A Storage Pricing Mechanism for Learning Agents in Masdar City Smart Grid

(Extended Abstract)

Fatimah Ishowo-Oloko[1], Perukrishnen Vytelingum [2], Nick Jennings[2], Iyad Rahwan[1,3]
[1]Masdar Institute of Science & Technology, UAE
[1]University of Southampton, UK
[3]Massachusetts Institute of Technology, USA

ABSTRACT

Masdar City in the United Arab Emirates is designed to be the first modern city powered solely by renewable energy. However, the stochastic nature of renewable energy generators has remained a major challenge in their sole and large-scale deployment. Traditional approaches couple large-scale storage systems to renewable generators while more recent approaches also study how emerging technologies such as electric vehicles and micro-batteries can be used as consumer-side storage. Future smart grids are however likely to contain both forms of storage. We present a novel model of joint-storage management that allows both renewable energy suppliers and consumers to coordinate in a decentralized manner by gradually adopting storage abilities. For this model, we present a dynamic storage-pricing mechanism that makes use of the storage information from the renewable supplier to generate daily, real-time electricity prices which are communicated to the consumers.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent systems*

General Terms

Economics,Experimentation

Keywords

Energy and emissions, Simulation

1. INTRODUCTION

The growing threat of climate change and the depletion of non-renewable energy sources have led to the growth of sustainable development projects. In particular, sustainable urban development has been advocated as one of the factors in changing the way we produce and use energy. For example, urban planning in the future would not only involve designing buildings that minimize in-house energy use, it would also have to consider the effects of distributed energy resources like wind turbines and solar panels on land-use patterns. Thus, future cities would have to be designed in ways that are sustainable, attractive and commercially viable. Masdar City[1] is built to be a pioneering model for such future cities and it is currently fully powered by onsite renewable energy.

Given the above features of the Masdar city grid, there arises the challenge of balancing supply and demand on a constant basis. Previously, conventional energy suppliers ensured the matching of supply and demand by maintaining a generation capacity that was always much higher than demand. With renewable generation, maintaining excess capacity does not solve the problem as excess capacity is still subject to intermittency and cannot be dispatched at will. To address this challenge, electricity storage devices in the form of large utility-scale batteries [1] and small domestic batteries [3, 4] have been proposed for use with renewable energy generators.

Here, we propose the use of both utility and domestic batteries to form a decentralized energy storage-solution that can be coupled with renewable generators. Given the decentralized nature of the domestic storage and the different consumption patterns of houses, each storage unit is best represented as an autonomous agent that aims to maximize its own preferences. In line with the Abu Dhabi Economic Vision 2030 of increasing the penetration of renewable energy, we provide a novel mechanism by which renewable generators can determine the best price signal to send to their consumers giving their particular seasonal and daily patterns. This dynamic pricing mechanism improves the system efficiency and consumer savings by up to 23% and 35% respectively. Thus, it outperforms the existing fixed price mechanism.

2. MODELING THE MASDAR CITY GRID

The city is designed to be powered solely by renewable energy with a target residential population of about 40,000. We model the grid using real data as consisting of wind and solar generators and batteries at the supply end. At the consumption end, home models which may possess electricity storage capacity (either batteries or electric vehicles) are represented by agents that decide their behavior. In our models, we consider fixed time intervals consisting of

Appears in: *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems – Innovative Applications Track (AAMAS 2012)*, Conitzer, Winikoff, Padgham, and van der Hoek (eds.), 4-8 June 2012, Valencia, Spain.

[1]www.masdarcity.ae

single days, each divided into a set of half-hourly intervals $I = \{1, 2, ..., 48\}$.

Specifically, the wind speed data was obtained from Masdar City Meteorological station for the period of August 2008 to June 2009. We modeled the stochastic process of the wind speed with the Weibull probability distribution [2] and the power outputs of the wind turbine at recorded speeds for each time interval were then obtained.

For the solar generator, the time data series of the power output from a test PV panel located at Masdar City PV contest site was used. The output was recorded every 5 minutes (288 readings per day) for the period of August 2008 to June 2009. The average of the six readings in each half-hour readings was then obtained for each time interval $i \in I$.

The utility-scale storage was modeled based on the Sodium Sulphur (NaS) deep-cycle batteries produced by NGK.[2] Our choice was based on its high power, energy density and capacity which makes them suitable for utility scale storage. Each generator and battery model has an associated levelized daily cost. Our objective was to determine the optimal supply configuration that will minimize total daily costs while ensuring that the demand of the consumers are fully met.

Finally, we built our consumer model upon the recent model for homes equipped with smart meters by Vytelingum et al [5]. Specifically, each agent $a \in A$ has a consumption profile defined as the actual amount of electricity used by agent a for time interval i during each day and a demand profile defined as the amount of electricity demanded (purchased) by the agent from the energy supplier for the corresponding time interval. In our model we assume that this consumption profile is fixed but an agent can minimize its costs by changing its demand profile.

3. THE STORAGE PRICING MECHANISM

The storage pricing mechanism (SPM) uses the availability of real-time storage information that is known to the supplier. For every generation interval, the electricity generated satisfies the demand of consumers while the excess is stored in the batteries. Thus the amount of electric charge in the utility batteries captures the amount of renewable generation that is available but not being demanded by the consumers. Using this information, the supplier can then determine when to decrease its electricity price to encourage more demand and also by how much it should decrease the price and vice versa. Therefore, our mechanism uses the correlation between the amount of charge (or discharge) and the excess (or deficit) generation.

The deviation from the previous day's price ϵ (in dollars/kWh) is given by the ratio of the cost of the batteries and the amount of electric energy that is charged into them. We define the ϵ at each interval as

$$\epsilon = \frac{c_b \times n_b}{\sum_{i \in I} P_i^{ch}} \tag{1}$$

where c_b is the levellized daily cost of each battery, n_b is the number of batteries installed and P_i^{dch} is the power output from the battery at time i. Thus, the supplier offers the consumer the incentive of savings in line with how much it also saves when it avoids using storage by reducing the price by ϵ. More formally, the price for the following day p_i^{t+1} is computed as ϵ less than the retail price of electricity i.e. $p_i^{retail} - \epsilon$ for some $i \in I$, i.e., the time periods when the amount demanded can be directly satisfied by the supplier from its generation. At all other times, the electricity is priced based on the retail price of electricity p_i^{retail}.

Given the above, a self-interested agent (with storage ability) that is interested in minimizing its cost responds by adapting its storage profile in line with changes in daily electricity prices. In more detail, the consumer agent adopts the day-ahead best-response adaptive strategy by [5]. As opposed to their model however, the agent does not need to predict the next day's price for each time slot as this is given by the supplier on a day-ahead basis. Via optimizations, the agent first computes the optimal storage capacity (maximum energy stored) required for it to minimize its cost and then it obtains the daily storage profile of energy.[3]

4. RESULTS IN BRIEF

We simulated the performance of the mechanism based on the Masdar City model and evaluated it in terms of the system efficiency and consumer benefits. The results showed that unlike the fixed pricing mechanism (currently in use in UAE) which achieves a system efficiency of 74%, the storage pricing mechanism achieved a system efficiency of up to 97.4% with all consumers having storage devices and smart meters installed in their homes. Moreover, the consumers with storage devices were able to make an average savings on their electricity bills of 35% when all the consumers are equipped with storage devices.

5. REFERENCES

[1] E. Jim and C. Garth. Energy storage for the electricity grid: Benefits and market potential assessment guide. Technical report, Sandia National Laboratories, 2010. Section 3.6.1.2, Energy Time-shift from Wind Generation.

[2] T.-Y. Lee. Operating schedule of battery energy storage system in a time-of-use rate industrial user with wind turbine generators: A multipass iteration particle swarm optimization approach. *Energy Conversion, IEEE Transactions on*, 22(3):774 –782, sept 2007.

[3] S. D. Ramchurn, P. Vytelingum, A. Rogers, and N. R. Jennings. Agent-based homeostatic control for green energy in the smart grid. *ACM Trans. Intell. Syst. Technol.*, 2:35:1–35:28, July 2011.

[4] T. Voice, P. Vytelingum, S. Ramchurn, A. Rogers, and N. Jennings. Decentralised control of micro-storage in the smart grid. In *AAAI Conference on Artificial Intelligence*, 2011.

[5] P. Vytelingum, T. D. Voice, S. Ramchurn, A. Rogers, and N. R. Jennings. Agent-based micro-storage management for the smart grid . In *9th International Joint Conference on Autonomous Agents & Multi Agent Systems, AAMAS'2010, Toronto, Canada*, 2010.

[2] `http://www.ngk.co.jp/english/products/power/nas/index`

[3] We used IBM ILOG CPLEX 12.2 to implement and solve the optimization problem