Evaluating approaches for estimating the water value of a hydropower plant in the day-ahead electricity market

Ignacio Guisández, Juan I. Pérez-Díaz
Department of Hydraulic, Energy and Environmental Engineering
Technical University of Madrid (UPM)

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1. Motivation and objective

There is a wide number of recent articles dealing with the use of “complex algorithms” (MILP, MIQP, Lagrangian Relaxation, etc.) to solve the decomposed decision problems of DP-based medium-term scheduling models (water value)
1. Motivation and objective

The motivation for such a big research effort has been rather diverse, namely:

- Head-effects (H)
- Discharge-effects (Q)
- Units’ start-ups
- Reserve markets
- Price-making effects
- Bid curves
- Risk aversion
- ...

\[ P = \gamma \eta(Q,H)QH(Q) \]
1. Motivation and objective

Research questions:

1. Is the use of “complex algorithms” to solve the decomposed decision problems of a DP-based medium-term scheduling model a fruitful/profitable/reasonable/… PRACTICAL effort?

2. In what circumstances is it practical?
1. Motivation and objective

Our focus

- SDP
- MILP
- Benders cuts
- LP
- MIQP
- SDDP
- SDDiP
- Risk aversion
- Head-effects
- Discharge effects
- Lagrangian relaxation
- Price-making effects
- Units’ start-ups
- Reserve markets
- Heuristic-based locally valid cuts
- Lagrangian cuts
- Bid curves
- Discharge effects
Our focus

PRELIMINARY WORK!
2. Methodology

- 1 hydropower reservoir
- 1 hydropower plant equipped with 1 Francis unit
- 4 medium-term scheduling models

$\text{SDP+LP (LP)} \rightarrow WV_{LP}$

$\text{SDP+MILP (MILP-1)} \rightarrow WV_{MILP-1}$

$\text{SDP+MILP (MILP-2)} \rightarrow WV_{MILP-2}$

$\text{SDP+MILP (MILP-3)} \rightarrow WV_{MILP-3}$

Simulations & Comparison

$WV = \text{Water value}$
2. Methodology

Common features of the medium-term scheduling models:

✓ 1-year planning period
✓ 1-week decision stages
✓ 1-hour time steps
✓ Aimed at maximizing the profit in the energy market
✓ Consider the unit’s start-up and wear and tear costs
✓ 2 exogenous stochastic variables: water inflow volume and average energy price
✓ The exogenous stochastic variables are modelled each by means a discrete first-order Markov chain (no cross-correlation)
✓ The realizations of the exogenous stochastic variables are assumed known in each decomposed decision problem
✓ The initial state of the decomposed decision problem is defined by the initial storage and the exogenous stochastic variables
✓ The initial storage is discretized into 9 equidistant values
2. Methodology

Differences between the medium-term scheduling models:

- **MILP-1**
  - Taken from Chang et al., IEEE Trans. on Power Syst. 16(4), 743-749, 2001.

- **MILP-2**
  - Taken from Conejo et al., IEEE Trans. on Power Syst. 17(4), 1265-1272, 2002.

- **MILP-3**

- **LP**
  - Taken from Piekutowski et al., in Proc. 1994 IEEE Power Industry Computer Application Conference.
2. Methodology

**Differences between the medium-term scheduling models:**

- MILP-1/2/3 use a binary variable to mode the unit’s start-ups.
- The breakpoints of the power-discharge curves used by MILP-1/2/3 correspond to the minimum turbine flow, best efficiency and maximum turbine flow.
- The breakpoints of the power-discharge curve used by LP correspond to zero, best efficiency and maximum turbine flow.
- The power-discharge curves used by MILP-2/3 in each decision correspond to different heads uniformly distributed over the range of feasible heads.
- LP uses a linear formulation based on Warland et al. (2008)* to minimize the occurrence of discharges between 0 and the minimum turbine flow.

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2. Methodology

Power plant data

✓ Virtually located in Spain
✓ Installed power capacity 55 MW
✓ Maximum gross head 65 m
✓ Performance curves Krueger et al. (1976)\(^1\)
✓ Rated head loss 1 % of rated head
✓ Tailwater level variation El-Hawary & Christensen (1979)\(^2\)
✓ Inflow distribution pattern Spanish oceanic fluvial data
✓ Evaporation rates Dragoni & Valigi (1994)\(^3\)
✓ Reservoir curve Lehner et al. (2011)\(^4\)

2. Methodology

Simulations

- **1000-year long synthetic series** have been generated from the discrete Markov chains used to compute the Water Value by means of a heuristic sampling procedure
- **MILP-3** is used in the simulations on a rolling horizon basis
- **A perfect foresight** of both the hourly water inflows and energy prices is assumed in the simulations

![Graph showing energy price profiles](image)

Average, maximum and minimum hourly values of the synthetic weekly profiles of the energy prices
3. Results and conclusions

For the system under study the use of **MILP-1** to compute the WV seems to be **practical**

**MILP-1** has **outperformed** **MILP-2/3**

Considering the small size of the system under study, the expected increase in the computation time **for a realistic system**, with several reservoirs and tens of hydropower units, would make **the use of MILP-1/2/3 definitely impractical**

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The WV has been calculated by using one of the cores of an Intel® Xeon® E5 with 64 GB RAM at 3.1 GHz.
4. Future work

Reviewers’ suggestions

- Replicate the study in other more realistic hydropower systems with a larger number of reservoirs and complex topologies
- Add downstream equations (e.g. environmental constraints)
- Use a finer discretization for the initial storage and exogenous stochastic variables

We are still working with a single-reservoir system and plan to obtain soon similar results with different:

- Downstream constraints
- Price profiles
- Inflow patterns
- Inflow-discharge-storage ratios
- Number of hydropower units
- Performance curves of hydropower units
- Discretizations

To come in early 2019!
Thank you very much for your attention!

Any questions?

Juan I. Pérez-Díaz
ji.perez@upm.es