Unit Commitment and Generation Dispatch of a Hydropower Plant in a Competitive Electricity Market

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Abstract. This paper presents a model to solve the short-term scheduling problem of a hydropower plant in a deregulated system, based on dynamic programming techniques. The objective of this model is to maximize the revenue obtained by selling energy in a competitive electricity market. The time horizon of the model is divided into hourly periods and ranges from one day to one week. The proposed model determines both the unit commitment and the power to be generated in each hour of the time horizon. The power is considered as a nonlinear function of the water discharge and the reservoir volume; the dependence of the units and plant operating limits on the available gross head has been taken into account; and the water discharged through the spillway has been also allowed for in the model. This approach has been applied to a practical case study, the results of which are analyzed in detail.

Key words. Hydropower plant, competitive electricity market, short-term scheduling, head dependence, dynamic programming.

1. Interest of the work

This paper considers a price-taker hydropower plant that sells its energy in the day-ahead electricity market, i.e., it does not have influence on the hourly market clearing prices. Bidding strategies considering the effect of the plant production on the market clearing procedure are therefore outside the scope of this paper.

One of the main difficulties faced by most hydro scheduling models lies in the nonlinear relationship existing among the power generated, the water discharge and the net head. For short-term studies the head dependence is usually neglected, especially in the case of large reservoirs, as their variation throughout the planning time horizon is barely significant. Nevertheless, in Spain, and in many other countries all over the world, there are many hydro plants associated to a reservoir the regulating capacity of which is weekly, daily or even smaller, as it is the more and more frequent case of small to medium head hydropower plants with a limited and environmentally respectful flooded area. In these cases, the head dependence should be considered in order to obtain realistic results.

Several methods have been used to solve the short-term scheduling of a hydro plant: linear programming [1], mixed integer linear programming [2], nonlinear programming [3] and dynamic programming [4], among others. It should be noted that, depending on the market environment, the plant regulating capacity and whether the power generation system is hydro- or thermal-based, the focus of the models may vary slightly but essentially, most approaches proposed in the literature are applicable in a broad range of cases.

In linear programming based models, the hydro generation characteristic is usually reduced to a single unit performance curve approximated either through a piecewise linear curve [5], or by modeling the so-called local best efficiency points [6], the head dependence being therefore neglected. This dependence has been partially considered in only few mixed integer linear programming based models: in [7] the hydro plant generation characteristic is represented by three unit performance curves, each of which is approximated by a nonconcave piecewise linearization; in [8,9], an iterative procedure, formally known as successive mixed integer linear programming, is presented. The problem in this case is that there is no guarantee that the algorithm converges to an optimal solution.

In nonlinear programming based models it is important to avoid the nonconcavity, or nonconvexity (depending on the considered approach), of the objective function since it may result in multiple local optima. In addition, the management of the unit start-ups and shut-downs by means of binary variables leads in these cases to nonlinear mixed integer programming problems [10], the solution of which has not yet reached the maturity of linear or nonlinear programming methods [11].

Due to the inherent complexity of the problem, it is usual to find in the literature approaches that decompose it into a unit commitment subproblem (UCS) to determine the unit status (on/off), and a generation dispatch subproblem (GDS) to determine the optimal power generation. In [12], the UCS is solved by means of a heuristic approach and Lagrangian relaxation is used to solve the GDS, whereas in [13], a genetic algorithm solves the UCS and Lagrangian relaxation is again used to solve the GDS.

Dynamic programming is probably one of the first methods used to solve hydro scheduling problems, whatever the time horizon or the predominant source of energy in the system. Recent studies [14,15] have shown that interest on this technique is still relevant. Although it can easily overcome the nonlinear and nonconcave character of the hydro scheduling problem, it poses difficulties to manage the unit start-ups and shut-downs.

This paper presents a dynamic programming model to solve the short-term scheduling problem of a hydropower plant associated to a reservoir the regulating capacity of which is weekly, daily or even smaller. The solution of the problem provides in each stage of the time period considered the optimum values of the following variables: the plant status (on/off); the power output; the reservoir volume; the flow released through the turbines; and the flow spilled through the spillway. It should be noted that the units status (on/off) is implicit in the solution of the problem since the plant generation characteristic is previously obtained by solving successively a series of load dispatch problems by dynamic programming.

Due to the short-term planning period, the model has been developed in a deterministic framework in the sense that certain variables, such as the water inflow to the reservoir and the hourly market clearing prices, are represented by their forecasted average values. Also, the reservoir volumes at the end and at the beginning of the planning period are assumed to be determined a longer term planning procedure. The model has been applied to a practical case study, the results of which are reported and discussed in detail.

2. Objectives

The ultimate goal of this study is to develop a detailed plant level short-term scheduling model of a hydropower plant, the objective of which is to maximize the income obtained by selling energy in a competitive electricity market. In this framework, the model may be used by a hydro generating company as a decision making tool that helps to submit bids for selling energy in the electricity market. The time step of the model is one hour and the planning time horizon ranges from one day to one week.

3. Main contributions

The main contributions of this study are the following:

- A thoroughly detailed hydropower production model that considers: the dependence of the power generated on the water discharge and the net head; the dependence of the units and plant generating limits on the available gross head; and the inclusion of water spillage above a determined reservoir level.
- A novel discretization procedure of the feasible region that allows to obtain simultaneously the optimal units status (on/off) and the optimal power output.

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