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Mixed-integer nonlinear approach for the optimal scheduling of a head-dependent hydro chain

J.P.S. Catalão[a,*], H.M.I. Pousinho[a], V.M.F. Mendes[b]

[a] Department of Electromechanical Engineering, University of Beira Interior, R. Fonte do Lameiro, 6201-001 Covilha, Portugal
[b] Department of Electrical Engineering and Automation, Instituto Superior de Engenharia de Lisboa, R. Conselheiro Emídio Navarro, 1950-062 Lisbon, Portugal

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ABSTRACT

This paper is on the problem of short-term hydro scheduling (STHS), particularly concerning a head-dependent hydro chain. We propose a novel mixed-integer nonlinear programming (MINLP) approach, considering hydroelectric power generation as a nonlinear function of water discharge and of the head. As a new contribution to earlier studies, we model the on–off behavior of the hydro plants using integer variables, in order to avoid water discharges at forbidden areas. Thus, an enhanced STHS is provided due to the more realistic modeling presented in this paper. Our approach has been applied successfully to solve a test case based on one of the Portuguese cascaded hydro systems with a negligible computational time requirement.

1. Introduction

In this paper, the short-term hydro scheduling (STHS) problem of a head-dependent hydro chain is considered. Hydro plants with a small storage capacity are known as run-of-the-river. Typically, run-of-the-river hydro plants are considered to operate under stationary conditions with constant head and at the maximum water level in the reservoirs, corresponding by design to the optimum efficiency operating point. However, it is often desirable to change this policy, thus incurring into head changes. The operating efficiency is sensitive to the head–head change effect [1].

Significant loss of efficiency can occur in operating hydro plants away from their most efficient operating point. Thus, hydroelectric power generation has to be considered as a function of water discharge and also of the head in order to avoid this loss of efficiency, that is, in order to take in account the head change effect.

In a run-of-the-river cascaded hydraulic configuration an upstream reservoir highly influences the operation of the next downstream reservoir. The latter reservoir also influences the upstream plant by its effect on the tail water elevation and effective head [2]. Actually, the cascaded hydraulic configuration coupled with the nonlinear head change effect, augments the problem dimension and the complexity, but they should be considered because they are important for the most advantageous management of the conversion of the potential energy available in the reservoirs into electric energy.

In a competitive environment, such as the Norwegian case [3], the most advantageous management of the conversion of the potential energy available in the reservoirs into electric energy, without affecting future operation use, represents a major advantage for the hydroelectric utilities to face competition [4]. STHS models provide decision support for the operational task of bidding in the energy and system services markets [5].

Hydro plants particularly run-of-the-river hydro plants are considered to provide an environmentally friendly energy option, while fossil-fuelled plants are considered to provide an environmentally aggressive energy option, but nevertheless still in nowadays a necessary option [6]. The Portuguese fossil fuels energy dependence is among the highest in the European Union. Portugal does not have endogenous thermal resources, which has a negative influence on Portuguese economy. Moreover, the Portuguese greenhouse emissions are already out of Kyoto target and must be reduced in the near future. Hence, promoting efficiency improvements in the exploitation of the Portuguese hydro resources reduces the reliance on fossil fuels and decreases greenhouse emissions.

In the STHS optimization problem a time horizon of 1–7 days is considered, usually discretized in hourly periods. Hence, the

* Corresponding author. Tel.: +351 275 329914; fax: +351 275 329972.
E-mail address: catalao@ubi.pt (J.P.S. Catalão).

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