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Managing the financial risks of electricity producers using options

S. Pineda, A.J. Conejo *

Department of Electrical Engineering, Univ. Castilla-La Mancha, Campus Universitario s/n, 13071 Ciudad Real, Spain

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ABSTRACT

Electricity producers participating in electricity markets face risks pertaining to both selling prices and the availability of the production units. Among electricity derivatives, options represent an adequate instrument to manage these risks. In this paper, we propose a multi-stage stochastic model to determine the optimal selling strategy of a risk-averse electricity producer including options, forward contracts, and pool trading. A detailed case study highlights the advantages of an option vs. a forward contract to hedge against the financial risks related to pool prices and unexpected unit failures.

1. Introduction

1.1. Motivation and purpose

Over the last decade, electricity energy systems worldwide have undergone major restructuring, introducing competition among electricity suppliers. In this environment, electricity is commonly traded in a pool. Due to the non-storability of electricity, the uncertain and inelastic demand, and the physical capacity of transmission limits, electricity pool prices are highly volatile. Thus, electricity producers need to manage the risk associated with the volatility of the pool price to avoid financial losses. Additionally, unexpected failures of production units entail a financial risk because of the impossibility of delivering the energy pertaining to contract obligations during those time steps in which some of the production units are forced out. Forward contracts and options are the main derivatives for risk management in electricity markets (Deng and Oren, 2006; Liu and Wu, 2007).

Forward contracts are agreements to buy/sell a fixed amount of electricity at a given price throughout a certain time span in the future. Selling electricity through a forward contract at a fixed price allows electricity producers to hedge against the risk due to pool price volatility. On the other hand, the main disadvantage of a forward contract is that its delivery is mandatory, i.e., if the electricity producer is unable to deliver the agreed amount of energy, then it must buy the corresponding energy in the pool to indirectly deliver it. If the pool price is high during these time steps, then financial losses may occur. Although usually neglected in long-term trading, forced outages of production units may have significant effects on short and medium-term trading (Haghighat et al., 2008). For example, considering the Generating Availability Data System of NERC (NERC, 2010), the average forced outage rates of coal, oil and gas production units between 2002 and 2006 were 4.1%, 7.8%, and 2.6%, respectively. Therefore, a risk-averse producer has to decide its optimal forward contract portfolio taking into account the volatility of the pool price (*price risk*) and the possibility of experiencing production unit failures (*availability risk*) (Beenstock, 1991; Pineda et al., 2008).

* Corresponding author. Tel.: +34 926 295433; fax: +34 926 295361.
E-mail addresses: salvapineda2@gmail.com (S. Pineda), Antonio.Conejo@uclm.es (A.J. Conejo).

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As an alternative to selling electricity through forward contracts, a producer can sell its production through options. An option is a contract which gives the holder of the option the right (not the obligation) to buy/sell a specified amount of energy during a certain future time at the so-called *strike price* (Hull, 2003). Therefore, an option provides more flexibility than a forward contract since the holder can decide whether or not the option is exercised at a future time depending on the availability of its production units and/or the pool price. On the other hand, whereas signing a forward contract entails no cost, there is a non-refundable cost to acquire an option, which is called *option price*. In this paper, we consider options on physical forward contracts, i.e., the exercising of the option necessarily implies the physical delivery of the agreed amount of electricity (Deng and Oren, 2006; Oum et al., 2006).

1.2. Literature review and contribution

Although the technical literature is not broad, several works analyze the different types of risks faced by electricity producers as well as the derivatives to manage these risks (e.g., Deng and Oren (2006), Liu and Wu (2007), Paravan et al. (2004), and Tan et al. (2005)). Kaye et al. (1990) and Tanlapco et al. (2002) analyze forward contracts as derivatives to manage price risk in electricity markets. On the other hand, Quan and Hao (2004) show that options reduce the price risk and allow market participants to increase their potential profits. Since electricity cannot be stored, the well-known Black–Scholes' equation (Wu, 2004) is not generally a good method for pricing electricity derivatives. In this context, Lane et al. (2000) propose a heuristic algorithm to value electricity options. Richter and Sheblé (1998) analyze the impact of options and forward contracts on the offering strategies of electricity market agents. Oum et al. (2006) and Xu et al. (2006) discuss the possibility of mitigating the risks faced by load serving entities using electricity options.

Within the context above, the contribution of this paper consists in analyzing electricity options as instruments to manage the two main risks faced by price-taker electricity producers: price and production-availability risks. This is achieved through a multi-stage stochastic programming model (Benth and Koekebakker, 2008; Fleten and Kristoffersen, 2008), which is used to decide the optimal portfolio of forward contracts and options for a risk-averse electricity producer taking into account the pool price volatility, the unexpected production unit failures, and the uncertain forward prices. Although contributions to manage price risk through options have been reported in the literature, contributions to manage availability risk have not.

1.3. Paper organization

The rest of this paper is organized as follows. Section 2 describes the model proposed, including a characterization of production units, pool prices, forward contracts, and options. The corresponding multi-stage stochastic optimization problem is explained in Section 3. Section 4 reports a case study whose results highlight the advantages of managing risk using options. Relevant conclusions are stated in Section 5. The modeling of the Conditional Value-at-Risk (CVaR) is briefly presented in Appendix A. Appendix B provides the notation used in this paper.

2. Model characterization

2.1. Model assumptions

The following modeling assumptions are made:

1. The production units owned by the electricity producer are thermal units, being each one a dispatchable source of electricity whose cost is modeled by a piecewise linear function and whose power output is limited by minimum and maximum bounds. Ramp limits and minimum up and down times are short-term operating constraints disregarded in the proposed model.
2. The electricity producer can sell its production in the pool at volatile prices, or at fixed prices through forward contracts or options. For the sake of clarity, the arbitrage (understood as the practice of making profit by a simultaneous purchase and sale of the same commodity) between these markets is avoided in the proposed model.
3. The prices of forward contracts and options are not affected by the decisions made by the electricity producer, which is assumed to behave as a price-taker.
4. Three uncorrelated sources of uncertainty are considered in the proposed model: the pool price, the availability of the production units, and the forward prices.
5. Although both physical and financial options are available in electricity markets, due to the energy-oriented approach of the work reported in this paper, all the considered options imply the physical delivery of the option power.
6. Options can usually be traded any time up to their expiration date. However, the trading process is simplified in the proposed model by allowing the producer to trade the available options only on the first day of the decision horizon. Moreover, and also for the sake of simplicity, the options acquired by the power producer are assumed to be European options, i.e., options that can only be exercised on the expiration date itself.
7. The time throughout the decision horizon is measured in hourly steps.

2.2. Production unit availability

In this section we present the availability characterization of a single production unit. Taking into account that the failure and repair rates of this unit are constant, the probability that the unit is available in time t is (Dhillon, 2007):

$$p(k_t=1)=\frac{\mu}{\lambda+\mu}+\frac{\mu\cdot(k_0-1)+\lambda}{\lambda+\mu}e^{-(\lambda+\mu)(t-t_0)}, \tag{1}$$

where k_0 is equal to 1 if the unit is available at t_0 and 0 otherwise, λ is the production unit failure rate, and μ is the production unit repair rate. The probability that the production unit is unavailable in t is equal to $1-p(k_t=1)$.

The failure rate (λ) and repair rate (μ) are equal to the inverse of the mean time to failure (MTTF) and mean time to repair (MTTR), respectively, i.e., $\lambda=\frac{1}{\mathrm{MTTF}}$ and $\mu=\frac{1}{\mathrm{MTTR}}$. The values of the MTTF and MTTR are determined based on historical data. The forced outage rate (FOR) is the percentage of time that the production unit is unavailable, i.e., $\mathrm{FOR}=\frac{\mathrm{MTTR}}{\mathrm{MTTF+MTTR}}$, (Billinton and Allan, 1984).

As stated in Billinton and Allan (1984), if the unit is initially available ($k_0=1$), the probability that the unit is available in the next hour is equal to

$$p(k_1=1)=\frac{\mu}{\lambda+\mu}+\frac{\lambda}{\lambda+\mu}e^{-(\lambda+\mu)\cdot 1}. \tag{2}$$

Randomly simulating a Bernoulli distribution with success probability $p(k_1=1)$, we obtain a possible realization of the availability of the unit for the first hour of the study horizon. Repeating the same process for each hour of this study horizon and updating the success probability of the Bernoulli distribution as

$$p(k_t=1)=\frac{\mu}{\lambda+\mu}+\frac{\mu\cdot(k_{t-1}-1)+\lambda}{\lambda+\mu}e^{-(\lambda+\mu)\cdot 1}, \tag{3}$$