SEC Forecasting, Planning and Stability of Smart Energy Markets

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This project is aimed at developing novel control mechanisms for future energy systems and markets. We studied the current energy market and its possible flaws (e.g., flash crashes) prior the design of the new model. Our proposal fits in the scope and hierarchical market structure of the Universal Smart Energy Framework (USEF), and in particular, treats the following stakeholders:

- Balance Responsible Party (BRP): responsible for maintaning the supply-demand balance,
- aggregators: accumulates prosumer flexibilities for larger balancing power,
- prosumers: end-users that not only consume, but are also capable of producing electricity,
- Distribution System Operator (DSO): responsible for congestion management.

The main problem we investigate is to balance between the (day-ahead) forecasted and the actual supply and demand within the network. A deviation between the two portfolio can arise due to the fluctuating generation from renewable energy sources, and minimizing this deviation is important for grid stability, as well as for economic considerations. We design controllers that coordinate a network of prosumers with flexible thermal appliances – devices that are capable of shifting their electricity production or consumption in time.

The research was carried out, among others, with the help of several Bachelor's and Master's students.

Deliverables (for details, see the reports):

- **Analysis of control mechanisms in other distributed systems**
  A short study on various distributed control mechanisms, including the early d-MPC method developed at the university, was conducted and summarized in [1]. Furthermore, we authored a book chapter that describes the general (distributed) optimal control approach to supply-demand matching in smart energy grids [11].
- **Root-cause analysis of examples of flash crashes**
  A preliminary investigation on flash crashes in energy markets was reported in [3]. In [4], based on extensive literature review and expert interviews, it was concluded that Intermarket Sweep Orders (ISO) and High-Frequency Trading (HFT) are the most common type of flash crashes in financial markets. However, none of them can occur in energy markets because of the different market characteristics (e.g., time-scale).

- **Setup of a benchmark for stability of economic optimization through market control mechanisms in smart energy systems**
  In [5], a benchmark for smart grids was developed. Through interviews with experts, key performance indicators and device properties were derived, but due to the limited timeframe of a Bachelor's thesis, only a small-scale model was proposed.
- **Analysis of existing market control mechanisms**
  Existing market control mechanisms (e.g., PowerMatcher and TRIANA) were overviewed in [2]. It was concluded that although these are interesting methods with promising results, they do not fit in the market structure specified in USEF.
- **Embedding of prediction and planning in the design**
  Continuing previous research at the university, a distributed model predictive controller was proposed to minimize the supply-demand imbalance within networks of interconnected prosumers of a smart electricity grid. The algorithm uses only local information of the prosumers to obtain the optimal solution, and is able to take prediction of future events into account. Articles published in the topic are [12, 14], contributing theses are [6, 7, 8]. We are currently working to incorporate the plan phase of USEF into the model [16].
- **Adapting the designs for making the control methods robust against failures in the network**
  In all of our systems, we use distributed control methods, which, if designed properly, are robust against failures in the network. In that way, we have taken that into account in the newly developed algorithms. Related deliverables are the same as before, i.e., articles [12, 14] and theses [6, 7, 8].
- **Analysis of interactions between control mechanisms for pluriform markets with multiple market control mechanisms at work**
  In [13, 15], we extended the scope of our control mechanism to multiple levels within the USEF market structure by introducing pricing. The new model allows different stakeholders to optimize towards their different (economic) interests, and more specifically, allows interactions between the BRP, aggregators, prosumers, and DSO. Theses that contributed to this work are [9, 10].
- **Simulation of at least 2 market control mechanisms for the benchmark**
  The articles [12, 13, 14, 15, 16] all include simulations of the respective market control mechanisms. However, the other existing methods (PowerMatcher, TRIANA) were not yet simulated due to them being very complex. They have turned out to be not easily compatible with the USEF market structure, and are therefore ignored.

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Publications

[16] D. B. Nguyen, J. M. A. Scherpen, and F. Bliek, "Optimization in the USEF plan phase", Working title, Manuscript in preparation

[15] D. B. Nguyen, J. M. A. Scherpen, and F. Bliek, "Modeling and Optimization in Hierarchical Smart Energy Markets", Manuscript submitted for publication

[14] D. B. Nguyen, J. M. A. Scherpen, and F. Bliek, "Distributed Optimal Control of Smart Electricity Grids With Congestion Management", *IEEE Trans. Automation Science and Engineering*, vol. PP, no. 99, pp. 1–11, 2017 [Online] Available: https://dx.doi.org/10.1109/TASE.2017.2664061

[13] D. B. Nguyen, J. M. A. Scherpen, F. Bliek, and B. ter Haar, "Modeling and Optimization in USEF-compliant Hierarchical Energy Markets", in *Proc. 2016 IEEE PES Innovative Smart Grid Technologies Conf. Europe*, Ljubljana, Slovenia, 2016, pp. 1–6

[12] D. B. Nguyen, J. M. A. Scherpen, F. Bliek, W. Kramer, and G. K. H. Larsen, "Distributed Optimal Control and Congestion Management in the Universal Smart Energy Framework", in *Proc. 15th European Control Conf.*, Aalborg, Denmark, 2016, pp. 910–91

[11] D. B. Nguyen, D. Alkano, and J. M. A. Scherpen, "The Optimal Control Problem in Smart Energy Grids", in *Smart Grids from a Global Perspective: Bridging Old and New Energy Systems*, A. Beaulieu, J. de Wilde, and J. M. A. Scherpen, Eds. Switzerland: Springer, 2016, pp. 95–111

Theses (University of Groningen)

[10] H. van der Werf, "A non-cooperative market model extension for USEF", Master's thesis, 2017

[9] B. ter Haar, "Modeling and Optimization of USEF's Market Mechanisms", Master's thesis, 2016

[8] C. Lakenvelt, "Hierarchical Control using DMPC as a control method in USEF", Master's thesis, 2016

[7] W. Kramer, "The Distribution System Operator in a d-MPC application for USEF", Master's thesis, 2015

[6] L. Doddema, "Scalability of DMPC Demand Response in the Context of the Universal Smart Energy Framework", Master's thesis, 2015

[5] D. van Dortmont, "Benchmarking for smart electricity grids", Bachelor's thesis, 2015

[4] T. Schnaar, "Flash crashes in smart grid energy markets", Bachelor's thesis, 2015

Reports (University of Groningen)

[3] D. B. Nguyen, "Report – September 10, 2014", 2014

[2] D. B. Nguyen, "Preliminary report – May 12, 2014", 2014

[1] D. B. Nguyen, "Introductory report – September 24, 2013", 2013