SMART DEMAND SIDE MANAGEMENT:
STORING ENERGY OR STORING CONSUMPTION – IT IS NOT THE SAME!

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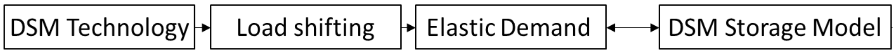
Overview

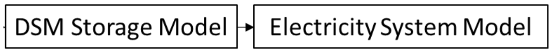
Emerging countries face the challenge to develop their economies while reducing CO_2 as well as local emissions to avoid environmental damage. The shaping of their quickly growing energy systems thus requires even more than in developed countries resource preserving and efficient solutions. The latter include energy storage and demand side management. Both technology options can unfold their potential as in future energy systems the share of intermittent renewable generation with low guaranteed capacity will rise. This will result in increasingly long- and short-term fluctuations of the load. Their safe and efficient handling can be ensured by technical options such as supply-sided renewable curtailment, the improvement of generation flexibility and the introduction of storage technologies. On the demand side, also load shifts are suitable to control the energy system with high proportions of renewables. The latter is referred to as demand side management (DSM) or response (DSR) and has considerable potential (Strbac, 2008).

In detail, either thermal storage (refrigerator, melted aluminium) could be used or the indifference in electricity demand timing (washing machine) could be exploited to shift electrical loads in time in the industrial and domestic sector. This technology is commonly interpreted as a low-fixed-cost storage technology with given ‘convenient’ time bounds of load shifting (Zerrahn and Schill, 2015). This makes DSM a very attractive technology possibly substituting classical storage, especially in the short run.

But even if the control effort could be comprehensively delegated by electronic data processing and transmission at low cost the analysis of power outages (e.g. Kufeoglu and Lehtonen, 2015) reveals significant opportunity cost of – even expected – outages. Similar opportunity costs of load shifting can be expected. This is very plausible as the opportunity cost of switching off a refrigerator might be close to zero for few hours but afterwards the probability of spoiling food will increase and raise the cost of time shifting. Thereafter the fridge will have to be turned on again and the system will be stressed. Suddenly released demand will then increase prices and possibly undermine the DSM business model. Intermittent renewables might further tighten this problem. The operator of a conventional low-self-discharge battery, in contrast, would limit losses by waiting for a favourable time to unload.



The ‘fridge’-example makes clear, that DSM reduces consumer’s effort to participate in real time electricity markets, induces load shifting and thereby causes an elasticity of demand. We formalize this intuition in a rational dynamic electricity consumption model taking into account electricity prices and opportunity cost of load shifting. We are able to show that this managed electricity demand is equivalent to the demand generated by a rationally operated constrained storage device (DSM storage model). This “microfounded” DSM storage model differs from the commonly applied ad hoc DSM storage models with respect to its constraints - but remains sufficiently simple to be applicable.



As we are specifically interested in the relation of DSM and conventional storage (like batteries) the DSM storage model is applied to investigate its impact on the syetem level. As mentioned before there is a significant difference in the cost structure of conventional storage with at most zero operating cost and high fixed cost and DSM with nonlinear storage cost and low fixed cost. We are going to analyse the effect of this difference for individual decision making and in the system context – with a focus on the identification of the differences to classical storage and on increasing system uncertainty. We thus answer the questions of whether DSM and storage are complements or substitutes to classical storage and if prices can coordinate DSM sufficiently to implement a value for the system.

Methods

We start our analysis with a comprehensive review of technological approaches to load shifting, including coordination, communication infrastructure and its costs. To determine the opportunity costs of DSM, we review quantitative approaches to the costs of power failures and discuss its suitability as proxy. Differences can be expected as devices with least opportunity cost can be selected for load shifting which is impossible in a general outage.

Based on this carefully adapted empirically qualified cost model we define individual rational electricity demand under price uncertainty. In detail, it is assumed that for each consumer there is a most convenient electricity consumption path. Shifting consumption and deviating from this path causes costs modeled in the previous section. Considering these losses electricity is bought at real time price to maximize utility. In this setting price uncertainty induces incentives to postpone consumption in the case of high prices – as there is a chance of decreasing prices – and pulling consumption ahead in times of low prices – as there is a risk of rising prices. In doing so, we consider the option value of load shifting, identify asymmetries between postponing and pulling ahead electricity consumption and analyse the influence of stochastic properties of the residual load.

We are able to show for a series of examples (and expect to proof generally) that the optimal consumption path equals the demand of a rationally operated constrained storage (DSM storage model). This shows that the common approach to interpret DSM as storage – viewed as best practice by Zerrahn and Schill (2015) – is coherent and a ‘tracking’ of shifted energy over time to consider the duration dependent opportunity cost is not necessary.

The DSM storage model will finally be used to analyse the impact of DSM on the electricity system - based on Geske and Green (2016) - under residual load uncertainty. For this purpose, uncertainties are modelled as a Markov Process in a stationary, stochastic optimization model (Markov Decision Process, MDP) including the DSM storage model, a classical battery storage and residual load uncertainty.

Results

Data on the investment costs of DSM are obtained from the technology review. By discussing and adapting common cost models of power failures, a dynamic device specific utility function is defined that balances the opportunity costs of load shifting (value of lost load, VoLL) with the monetary benefit from flexibility. From this devicespecific consideration and a distribution of device characteristics we deduce an aggregate cost function of load shifting. Under specific assumptions the aggregate cost function has a quadratic shape depending on the VoLL and distribution parameters.

Based on this, a dynamic stochastic decision problem can be defined over the execution times of the electricity demand. The solution of this model consists of price-dependent, temporal thresholds for the execution of demand. This solution is then used to derive consumption paths from price paths. As previously described, it can be shown that a rationally operated, restricted storage generates the same demand paths. The according DSM storage model is used to examine how the properties of the residual load process influence the distribution of ‘functions’ between the DSM and a classical storage. Which storage takes over e.g. the holding of a reserve due to the different cost structure?

Conclusions

We interpret DSM as a technology that reduces consumer’s effort to participate in real time electricity markets, thereby induces load shifting and causes an elasticity of demand. Considering the opportunity cost we derive DSM enabled consumption paths and its impact on the energy system under uncertainty. This analysis thus extends the understanding of the incentives to apply DSM, including its option values and the value of its integration into the system, which is likely to rise with renewable penetration. Thus, the analysis of DSM is raised to a new level and the quality of its economic evaluation is considerably deepened. The results can be expected to be of particular relevance for the governance of fast growing energy systems in emerging countries.

References

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