Modeling Load Shifting Potentials of Electric Vehicles

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(1) Overview

In the discussion about the Energiewende (German energy transition) Demand Side Management[i] is attracting more and more notice as an approach to make the flexibility of electricity demand accessible. Due to the objective of the Energiewende to reduce greenhouse gas emissions by increasing generation from volatile renewable energies, the flexibility of the electricity generation is reducing while the electricity demand should increase its flexibility in the future. Along with this, in the transport sector the transition from combustion engines to electric drives with large batteries is going forward worldwide.

Therefore, the questions raise how to describe load shifting potentials as one important part of demand side management and how to integrate them in energy models to evaluate the effects for the electricity system. In the following contribution we explore these two questions and discuss possible solutions for modeling load shifting potentials. We take the example of electric vehicles (EV), because they are assumed to provide high load shifting potentials for private households in the future. The reasons for these high potential, especially compared to household appliances, are seen in their automatized charging, long parking times, high charging power and energy.

(2) Methods

Describe and quantify load shifting potentials

Load shifting potentials are difficult to describe and to quantify because a plenty of parameters are involved. In general both electrical power and energy demand have to be defined and the maximum and minimum limits too. Additionally, time dependencies can be implied by fixed load curves or notable time periods. To analyze economic feasibility of load shifting potentials also price incentives are needed, while acceptance indicators additionally consider possible implementation barriers. Nevertheless, several studies focus on electrical power only to quantify load shifting potentials, as shown e. g. in VDE-Study (2012). Thus we analyze the status-quo and identify advantages and disadvantages of the different approaches.

Electric vehicles load shifting potentials in energy modeling

Beside the method to quantify load shifting potentials there are several approaches how to integrate them appropriately into energy modeling. Each possible approach is characterized by individual advantages and disadvantages and therefore they are suited for different research questions. Using the example of EV several possibilities of integrating their load shifting potential in an energy model exist (cf. Tab 1). These approaches range from modeling each single EV separately to cumulating the total EV fleet. To analyze the characteristics of these approaches we compare them in terms of modeling accuracy and solving complexity. The results of our analysis could serve as a decision support for modeler to choose the adequate approach for their research question.

Tab. 1: Overview for approaches modeling load shift potentials of electric vehicles

classification of modeling aggregation	*example for EV in Germany*	*modeling accuracy*	*solving complexity*	*example for complexity n*TS*REG*
A1: each vehicle	every 40 million EV	exact	high	$40*10^6*1*672 = 2.7*10^{10}$
A2: representative groups	500 EV representing all EV	high	medium	$500*350*672 = 1.2*10^8$
A3: whole EV fleet	all EV aggregated in one	acceptable*	low	$350*672 = 2.0*10^4$

EV.. electric vehicle, n.. number of EV, TS.. time slices, REG.. region, * depending on the research question

For further analyzing the approaches we developed an implementation of EV for an optimization model with the objective to optimize the charging power $P_{charge}^{n}(t)$ considering energy economic requirements. In doing so, it is necessary to know the lower and upper bounds of the state of charge of the EV batteries $\mathrm{SoC}_{max}^{n}(t), \mathrm{SoC}_{min}^{n}(t)$ and the SoC during driving $\Delta\mathrm{SoC}_{drive}^{n}(t)$ as well as the available charging power $P_{max}^{n}(t)$. These values are calculated based on mobility study data from the German Mobility Panel (Zumkeller et al. 2010). The model optimizes the state of charge $\mathrm{SoC}_{opt}^{n}(t)$ for each EV (n) from a system perspective. By modeling each vehicle (A1) or using representative groups (A2), these variables, parameters and limits can be integrated into an energy model without further simplifying.

Comparison of approaches for modeling the available upper charging power limit for a whole EV fleet

For modeling a whole EV fleet (A3) as required for large energy system models, it is necessary to aggregate the mentioned values. This might cause problems in modeling accuracy due to (1) neglecting instant charging processes, where no load shifting potential is given. This can be solved by calculating each instant charging processes on the basis of the mobility input data and sum them up to the charging power of the total EV fleet $P_{charge,instant}^{total}(t)$. And second (2) the problem to determine the upper charging power limit of the total EV fleet $P_{max}^{total}(t)$, because the available upper charging power limit of each EV P_{max}^{n} depends on its SoC (cf. C2). We illustrate a reasonable range of possible approaches to determine $P_{max}^{total}(t)$ and evaluate the effects especially concerning the modeling accuracy. These approaches are listed in the following:

C1. Determine $P_{max}^{total}(t)$ for different charging scenarios.

C2. Determine the maximum error by varying the assumptions for the function $P_{max}^{n}(SoC)$.

a. $P_{max}^{n}(SoC) = P_{max}^{max} \in SoC = 0..1$

b. $P_{max}^{n}(SoC) = P_{max}^{max}(1 - SoC) \in SoC = 0..1$

c. $P_{max}^{n}(SoC) = P_{max}^{max} \in SoC = 0..0.75$ and $P_{max}^{n}(SoC) = P_{max}^{max}(-4SoC + 4) \in SoC = 0.75..1$

d. $P_{max}^{n}(SoC) = P_{max}^{max} \in SoC = 0..0.75$ and $P_{max}^{n}(SoC) = 0 \in SoC = 0.75..1$

C3. Derive from real mobility data collected in field tests a function for $P_{max}^{total}(SoC)$.

(3) Results

Each examined possibility lacks accuracy to exactly determine $P_{max}^{total}(t)$ due to the required assumptions. The possibility C1 (derive $P_{max}^{total}(t)$ from different charging scenarios) cannot map all behaviors of different persons at once. Assuming one charging strategy for all EV leads to a very low variance of SoC between EV. However the results of $P_{max}^{n}(SoC)$ (cf. Fig. 1) are straightforward and usable for linear programming (LP) through possible linearized relation between P_{max}^{total} and SoC. By varying the function $P_{max}^{n}(SoC)$ based on the listed possibility C2, we identified significant differences in P_{max}^{total}. The possibility C3 depends on EV data, which are not available, yet. But with rising numbers of EV, especially in field tests, in future they might be available. Then we can derive from these data $P_{max}^{total}(SoC)$ and compare our modeling approaches.

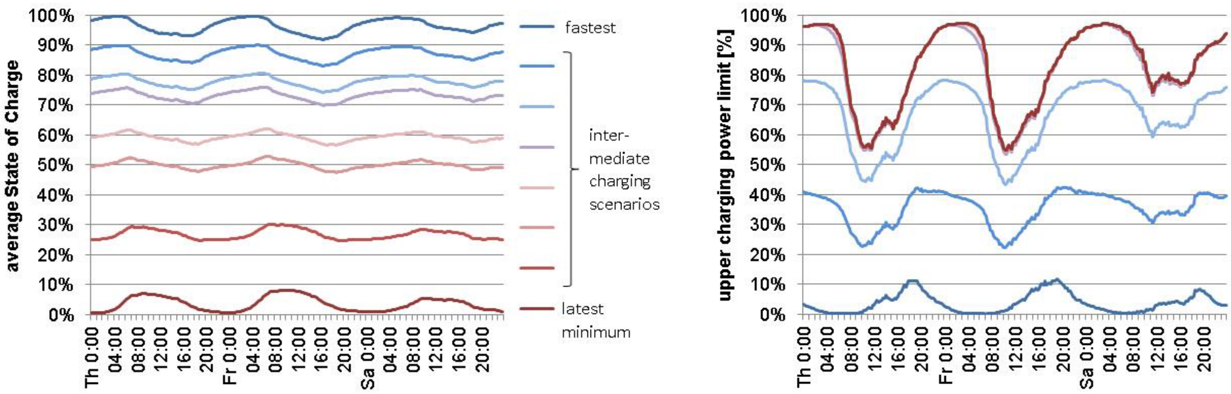

Fig. 1: Average SoC and available upper charging power limit in different charging scenarios (C1)

(4) Conclusions

In the paper we give an outline of load shifting potentials and discuss the status-quo. Through the complexity of modeling load shifting potentials of EV several approaches exist of how to integrate them into energy models. Each approach has specific advantages and disadvantages. We analyze them in terms of modeling accuracy and solving complexity. Especially the approach considering a whole EV fleet (A1) raises the problem of determining the available upper charging power limit caused by the characteristic charging function (cf. C2). We give an overview of possibilities to model the upper charging power limit and evaluate the effects especially concerning the modeling accuracy.

References

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[i] Demand Side Management is here defined according to Paetz et al. (2012) as the generic term for Demand Response (load shifting through both load management and control) and Energy Response (Energy Conservation and Efficiency).