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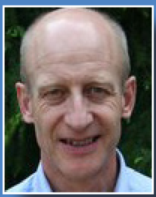
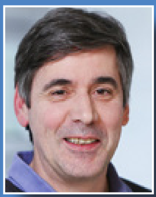
HeatReserves

DEMAND RESPONSE FOR ANCILLARY SERVICES: THERMAL STORAGE CONTROL



Prof. Göran Andersson, ETHZ



Prof. Jan Carmeliet, EMPA

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What it's about…

Using thermal loads of buildings as reserves to enhance renewable energy integration.

Context and project goals

Control reserves are traded in the control reserve market and are today mainly covered by conventional generators. In Switzerland, control reserves are prominently provided by hydro power plants, which pump water to high altitudes in case of power surplus and release water through turbines in case of power shortage. Although in Switzerland the electricity production of wind and solar is currently limited, the need for ancillary services is significant also here, because of the nuclear phase-out as well as business opportunities with neighboring countries with substantial renewable generation such as Germany.

We propose to use thermal loads as additional means for ancillary services to account for the expected increase in renewables. To achieve this, we will develop appropriate demand response schemes for the thermal loads. One advantage of thermal loads is their ability to react locally, whereas control reserves from hydro power plants can lead to congestions in the transmission network. The increase in the number of ancillary service providers also leads to higher market liquidity. Finally, demand response can help to reduce electricity peaks. We propose two main options for providing ancillary services with thermal loads: first, control of Heating, Ventilation, and Air Conditioning (HVAC) systems of an aggregate of several office buildings; second, control of a large number of household appliances. These two options share a number of challenges, which can be categorized as follows:

Modeling and estimation: the challenges are due to modeling the fast dynamics of buildings given their complex HVAC systems as well as uncertainty in building parameters and weather forecasts; and due to modeling a large-scale and distributed population of household appliances in the power grid and (currently) very limited measurement possibilities for household appliances.

Control and communication: the models in both options are large-scale, distributed, hybrid (discrete and continuous modes of operations) and stochastic. Effective and tractable control schemes for these systems have to be developed. For office buildings the communication infrastructure is already in place (internet access of most building management systems), but privacy considerations put limitations on the information exchanged. For household appliances communication infrastructure still needs to be developed considering the trade-off between performance and investment costs.

Economic considerations and user incentives: even if all technical problems are solved, the crucial factor for a successful implementation of demand response will be whether users take part in the proposed schemes. This, to some extent, will be determined by economic incentives balancing benefits to the grid (Transmission System Operator) with potential losses or investments to the participants. To ensure user participation, we will investigate market structures, consumer behaviors and design incentives such as rewards, or lottery schemes.

Demand response options for both office buildings and for household appliances will be addressed by developing appropriate methodologies, tackling the computational complexity of the large-scale aggregated systems, validating the proposed methods in large-scale simulations, and finally case study implementations. The demand response schemes developed will provide additional ancillary services to the grid while optimizing energy use of each building/household unit. To tackle the multi-disciplinary problems, the project partners provide an outstanding mixture of expertise in the relevant areas of power grids, control theory, building simulations and economics. The expected outcome of the project is guidelines for Switzerland on the methodology and costs for implementation of demand response schemes for ancillary services and incentives for user participation in the schemes.

How it differentiates from similar projects in the field

The team consists of multi-disciplinary researchers from the fields of control theory (ETHZ-IfA), power systems (ETHZ-PSL), building systems (EMPA), grid operation (SwissGrid) and economics (St. Gallen). This allows for a holistic approach to address the proposed problem, including its technical, economic, and user acceptance implications.

Quick summary of the project status and key results

An integrated building modeling and simulation environment was developed in collaboration between ETH and EMPA. This platform is serving as a testbed for the control schemes developed.

In collaboration with Swissgrid, ancillary service requirements and the market structure were explored and the data from Swissgrid was used in the control schemes. The first round of the market study was conducted by St. Gallen, aiming to determine factors influencing user acceptance of thermal load demand response schemes. Six Semester and Master thesis were advised on topics of the project.

Collaborations with industrial partners of Cofely AG and Repower were established. Numerous papers were published in high impact journals and conference proceedings and several others are submitted for publication. A large number of presentations were given by the project partners in prestigious power and control conferences.

Success stories

Through a series of meetings with Swissgrid, several challenges and opportunities for participation of thermal loads in ancillary service market were identified.

Through collaboration of ETH Zürich partners with EMPA, a novel modeling and simulation platform for commercial buildings was developed. This platform contains a database of typical Swiss office buildings. It enables simulation of the buildings under various demand response schemes and can be used for accurate quantitative analysis of the developed strategies for the future of Switzerland ancillary service market.

A methodological framework was established, to estimate the amount of building reserves that can be robustly extracted. Several theoretical and practical challenges had to be resolved in the process. To the best of the team's knowledge, this is the first systematic approach to this problem. It is currently being extended and validated on the simulation platform described above. Later in the project, the team plans to deploy this method on the NEST building, which is currently under construction by EMPA. Furthermore, effects of demand response schemes developed on the power grid frequency have been studied to ensure the closed loop system safety and security is not affected through the developed tools.

Although several approaches have been proposed to enable the participation of populations of Thermostatically Controlled Loads (TCLs) in ancillary service markets, detailed quantitative analysis of the potential of these loads was lacking. The project addressed the Energy Arbitrage problem, that is, it answered the question of whether an aggregation of TCLs could make profit by participating in wholesale electricity markets. The results of the paper are the first to quantify the answer to this question. The key scientific findings were that the arbitrage potential for individual residential units are very small. Although the study was performed for participation in the wholesale electricity markets and with California market data, it is expected that the results would be similar for ancillary service markets in Switzerland, a topic we are currently investigating. The team's results suggest that there is a clear need for incentive design mechanism to engage consumers for participation in such demand response schemes. This further motivated and defined the tasks on economic analysis. They also suggest that minimal investment in communication infrastructure can be expected in this case, further motivating the development of advanced distributed control algorithms.

Furthermore, a significant interaction effect was discovered for combining punishment, or rewards for participation in demand response, with reason, or without a reason: it appears that customers' acceptance of demand response programs can be increased with these insights without higher costs and without jeopardizing firm reputation. In addition, Swiss utilities expressed a notable interest in these first results. This motivates the next step on addressing how to integrate these insights into the customer engagement program of Swiss utilities. The team has been collecting data from interactions with about 3000 Swiss energy consumers in a series of eight distinct experimental studies.

Main publications

J. L. Mathieu, M. Kamgarpour, J. Lygeros, G. Andersson and D. S. Callaway, Arbitraging Intraday Wholesale Energy Market Prices with Aggregations of Thermostatic Loads, IEEE Transactions on Power Systems.

E. Vrettos, J. L. Mathieu, and G Andersson , Control of Thermostatic Loads Using Moving Horizon Estimation of Individual Load States, IEEE Power Systems Computation Conference.

X. Zhang, K. Margellos, P.J. Goulart, J. Lygeros, Stochastic Model Predictive Control Using a Combination of Randomized and Robust Optimization, Control and Decision Conference.

E. Vrettos, X. Zhang, F. Oldewurtel, M. Kamgarpour, J. Lygeros, G. Andersson, Exploring the Potential of Buildings in the Swiss Ancillary Service Market, Computational Optimisation of Low-Energy Buildings.

M. Kamgarpour, E. Vrettos, G. Andersson, J. Lygeros, Popluation of Thermostatically Controlled Loads for the Swiss Ancillary Service Market, Computational Optimisation of Low-Energy Buildings.

J. L. Mathieu, M. Kamgarpour, J. Lygeros, G. Andersson and D. S. Callaway, Energy Arbitrage with Thermostatically Controlled Loads, European Control Conference.

T. Borsche, F. Oldewurtel, G. Andersson, Balance Group Optimization by Scenario-based Day-ahead Scheduling and Demand Response, IEEE Innovative Smart Grid Solutions Europe (ISGT-EU).

X. Zhang, E. Vrettos, M. Kamgarpour, G. Andersson, and J. Lygeros, Stochastic Frequency Reserve Provision by Chance-Constrained Control of Commercial Buildings , European Control Conference 2015.

X. Zhang, S. Grammatico, G. Schildbach, P. Goulart, and J. Lygeros, On the Sample Size of Random Convex Programs with Structured Dependence on the Uncertainty, Automatica (prov. Accepted).

S. Grammatico, X. Zhang, K. Margellos, P. Goulart, and J. Lygeros, A scenario approach for non-convex control design, IEEE Trans. On Aut. Control (prov. Accepted).

X. Zhang, S. Grammatico, K. Margellos, P. Goulart, and J. Lygeros, Randomized Nonlinear MPC for Uncertain Control-Affine Systems with Bounded Closed-Loop Constraint Violations, IFAC World Congress 2014.

G. Ledva, E. Vrettos, S. Mastellone, G. Andersson, and J. Mathieu, Applying Networked Estimation and Control Algorithms to Address Communication Bandwidth Limitations and Latencies in Demand Response, Hawaii International Conference on System Sciences.

E. Vrettos, C. Ziras, and G. Andersson, Integrating Large Shares of Heterogeneous Thermal Loads in Power System Frequency Control, IEEE PowerTech conference 2015 (prov. Accepted).

C. Ziras, E. Vrettos, and G. Andersson, Primary Frequency Control with Refrigerators under Startup Dynamics and Lockout Constraints, IEEE PES General Meeting 2015 .

M. Balandat, F. Oldewurtel, M. Chen, C. Tomlin, Contract Design for Frequency Regulation by Aggregations of Commercial Buildings, Allerton Conference 2014.

T. Borsche, Andreas Ulbig, Göran Andersson, Impact of Frequency Control Reserve Provision by Storage Systems on Power System Operation, IFAC World Congress 2014.