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Reservoir-type hydropower equivalent model based on a future cost piecewise approximation

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ABSTRACT

The long-term (LT) scheduling of reservoir-type hydropower plants is a multistage stochastic dynamic problem that has been traditionally solved using the stochastic dual dynamic programming (SDDP) approach. This LT schedule of releases should be met through short-term (ST) scheduling decisions obtained from a hydro-thermal scheduling that considers uncertainties. Both time scales can be linked if the ST problem considers as input the future cost function (FCF) obtained from LT studies. Known the piecewise-linear FCF, the hydro-scheduling can be solved as a one-stage problem. Under certain considerations a single segment of the FCF can be used to solve the schedule. From this formulation an equivalent model for the hydropower plant can be derived and used in ST studies. This model behaves accordingly to LT conditions to be met, and provides a marginal cost for dispatching the plant. A generation company (GENCO) owning a mix of hydro, wind, and thermal power will be the subject of study where the model will be implemented. The GENCO faces the problem of scheduling the hydraulic resource under uncertainties from e.g. wind and load while determining the market bids that maximize its profit under uncertainties from market prices. A two-stage stochastic unit commitment (SUC) for the ST scheduling implementing the equivalent hydro model will be solved.

1. Introduction

The scheduling of reservoir-type hydropower stations in the short-term (ST) has an impact on future operation costs. For this reason, this type of units has to be studied in the long-term (LT) timescale considering uncertainties from inflows, load, system expansion, etc. Due to computational complexity and tractability issues, this LT coordination problem cannot address a time step of hours. Depending on the coordination horizon, it is solved using a time step of days, weeks or even months. Some methods have tried to address this issue by using nested structures or multi-horizon approaches that address mid-term and ST timescales [1].

A methodology for the solution of multi-stage stochastic optimization problems known as stochastic dual dynamic programming (SDDP) [2] deals with the dimensionality problem of the dynamic programming method since combinatorial explosion is avoided. In order to improve tractability and accuracy, a hybrid method that unifies the sample-based approach (using SDDP) and the scenario-based approach (using a deterministic equivalent) has been developed in [3].

To avoid dimensionality issues due to different time resolution for ST and LT, time scales can be interlaced. A methodology developed in [4] solved the mid/short-term hydro-thermal coordination by translating the electrical problem at short-term level into constraints to be added to the mid-term scheduling problem. ST hydro-scheduling could be solved to meet end-point conditions to comply with a pre-established long-term water release schedule [5], as developed in [6] where the scheduling problem was solved using a piecewise-linear future cost function (FCF).

Another issue regarding hydro-scheduling concerns the assess of the actual monetary value of the hydraulic resource in present decisions. In the short-term operation, the system operator has to make decisions regarding re-dispatch of units. Considering a negligible marginal cost for the hydropower [7], the ST scheduling problem has been solved using different operations research approaches, applying Bender's decomposition [7,8], Lagrangian relaxation [9–11], continuation methods [12], extended differen-

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Nomenclature

Cmg	marginal cost (€/MWh)
C_x	no load cost (€)
C_y	star-up cost (€)
C_z	shut-down cost (€)
I	river inflow of a hydro-reservoir (hm^3/h)
K_f	future cost coefficient of a hydropower plant (€/hm^3)
MTU	minimum time up of a thermal unit (h)
MTU	minimum time down of a thermal unit (h)
NBC	number of bilateral contracts with retailers
NSU	number of storage units
N_t	number of periods of the study
NTU	number of thermal units
NHU	number of hydro units
NWU	number of wind-power units
P_{buy}	GENCO's buying bid (MW)
P_h	active power produced by a hydropower plant (MW)
P_L	active power load (MW)
P_{sell}	GENCO's selling bid (MW)
P_T	active power produced by a thermal plant (MW)
P_w	wind power (MW)
RU	ramp up rate of a thermal unit (MWh)
RD	ramp down rate of a thermal unit (MWh)
S	spill flow of a hydro-reservoir (hm^3/h)
u_x	stand-by binary decision
u_y	start-up binary decision
u_z	shut-down binary decision
V_0, V_f	initial and final volume of a reservoir (hm^3)
Δt	interval of coordination (h)
γ, λ	equality constraints Karush–Kuhn–Tucker (KKT) multipliers
η, μ	inequality constraints KKT multipliers
ρ_{BC}	bilateral contract fee (€/MWh)
ρ_M	market price (€/MWh)

tial dynamic programming [13], multi-pass dynamic programming [14], and genetic algorithms [15], among other methods.

Other issue regarding the use of hydropower concerns its participation in the provision of ancillary services. The ancillary services have been addressed within the solution of the ST hydro-scheduling problem, by allocating reserves in a cost-based centralized dispatch as presented in [16], by considering the participation of the hydropower producers in the ancillary services market as presented in [17], and by solving the joint day-ahead scheduling and real-time bidding in the ancillary service market as presented in [18].

This work will address the problem of time-scale interlacing and at the same time will provide an equivalent marginal cost for the hydropower to assess ST operational decisions. This will be achieved by developing a reservoir-type hydropower equivalent model (HEM), based on a one-stage problem formulation that assumes the cost-to-go function is known. A demonstration on how this model is obtained will be provided and the model will be tested on a ST stochastic unit commitment. This way ST and LT uncertainties will be linked and the dispatch of the hydropower will be achieved in consideration of a LT schedule of releases. Cascaded plants will be used to demonstrate the generality of the model.

The remainder of this work is organized as follows: Section 2 will describe the derivation of the HEM. Section 3 will show the formulation of the SCU where the HEM will be tested. Section 4 will describe the study case. Section 5 will show the results and analysis

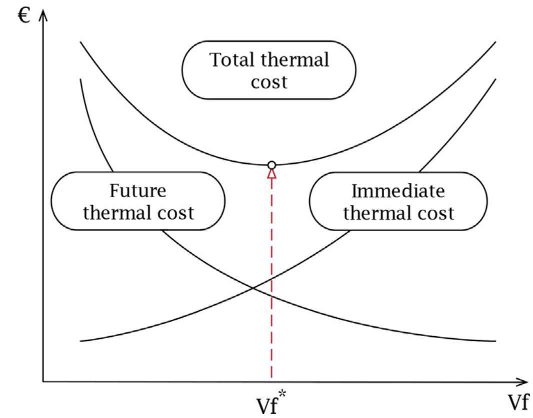

Fig. 1. Immediate and future thermal costs in €.

of the implementation of the HEM on the study case. Finally Section 6 contains the conclusions and recommendations of this work.

2. Hydropower equivalent model – HEM

The hydro-schedule defines a trajectory for the reservoir releases in order to balance thermal production and serve system demand over the period of coordination [5]. The sequence of releases is obtained by decomposing the coordination horizon into several one-stage problems where the objective is to achieve the minimum compromise between immediate and future operational costs, as shown in Fig. 1.

In the scheduling of hydro reservoirs using SDDP [19], a set of supporting hyperplanes or equivalent benders cuts are used to represent the expected cost-to-go function in a piecewise-linear fashion. This piecewise FCF translates the costs of future stages as a function of the first stage decisions.

If the FCF is available, the problem can be solved as one stage problem [2], modeling the FCF through special ordered sets [20]. This one-stage problem can be used to assess short-term decisions while considering the impact in future stages costs. A work developed in [6] solves the hydro-thermal generation scheduling using a unit commitment (UC) problem formulation for the ST, with a GA implementation that uses a piecewise-linear FCF representation.

The work presented here proposes a model for the hydropower plant that couples LT costs with ST decisions through the use of the FCF. This model approaches day-ahead hydro-thermal coordination, with the following assumptions [21]:

- In the day-ahead the weather forecast accuracy is around 85% [22].
- The load forecast accuracy for the next 24 h is around 97% [23].
- The present conditions of the reservoir are known.
- The head of water in the reservoir can be considered constant during the next 24 h.
- The thermal units that will be operating during the next 24 h are known.

The system operator could approximate the FCF to a single linear segment. The choice of this segment could be done according to the estimation of the final state of volume of water in the day ahead according to the described assumptions, but most important, according to the LT hydraulic schedule of the reservoir.