MODELLING METHOD FOR THE OPTIMAL OPERATION OF SENSIBLE THERMAL ENERGY STORAGES

Martin Koller, René Hofmann*

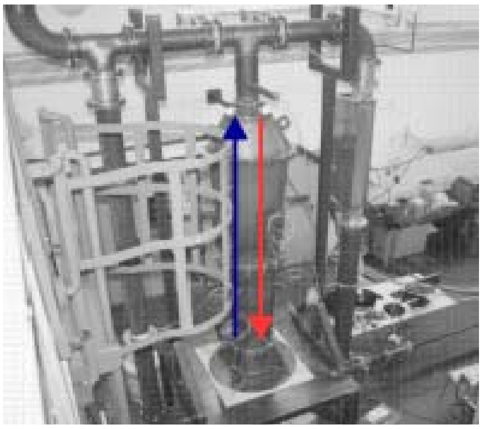
E302 - Institute of Energy Systems and Thermodynamics at TU Wien

INTRODUCTION

To reach the EU's climate targets, an important topic is energy efficiency in energy-intensive industry and integration of renewable energy using energy storages. In Europe industrial processes have a share of 25.3% of the total energy consumption[1], therefore improvements in this sector have a huge impact. In this regard, a smart energy system approach[2] is promising, interconnecting industry with electricity, heat and gas networks. This allows a better integration of renewable and higher overall efficiencies due to higher flexibility. Though, these interconnections create a complex system, which needs to be operated in an optimal way. In such an energy system, there are lots of different generating units, storage units, interconnections, etc. The problem of optimal operation of these units is referred to as unit commitment (UC) problem[3], which can be solved, e.g. with mixed integer linear programming (MILP), a mathematical optimisation method. In this contribution, a novel method for optimal operation of a sensible thermal storage is presented.[4]

METHODOLOGY

The fixed bed regenerator (Picture 1) is a sensible thermal energy storage, meaning that the storage is charged by increasing the temperature of the storage medium and discharged by decreasing its temperature. The storage behaviour has nonlinearities, as most real physical system have, but MILP allows only linear terms, therefore the nonlinearities need to be approximated appropriately. Note that there are as well nonlinear optimization methods, but these could find just a local and not the global optimum of the optimisation problem or they are too inefficient to solve the problem in reasonable time. The realistic dynamic behaviour of the storage is depicted in Picture 2. It can be seen, that the charging/discharging power is not only dependent on the storage fill level, but also on the fill level at the beginning of the current phase (charging or discharging). Storages in MILP-UC problems are mostly modelled with a fixed maximum charging and discharging power (Q). Such a simple storage model (Model A) can be described with the following equations.

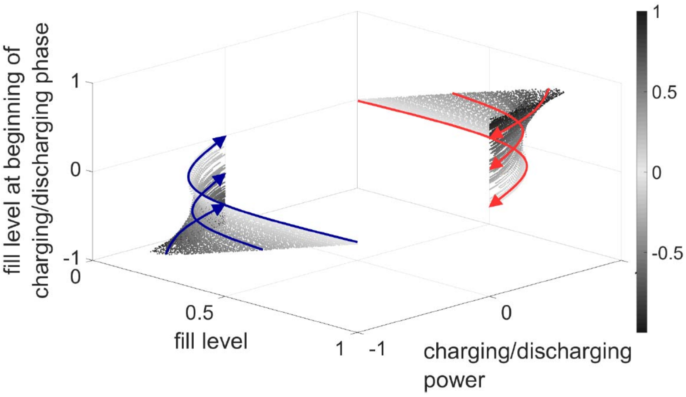


Picture 1: Fixed bed regenerator (Sensible thermal energy storage) [4]

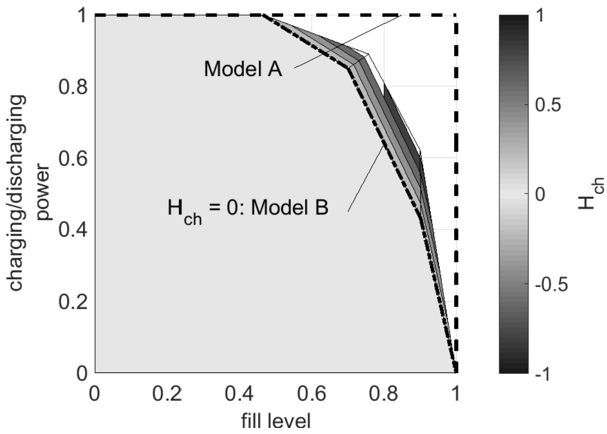
$$S_{t+1} = S_t + (\dot{Q}_{ch,t} - \dot{Q}_{dis,t}) \cdot \Delta t, \quad 0 \leq S_t \leq S_{max}$$

$$\dot{Q}_{ch,t} \leq \dot{Q}_{ch,max}, \quad \dot{Q}_{dis,t} \leq \dot{Q}_{dis,max}$$

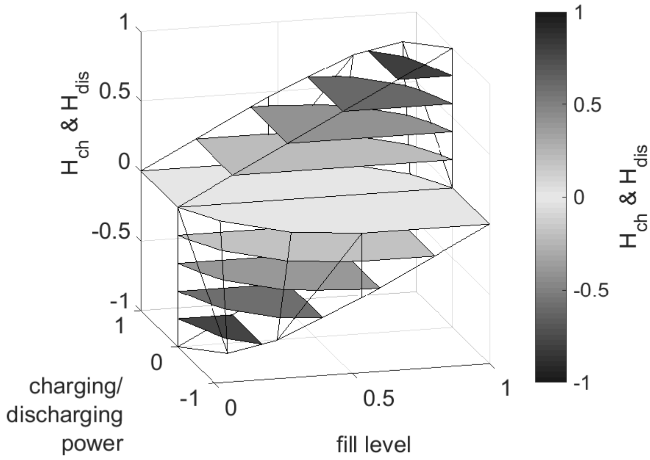
According to Picture 2, the maximum charging or discharging power is not fixed. To this end, the model can be extended as follows (Model B).



Picture 2: Dynamic operation of the fixed bed regenerator[4]



Picture 3: Model A, B and C (bottom view of charging part) [4]



Picture 4: Model C[4]

$$\dot{Q}_{ch,t} \leq a + b \cdot S_t \quad , \quad \dot{Q}_{dis,t} \leq a + b \cdot (S_{max} - S_t)$$

Picture 3 shows the maximum power for Model A, which is constant, for Model B, which is just dependent on the fill level (*S*). Model C is a further extension of Model B with more complex constraints, where additionally the fill level at the beginning of the current phase is considered (H). Model C is illustrated in Picture 4. Picture 3 shows the bottom view of the charging part of Model C. Compared with Picture 2, Model C is the most precise of the three Models.

RESULTS AND DISCUSSION

The presented models were compared with a test case, which consists of a combined heat and power (CHP) unit and the presented storage. A predefined heat load has to be satisfied, the fuel costs for the CHP unit are constant, and the electricity prices are taken from historic spot market. Model A has the worst feasibility and objective value, Model B is a very reliable and feasible representation, but cannot exploit the storage capabilities to its fullest. Model C can represent the storage most accurate, but needs higher computational effort.

CONCLUSION

Compared to the simple formulation of energy storages, the presented extended MILP model C for sensible thermal energy storages is able to better exploit the storage flexibility and decrease prediction errors that would lead to further efficiency reductions. With this more precise storage modelling, the efficiency of the overall energy systems will be increased. This modelling approach, as well as other studies of the authors[5], can be integrated in state of the art MILP-UC formulations. Currently the authors develop an efficient MILP formulation for multiple identical generating units and investigate the impact of different time step sizes on the MILP-UC problem.

REFERENCES

[1] eurostat, Consumption of energy, URL: *http://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy#Further_Eurostat_information*, last visited: 11.03.2018.

[2] Lund, H., Østergaard, P. A., Connolly, D., Ridjan, I., Mathiesen, B. V., Hvelplund, F., Thellufsen, J. Z., Sorknæs, P., Energy storage and smart energy systems, International Journal of Sustainable Energy Planning and Management 11, 3–14, 2016

[3] Padhy, N. P., Unit commitment—a bibliographical survey, IEEE Transactions on Power Systems 19 (2), 1196–1205, 2004

[4] Koller, M., Hofmann, R., Mixed Integer Linear Programming Formulation for Sensible Thermal Energy Storages, Computer Aided Chemical Engineering, 2018. (accepted)

[5] Koller, M., Hofmann, R., Mixed-Integer Linear Programming Formulation of Combined Heat and Power Units for the Unit Commitment Problem, J. sustain. dev. energy water environ. syst., 2018. (accepted)