricity market competition.
- Wind Energy is the fast growing renewable energy.

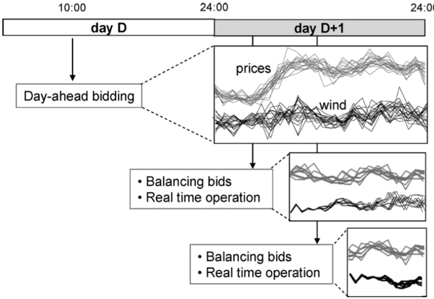
Drawbacks of Wind

- uncontrollable
- uncertain
- fluctuated

Solution

the Joint Operation of wind power and pumped-storage units in electricity market.

Renewables in the Spot Market



For a wind producer in market:

- **BF 10** forecast his production, build bids (for Day-ahead Market)
- **BF 10** submit hourly bids for the following day
- **D+1** (optional) submit balancing bids in real-time market
- **D+1** optimize its operation/output
- **D+1** Penalty because of the output deviation from the bids

Stochastic Programming

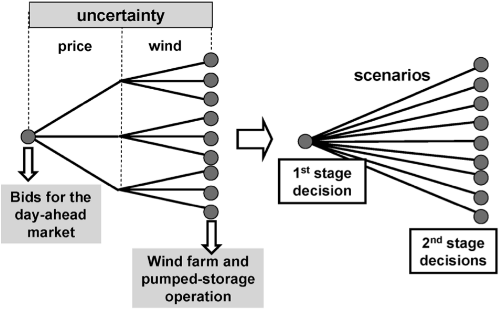
Uncertainty

Day-ahead forecast error of wind power is huge (30% - 50%)
Also uncertainty about market price.

Solution - Stochastic Programming

Stochastic Programming deals with the problems of making optimal decisions under uncertainty.

Two Stage Stochastic Programming



1st-Stage Hourly bids submitted to the day-ahead market

2nd-Stage Operation of the wind power and pumped-storage units

Uncoordinated Operation (UO)

Model of Wind Power

$$\max \sum_{s \in S} \rho_s \cdot \sum_{h \in H} [\pi_{s,h} \cdot g_{s,h}^W - \omega \cdot \pi_{s,h} \cdot |g_{s,h}^W - x_h^W|] \qquad (1)$$

Bid constraints, output constraints

The subscript s, h means **in scenario** s**, in period** h

Constants

- S, s Set and index of scenarios
- H, h Set and index of hourly periods
- ρ_s Probability of scenarios
- ω Penalty factor over the market price energy imbalances
- $\pi_{s,h}$ Expected market price in scenario s period h

Variables

- x_h^W Energy bid to the day-ahead market by the wind farm in period h
- $g_{s,h}^W$ Power output of the wind farm in scenario s in period h

Uncoordinated Operation (UO)

Model of Pumped-Storage Plant

$$
\begin{aligned}
\max \sum_{s \in S} \rho_s \cdot \sum_{h \in H} [\pi_{s,h} \cdot (g^p_{s,h} - d^p_{s,h}) - c^{su} \cdot y_{s,h} - c^{sd} \cdot z_{s,h} \\
- \omega \cdot \pi_{s,h} \cdot |g^p_{s,h} - d^p_{s,h} - x^p_h|]
\end{aligned} \tag{2}
$$

The subscript s, h means **in scenario s, in period h**

Constants

c^{su}, c^{sd} Start-up and shut-down costs of pumping units

Variables

$g^p_{s,h}$ Discharge power output of pumped-storage plant

x^p_h Energy bid to the DA market

$d^p_{s,h}$ Pumping power input of the pumped-storage plant

$y_{s,h}, z_{s,h}$ (Integer)The number of units that are start-up and shut-down in the pumping mode

Joint Optimization (JO)

Model of Pumped-Storage Plant

$$\max \sum_{s\in S}\rho_s \cdot \sum_{h\in H}[\pi_{s,h}\cdot(g^W_{s,h}+g^p_{s,h}-d^p_{s,h}) - c^{su}\cdot y_{s,h} - c^{sd}\cdot z_{s,h}$$
$$-\omega\cdot\pi_{s,h}\cdot|g^W_{s,h}+g^p_{s,h}-d^p_{s,h}-x^{wp}_h|]$$

Bidding constraints, operation constraints

The subscript s, h means **in scenario s, in period h**

Variables

- $g^p_{s,h}$ Discharge power output of pumped-storage plant
- $g^W_{s,h}$ Power output of the wind farm
- x^{wp}_h Joint bid to the DA market
- $d^p_{s,h}$ Pumping power input of the pumped-storage plant
- $y_{s,h}, z_{s,h}$ (Integer)The number of units that are start-up and shut-down in the pumping mode

Scenarios

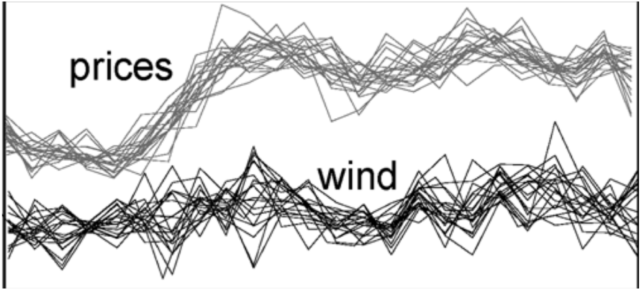


Figure : Scenarios

Number of Price scenarios: 20
Number of Wind Production scenarios: 21
Total Scenarios: $21 \times 20 = 420$

Obtained Optimal Hourly Bid

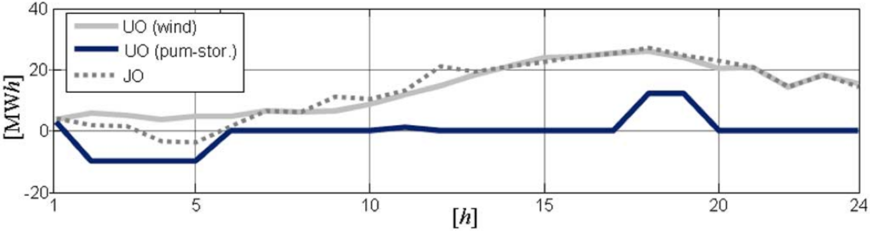
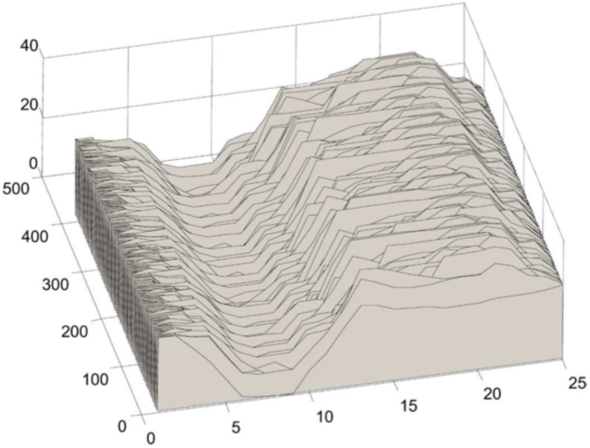


Figure : Optained Hourly Bid

Obtained Operation Through the Day in the Lower Reservoir For Each Scenario in the Joint Optimization



Economic Results

Configuration		Mean value [Eur]
UO	Wind farm	16301
	Pumped-storage	193
	Sum	16494
JO		16912

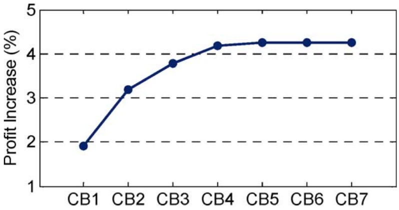
Figure : Profits (UO vs JO)

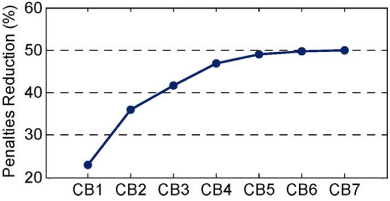
Configuration	Penalties [Eur]
UO	1653
JO	1066

Figure : Penalties (UO vs JO)

- Joint Operation has more profits.
- Joint Operation has less penalties.

The influence of pumped-storage size





From CB1 to CB7: the capacity of pumped-storage plant increases.

- When the pumped-storage plant dimensions are small compared to the wind farm power, profits increase faster
- When the value of the pumping capacity approaches that of the wind farm, profits remain almost constant.

Conclusions and Future Work

- In this paper, the author demonstrated that a joint short-term operation of a wind farm and of an isolated pumped-storage plant can be obtained by solving the presented optimization model.
- Two-stage stochastic programming approach has proven to be an effective way to model the real decision making process that wind park operators face in a spot-market framework under uncertainty.
- the models presented in this paper could be useful for assisting in investment decisions about new pumped-storage facilities.

Future research: introduce in the optimization model some risk-aversion measures.

Possible Problems

- The scenarios (price and wind) are not convincing
  - Price Scenarios are based on **"Modeling and forecasting electricity prices with input/output hidden Markov models," published on IEEE Trans. Power Syst., vol. 20, no. 1, pp. 112, Feb. 2005.**
  - Not mention how to generate wind scenarios? The characterics of wind scenarios? Special scenarios?
- Some deep analysis?