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Portfolio optimization in electricity markets

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Abstract

In a competitive electricity market, Generation companies (Gencos) face price risk and delivery risk that affect their profitability. Risk management is an important and essential part in the Genco's decision making. In this paper, risk management through diversification is considered. The problem of energy allocation between spot markets and bilateral contracts is formulated as a general portfolio optimization problem with a risk-free asset and *n* risky assets. Historical data of the PJM electricity market are used to demonstrate the approach.

Keywords: Trading scheduling; Portfolio theory; Risk management; Electricity market

1. Introduction

Deregulation in the electricity industry has introduced competitive markets. Generation companies (Gencos) no longer enjoy guaranteed rate of return as in the old regulated environment. The price of electricity Gencos receive in a competitive market depends on many factors: bidding prices of all market participants, load demand, unit outages, etc. It is uncertain and volatile. There is usually more than one market for a Genco to enter. Gencos are faced with the prospect of making more profit or the risk of losing money. The scheduling decisions of Gencos are important in determining their profitability. Recognizing market risk and management of such risks are essential for Gencos in a competitive market.

Risk refers to the possibility of suffering harm or loss; danger or hazard. Risks result from uncertainty. However, there is a difference between risk and uncertainty: risk is something that usually can be controlled whereas uncertainty is beyond anybody's control. In the electricity market, the profits of Gencos are influenced by many uncertain factors: unit outage, other genco's bidding strategy, congestion in transmission, demand change, etc. These uncertainties bring about risks in electricity pricing and delivery. Risks of spot price volatility in electricity markets are especially significant. Operating data have shown that daily spot price volatility in electricity is much higher than that of any other commodity. The main reason for this may be attributed to the particular characteristic of non-storability of electricity.

Risk management is the process of achieving a desired return/profit, taking into considerations of risks, through a particular strategy. In the financial field, there are two means to control risk. One is through risk financing by using *hedging* to offset losses that can occur and the other is through risk reduction using diversification to reduce exposure to risks. Instruments for risk management include forward contracts, futures contracts, options, etc. Forward contracts are agreements to buy/sell an agreed amount of the commodity at a specified price at a designated time. Futures contracts are standardized forward contracts that are traded on exchange and no physical delivery is necessary. Options are contracts that provide the holder the right but not the obligation to buy/sell the commodity at a designated time at a specified price. Hedging is to use these financial instruments with the payoff patterns to offset the market risks. Diversification is to engage in a wide variety of markets so that the exposure to the risk of any particular market is limited. Applying this concept to energy trading in an electricity market, diversification means to trade energy through different physical trading approaches.[1] In the energy market, both physical trading approach (e.g., spot

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[1] Physical trading approach refers to the trading approach in which actual physical energy are traded while financial trading approach only involves financial settlement, no actual physical energy are traded through financial trading.

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market, contract market) and financial trading approach (e.g., futures contracts, options, swaps, etc.) are available. A combination of these trading approaches is defined as a *portfolio* and the corresponding risk-control methodology is called *portfolio optimization*.

A commonly adopted measure for risk assessment, i.e., assessing risk exposure of financial portfolios, is the Value at Risk (VaR), which is the monetary value that the portfolio will lose less than that amount over a specified period of time with a specified probability.

Various aspects of risk management have been applied to the electricity market. Different forward contracts that can provide hedging to the risk of spot prices for market participants are proposed [1–4]. The usefulness of the application of futures contracts in an electricity market is demonstrated in [5–8]. Valuation of different contracts is considered in [9–11]. Monte Carlo simulation and decision analysis have been applied to find the optimal contract combination [12–15]. Various issues related to the combined spot/bilateral-contract dispatch are investigated in [16–18]. VaR has been applied to risk assessment in electricity markets [19–22]. Concepts from financial option theory have been utilized in the valuation of generation assets [23–25].

We are addressing the problem of trading scheduling for a Genco, i.e., to optimally use both physical trading approaches and financial trading approaches to maximize its profit potential, taking into consideration the associated risk factors. It involves the optimal allocation of the Genco's output energy among multiple markets (e.g., spot market, contract market, futures market, etc.) with the objective of maximizing its benefit and minimizing the corresponding risk. We apply the approaches of portfolio optimization in Modern Portfolio Theory (MPT) [26] to the problem. The method explicitly considers decision-makers' risk aversion and the statistical correlation among alternative outcomes. Although MPT is widely known in the financial literature, its application in electricity markets might be of interest. The reason is that electricity contracts have different risk characteristics under different electricity markets with different pricing systems, which is due to the congestion in transmission. It is further explained in Section 2 through the introduction of trading environment in electricity markets. Only price risk, delivery risk and physical trading approaches are considered in this paper. Price risk due to spot market fluctuations and delivery risk due to transmission congestion are related to power system operation.

In terms of applications, an electricity spot market that adopts uniform marginal pricing scheme displays only price risk and a spot market that adopts locational marginal pricing or zonal pricing displays not only price risk but also delivery risk. In the following, Section 2 introduces the background of the electricity market with different pricing system which includes the trading environment and associated risks. Section 3 describes the basic theory and methodology to portfolio optimization which can be applied to electricity markets with different pricing system. Section 4 develops an approach to energy allocation among physical trading approaches, i.e., spot market and contract market. Example demonstrates the proposed energy allocation method using historical data of the PJM market. Finally, Section 5 concludes the paper.

2. Electricity markets

Most electricity markets provide two types of markets in which energy is traded: the spot market and the (physical) forward market [27]. In the contract market, Gencos trade energy by way of signing contacts, which are referred to as physical forward contracts, with their counterparters (e.g., energy consumers). Specific details such as trading quantity (MW), trading duration (h), trading price ($/MWh) and delivery point are bilaterally negotiated between Gencos and consumers or their agents. Bilateral contracts are signed before the actual trading period. In other words, trading quantity and price are set in advance. Physical forwards can be traded on an exchange or in a bilateral manner through over the counter (OTC)[2] transactions.

As for the spot market, in this paper, we adopt FERC definition in its standard market design [28] that all the energy traded in the real-time and day-ahead market as spot energy. The common ground among these markets is that they all involve a centralized auction mechanism, by ISO, RTO or any such organization, to determine which generation units should be deployed and how much energy each selected unit should produce to meet the demand. From a Genco's point of view, selling energy in the spot market means to submit a bid (price and quantity) to the exchange (Power Pool/ISO) and get either of the two alternative results: (1) the exchange accepts the Genco's bid and pays the Genco the market clearing price (MCP) for its actual energy output; or (2) the exchange rejects the Genco's bid, i.e., the Genco sells nothing in the spot market. The MCP depends on everybody's bids, as well as the load demand, and is therefore uncertain. Three types of pricing systems have been adopted in the spot market: uniform marginal pricing, zonal pricing and nodal pricing (or locational marginal pricing (LMP)).

Uniform marginal pricing was adopted in the earlier England and Wales market and is followed by many markets around the World. In such a market, only one energy price is used for ex post settlement for each trading interval. Uniform marginal pricing makes it easier to achieve market liquidity. A Genco, on the other hand, can make certain of its revenue by signing bilateral contracts with its customers at fixed energy prices. Hence, bilateral contracts can be considered as risk-free transactions if the Genco's production cost is assumed deterministic.[3] Trading schedule in an electricity market with uniform pricing is to optimally allocate energy between risky spot market and risk-free contract market.

In a zonal pricing system, an interconnected power system is partitioned into pre-defined geographical areas, called zones, based on the knowledge that limitations in transmission exist between these zones.[4] When there is no congestion, one uni-

[2] OTC is a kind of derivatives market in which non-standard products (e.g., contracts) are traded. Trades on the OTC market are negotiated directly through dealers.

[3] Only fuel-fired plants are considered and fuel prices are assumed deterministic in order to focus on the risk of electricity prices in this paper.

[4] Transmission system has operating constraints that limit the maximum amount of power that are allowed to flow through transmission lines. The limit is set either by conductor thermal loading limit or by system stability consid-