On the Computational Studies of Deterministic Global Optimization of Head Dependent Short-Term Hydro Scheduling

Ricardo M. Lima, Marian G. Marcovecchio, Augusto Queiroz Novais, and Ignacio E. Grossmann

***Abstract*—This paper addresses the global optimization of the short term scheduling for hydroelectric power generation. A tailored deterministic global optimization approach, denominated sHBB, is developed and its performance is analyzed. This approach is applied to the optimization of a mixed integer nonlinear programming (MINLP) model for cascades of hydro plants, each one with multiple turbines, and characterized by a detailed representation of the net head of water, and a nonlinear hydropower generation function. A simplified model is also considered where only the linear coefficients of the forebay and tailrace polynomial functions are retained. For comparison purposes, four case studies are addressed with the proposed global optimization strategy and with a commercial solver for global optimization. The results show that the proposed approach is more efficient than the commercial solver in terms of finding a better solution with a smaller optimality gap, using less CPU time. The proposed method can also find alternative and potentially more profitable power production schedules. Significant insights were also obtained regarding the effectiveness of the proposed relaxation strategies.**

***Index Terms*—Global optimization, mixed integer nonlinear programming (MINLP), short term hydro scheduling.**

NOMENCLATURE

A. Indices and sets

i, k, I	Hydro plants.
IC	Pairs of upstream and downstream plants.
qq, G	Grid points for the relaxations of bilinear terms.
j, J	Turbines.
M	Pairs of plants and turbines.
n, N	Grid points for the relaxation of $hdn_{i,t}$.
R	Grid points for supporting hyperplanes.
$T_{t,\tau_{k,i}}$	Time periods to build wrap around constraints.
UI	Turbines with identical features in the same plant.

B. Parameters

$a_{i,l}$	Coefficients for the forebay level polynomials.
$b_{i,l}$	Coefficients for the tailrace level polynomials.
$D_{i,t,n}$	Grid points for the partition scheme for $d_{i,t}$.
H_i	Water head [m].
H_i^L	Minimum water head [m].
H_i^U	Maximum water head [m].
$SC_{i,j}$	Start-up cost of turbine j in plant i [m.u.].
$P_{i,j}^{UP}$	Maximum power of turbine j in plant i [MW].
$Q_{i,j}^L$	Minimum outflow of turbine j in plant i when in operation $[\mathrm{m}^3/\mathrm{s}]$.
$Q_{i,j}^U$	Maximum outflow of turbine j in plant i $[\mathrm{m}^3/\mathrm{s}]$.
$Q_{i,j,t,qq}$	Grid points for the partition scheme for $q_{i,j,t}$.
V_i^{UP}	Target for the maximum storage of the reservoir of plant i at the end of the time horizon $[\mathrm{Hm}^3]$.
V_i^{LO}	Target for the minimum storage in plant i at the end of the time horizon $[\mathrm{Hm}^3]$.
$V0_i$	Initial storage of the reservoir of plant i [%].
VC	Conversion factor from $[\mathrm{m}^3/\mathrm{s}]$ to $[\mathrm{m}^3/\mathrm{h}]$.
WI_i	Forecast natural water inflow of plant i $[\mathrm{m}^3/\mathrm{s}]$.
$\eta_{i,j}$	Average generation efficiency $[\mathrm{MW}/((\mathrm{m}^3/\mathrm{s}).\mathrm{m})]$.
λ_t	Forecast price of energy in period t [m.u./MWh].
$\tau_{i,k}$	Time delay between plant i and plant k [h].
$\varphi_{i,j}$	Penstock head losses as a fraction of the net head.
$\phi_{i,j}$	Constant, where $\phi_{i,j} = \eta_{i,j}(1 - \varphi_{i,j})$.

C. Variables

$c_{i,j,t}$	Start-up cost of unit j in plant i in period t [m.u.].
$d_{i,t}$	Total water discharge of plant i in period t $[\mathrm{m}^3/\mathrm{s}]$.

Manuscript received November 12, 2012; revised December 05, 2012 and May 11, 2013; accepted July 20, 2013. The work was supported by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n. PCOFUND-GA-2009-246542 and from the Foundation for Science and Technology of Portugal. Paper no. TPWRS-01265-2012.

R. M. Lima and A. Q. Novais are with the Portuguese National Laboratory for Energy and Geology (LNEG), Lisbon, Portugal (e-mail: ricardo.lima@lneg.pt; augusto.novais@lneg.pt).

M. G. Marcovecchio is with INGAR/CONICET, Instituto de Desarrollo y Diseño and UNL, Universidad Nacional del Litoral, Santa Fe, Argentina (e-mail: mariangm@santafe-conicet.gov.ar).

I. E. Grossmann is with the Chemical Engineering Department, Carnegie Mellon University, Pittsburgh, PA 15213 USA (e-mail: grossmann@cmu.edu).

Digital Object Identifier 10.1109/TPWRS.2013.2274559

0885-8950 © 2013 IEEE