



# Power portfolio optimization considering locational electricity prices and risk management



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## ABSTRACT

This paper presents a medium term power portfolio optimization model for a power producer in a competitive electricity market, considering locational electricity prices and risk management. The methodology developed includes modeling the multivariate stochastic evolution of locational electricity prices, the construction of a scenario tree that represents this evolution, and the formulation and solution of a stochastic optimization model. Using this methodology a power producer holding thermal generating units in more than one location may maximize expected profit while keeping a limited risk exposure. The model considers the possibility of trading electricity forward contracts in different locations and contracts for difference. In addition, its output includes amounts of electricity transactions in locational spot markets and power production in generating units. The computational experiments performed indicate that the correlation between locational electricity prices is very relevant for power producers holding generating units in those locations, since it significantly affects the relation between expected profit and risk.

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## 1. Introduction

Power producers in competitive electricity markets are exposed to multiple risks associated to uncertain factors such as electricity spot prices, fuel prices, water inflows and failure of generating units [15]. In order to hedge these risks power producers can engage in different contracts and operate generating units according to contractual obligations.

Given that transmission of electricity is affected by power losses and congestion, electricity supply and demand conditions may be highly local. This means that electricity prices depend on the location in which electricity is delivered, which gives rise to “spatial risk”, related to random differences between locational electricity prices. The motivation for this work comes from the fact that this risk is relevant for power producers owning electricity generators in more than one location of the same market. This paper deals with the management of such risk by developing a methodology for computing contractual positions that maximize expected profit while appropriately balancing risk exposure, with a

particular interest on the effects of dependence between locational electricity prices.

The management of contracts for the purpose of balancing risk exposure and expected profit is fundamental for power producers. Many energy derivatives are usually available for this purpose, which are contracts derived from an underlying energy related commodity. According to Ref. [16] the most common derivatives in electricity markets are futures, forwards, swaps, and options. A forward contract is an agreement to buy or sell a commodity at a future time, with a price to be paid at delivery specified at the moment of signing the contract. Refs. [4,23,33,43] show the importance of forwards and futures in electricity markets. Ref. [28] presents an introduction to contracts for difference (CfDs), which are electricity forward contracts on a locational price spread, or equivalently, on the price difference between two zones over a specified time span. Ref. [10] deals with spread options, which are generalizations of the typical call and put options and also depend on more than one underlying asset. Ref. [36] deals with financial transmission rights, which are fundamental for market participants to hedge against spatial risks.

The convenience of jointly deciding the contractual involvement and the generation plan of power producers is significant. Some authors have named this combined perspective as *power portfolio optimization* (e.g. [41,45]) and others as *integrated risk management* (e.g. [8,30]), depending on the particular emphasis. Many medium term stochastic programming approaches for problems in this area have been developed (with “medium term”, we

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<sup>1</sup> A substantial part of the work presented in this paper was carried out while Álvaro Lorca was an M.S. student and José Prina an Assistant Professor at the Department of Industrial and Systems Engineering at Pontificia Universidad Católica de Chile.

denote problems on a time horizon of approximately one year, to differentiate from short term operational problems and long term investment problems). Refs. [17,18] present a stochastic programming model for the coordination of physical generation resources with contracts of financial nature, where electricity prices, prices on forward contracts, and water inflow to reservoirs are modeled stochastically. Refs. [30,42] present a similar approach. Ref. [35] also presents a similar model but incorporating thermal generating units. Ref. [48] also deals with the management of contracts and generation for a hydropower producer. From another perspective, Ref. [8] presents a model for a hydrothermal generation company, considering fuel price, electricity demand and water inflows as stochastic variables, obtaining electricity price and the company generation on every scenario through the use of a market equilibrium model. Ref. [45] considers thermal, pumped storage and hydro units on the generation side, and forwards and options on electricity on the contracts side, assuming stochastic electricity prices. Ref. [41] considers thermal generating companies with the possibility of signing forward contracts on electricity and natural gas, assuming electricity price and demand as stochastic, with forward and spot market decisions taken over monthly time periods, and generation decisions determined over shorter time periods. Ref. [12] develops a model for a thermal generating company focusing on electricity futures, assuming stochastic electricity prices. Ref. [37] explores the impact of forced unit outages over forward decisions. Ref. [19] develops a short term model for scheduling thermal generating units and forward positions, assuming stochastic electricity prices and operational details of generating units. Ref. [9] develops a model for a hydrothermal generation company in an oligopolistic electricity market, assuming the generation company acts as a price maker. Ref. [2] presents an approach considering options for a power producer to hedge against pool price volatility.

In this paper we consider a company that holds generators in more than one location of a competitive electricity market, with the joint evolution of locational electricity prices modeled explicitly through a scenario tree. The possibility of entering into electricity derivatives, particularly forwards and CfDs, is an essential part of the approach presented. Further, we consider the fact that electricity transactions in locational spot markets and power production in generating units can adapt to the realization of locational electricity prices, in coordination with the selected contractual positions. We model this power portfolio optimization problem as a stochastic program with recourse. A fundamental difference of our approach with respect to the model presented in Ref. [12] is the consideration of more than one electricity price location, bringing about the difficult challenge of determining a scenario tree that represents the joint evolution of locational electricity prices in a proper way. For this purpose, we use a time series model that captures the temporal and spatial correlations of locational electricity prices and an effective scenario tree construction method based on this model. None of the papers addressed above involves more than one locational electricity price process. Refs. [25,26,47] address the planning of contracts taking into account various locational electricity prices, but based on a Markowitz mean-variance scheme, not on stochastic programming. Many authors have used conditional value at risk (CVaR) for risk measuring (e.g. [8,12,35]) and the same approach is used here.

The main contribution of this paper is to provide a model for optimizing medium term commercial decisions of a power producer holding generating units in more than one location of a competitive electricity market, considering electricity prices at different locations explicitly. Another contribution is to test and integrate into the model an implementation of a moment matching method for the generation of a scenario tree that approximates the stochastic evolution of locational electricity prices. Further, the

possibility of entering into CfDs is part of the modeling approach. Furthermore, we use our approach to study the effects of the correlation between locational electricity prices over the tradeoff between expected profit and risk. A case study based on the New York State electricity market is presented.

The rest of this paper proceeds as follows. Section 2 describes the problem. Section 3 presents the method used for generating scenario trees that represent the evolution of locational electricity prices. Section 4 provides the mathematical formulation of the decision making problem. Section 5 presents the case study. Section 6 concludes the paper.

## 2. Problem description

### 2.1. Decision framework

We consider a generation company facing the problem of determining a power portfolio consisting of contractual positions, spot market transactions and generation decisions. A time horizon of  $T$  time periods (months or weeks) is considered. Contractual decisions are made at the beginning of the time horizon, as “here-and-now” decisions, affecting the whole time horizon, and spot market trading as well as generation decisions are made throughout the horizon, as “wait-and-see” decisions, contingent on the unfolding of uncertain events. In other words, contractual decisions are made at the “present time” (or at time period  $t=0$ ), without a precise knowledge of future locational electricity prices, based on the contractual possibilities available in the market at that time, inducing obligations and benefits throughout the horizon (at time periods  $t=1, \dots, T$ ), and given these fixed contractual positions, spot market trading and generation decisions are made in each time period  $t=1, \dots, T$  depending on the realization of locational electricity prices.

Locational electricity prices are incorporated explicitly, assuming that in each location there is a liquid spot market for electricity and that the spot price at every location and time period is known right before deciding the amount of electricity to be sold or bought at each locational spot market and the amount of electricity to be generated at each unit.

### 2.2. Scenario tree and hour groups

Electricity spot prices at the different locations form a stochastic vector process approximated using a scenario tree. Average monthly prices depend on the scenario and hourly electricity prices are constant within each hour group. Specifically, the price at a particular hour of a given time period, scenario and location, is computed multiplying a monthly average price determined by the scenario tree ( $P_{lst}^E$ ) by a factor associated with the corresponding hour group ( $\beta_{ltk}$ ). Electricity prices should be relatively stable in each hour group for this assumption to be appropriate.

### 2.3. Generating units

The power producer holds a set of thermal generating units in each location. Each unit is characterized by a variable production cost, and minimum and maximum power outputs. In addition, given that electricity production is modeled in a medium term manner, restrictions on the electricity produced during different hour groups of every time period are influenced by short term operation restrictions, such as ramping limits. Following Ref. [12] we assume that these restrictions result in minimum levels of power output in low-price hour groups such that the electricity produced in them is at least a certain percentage of the electricity generated during their associated high-price hour groups. The power producer

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