Cash-settled options for wholesale electricity markets

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Abstract: Wholesale electricity market designs in practice do not provide the market participants with adequate mechanisms to hedge their financial risks. Demanders and suppliers will likely face even greater risks with the deepening penetration of variable renewable resources like wind and solar. This paper explores the design of a centralized cash-settled call option market to mitigate such risks. A cash-settled call option is a financial instrument that allows its holder the right to claim a monetary reward equal to the positive difference between the real-time price of an underlying commodity and a pre-negotiated strike price for an upfront fee. Through an example, we illustrate that a bilateral call option can reduce the payment volatility of market participants. Then, we design a centralized clearing mechanism for call options that generalizes the bilateral trade. We illustrate through an example how the centralized clearing mechanism generalizes the bilateral trade. Finally, the effect of risk preference of the market participants, as well as some generalizations are discussed.

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1. INTRODUCTION

Various states in the U.S. and countries around the world have adopted aggressive targets for the integration of renewable energy resources. Wind and solar energy are two of the most prominent resources. The inherent variability of these resources makes it difficult to maintain the balance of demand and supply of power at all times. By variable, we mean they are uncertain (errors in day-ahead forecasts are significantly higher than those in bulk power demand), intermittent (shows large ramps over short time horizons), and non-dispatchable (output cannot be varied on command). See Bird et al. (2013) for a comprehensive discussion on the challenges of renewable integration.

Energy is typically procured in advance to meet the demand requirements. Forward planning is necessary since many generators – such as the ones based on nuclear technology or coal – cannot alter their outputs arbitrarily fast to track demand requirements; some lead time is necessary. In its simplest abstraction, one can model the system operation to proceed in two stages: a forward stage, conducted a day or a few hours in advance, and the real-time stage. Roughly, the forward stage optimizes the dispatch against a forecast of the demand and supply conditions at real-time. The impending deviation from such forecasts are then balanced in real-time. While demand forecasts even a day in advance are within 1-3% accuracy, the same forecasts in the availability of variable renewable resources can be significantly higher; they can be as high as 12%.1 For more details on the statistics, see Bird et al. (2013). Variability in supply in resources like wind and solar exposes market participants to increased financial risks. The forward market design in practice does not allow participants in the wholesale market to adequately hedge their financial risks. This paper proposes a financial instrument for the same. The deepening penetration of variable renewable supply will increase the volatility in payments to market participants and hence, increase the financial risks borne by market participants (see Wang et al. (2011); Cochran et al. (2013)).

Electricity market participants engage in trading financial derivatives, i.e., instruments that derive their values based on the prices in the wholesale market. Traded financial derivatives in practice include electricity forwards, futures, swaps, and options. See Deng and Oren (2006); Kovacevic and Pflug (2014); Kluge (2006) and the references therein. Some are traded on an exchange and many are traded bilaterally.

In this paper, we consider how an intermediary (called the ‘market maker’) can convene a financial market for trading in cash-settled call options, and how such a financial market can reduce payment volatilities of wholesale electricity market participants. Upon buying one unit of a cash-settled call option at a negotiated option price, the buyer is entitled to receive a cash payment equal to the real-time price of a commodity (that is electricity in our case) less the negotiated strike price. In order to apply the market design to electricity markets, we adopt an economic dispatch and pricing model in Section 2 to provide us with a real-time (spot) price of electricity. Then, we use that model on a stylized example in Section 3 and illustrate that a bilateral trade in cash settled call-options between a renewable power producer and a dispatchable peaker power plant can lower their respective payment volatilities.

We recognize that engaging in multiple bilateral option trades on a daily basis will likely be difficult in a practical electricity market setting, and will adversely affect the li-
udity of such trades. The remedy we offer is a centralized market clearing mechanism for call options in Section 4 for its use among electricity market participants. Such a mechanism will make option trading more viable in practice and attractive to market participants. We delineate the salient features and discuss possible generalizations of our design in Section 5, and we conclude in Section 6.

Our proposed mechanism is compatible with alternate wholesale electricity market designs (see Wong and Fuller (2007); Pritchard et al. (2010); Bouffard et al. (2005a,b); Bose (2015)). Even with different designs, market participants can have incentives to strategize their actions in the electricity market and the option trade together. Such interactions can adversely affect the market outcomes. However, we relegate such considerations for future work.

Notation: We let $\mathbb{R}$ denote the set of real numbers, and $\mathbb{R}_+$ (resp. $\mathbb{R}_{++}$) denote the set of nonnegative (resp. positive) numbers. For $z \in \mathbb{R}$, we let $z^+ := \max\{z, 0\}$. We let $\mathbb{E}[Z]$ denote the expectation of a random variable $Z$. For any set $\mathcal{Z}$, we denote its cardinality by $|\mathcal{Z}|$. For an event $\mathcal{E}$, we denote its probability by $\mathbb{P}\{\mathcal{E}\}$ for a suitably defined probability measure $\mathbb{P}$. The indicator function for an event $\mathcal{E}$ is given by

$$\mathbf{1}_{\{\mathcal{E}\}} := \begin{cases} 1, & \text{if } \mathcal{E} \text{ occurs}, \\ 0, & \text{otherwise}. \end{cases}$$

In any optimization problem, a decision variable $x$ at optimality is denoted by $x^*$.

2. DESCRIBING THE MARKETPLACE

The wholesale electricity market is comprised of consumers and producers of electricity. The consumers in this market are the load-serving entities that represent the retail customers they serve within their geographical footprint. Examples of such load-serving entities are the utility companies and retail aggregators. Bulk power generators are the producers in this market. We distinguish between two sets of generators. The first type is a dispatchable generator that can alter its output within its capabilities on command. Such generators are fuel based; e.g., they run on nuclear technology, or fossil fuels like coal or natural gas, or dispatchable renewable resources such as biomass or hydro power. The second type is a variable renewable power producer. Its available capacity of production depends on an intermittent resource like wind or solar irradiance. The system operator, denoted by $SO$, implements a centralized market mechanism that determines the production and consumption of each market participant and their compensations. It does so in a way that balances demand with supply, and the power injections across the grid induce feasible power flows over the transmission lines. Most electricity markets in the United States have a locational marginal pricing based compensation scheme. In this paper, we ignore the transmission constraints of the grid and hence, describe an electricity market with a marginal pricing scheme. Generalizing this work to the case with a network is left for future work.

Modeling uncertainty in supply: To model uncertainty in supply conditions, we consider a two-period market model as follows. Let $t = 0$ denote the ex-ante stage, prior to the uncertainty being realized. At this stage, one only has forecasts of the uncertain parameters. The uncertainty is realized at $t = 1$, the ex-post stage. One can identify $t = 0$ as the day-ahead stage and $t = 1$ as the real-time stage in electricity market operations. Let $(\Omega, \mathcal{F}, \mathbb{P})$ denote the probability space, describing the uncertainty. Here, $\Omega$ is the collection of possible scenarios at $t = 1$ (which could be uncountably infinite) $^4$. $\mathcal{F}$ is a suitable $\sigma$-algebra over $\Omega$, and $\mathbb{P}$ is a probability distribution over $\Omega$. We assume that all market participants know $\mathbb{P}$.

Modeling the market participants: Let $d$ denote the aggregate inflexible demand that is accurately known a day in advance. $^5$ Let $\mathfrak{G}$ and $\mathfrak{R}$ denote the collection of dispatchable generators and variable renewable power producers, respectively. We model their individual capabilities as follows.

- Let each dispatchable generator $g \in \mathfrak{G}$ produce $x_g^\omega$ in scenario $\omega \in \Omega$. We model its ramping capability by letting $|x_g^\omega - x_g^0| \leq \ell_g$, where $x_g^0$ is a generator set point that is decided ex-ante, and $\ell_g$ is the ramping limit. Let the installed capacity of generator $g$ be $x_g^{cap}$, and hence $x_g^\omega \in [0, x_g^{cap}]$. Its cost of production is given by the smooth convex increasing map $c_g : [0, x_g^{cap}] \to \mathbb{R}_+$.  
- Each variable renewable power producer $r \in \mathfrak{R}$ produces $x_r^\omega$ in scenario $\omega \in \Omega$. It has no ramping limitations, but its available production capacity is random, and we have $x_r^\omega \in [0, x_r^{cap}]$. That is, $x_r^{cap}$ denotes the random available capacity of production, and $x_r^{cap}$ denotes the installed capacity for $r$. Similar to a dispatchable generator, the cost of production for $r$ is given by the smooth convex increasing map $c_r : [0, x_r^{cap}] \to \mathbb{R}_+$.

We call a vector comprised of $x_g$ for each $g \in \mathfrak{G}$ and $x_r$ for each $r \in \mathfrak{R}$ a dispatch.

Conventional dispatch and pricing model: The SO balances demand and supply of power in each scenario. It determines the dispatch and the compensations of all market participants. In the remainder of this section, we describe the so-called conventional dispatch and pricing scheme. This market mechanism serves as a useful benchmark for electricity market designs under uncertainty, e.g., in Morales et al. (2014, 2012).

We assume that the SO knows $c_g, x_g^{cap}$ for each $g \in \mathfrak{G}$ and $x_r, x_r^{cap}$, for each $r \in \mathfrak{R}$. In practice, the cost functions are derived from supply offers from the generators. The market participants, in general, may have incentives to misrepresent their cost functions. Analyzing the effects of such strategic behavior is beyond the scope of this paper.

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$^2$ As such, markets for financial derivatives associated with electricity markets have been known to suffer from low liquidity. For example, see de Maere d’Aerttycke and Smears (2013).

$^3$ For discussions on how market participants can strategize their actions across the electricity markets and their associated financial instruments, we refer to Ledgerwood and Pfiefenberger (2013); Prete and Hogan (2014).

$^4$ In this paper, we use “distribution” and “measure” interchangeably, as appropriate.

$^5$ Day-ahead demand forecasts in practice are typically quite accurate. Notwithstanding the availability of such forecasts, our work can be extended to account for demand uncertainties.
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