UTRECHT UNIVERSITY

Economic and environmental assessment of electricity storage at small to medium scale applications in Switzerland

Master thesis - Energy Science

by

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Abstract

Due to the phase out of nuclear power in Switzerland, Distributed Energy Resources (DERs) are implemented to replace fossil-fuel based residential energy systems. One of the Swiss goals is to reduce CO_2-emissions by using renewable energy sources, such as wind and solar. This makes the replacement of nuclear power even more challenging since wind and solar are intermittent, while nuclear power shows a stable generation profile. Energy Storage Systems (ESSs) are one of the promising solutions to overcome issues related to the intermittent nature of renewable energy sources. Nevertheless, costs and environmental impacts of some ESSs (e.g. batteries) are high. Therefore, Part A aims to determine the economic and environmental performance of alternative residential energy systems with heat and electricity storage.

Part A

Part A proposes two all-electric system designs: Home Energy Storage (HES) and Community Energy Storage (CES). The following research questions are generated to examine the proposed system designs on operation and lifetime performance:

What is the optimal system operation for HES and CES, from an economic and environmental perspective, in the context of all-electric microgrids in the built environment?

And as second research question:

What alternative performs best, from an economic and environmental lifetime perspective, to substitute fossil fuel based residential energy systems?

To examine this, a multi-objective Mixed Integer Linear Programming (MILP) model is developed. The MILP model is tested on a community situated in Cernier (Switzerland), while including a high penetration of Battery Electric Vehicles (BEVs) and self-generated Photovoltaic (PV) electricity. Two HES alternatives and one CES alternative are proposed to substitute a fossil-fuel based baseline scenario. The first HES alternative contains of a standardized battery (i.e. a storage capacity of 13.5 kWh), while the batteries of the other alternatives are optimally sized to reduce grid injection of PV electricity. After that, the investment costs and CO_2-emissions during the production phase are included to compare the alternatives from an economic and environmental lifetime perspective.

The results demonstrate that the best system operation is obtained from the HES alternative with the standardized battery (i.e. 13.5 kWh) because of the larger storage capacity. However, CES performs best on both costs and CO_2-emissions when the lifetime is considered, due to economies of scale and the optimally sized battery in CES. Therefore, it is recommended to adopt a CES approach to substitute fossil-fuel based energy systems.

Currently, none of the proposed alternatives is economically feasible due to high battery and heat pump costs. However, the sensitivity analysis emphasizes that a profitable system design can be obtained, for both HES and CES, when the electricity storage size is reduced and the heat storage size is increased. In addition, a future scenario (2040) indicates that all alternatives could become economically feasible.

CES turns out to be a promising solution to offer profitability and to reduce CO_2-emissions. Part A focuses on storage applications from the perspective of residential households. Additionally, CES could offer other promising applications, such as Energy Arbitrage (EA) and peak shaving from the perspective of an aggregator and a Distribution System Operator (DSO).

Part B
Therefore, a third research question is generated to examine costs and CO_2-emissions of EA and peak shaving for CES deployment from the perspective of an aggregator and a DSO. However, the economic and environmental performance could differ when using different battery technologies, hence several battery technologies are considered.

What is the best economic and environmental CES scenario for the energy arbitrage application, considering different battery technologies?

To examine this, two scenarios of CES ownership are proposed. Firstly, an EA scenario where an aggregator aims to minimize costs and CO_2-emissions of an energy portfolio by trading in the intra-day electricity market. Secondly, an Energy Arbitrage - Peak Shaving (EA-PS) scenario is developed, which is based on a shared ownership between a DSO and an aggregator. A new MILP model is developed to minimize the operation costs and CO_2-emissions of a community situated in Cernier (Switzerland), using different battery technologies.

The results demonstrate that a profitable system design can be obtained for both scenarios, for all Lithium-ion-Batteries (LiBs). However, the performance of the EA scenario is slightly better, due to power boundaries on grid absorption and injection to achieve peak shaving in the EA-PS scenario. However, the differences in performance between the EA and EA-PS scenarios are small. Consequently, the combination of peak shaving and EA shows promising potential. Transformer stations turn out to be critical elements within the current infrastructure. Therefore, it is recommended to combine peak shaving with EA to prevent problematic loads on the distribution transformer.

In addition, Pareto frontiers demonstrate that LiBs perform best on both economic and environmental performance, with the best economic and environmental performance for the Lithium-Nickel-Manganese-Cobalt (NMC) battery.