Energy Conversion and Management 50 (2009) 2593–2599

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Portfolio management of hydropower producer via stochastic programming

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ARTICLE INFO

Article history:
Received 10 November 2008
Accepted 8 June 2009
Available online 12 July 2009

Keywords:
Hydropower scheduling
Stochastic programming
Portfolio management
Value of stochastic solution

ABSTRACT

This paper presents a stochastic linear programming framework for the hydropower portfolio management problem with uncertainty in market prices and inflows on medium term. The uncertainty is modeled as a scenario tree using the Monte Carlo simulation method, and the objective is to maximize the expected revenue over the entire scenario tree. The portfolio decisions of the stochastic model are formulated as a tradeoff involving different scenarios. Numerical results illustrate the impact of uncertainty on the portfolio management decisions, and indicate the significant value of stochastic solution.

1. Introduction

With the restructuring of the power industry, the optimal management of hydropower resources has changed to participate in the market with the sole objective of maximizing profits. The economic impacts due to uncertainties are concerned accordingly, for large volatility in market prices and inflows means a large variability in profit. Meanwhile, hydropower producers are required to devise their own strategies on how to allocate generation proportions for exchanges in bilateral contract and spot market on medium term. Thus, it is necessary and important for hydropower producers to incorporate the uncertainty of market prices and inflows into the portfolio management problem.

There are various approaches to deal with the stochasticity in hydropower scheduling problem. The most general way of solving the stochastic scheduling problem is to use stochastic dynamic programming (SDP) to find an optimal operation policy, which usually requires discretization of the state variables [1]. However, SDP becomes intractable for any system with more than a few state variables. Therefore, effective approximation methods have been developed in the literature [2]. Most of these approaches are based on SDP, which are meant to reduce the number of state variables and retain the stochastic structure [3,4].

Another way of dealing with stochasticity is to simplify the representation of the stochastic inflow process through the multiple-scenario methods. Stochastic dual dynamic programming approach (SDDP) further developed this method to model inflow uncertainty, via a combination of sampling and decomposition [5,6]. However, when market price uncertainty is also considered as state variable due to the strong autocorrelation, the objective function is made nonconvex and SDDP can not be used directly. But for each discrete price value in the price model, SDDP is available since the price is fixed. Accordingly, the approach with the combination of SDDP and SDP is proposed [7].

Alternatively, many researchers have come to emphasize the need for applying stochastic programming to hydropower scheduling problem [8–11]. In deregulated power market, portfolio management is coupled with the hydropower scheduling problem. The portfolio exchange of hydropower producer can be regarded as a dynamic problem, for the tradeoff is gained through diversification in bilateral contract market and spot market. Moreover, hydropower scheduling is also a dynamic problem, where a scheduling decision in a given stage is linked to the future consequences of this decision. Thus, for hydropower producer, a stochastic programming approach is appropriate to support the portfolio management. Two-stage stochastic linear programming with recourse has been recognized as a natural way of modeling hydropower operation management problem under uncertainty [12]. When uncertainty is involved, the selected decisions may not be feasible after the realization of random variables. Thus first-stage decisions have to be made without any information on realization of random variables. Next, second-stage decisions, called recourse actions, are made to restore feasibility. In the above framework, the stochastic linear program with recourse model was proposed to formulate the hydropower portfolio management problem.

The present paper does not focus on how to make decision on bilateral contracts [10]. Rather, the key contribution of this paper is to simulate the impact of uncertainty on the electric energy allocation between bilateral contract and spot market, and identify the advantage of proposed stochastic model through the calculation of the value of stochastic solution. The uncertainty in market prices

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doi:10.1016/j.enconman.2009.06.010

Nomenclature

t	time period
n	number of periods
V_t	water reservoir level
SP_t	spillage in period t
Q_t	generation in period t
I_t	expected inflow in period t
P_{st}	expected spot price in period t
Q_{bt}	bilateral contract signed for period t
P_{bt}	price for bilateral contract in period t
R_t	average revenue in each period
I_t^s	reservoir inflow associated with scenario s
P_{st}^s	spot price associated with scenario s
Q_t^s	corrective recourse action taken for generation in each period for scenario s
SP_t^s	recourse action taken for spillage in each period for scenario s
V_t^s	recourse action taken for reservoir level in each period for scenario s

and inflows is modeled as scenario tree, and the objective is to maximize the weighted–average profit over the entire scenario set. In practice, stochastic linear programming with discrete random variables leads to deterministic equivalents, which can be dealt with large-scale linear programming method.

The paper is organized as follows. Section 2 provides the stochastic formulation of the uncertainty of market prices and inflows. In Section 3 the medium term portfolio management problem is formulated based on stochastic program with recourse model. Numerical results are shown and discussed in Section 4. Finally, the conclusion is presented in Section 5.

2. Stochastic formulation

Without specifying the probability distribution of uncertainties, we even cannot formulate the portfolio management problem mathematically. To solve the corresponding stochastic programming problem, we generally resort to constructing scenarios. Each possible discrete outcome of market prices and inflows is called a scenario, and the generated set of scenarios, with the corresponding probabilities, can be viewed as a representation of the underlying probability distribution.

The generation of scenarios involves considerable effort in stochastic programming models. It is important to note that the decision made now will be based solely on the information available at the point of decision. Thus, the stochastic input model is needed to represent a well-defined problem, producing a nonanticipative solution that is in some sense optimal. For this purpose, a scenario tree which can represent the dynamic information about uncertainty in market prices and inflows should be considered. Fig. 1 shows the process how the information about uncertainty factor is modeled via a five-stage scenario tree, in which two branches leave each node, resulting in 16 scenarios.

The root node represents the decision today and hence is considered deterministic. The nodes further down represent conditional decisions at later stages. The arcs linking the nodes represent realization of the uncertain variables. In this way a scenario tree captures the dynamic of decision making since the decisions are adjusted to the currently available information.

For scenario construction, a survey of methods of generating sets of scenarios that form an approximation of the underlying random data process is given in [13]. For a decision maker choosing to incorporate the uncertainty into stochastic programming model, the uncertainty parameters must be specified. Sampling from historical time series or from statistical models is the most popular method for generating scenarios [14]. However, precise statistical characterization of the spot price and the inflow is not the main emphasis of this paper. In this study, the market price and inflow in each period under consideration are discretized based on the forecasted values of the expected price and inflow and their standard deviations, which are assumed to be calculated by applying techniques such as time series and artificial method network [15]. In this paper, the Monte Carlo simulation method is applied to generate scenarios [16].

Note that different scenario set would have impact on the portfolio decisions, which needs to be simulated. As can be known, the variation of inflows of historical years can be categorized as wet, normal and dry representative year, respectively. The inflows of years can be regarded as the cyclical among these three representative years. Thus, we can generate scenario set based on the specified statistical properties of representative year inflows. On the other hand, decisions made only on forecast value of uncertainty might be a bias, if the actual state of nature turns out to be different from the specification of the model input. From this prospect, we can generate scenario set based on extensive distribution properties of uncertainty, which is derived from historical inflows data. This approach would incorporate the forecast variation into the scenarios. Accordingly, the resulting market price and inflow scenarios are used as the input for the stochastic linear program with recourse model which determines an optimal strategy.

3. Portfolio management problem formulation based on stochastic program with recourse model

The philosophy of stochastic programming with recourse is that decisions and observations alternate, but that some decisions have to be taken that do not anticipate future data of the model. At the time these data are known, second-stage decisions follow which exploit the additional information and depend on the variables that were fixed in the first-stage.

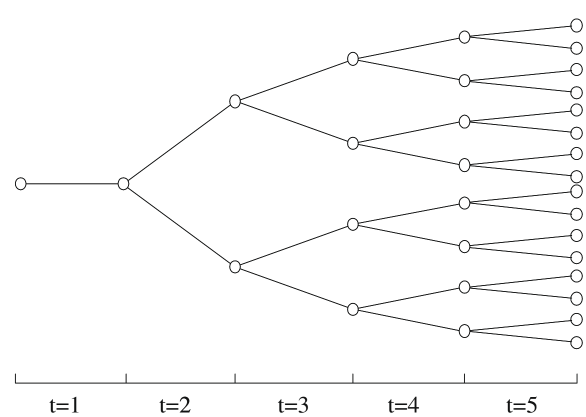

Fig. 1. Scenario tree example.