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Feasibility of renewable hydrogen based energy supply for a district

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Abstract

Renewable generation technologies (e.g. photovoltaic panels (PV)) are often installed in buildings and districts with an aim to decrease their carbon emissions and consumption of non-renewable energy. However, due to a mismatch between supply and demand at an hourly but also on a seasonal timescale; a large amount of electricity is exported to the grid rather than used to offset local demand. A solution to this is local storage of electricity for subsequent self-consumption. This could additionally provide districts with new business opportunities, financial stability, flexibility and reliability.
In this paper the feasibility of hydrogen based electricity storage for a district is evaluated. The district energy system (DES) includes PV and hybrid photovoltaic panels (PVT). The proposed storage system consists of production of hydrogen using the renewable electricity generated within the district, hydrogen storage, and subsequent use in a fuel cell. Combination of battery storage along with hydrogen conversion and storage is also evaluated. A multi-energy optimization approach is used to model the DES. Results of the model are optimal battery capacity, electrolyzer capacity, hydrogen storage capacity, fuel cell capacity and energy flows through the system. The model is also used to compare different system design configurations. The results of this analysis show that both battery capacity and conversion of electricity to hydrogen enable the district to decrease its carbon emissions by approximately 22% when compared to the reference case with no energy storage.

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Keywords: power-to-gas; fuel-cells; hydrogen storage; multi-energy optimization; renewable hydrogen production

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1. Introduction

Renewable or distributed energy generation such as rooftop solar panels are commonly installed in districts or communities. Interest in distributed generation can be attributed to five major factors: developments in generation technologies, constraints on the construction of new transmission lines, increased customer demand for highly reliable electricity, the electricity market liberalization, and concerns about climate change [1,2]. In most cases renewable generation capacity in districts is not designed to cover total electricity demand, and the districts do not intend to operate as stand-alone systems. Rather, renewable generation capacity is often installed with an aim to reduce non-renewable energy consumption or to reduce peak power demand of the district. Since renewable generation (PV) has hourly and seasonal variation (in European countries), time resolved energy balances show there is excess electricity produced during summer months while demand is higher during winter months. The intermittency and seasonal variability of this electricity production is usually balanced by the electricity grid.

However, accommodating an increasing amount of electricity generation from renewable sources will require new approaches to extending and operating the grid. Local storage of energy where it is produced would not only avoid issues with overloading the grid; but also enable districts and communities to use locally generated electricity. This would additionally provide them with new business opportunities such as arbitrage (buying and selling of electricity in order to take advantage of time-dependent prices), provision of ancillary services to the grid, and provision of energy for mobility (hydrogen and electric vehicles).

The aim of this research work is to evaluate if hydrogen production, storage and use in a fuel cell is a feasible, long term storage solution for a district. A case study is used as a basis for this evaluation; however the results could be translated to other similar districts. The selected case study is a newly built district situated in Risch Rotkreuz, Switzerland, with low energy commercial and residential buildings. PV and PVT panels installed on rooftops supply part of the electricity demand of the district and also feed heat into a low temperature network (LTN) which is connected to a borehole field. The installed capacity of PV and PVT panels is 800 kWp and a summary of the heating and electricity demand of the district is described in [3]. Use of thermal storage in the district has been assessed in [3], and the focus of this paper is on electricity storage. A secondary aim of this research is to compare different system configurations when considering installation of both short term (hourly or daily), and long term (seasonal) electricity storage.

In section 2 the different system configurations are described. A brief description of the model and the assumptions are also included in section 2. In section 3 the results of the optimization model and a comparison of the different system configurations are presented. Discussions and conclusions are presented in section 4 and 5.

2. System description

In the case study considered, the electricity demand of the district (sum of electricity demand of heat pumps, network pumps and other DES equipment) is met primarily with on-site PV generation. A mixed integer linear programming (MILP) model of the DES (energy hub model) is developed and the electricity demand of a full year with hourly time-steps is used as an input to the model. The objective of carbon minimization is used to derive optimal capacities for the specified DES system components. The results are used to compare the following system configurations:

Reference case: No battery, no electrolyser
1a: Battery and electrolyzer in series (battery discharge only used to stabilize operation of electrolyzer)
1b: Battery and electrolyzer in series (with battery also discharging for direct consumption)
2: Battery and electrolyzer in parallel
3: Electrolyser, hydrogen storage and fuel cell (no battery)
4: Battery storage only (no hydrogen production)

In figure 1, a representation of the model with configurations *1a*, *1b* and *2* is presented. Configuration *1b* includes the grey arrow, where the battery is also discharged to directly meet electricity consumption. The blue line in figure 1 represents hydrogen (energy), the black lines represent electricity flows and the red line represents heat.