SLA–Mechanisms for Electricity Trading under Volatile Supply and Varying Criticality of Demand

(Extended Abstract)

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ABSTRACT

The increasing adoption of renewable power generation makes volatile quantities of electricity available, the delivery of which cannot be guaranteed, if sold. However, if not sold, the electricity might need to be curtailed, thus foregoing potential profits. In this paper we adapt service level agreements (SLAs) for the future smart electricity grid, where generation will primarily depend on volatile and distributed renewable power sources, and where buyers’ ability to cope with uncertainty may vary significantly. We propose a contracting framework through SLAs to allocate uncertain power generation to buyers of varying preferences. These SLAs comprise quantity, reliability and price. We define a characterization of the value degradation of tolerant and critical buyers with regards to the uncertainty of electricity delivery (generalizing the Value of Lost Load, VoLL). We consider two mechanisms (sequential second-price auction and VCG) that allocate SLAs based on buyer bids. We further study the incentive compatibility of the proposed mechanisms, and show that both mechanisms ensure that no buyer has an incentive to misreport its valuation. We experimentally compare their performance and demonstrate that VCG dominates alternative allocations, while vastly improving the efficiency of the proposed system when compared to a baseline allocation considering only the VoLL. This article lays the groundwork for distributed energy trading under uncertainty, thereby contributing an essential component to the future smart grid.

1. INTRODUCTION

One of the biggest challenges that future energy systems will face due to the increasing adoption of renewable power generation is to maintain balance between available supply and demand. To this end demand-side management (DSM) is necessary. DSM is the behavior change of the demand-side, which can be enabled through, e.g., financial incentives [4]. Dynamic pricing and scheduling of consumption loads are considered as the main methodologies for balancing demand with uncertain supply. However, the former may introduce disruptive and unfavorable market behavior and thus planning and ahead prices are required [2], while the latter can violate the autonomy of the consumer agents. Other variants of DSM focus on the design of tariffs that forward the financial risks of balancing supply and demand to the demand-side [11, 15, 12].

Service level agreements (SLAs) can provide the contracting framework for balancing volatile supply with demand between buyers and sellers of electricity. While previous work has considered SLAs as a tool for monitoring and coordination to ensure trustworthiness between different stakeholders [5], or as a negotiation protocol [1], we interpret SLAs as a direct extension of conventional electricity tariffs.

To the best of our knowledge, we propose the first approach that adapts SLAs for energy trading under uncertain supply. We also provide two mechanisms to allocate SLAs to buyers of different preferences with regards to the criticality of their demand. The main contributions of this work can be summarized as follows:

- We define a contracting framework through SLAs that enables energy trading under uncertain supply.
- We propose an exponential family of functions that characterizes the buyers’ varying degrees of criticality, thus generalizing the Value of Lost Load with costs associated to the risk of failed delivery.
- We apply two mechanisms to assign SLAs to agents of different types, and incentivize truthfulness for strategic buyer agents.
- Results show that the social value vastly improves in face of buyers with varying abilities to cope with uncertainty.

2. CONTRIBUTION

In the proposed framework we assume that there is a single seller (producer) with uncertain generation. Ahead of time, the generation can be represented by the random variable \( Q \), while in the realization step, \( q \in \mathbb{R}^+ \) denotes the observed supply. Figure 1 (left) illustrates the function \( S(q) \), which denotes the reliability function of the generation. The reliability function determines the probability that the generation exceeds a certain value of \( q \), and therefore can satisfy any demand up to the observed generation \( q \).

We further consider the set \( B \) of buyers, each of which has a demand \( d_i \) that needs to be satisfied. However, given the reliability function, not all demand may be served with probability equal to 1. Therefore, we introduce SLAs that comprise the following features:
Figure 2: Social value with regards to the diversity of criticality, for very low values of \( \beta \)-diversity all buyers have neutral attitude towards uncertainty in the delivery. For higher values of \( \beta \)-diversity buyers have increasingly varying criticality.

can be shown that computing the optimal allocation in the VCG mechanism can be solved optimally in polynomial time \( O(n^3) \) by the Hungarian method, given that it is equivalent to the linear assignment problem [9]. Under some realistic, for the setting, assumptions (e.g., no price discovery, no over-bidding) both mechanisms are dominant strategy incentive compatible (DSIC). The dominant strategy of buyers is to truthfully report their valuations.

Figure 2 presents the social value (average value gained per buyer resulting from the assignment of the SLAs over 100 simulations) for varying diversity of the criticality \( \beta \), where \( \beta \) is sampled uniformly in the range \([-D,D]\) (\( D \) is the \( \beta \)-diversity). The random variable of the supply, \( Q \), is normally distributed (\( \mu_Q = 20, \sigma_Q = 5 \)), while the total demand exceeds the expected supply by 20% (24 unit-demand buyers). We illustrate the social value under four different mechanisms: VCG, SSPA with decreasing/increasing reliability SLAs (SPD/SPI), and a greedy baseline allocation method (GB) that uses only the VoLL for the allocation of the SLAs. The diversity in criticality \( \beta \) affects the social value achieved by the studied mechanisms. We observe high system inefficiency when buyers demonstrate extreme behavior with regards to the criticality (for large values of \( \beta \)-diversity). Furthermore, SSPA with SLAs of increasing reliability (SPI) performs better than auctioning off SLAs of decreasing reliability (SPD) in terms of the social value. In all settings, the VCG mechanism yields higher social value than all other mechanisms, setting the upper bound due to its socially optimal allocation.

3. CONCLUSION

We proposed a contracting framework through SLAs for electricity trading under uncertain supply and varying demand criticality of the buyers. In view of the attained properties and performance, we believe that using SLAs as we delineated here provides a promising avenue for addressing electricity trading in future smart grids. This work lays the ground for distributed energy trading under uncertainty, serving as a broad basis for future extensions.

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REFERENCES


