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

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0. Index

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)

Optimal Multipurpose-Multireservoir Operation Model with Variable Productivity of Hydropower Plants

Q. Goor[1]; R. Kelman[2]; and A. Tilmant[3]

Stochastic dual dynamic programming applied to nonconvex hydrothermal models

Santiago Cerisola*, Jesus M. Latorre, Andres Ramos

Approach of Integrating Ancillary Services into a medium-term Hydro Optimization

Hubert ABGOTTSPON[1], Göran ANDERSSON

A model for optimal scheduling of hydro thermal systems including pumped-storage and wind power

Arild Helseth[1], Anders Gjelsvik[1], Birger Mo[1], Úlfar Linnet[2]

Assessing hydropower operational profitability considering energy and reserve markets

Arild Helseth[1], Marte Fodstad[1], Magnus Askeland[1], Birger Mo[1], Odd Bjarte Nilsen[2], Juan Ignacio Pérez-Díaz[3], Manuel Chazarra[3], Ignacio Guisández[3]

Dynamic convexification within nested Benders decomposition using Lagrangian relaxation: An application to the strategic bidding problem

Gregory Steeger, Steffen Rebennack*

Long-term optimal allocation of hydro generation for a price-maker company in a competitive market: latest developments and a stochastic dual dynamic programming approach

B.C. Flach[1,2] L.A. Barroso[1] M.V.F. Pereira[1]

Optimizing Trading Decisions for Hydro Storage Systems Using Approximate Dual Dynamic Programming

Nils Löhndorf, David Wozabal, Stefan Minner

Medium-term optimization of pumped hydro storage with stochastic intrastage subproblems

Hubert Abgottspon, Göran Andersson

Nonconvex Medium-Term Hydropower Scheduling by Stochastic Dual Dynamic Integer Programming

Martin N. Hjelmeland, *Student Member, IEEE*, Jikai Zou, Arild Helseth, *Member, IEEE*, and Shabbir Ahmed, *Senior Member, IEEE*

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
- ✓ …

→ $P = \gamma.\eta(Q,H).Q.H(Q)$

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

Risk aversion

Heuristic-based locally valid cuts

MILP

Head-effects

Lagrangian cuts

Benders cuts

LP

SDDP

SDDiP

Bid curves

Discharge effects

Discharge effects

MIQP

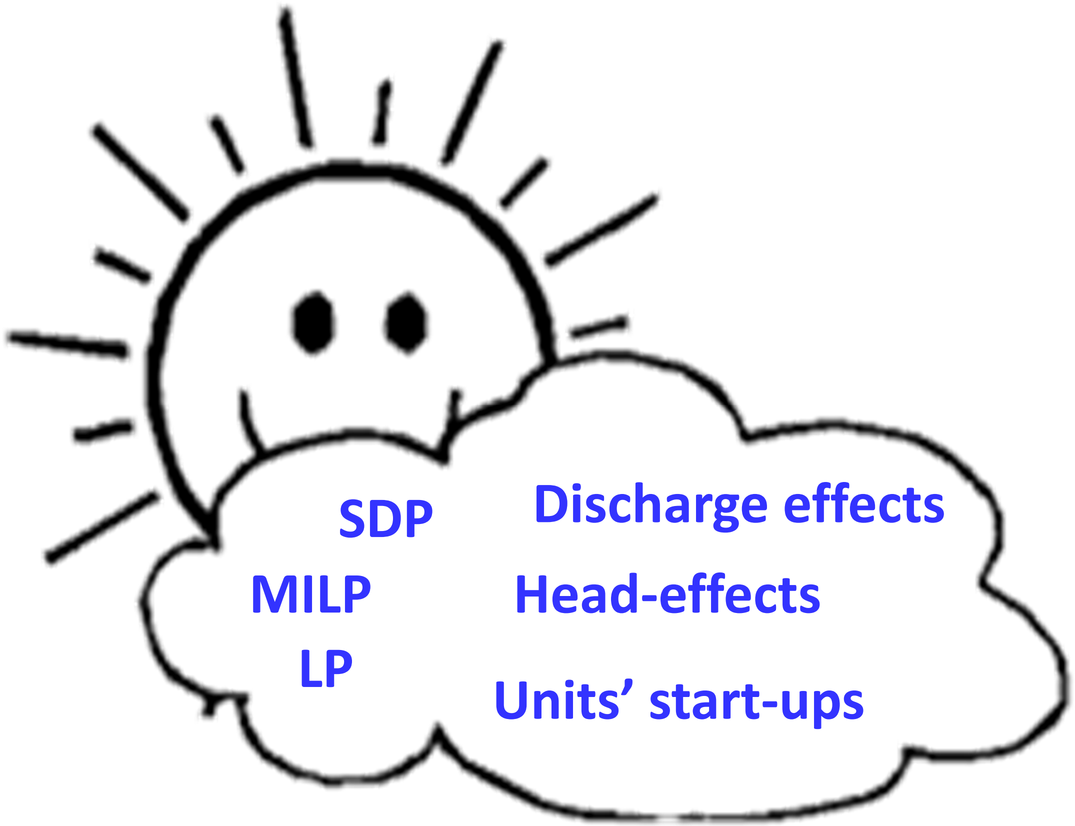
Lagrangian relaxation

Price-making effects

Units’ start-ups

Reserve markets

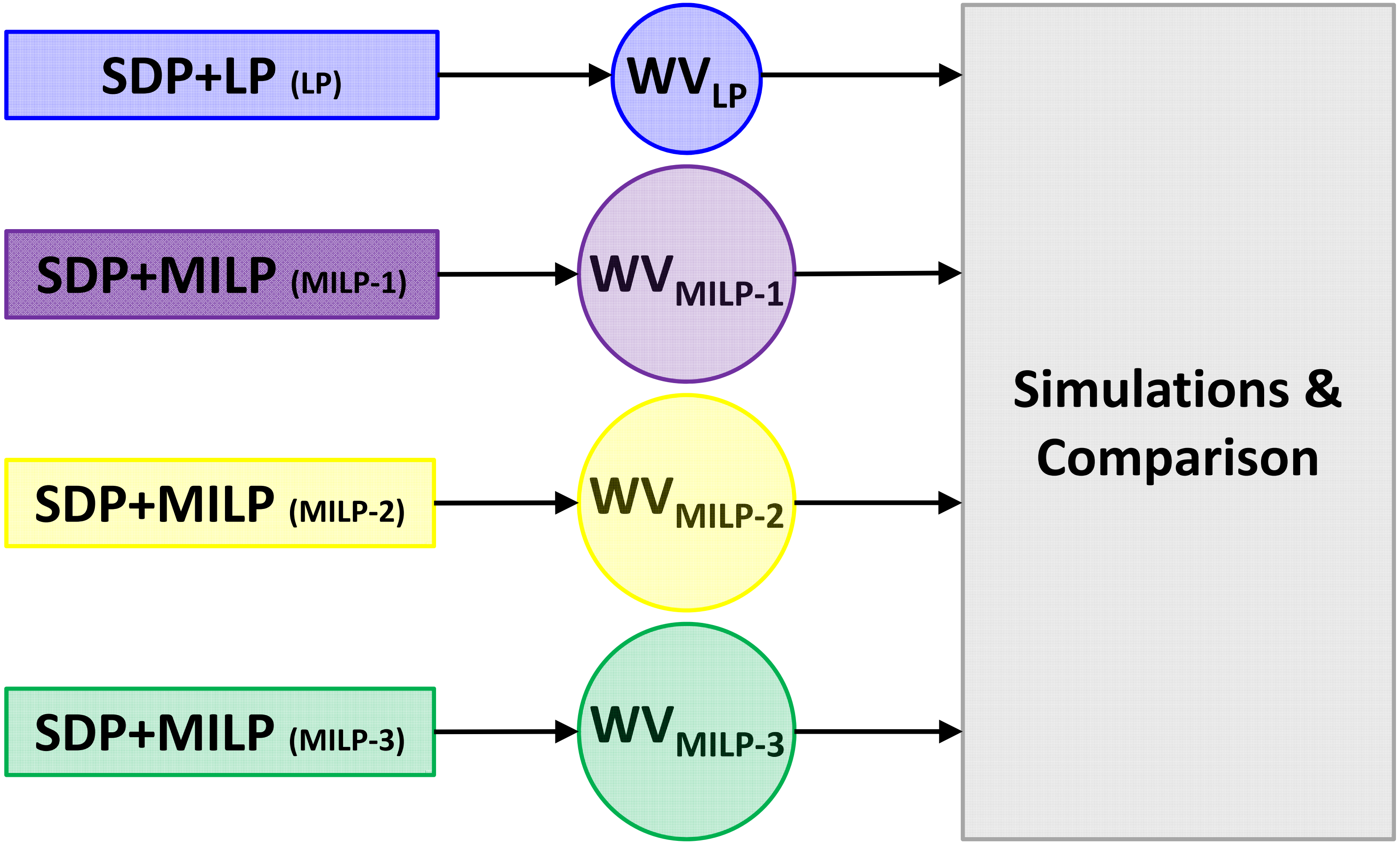
Our focus



PRELIMINARY WORK !

2. Methodology

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



WV = Water value

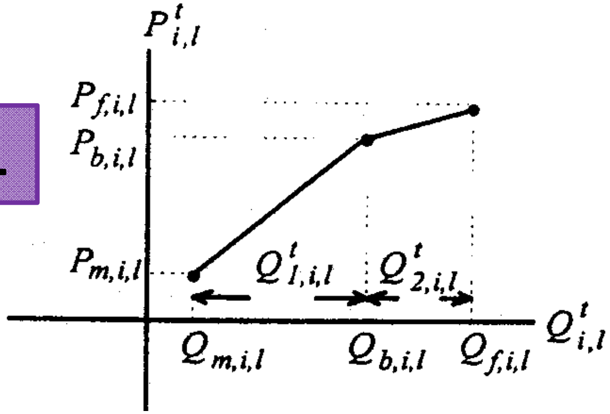
2. Methodology

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

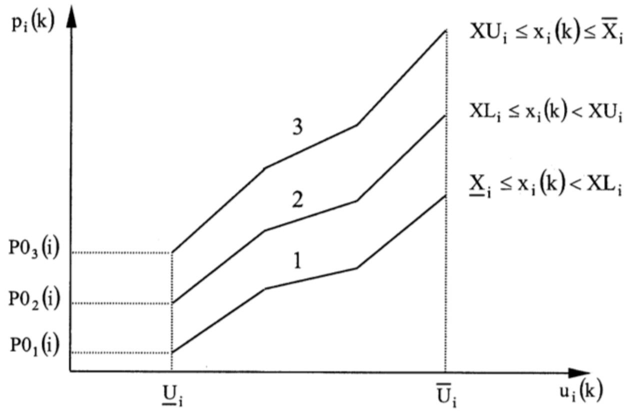
Differences between the medium-term scheduling models:

MILP-1



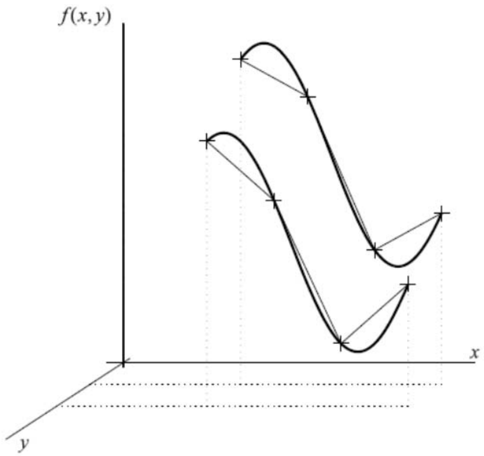
Taken from Chang et al., IEEE Trans. on Power Syst. 16(4), 743-749, 2001.

MILP-2



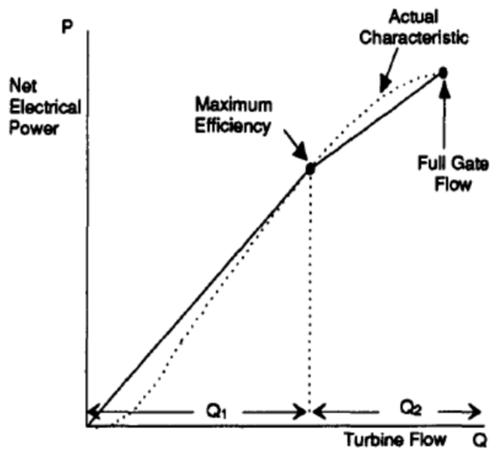
Taken from Conejo et al., IEEE Trans. on Power Syst. 17(4), 1265-1272, 2002.

MILP-3



Taken from D'Ambrosio et al., Operations Research Letters 38(1), 39-46, 2010.

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

* G. Warland, A. Haugstad, E.S. Huse, "Including thermal unit start-up costs in a long-term hydro-thermal scheduling model," in Proc. 2008 16th Power Systems Computation Conference (PSCC).

2. Methodology

Power plant data

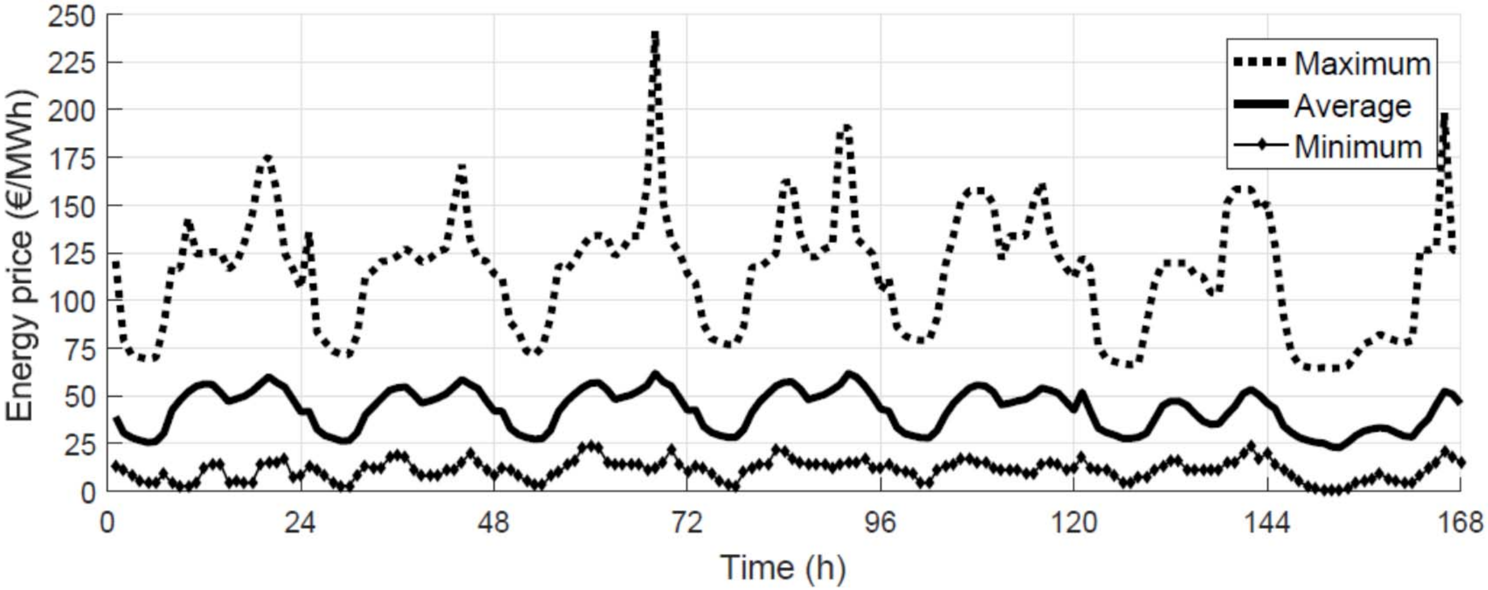
✓ Virtually located in Spain	
✓ Installed power capacity	55 MW
✓ Maximum gross head	65 m
✓ Perfomance curves	Krueger et al. (1976)[1]
✓ Rated head loss	1 % of rated head
✓ Tailwater level variation	El-Hawary & Christensen (1979)[2]
✓ Inflow distribution pattern	Spanish oceanic fluvial data
✓ Evaporation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

[1] R.E. Krueger, I.A. Winter, R.N. Walters, G.C. Bates: Selecting hydraulic reaction turbines. A water resources technical publication engineering monograph no. 20. Tech. rep., USBR, Denver, USA (1976).
[2] M.E. El-Hawary, G.S. Christensen: Optimal economic operation of electric power systems, vol. 26. Academic Press, New York, USA (1979).
[3] W. Dragoni, D. Valigi: "Contributo alla stima dell evaporazione dalle superfici liquide nell Italia Centrale". Geologica Romana 30, 151-158 (1994).
[4] B. Lehner et al.: High-resolution mapping of the world's reservoirs and dams for sustainable river-fow management. Front. Ecol. Environ. 9(9), 494-502 (2011).

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



Average, maximum and minimum hourly values of the synthetic weekly profiles of the energy prices

3. Results and conclusions

WV calculator	Average annual profit		Average head		WV calculation time	
	[M€]	Variation	[m]	Variation	[h]	Variation
MILP-1	7.5901		58.56		1.9	
MILP-2	7.5896	-0.01%	58.68	0.21%	62.6	3,249.44%
MILP-3	7.5881	-0.03%	58.62	0.11%	4.6	145.13%
LP	7.5803	-0.13%	58.94	0.66%	1.6	-14.79%

- 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**

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! (Downstream constraints, Price profiles, Inflow patterns, Inflow-discharge-storage ratios)

Thank you very much for your attention!

Any questions?

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