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Autonomous Trading in Modern Electricity Markets

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Introduction

The *smart grid* is envisioned to be a main enabler of sustainable, clean, efficient, reliable, and secure energy supply (U.S. Department of Energy, 2003). One of the milestones in the smart grid vision will be programs for customer participation in electricity markets through *demand-side management* and distributed generation; electricity markets will incentivize customers to adapt their demand to supply conditions, which will help to utilize intermittent energy resources such as from solar and wind, and to reduce peak-demand.

Since wholesale electricity markets are not designed for individual participation, *retail brokers* could represent customer populations in the wholesale market, and make profit while contributing to the electricity grid's stability and reducing customer costs (Ketter, Collins, & Reddy, 2013). A retail broker will need to operate continually and make real-time decisions in a complex, dynamic environment. Therefore, it will benefit from employing an *autonomous broker agent*. The principal question addressed in this dissertation is:

> How should an autonomous broker agent act to maximize its utility by trading in time-constrained, modern electricity markets?

Problem Domain

Electricity markets are going through a major transition from traditional, regulated monopolies into deregulated, competitive markets (Joskow, 2008). While in principle, deregulation can increase efficiency, in practice, the California energy crisis (2001) has demonstrated the high-costs of failure due to flawed deregulation (Borenstein, 2002), and the importance of testing new market structures in simulation before deploying them. This is the focus of the Power Trading Agent Competition (Power TAC) (Ketter et al., 2013), which we use throughout this dissertation as a substrate domain for our research.

Power TAC uses a realistic simulator for modeling and testing competitive retail power market designs and related automation technologies. Figure 1 shows the structure of Power TAC's simulation environment, which includes a future smart grid with about 57,000 customers (about 50,000 consumers and 7,000 renewable producers), smart-metering, autonomous agents acting on behalf of customers. In this simulation environment, autonomous broker agents compete with each other to make profits by trading in retail, wholesale, and balancing markets. In the retail market, a broker publishes tariff contracts that attract consumers and distributed producers (such as rooftop solar and wind turbines). In the wholesale market, a broker bids for future energy contracts. The balancing market financially incentivizes the broker to maintain supply-demand balance in its portfolio. Power TAC uses realistic market designs: the wholesale market represents a traditional energy exchange, such as Nord Pool or EEX, and the retail market is similar to ERCOT's[1].

Operating profitably as a retail broker is a challenging problem. A broker needs to continually select among a large set of actions, under real-time constraints, while incorporating large amounts of information and complex calculations into its decision process, so that its long term profit is maximized in a competitive, dynamic, and stochastic environment.

Contributions

Due to the complexity of the broker's electricity trading problem, a first observation that can

[1] See www.nordpoolspot.gov, www.eex.com, www.ercot.com

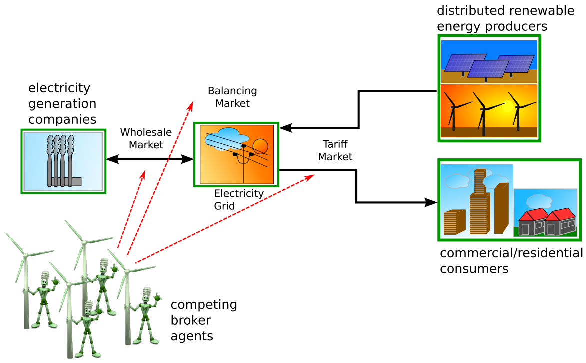

Figure 1: Structure of the Power TAC simulation environment

be made is that designing an autonomous broker that acts optimally would be an impossible task. Thus, a primary research goal of this dissertation is designing and investigating autonomous electricity trading strategies that approximate the optimal strategy and perform well empirically.

With this motivation in mind, this dissertation makes five main contributions to the areas of artificial intelligence, smart grids, and electricity markets.

First, this dissertation formalizes the problem of autonomous trading by a retail broker in modern electricity markets. Since the trading problem is intractable to solve exactly, this formalization provides a guideline for approximate solutions.

Second, this dissertation introduces a general algorithm for autonomous trading in modern electricity markets, named LATTE (Lookahead-policy for Autonomous Time-constrained Trading of Electricity). LATTE is a general framework that can be instantiated in different ways that tailor it to specific setups.

Third, this dissertation contributes fully implemented and operational autonomous broker agents, each using a different instantiation of LATTE. These agents were successful in international competitions and controlled experiments and can serve as benchmarks for future research in this domain. Detailed descriptions of the agents' behaviors as well as their source code are included in this dissertation.

Fourth, this dissertation contributes extensive empirical analysis which validates the effectiveness of LATTE in different competition levels under a variety of environmental conditions, shedding light on the main reasons for its success by examining the importance of its constituent components.

Fifth, this dissertation examines the impact of Time-Of-Use (TOU) tariffs in competitive electricity markets through empirical analysis. Time-Of-Use tariffs are proposed for demand-side management both in the literature and in the real-world.

Conclusion. The success of the different instantiations of LATTE demonstrates its generality in the context of electricity markets. Ultimately, this dissertation demonstrates that an autonomous broker can act effectively in modern electricity markets by executing an efficient lookahead policy that optimizes its predicted utility, and by doing so the broker can benefit itself, its customers, and the economy.

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Daniel Urieli received his Ph.D in Computer Science in 2015 from The University of Texas at Austin, under the supervision of Prof. Peter Stone. Daniel's research interests in AI include machine learning (especially reinforcement learning), multi-agent systems, and computational sustainability.