Simulating a direct energy market

Products, performance, and social influence

Sascha Holzhauer[1], Friedrich Krebs[1], Christoph Nölle[2]

[1]Research Group Integrated Energy Systems, University Kassel
Kassel, Germany
{sascha.holzhauer,fkrebs}@uni-kassel.de
[2]Fraunhofer Institute for Energy Economics and Energy System Technology
Kassel, Germany
christoph.noelle@iee.fraunhofer.de

Keywords: energy system; energy market; bidding strategies; prosumer; agent-based modelling; demand side management

Abstract. We present modelling results of a direct, high frequency energy market (DEX) where many heterogeneous (individually configured), situated (distributed), generation and consumption units of various types (photovoltaic systems, combined heat and power plants, heat pumps, wind energy converters etc.) are able to trade energy and react to fluctuations in real time. These prosumers utilise so-called energy management gateways (EMG) which automatically interact with the DEX, following bidding strategies and preferences chosen by their owners. We simulate the market performance with an agent-based model representing prosumers as heterogeneous, autonomous entities. Results indicate that the direct market is well able to reflect scarcity through prices promptly, and sets of market products can be defined to suit participants' needs.

1 Introduction

The future energy system is characterised by a substantial increase of distributed power generation by renewables [1], meaning a shift of the system's core characteristics: Whereas in past energy was generated by relatively few power plants as demanded and distributed through a hierarchical and unidirectional grid, nowadays more and more distributed PV plants and wind turbines generate fluctuating energy as they depend on meteorological conditions. Households become "prosumers" as they not only consume energy but also generate, e.g. by PV plants. At the same time, the demand for electricity rises as the mobility and heat sector are going to be decarbonised. Besides investments in renewable power generation and storage, increasing demand and fluctuating generation require demand side management, i.e. means to align energy consumption to energy generation.

Energy prices may indicate surplus and scarcity and incentivise according energy consumption. However, due to access restrictions the current energy market is characterised by few participants dealing large volumes of energy for relatively long intervals. Therefore, most consumers are cut off from price fluctuations and unable to react to volatile generation in real-time. The integration of prosumer entities into future electricity markets requires a shift from centralised control to decentralised self-organisation [2].

We develop a software architecture design for the deep integration of the technical and economical processes of the future energy system. By harmonizing and standardisation, presently loosely connected software solutions in the different sectors of the energy system could be merged into a "Self organising energy automation system" (SOEASY). An experimental platform allows us to study the complex interplay of economic and technical processes of generation and transmission of electric energy in a close-to-reality simulation, utilizing agent-based modelling.

While ABM has been widely applied in the diverse subdomains of energy systems [3, 4] the research focus was either on actor behaviour in wholesale electricity markets [5, 6] or on the opposite end of the electricity supply chain namely electricity-related (household) behaviours [7–9]. The investigation of the market integration of decentralised generation and flexible consumption combines the two perspectives and is an emerging field of energy related ABM studies. For instance, in [10], mobility behaviours are assigned to electric vehicles that seek to minimise charging costs by reacting to variable prices. The neighbourhood exchange of electricity to reduce electricity costs by dynamical demand adjustment has been analysed by [11].

In the paper at hand we report early simulation results of a direct, high frequency energy market (SOEASY-DEX) where many heterogeneous (individually configured), situated (distributed), generation and consumption units of various types (photovoltaic systems, combined heat and power plants, heat pumps, wind energy converters etc.) are able to deal energy and react to fluctuations in real time. These prosumers utilise so-called energy management gateways (EMG) which automatically interact with the DEX, following bidding strategies and preferences chosen by their owners. We simulate the market performance with an agent-based model representing prosumers as heterogeneous, autonomous entities.

2 Method

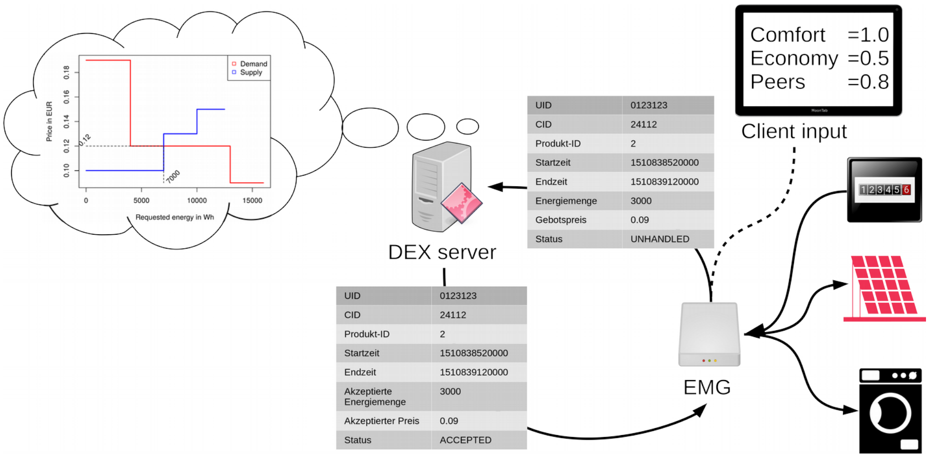

Fig. 1. Schematic overview of the direct market exchange (DEX) including the client-controlled, automated energy management gateway (EMG) and protocols to communicate asks.

Fig. 1 gives an overview of the system’s architecture. The SOEASY-DEX server allows clients to submit their asks of energy supply and demand via a REST interface, performs uniform clearing, and provides an interface for clients to obtain results of the clearing process. It furthermore controls the real net energy consumption by processing meter readings and determines fees for untraded energy and missing meter readings.

The DEX provides a set of market products with different delivery periods and auction settings, including auction opening and closing times as well as auction intervals. Consequently, auctions may take place several times for the same delivery period, allowing clients to adjust their requests if not successful.

Clients are assigned a set of components that either generate energy (PV plant, wind turbine), consume energy (load profile), or store energy. The EMG is able to forecast consumption and generation and then buys and sells electricity at the DEX as required in an automated, optimal way. It considers provided market products and follows bidding strategies as selected by autonomous agents who represent human actors. The EMG may consider user preferences such as price sensitivity, comfort, and eco-friendliness to shift loads such as charging electric vehicles or heat pumps.

The simulation framework allows the analysis of clearing prices, traded energy, as well as individual evaluations of bidding strategies and performance.

3 Results

We simulated the market behaviour of 30 heterogeneous clients on the direct energy exchange with different market products. The products vary by the delivery interval, i.e. clients may bid a certain amount of energy generation or consumption during five or fifteen minutes. Whereas loads are constant for reasons of easier analyses, generation follows a time-variant profile to simulate volatile energy sources from wind turbines and PV. Both are calibrated with an annual energy figure which is randomly assigned each client.

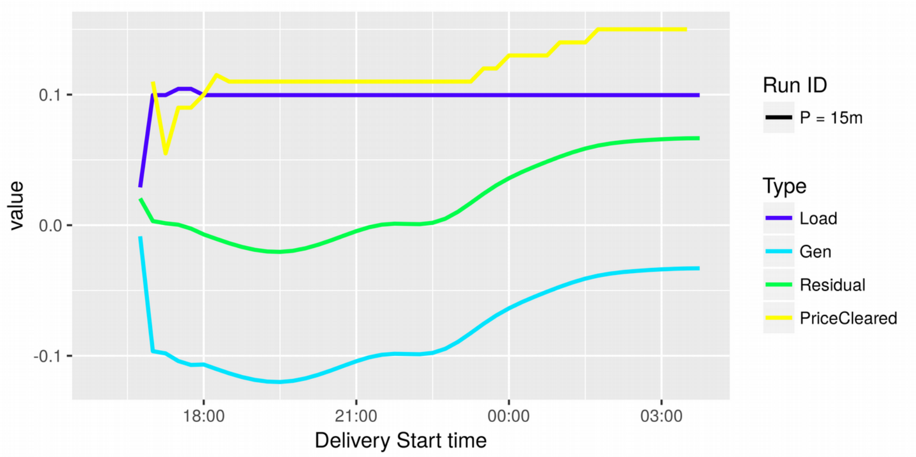

Fig. 2. Constant load, generation (modelled as negative load), and residual of requested energy as well as clearing price for 30 clients and a market product with delivery interval = 15 minutes.

As shown in Fig. 2, the resulting, increasing clearing price reflects the volatile, here decreasing electricity generation well.

Fig. 3. Comparison of clearing price between a market with only one product (15 minutes delivery interval) and a market with two products (5 minutes and 15 minutes delivery time).

The benefit of a flexible definition of market products is illustrated by Fig. 3. The market with two products allows participant to react to fluctuations in consumption and generation: they may forecast and ask for longer delivery products accordingly, and then balance deviations in nearly realtime by short term products. With more product options, the resulting clearing price is slightly lower.

4 Discussion

Innovative, decentralised, high frequency markets have a great potential to boost demand side management, but the complex nature of the energy system requires thorough analyses of the interplay of the technical infrastructure and their human users. The presented simulation environment enables assessments of effects such as market frequency, number of participants and social influence on bidding strategies.

In terms of the market server we are going to implement more innovative mechanisms besides uniform clearing. The energy management gateways are extended in order to better reflect their users' preferences such as comfort, economic performance, and social norms. For instance, some users prefer a high degree of comfort, meaning rather small intervals or fixed times when they expect certain applications like dish washers, heat pumps or charging electric vehicles to operate. Others put more weight on a sustainable lifestyle and seek to consume energy when it is available. Nevertheless, such considerations evolve in a social context, and that is why we also investigate effects of social influence on these preferences when individuals interact with each other in their neighbourhood and on social network topologies.

To test the impact of real world performance we are currently setting up a distributed environment of 60 Raspberry Pi 3B+ and Zero machines that independently communicate with the market server.

5 Acknowledgements

The research presented in this article was partly funded by the German Ministry for Education and Research (BMBF) under contract no "03SFK4F1".

6 References

1. International Energy Agency (IEA): Medium-Term Renewable Energy Market Report 2015. Market Analysis and Forecasts to 2020 (2015)
2. Niesse, A., Lehnhoff, S., Troschel, M., Uslar, M., Wissing, C., Appelrath, H.-J., Sonnenschein, M.: Market-based self-organized provision of active power and ancillary services. An agent-based approach for Smart Distribution Grids. In: Complexity in engineering (COMPENG), 2012. 11 - 13 June 2012, Aachen, Germany ; second edition of the IEEE Workshop on Complexity in Engineering, pp. 1–5. IEEE, Piscataway, NJ (2012)
3. Ringler, P., Keles, D., Fichtner, W.: Agent-based modelling and simulation of smart electricity grids and markets – A literature review. Renewable and Sustainable Energy Reviews 57, 205–215 (2016)
4. Rogers, A., Jennings, N.: Intelligent Agents for the Smart Grid. PerAda Magazine (2010)

5. Sensfuß, F., Genoese, M., Ragwitz, M., Möst, D.: Agent-based Simulation of Electricity Markets -A Literature Review-. Energy Studies Review 15 (2007)
6. Weidlich, A., Veit, D.: A critical survey of agent-based wholesale electricity market models. Energy Economics 30, 1728–1759 (2008)
7. Krebs, F.: An Empirically Grounded Model of Green Electricity Adoption in Germany: Calibration, Validation and Insights into Patterns of Diffusion. Journal of Artificial Societies and Social Simulation 20, 10 (2017)
8. Sorda, G., Sunak, Y., Madlener, R.: An agent-based spatial simulation to evaluate the promotion of electricity from agricultural biogas plants in Germany. Ecological Economics 89, 43–60 (2013)
9. Zhang, T., Nuttall, W.J.: Evaluating Government's Policies on Promoting Smart Metering Diffusion in Retail Electricity Markets via Agent-Based Simulation. Journal of Product Innovation Management 28, 169–186 (2011)
10. Dallinger, D., Wietschel, M.: Grid integration of intermittent renewable energy sources using price-responsive plug-in electric vehicles. Renewable and Sustainable Energy Reviews 16, 3370–3382 (2012)
11. Kahrobaee, S., Rajabzadeh, R.A., Soh, L.-K., Asgarpoor, S.: Multiagent study of smart grid customers with neighborhood electricity trading. Electric Power Systems Research 111, 123–132 (2014)