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# Power TAC: A competitive economic simulation of the smart grid

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ABSTRACT

Sustainable energy systems of the future will need more than efficient, clean, low-cost, renewable energy sources; they will also need efficient price signals that motivate sustainable energy consumption as well as a better real-time alignment of energy demand and supply. The Power Trading Agent Competition (Power TAC) is a rich competitive simulation of future retail power markets. This simulation will help us to understand the dynamics of customer and retailer decision-making and the robustness of market designs, by stimulating researchers to develop broker agents and benchmark them against each other. This will provide compelling, actionable information for policymakers and industry leaders. We describe the competition scenario in detail, and we demonstrate behaviors that arise from the interaction of customer and broker models.



## 1. Introduction

Many of the sustainable energy resources (solar, wind, tidal, etc.) that could displace our dependence on fossil fuels are diffuse and do not necessarily produce power when it is needed. They are therefore difficult to integrate into our power grids and into their traditional control and capital structures. There have been many proposals to upgrade our electric power infrastructure into a "smart grid" (Amin and Wollenberg, 2005; United States Department of Energy, 2012) with components that can monitor energy usage in real time and help consumers better manage their energy usage. However, this is only the technical foundation. There is a clear need for new market structures that motivate sustainable behaviors by all participants. Energy prices that truly reflect energy availability can motivate consumers to shift their loads to minimize cost, and more effectively utilize distributed, small-scale energy storage and production resources (Joskow and Tirole, 2006). Unfortunately, it can be difficult to introduce creative and dynamic pricing schemes when energy is produced and sold by regulated monopolies, and transitions to competitive markets can be risky (Borenstein, 2002).

There is hope — energy markets are being opened to competition around the world in much the same way the telecom markets were opened in the 1990's (Lazer and Mayer-Schonberger, 2001). However, the scope of retail electric power markets is limited in the absence of smart metering infrastructure that allows a retailer to observe the consumption behavior of its customer portfolio, and where technical infrastructure does not effectively support energy storage and production in the retail (or "distribution") domain.

Any serious proposal to change the way the electric power enterprise works must address several significant challenges:

*Reliability*: Frequency, voltage, and power factor must be closely managed to ensure safety and prevent outages.
*Balancing*: Supply and demand must be kept in balance, through a combination of supply and demand management.
*Peak demand management*: The need to serve peak demand that substantially exceeds steady-state demand drives investment in under-utilized supply and transmission resources.
*Energy efficiency*: Investment in demand reduction must be balanced against investments in production capacity.

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*Externality reduction*: Production of energy has been the cause of considerable environmental degradation and resource depletion, a cost that must be borne by future generations.

What is needed is a low-risk means for modeling and testing market designs and other policy options for retail power markets. We are addressing this need by organizing an open competition that will challenge participants to build autonomous, self-interested agents to compete directly with each other in a rich simulation focused on the structure and operation of retail power markets. The Power Trading Agent Competition (Power TAC) (Ketter et al., 2012b) is an example of a Trading Agent Competition[1] (Wellman et al., 2007) applied to electric power markets. It addresses important elements of the smart grid challenges outlined in Ramchurn et al. (2012), since many of these challenges involve economically motivated decisions of large numbers of actors. The Power TAC simulation can be used to evaluate a range of market-based approaches to addressing the challenges we have identified. It contains realistic models of energy consumers, producers, and markets, along with environmental factors, such as weather, that affect energy production and consumption. Alternative market mechanisms and policy options can be applied to the simulation model and tested in open competitions. Research results from Power TAC will help policy makers create mechanisms that produce the intended incentives for energy producers and consumers. They will also help to develop and validate intelligent automation technologies that can support effective management of participants in these market mechanisms.

The paper is organized as follows. In Section 2 we give an overview of the dominating Smart Grid challenges and related work regarding different simulation approaches. Section 3 describes the competition scenario in some detail, and Section 4 presents the simulation platform. In Section 5 we demonstrate the Power TAC platform and give an overview of pilot tournaments that took place in 2011 and 2012. We conclude with a call for participation in future Power TAC tournaments in Section 6.

## 2. Related work

### 2.1. Energy grids and markets

The power grid infrastructure today is largely organized as a strict hierarchy; at the high-voltage "transmission" level, a few centralized control centers manage relatively few large power plants and schedule their production according to market positions and energy demand forecasts. Demand forecasts typically come from historical consumption patterns and weather forecasts, and market positions arise from trading on day-ahead wholesale markets and from long-term contracts. Most buyers in these wholesale markets are "load-serving entities" (LSEs) who purchase power for delivery to their customers over local "distribution" grids. LSEs purchase (and sell) power for future delivery based on their own forecasts, and must ultimately balance supply and demand very closely. Any residual imbalances are dealt with through a "regulating market", which draws on a small subset of the total available production capacity that can be quickly ramped up or down to achieve balance. Prices in the regulating market are typically much less advantageous than short-horizon prices in the day-ahead market (Skytte, 1999). Traditionally, grid control is exercised primarily to adjust energy production to meet demand, on the assumption that demand can be influenced only by shutting off portions of it, either through imposing blackouts, or by exercising demand-management capabilities through "curtailments" in which selected loads, like large water heaters, can be shut off remotely for periods of time. Most customers get a monthly bill and have little or no awareness of how much power they are using at various times or for different purposes, or what it costs.

[1] See http://www.tradingagents.org.

Effective use of variable-output sources such as wind and solar will require that energy users adapt to the availability of sustainable power, and a pricing regime that reflects availability will motivate many households and businesses to invest in some combination of energy storage (e.g. thermal storage or batteries), demand management (e.g. price-sensitive appliance controls), and supply resources (e.g. solar panels). Retail-level supply resources will primarily consist of small, distributed and variable-output sustainable energy sources, and potentially large numbers of electric vehicle batteries will become available to buffer imbalances between supply and demand. These connect to the medium and low voltage "distribution" grid, and are outside the direct control of centralized management. In parallel, installation of smart metering equipment and demand side management devices (DSM) at customer premises will help customers monitor and actively manage their own energy usage (Gottwalt et al., 2011). Consequently, demand elasticity will increase and demand predictions via historical load profiles will become more difficult, especially as new types of tariff contracts become available in which prices vary by time or day, day of week, or dynamically to reflect the real cost of energy.

Electricity production and distribution systems are complex adaptive systems that need to be managed in real time to balance supply with demand within relatively tight bounds. Electricity markets are undergoing a transition from regulated monopolies to decentralized markets (Joskow, 2008), but so far the retail "aggregators" or "brokers" in these markets are almost entirely limited to purchasing power in the wholesale markets and delivering it to their customers; they have not had to deal with significant volumes of power production among their customers. Until the advent of "smart meters", neither retail power suppliers nor their customers have had the ability to understand which customers are consuming power at particular times, and since suppliers cannot charge for power usage on timescales finer than their meter readings, there has been no ability to expose customers to prices that reflect the real-time costs of power. The increasing deployment of supply resources on the retail grid is challenging the ability of the existing centralized control regime to maintain reliability of energy supplies. The "virtual power plant" concept (Pudjianto et al., 2007) is an approach that makes these distributed resources visible, if not fully controllable, by centralized control systems. A critical unanswered question is the extent to which self-interested behaviors of market participants can effectively supplement hierarchical control of the physical infrastructure to balance supply and demand in such an environment.

Smart meters, virtual power plants, and retail competition alone will not be sufficient to align the variable output of renewable energy sources with consumption patterns of a modern industrial society. In areas with large hydroelectric power availability, this can be done by coordinating the output of hydro resources with the availability of other renewable sources (Matevosyan and Söder, 2007). Other cases will require large-scale investment in energy storage (Beaudin et al., 2010), and possibly in additional transmission capacity (Sveca and Söder, 2003). Energy storage can also be provided by plugged-in electric vehicles (Kempton and Tomić, 2005), and by thermal energy storage capacity (Stadler, 2008). In Table 1, we summarize the main contributions of these elements of the Smart Grid with respect to the challenges identified in the Introduction.

**Table 1**
Smart grid elements.

| Challenges | Smart grid elements | | | | |
|---|---|---|---|---|---|
| | Smart metering | EVs | Storage & DSM | VPP | Retail competition |
| Balancing | + | + | + | + | + |
| Energy efficiency | + | + | + | | + |
| Externality reduction | | + | + | + | |
| Peak demand mgt. | + | + | + | | + |
| Reliability | | | + | + | |