A New Tool for Bidding Hydropower Into a Competitive Market

By Andrés Ramos, Michel Rivier, and Mariano Ventosa

As the electricity supply industry becomes competitive, hydro plant operators need to be able to accurately estimate how much power they can generate at any given time. Computer models are useful in this endeavor. This article describes one such model developed for the Spanish electricity supply market.

Restructuring of electricity supply markets to allow open competition and trading of electricity as a commodity is underway throughout the world. In Spain, a completely new regulatory framework was enacted in January 1998, and power generators have been trading in an open market ever since. The country is considered to be at the forefront of electricity supply restructuring in Europe.

The electricity trading market in Spain features a day-ahead wholesale trading pool for buying and selling electricity. A market operator (MO) determines the actual operation of generating units, based on a simple hour-by-hour merit order of bids received. All fixed operating costs are internalized in the bids. The market clearing price is set each hour based on the highest accepted bid.

Under this framework, firms that generate electricity estimate their own unit commitment in order to decide — based on costs, prices, and quantities — the bids that they submit to the MO. In other words, these firms have to determine the amount of capacity to offer each hour and what the price should be. These bids, then, determine the actual operation of their units and, ultimately, their incomes. Making this estimate is especially challenging for hydro units owing to the intrinsic complexity of a series (chain) of hydroelectric plants on the same river system.

Consequently, hydropower generators are searching for computerized scheduling tools that can assist in this estimation. The purpose of these tools is twofold. On one hand, they have to consider in detail the technical operating constraints of the system and obtain the scheduling of stochastic hydro inflows. On the other hand, they must model the new competition framework with the objective of maximizing a firm's "contribution margin" (i.e., revenues minus operating costs).

One such tool, a computer model developed at the Instituto de Investigación Tecnológica, Universidad Pontificia Comillas, solves the problem of maximizing the contribution margin, while, at the same time, completes scheduling of stochastic hydro inflows. This model was developed for the Spanish utility Iberdrola, and currently is being tested and validated for the Spanish market.

Overview of the model

This brand-new computer model implements all of the main functions that hierarchically define operation of a hydro unit in three segments, or time steps:

- Short Term (a day ahead): Capacity bidding of the units is done at this level in an hour-by-hour basis.
- Medium Term (several months ahead): All of the information regarding inflow stochasticity can be fully incorporated into the model because time dependencies of natural inflows usually are one or two weeks long. Hydro scheduling at this level defines policies regarding the amount of water to be offered during the next months.

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• Long Term (a year): Annual budget and yearly productions for all plants are the main functions within this time horizon and the subsequent monthly updates.

One of the main characteristics of this model is flexibility. For example, it can be thought of as a short-term unit commitment model or as a long-term strategic model for yearly economic planning, where the representation of the electric system changes dramatically. Advantages of using one model to perform different types of analyses include: coherency in the origin and elaboration of data; use of similar mathematical methods; and convenient presentation of the results.

The foundation of the model is the decisions about *quantities* to be offered at the various time steps, in order to maximize the contribution margin of a firm that generates electricity. *Quantity* is a natural and familiar unit for trading and operations people. And, quantities are coherently passed down from the yearly predictions (long term) to the hourly bids for the next day (short term).

The model is coded in the GAMS algebraic modeling language.[1] This high-level language allows a powerful, fast, and compact implementation of optimization problems.

How the model works

The model performs hydro scheduling, seasonal operation of pumped-storage units, weekly and daily operation of pumped-storage units, and thermal unit commitment for the generation system. It is formulated as a large-scale linear optimization problem where many scenarios represent the stochasticity in water inflows. This medium-term hydro scheduling algorithm is solved using a state-of-the-art dual dynamic programming, also known as stochastic nested Benders decomposition.[2,3,4]

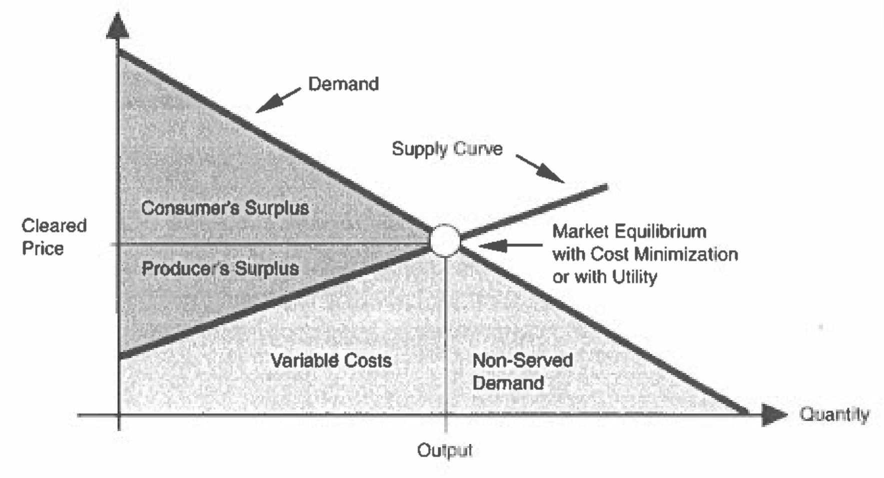
The objective function to be minimized is the total variable costs for the scope of the model subject to operating constraints. These can be classified into inter- and intra-period constraints. Inter-period constraints are associated with coordinating the use of limited resources (e.g., hydro inflows, seasonal pumping, storage, and generation). Intra-period constraints deal with the system operation in each period (balance between generation and demand, thermal unit commitment, weekly/daily pumping, storage, and all generation limits.) This stochastic scheduling capability is an extension of a previously developed production cost model.[5,6]

Introducing market equilibrium constraints requires only minor modifications to the intra-period constraints of the optimization problem. The purpose of these constraints is to incorporate the maximization of the contribution margin of a firm into the classical minimization problem while keeping all of the system's operation details. The same decomposition algorithm is used.

Traditionally, hydro plants have been scheduled to minimize the generation costs of thermal units. For example, hydro units have been used to equalize the system marginal costs over the time span considered. When maximizing the contribution margin of a power generator, an important result achieved is that hydro units equalize the firm's marginal costs.

A significant change in this model to other previously developed models is the introduction of the elasticity of the demand (i.e., the response of the demand to the price of electricity). In classic production cost models, the demand is inelastic and has to be met. In this model, the equilibrium quantity is obtained by maximizing the total surplus (defined as the sum of consumers' and generators' surpluses). Maximizing the total surplus is exactly equal to minimizing the area below the supply curve on the left of the equilibrium quantity (accepted generation) and below the demand curve on the right of this quantity (i.e., non-served demand). This concept is illustrated in Figure 1.

Figure 1



This figure illustrates how market equilibrium constraints are calculated. To do this, the total surplus of electricity is maximized, which is exactly equal to minimizing the area below the supply curve on the left of the equilibrium quantity (accepted generation) and below the demand curve on the right of this quantity (i.e., non-served demand).

In essence, hydro plant control room operators are becoming electricity traders in the new era of competitive electricity supply markets. Computer models are proving useful in determining how much power a hydro unit, or system of units, can generate at any given time. (Courtesy Iberdrola)

The contribution margin for a certain load level is calculated as the difference between revenues and costs. Revenues are calculated as the system marginal price (SMP) multiplied by the electricity produced by each power generator in the system, minus its variable costs. The profit maximization problem for a particular firm is formulated as the objective function of the firm's contribution margin subject to all of the operating constraints.

This problem can be solved by constructing the Lagrangian and then formulating the Karush-Kuhn-Tucker first order optimality conditions. However, the Lagrangian terms associated with the operating constraints can be neglected (because they also will be met by the production cost problem). Consequently, the equal sign of the optimality conditions is replaced by a greater or equal than sign. Therefore, for a power generator, in each load level, the derivative of the contribution margin with respect to electricity generated is determined through Equation 1.

Equation 1:

$$SMP + P_i \frac{\partial SMP}{\partial P} - MC(P_i) \geq 0$$

where:

SMP is the system marginal price;

P_i is the electricity generated by the firm, I;

$MC(P_i)$ is the marginal cost as a function of P_i; and

SMP/P is the change in the SMP due to a change in the capacity of the firm, which corresponds to the negative slope of the demand curve in Figure 1.

The first two terms of the constraints are the marginal revenues of the firm, and the last term corresponds to the marginal cost. So the equation meaning is: marginal revenue is equal to or greater than (≥) marginal cost.

Equation 2 can express the maximum generation that a power generator is willing to produce to maximize its profits as a function of the SMP, its marginal cost, and the slope of the demand curve in Figure 1.

Equation 2:

$$P_i \leq \frac{SMP - MC(P_i)}{-\partial SMP/\partial P}$$

An ascending stepped function represents a firm's marginal cost as a function of its own generation. The steps represent the variable costs (for fuel, consumables, and operation and maintenance) of the different committed generating units. Then, marginal cost of a firm is greater than any variable cost of a committed unit, and can be expressed as a function of the commitment binary variables, as shown in Equation 3.

Equation 3:

$$MC_i \geq \nu_g a_g \ \forall g \epsilon i$$

where:

MC_i is the marginal cost of the firm, I;

ν_g is the variable cost of the unit, g; and

a_g is the commitment state of unit g.

The market clearing price (or system marginal price) is represented by a linear function of the electricity demand, but simultaneously in the objective function is transformed into a descending stepping function (with the slope of the linear function) where each step is a fictitious demand bid, as shown in Equation 4.

Equation 4:

$$SMP = SMP_0 + \frac{\partial SMP}{\partial P} \sum_i P_i$$

The model should be used to predict the medium-term behavior of a firm as strategic or marginal, to understand how these strategies can affect results, and to determine what protection mechanisms can be incorporated in the firm's strategy. In that context, the model must take into account other components of revenues that influence a power generator's behavior, such as medium- and long-term contracts, transition costs, capacity payments, etc.

Using the model to bid

Once the model is used to obtain quantities that a power generator should produce at different time steps to maximize its contribution margins, a postprocessor module of the model is used to derive the bidding prices needed to achieve the quantities. These prices have the costs as their lower bound.

For bids made for hydro units, electricity quality has an important role. Run-of-the-river plants offer their electricity at zero prices to completely avoid spillage. However, to maximize revenues, hydro units in facilities with storage must bid their electricity at the estimated system marginal price, SMP, for each hour. Because the estimation of the SMP is difficult, a conservative approach should be used. For example, a great percentage of the electricity is offered at some price below the estimated SMP, and the remaining electricity is bid with a stepwise function around that value. This approach detects the true value of the SMP.

It is necessary to note that hydro units play an important role in providing ancillary services, such as secondary and tertiary reserve electricity. However, incorporating ancillary services is outside the scope of this model.

Summarizing the features of the model

The model described in this article is used to maximize the contribution margin of a firm, while simultaneously determining the scheduling of hydro units. This integrated approach keeps all of the system operation details in one model, and, at the same time, defines the strategic or marginal behavior of the power producers.

The model can be used to calculate the quantities of hydroelectricity that can be produced for a variety of time steps, ranging from short term (next day) to long term (a year). At the short-term time step, this quantity is transformed by a postprocessor module into a price that the power generator can offer to the market operator for each hour of the next day. ▲

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