Model based dispatch optimisation for residential districts – analysing the integration of electricity storage systems and their environmental impact

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Overview

Households account for 29% of the entire electricity consumption in the European Union (Eurostat 2017). As the electricity generation in the European Union is still covered to 74% by conventional power plants, households contribute significantly to the emission of greenhouse gases (Eurostat 2018). Consequently, designing a sustainable energy system for residential districts is important to mitigate climate change. Substituting fossil fuels by renewable energies includes the utilisation of energy carriers such as solar and wind energy. To address their fluctuation and the temporal shift between power generation and consumption, electricity storage systems are needed to secure a safe energy supply. There is a variety of storage technologies available, which cause environmental impacts by their utilisation, for instance resource depletion. Subsequently, finding an optimal economic and ecologic solution for residential districts is essential to balance resource use, climate change and costs. Recent literature applies energy system modelling mostly for component sizing, component location and operational management and mainly concentrates on large-scale systems (e.g. countries) or small-scale systems (e.g. micro-grids). Furthermore, environmental impacts are neglected or just one environmental aspect (e.g. CO_2-emissions) is examined (Bordin 2015). Even less studies conduct a comparison of different storage systems. Frequently, the variable costs and environmental impacts are based on installed capacity of the storage systems not considering different cycle life or efficiencies (Spanos et al. 2015; Peters et al. 2017). This paper searches for an optimal dispatch for lead-acid, lithium-iron-phosphate and vanadium-redox-flow batteries by considering their efficiencies and life expectancies in on-grid and off-grid situations to deduce an adequate battery capacity. To address a future shift to battery electric vehicles in residential districts different shares of electric vehicles are considered. Finally, a life cycle assessment, based on recent literature is conducted to evaluate the environmental impact of the utilised storage systems. Consequently, an innovative and open source model for the electricity supply of a residential district is created to address climate change by the utilisation of renewable energies under the consideration of security supply aspects as well as economic and ecologic factors.

Methods

A techno-economic bottom-up model for a residential district based on hourly data is created and combined with a life cycle assessment for the utilised electricity storage systems. The energy system model is created by using the open energy modelling framework (oemof) (Hilpert et al. 2018), which is an open source framework developed at the University of Applied Sciences in Flensburg. The parametrisation of the model is realised by a literature research for specific technologic and economic data for power generation plants, electricity storage systems and load profiles for consumers (households and electric vehicles). The created energy system model contains 74 households based on real measured data from 2010 (Tjaden et al.). The energy supply is provided by photovoltaics (PV), combined heat and power (CHP) and the electricity grid. Received electricity from the grid is priced by the EPEX spot market from 2017. The amount of battery electric vehicles is varying over the defined scenarios. The variable costs for the utilised electricity storage technologies (lead-acid, lithium-iron-phosphate and vanadium-redox-flow batteries) are calculated by using the ampere hours throughput model, thus considering their cycle life (Bindner 2005). The expected cycle life is based on manufactures data, whereas the prices for operation and maintenance rely on literature (Baumann et al. 2017). Different scenarios are defined especially considering the off-grid and on-grid situation of the residential district. The next step is the dispatch optimisation of the scenarios for one year and the deduction of the storage capacity size. Finally, a life cycle assessment is conducted for the storage systems based on recent literature and the ampere hour throughput model to add the ecological dimension to the model.

Results

The first on-grid optimisation scenario utilising a vanadium-redox-flow battery identifies that under the used price model the battery mainly charges electricity from the grid during low stock market prices and discharges to supply the district during high price phases. Under the limitation, that no electricity from the grid can be stored, the overproduction of electricity from the photovoltaic power plants is mainly kept. In that case high self-sufficiency rates of the residential district are received. Expected results of the on-grid scenario are the analyses of the storage technologies and their influence on the optimisation of the energy system to deduct economically storage capacities. As the storage systems suffer from energy loss over each time increment the storage size is of high interest. The influence of an increased electricity demand by the utilisation of electric vehicles will be analysed to detect whether more electricity is covered by the grid, PV or CHP. The off-grid scenario searches for conditions (installed storage capacity, installed power generation), which allow the modelled system to sustain self-sufficient. The life cycle impact assessment calculates the environmental impact of the storage system production. Finally, a comparison will be done by implementing all possible storage systems in the energy system model to detect the most economically storage system for the modelled energy system.

Conclusions

The first results suggest, that grid supply combined with a battery is more cost efficient due to lower prices at the electricity stock market compared to the variable costs of photovoltaic. The storage system assists to take advantage of low-price periods, especially the recent situation of negative prices is exploited by the dispatch model. In the used price model, a longer lifetime throughput of the battery will decrease the batteries variable costs and environmental impacts, thus further advancement in battery technology might change the outcome. An expected conclusion will be whether the examined storage systems are feasible to serve as long-term power stores in off-grid and on-grid scenarios and to what extent they are able to contribute to the self-sufficiency of residential districts. An increasing use of battery electric vehicles will influence the temporal shift between power generation and consumption.

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