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Power-to-Gas: Electrolyzers as an alternative to network expansion – An example from a distribution system operator

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HIGHLIGHTS

- Electrical and economic analysis of electrolyzers in the distribution grid.
- Utilizing cables for a network expansion is *current*ly a more cost-effective option.
- The higher electrolyzer cost can be met by other means (selling the hydrogen).
- Profitability is highly dependent on the full load hours of the electrolyzer.
- The results are derived from the scenario used and should not be generalized.

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ABSTRACT

The high share of fluctuating renewable energy sources (FRES) such as wind and photovoltaic (PV) necessitates the need for controllable generation, storage devices or adjustable consumption, due to the surplus arising from installed capacity that exceeds the conventional electrical load. The use of this surplus to produce hydrogen and oxygen via electrolysis is called "Power-to-Gas" (P2G). This study investigates the potential use of electrolyzers in the electrical distribution grid as an alternative to a network expansion with cables. For this purpose, an existing distribution grid was modelled and the possible size of an electrolyzer investigated so as to achieve the same effect as with an electrical cable in terms of, for example, the voltage level. The investment cost of both possibilities was compared and the hydrogen production costs analyzed. The results show that laying a cable is currently a more cost-effective option in comparison to an electrolyzer, costing around 30% of the overall investment required for the electrolyzer. The remaining 70% of the electrolyzer cost needs to be met by other means, for example by selling the hydrogen produced. However, profitability is highly dependent on the surplus in the grid and thus the full load hours of the electrolyzer. Furthermore, the results obtained cannot be generalized, since they are highly influenced by the scenario used.

1. Introduction

Fluctuating renewable energy generation has become a major contributor to many countries' electric energy systems. In 2013, the worldwide contribution of renewable energy sources (RES) amounted to 20%, or 22% if biomass is included [1]. In Germany, installed capacity grew from 17 to 93 GW between 2003 and 2015. In 2015, the main contributions were from wind and PV, with an installed capacity of 44.7 and 39.3 GW. This led to a share of 31.6% of the gross electric consumption in 2015 [2]. Due to the distributed locations of the RES, the transportation of the generated electricity with the electrical grid becomes crucial at the transmission, but in particular at the distribution level. Hence, it is necessary to undertake network expansions at both levels. However, even if the majority of the German public approves of the energy transition locally, the degree of landscape modification is one of the most important factors influencing acceptance; or the lack thereof [3]. Therefore, alternatives must be investigated. Furthermore, options to bridge long time periods without the feed in of RES need to be developed. One possible solution is the so-called "Power-to-Gas" (P2G) approach, which will be further described in Section 1.1. This

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approach will therefore be analyzed as an alternative for a network expansion such as laying new cables in the electrical distribution grid.

1.1. The Power-to-Gas approach

The Power-to-Gas approach is one promising approach for a country that intends to achieve almost zero CO_2 emissions. For this, such a country must rely heavily on fluctuating renewable energy sources (FRES). In times with a negative residual load, production by FRES is higher than the load, i.e., there is a surplus. During these periods, the surplus can be used to produce hydrogen and oxygen via electrolyzers. This concept is referred to as the Power-to-Gas (P2G) approach, and can be further categorized as Power-to-Hydrogen (P2H).[1]

The hydrogen produced in this manner offers different possibilities. For example, it can be used directly in fuel cell electric vehicles (FCEV) [4], in the industry for example in the steel-production [5] or added to the natural gas pipeline grid in limited concentrations. Furthermore, the hydrogen can be re-electrified via fuel cells or hydrogen gas power plants, and is therefore a long-term storage carrier. Especially if the hydrogen is saved in salt caverns for seasonal storage, it does not have any competitor in terms of energy density and economic feasibility [6–9]. With hydrogen and CO_2, it is possible to produce synthetic methane that could then be used for example for feed-in to the natural gas pipeline grid without any limitations hence it can be used in household applications [10,11]. In other words, hydrogen is an important energy carrier to link the sectors [12]. This pathway is included in the P2G approach. To differentiate it from P2H, it can be further categorized as Power-to-Methane (P2M).

1.2. Literature review and goal of this analysis

Kakran and Chanana [13] published a review that provides a detailed description of progress in the field of demand side management, demand response programs, distributed generation and technical issues with respect to their progress and key advantages for so-called "smart grids with distributed generation". An electrolyzer is not one of the potential applications, however.

Bibin et al. [14] proposes a comprehensive cost-benefit analytical method with respect to grid reinforcement. Analytical results of 8760 h power flow are acquired for the optimized planning of high penetration distributed photovoltaics. A P2G approach was not implemented. They conclude that the planning for distributed photovoltaics has considerable impact on the general economy (the annualized general cost benefit may differ by almost 40%). An optimized layout of distributed photovoltaic generation and distributed connections helps reduce curtailment and grid reinforcement and thus carries greater economic benefits. Furthermore, if the curtailment is large, grid reinforcement helps increase the general economy. A P2G approach was not therefore followed in this study.

Nevertheless the literature contains a wide range of studies analyzing different topics relating to the P2G approach. They differ in terms of the analyzed detail from approaches that consider P2G concepts for nationwide scenarios [7,15–19], those that analyze their effectiveness, their environmental impacts and so on, and therefore are on a deep technical level [11,20–24], or those that describe the status of pilot plants [25–27]. However, on the level of the integration of an electrolyzer into an electrical distribution grid, only a few studies are available.

Guandalini et al. [28] analyze the P2G (P2H) Pathway that produces hydrogen via electrolysis from wind-generated electricity. In the study, the produced hydrogen is injected into the natural gas pipeline grid. The main outcome is the optimal size of the system that is achieved by using a statistical approach to estimate wind farm productivity, forecasting errors and component load conditions. The distribution grid or electrical loads from households were not part of the analysis. Hence, the electrolyzer is directly connected to the wind turbine. Nevertheless, one main outcome of the study was that a hybrid system with an electrolyzer and gas turbine as balancing technologies leads to the best performance from an economic point of view.

Park et al. [29] qualitatively and quantitatively analyze the P2G (P2H) technologies in the future Swiss low voltage grid. Hydrogen is assumed to be sold in the mobility sector, for example for FCEVs. The scenarios investigated rely heavily on power produced via photovoltaics (PV). This is due to the fact that in Switzerland in 2050, up to one fifth of total energy production will be PV. A transformer (630 kW) as part of the distribution grid was considered in the simulation, with the assumption that it limits the electricity that can be used by the electrolyzer. Further analyses of the distribution grid were not conducted. The main outcome was that with a PV curtailment and additional electricity purchasing, the full load hours increase significantly, and hence the hydrogen production cost decreases.

Jaramillo et al. [30] developed a multi-objective mixed-integer linear programming model to define the optimized schedules of components in a grid-connected microgrid. Included in the model for analytical purposes was an alkaline electrolyzer, hydrogen cylinder bundles (with a capacity of $18\,m^3$ at 30 bar pressure), a proton exchange membrane fuel cell, PV panels for local generation and a fixed and flexible load profile. The fixed load profile is represented by electrical appliances of the connected office building, while the flexible load profile is from a battery-electric vehicle. The grid connection was represented such that there are costs of 0.25 €/kW h to get energy from the grid and earnings of 0.12 €/kW h to feed energy into it [30, P. 862]. The electrical grid was not further analyzed. The main outcome of the study was that energy storage is mainly used for trimming the peak of electricity drawn from the public grid.

Estermann et al. [31] conducted a study to analyze the feasibility of the implementation of a P2G system in Germany's distribution grid. The analysis was based on time series electricity data for 2012 from which future load profiles were computed, in accordance with the expected installed capacities of solar power for the period 2015–2025. The source of the time series is Bayernwerk's low voltage level network [32]. On a typical summer day, the load amounted to around 1.6 GW and on a typical winter day to some 2.3 GW. The solar generation totals on these days were around 1.8 and 0.5 GW [31, P. 13953]. This shows that the investigated area or the data that are analyzed are at a high aggregated level for the distribution grid. Further investigation of the distribution grid was not undertaken. The main conclusion was that to absorb 20% of excess solar energy, elektrolyzers of 370 MW_e installed capacity and a carbon dioxide source from biomass anaerobic digestion to produce synthetic methane (P2M) can be implemented into the distribution grid.

In Nykamp et al. [33] it was shown that storage operation and dimensioning in grids is effected substantially by the prevailing energy profiles if oriented on peak-shaving purposes – grids faced to the feed-in of wind require a storage capacity [kW h] which is a factor of 20 higher than in PV grids due to longer high-feed-in periods with a given power [kW] in both scenarios to reduce the surplus in the grids. Thus, storage systems with a limited and cost-driving capacity (such as batteries) are disadvantaged in wind grids compared to system without capacity restrictions (such as P2G).

Grüger et al. [34] analyze the economic potential of marketing P2G system flexibility. This system is equipped with an electrolyzer and fuel cell to produce hydrogen (P2H) and to re-electrify this. Their potential to reduce wind farm forecast errors, as well as the system's ability to provide a secondary control reserve in Germany, was investigated. The secondary control reserve dispatch power was implemented at a high temporal resolution and different bidding strategies were investigated.

[1] The use of nuclear power plants or coal-fired power plants to produce hydrogen and oxygen via electrolyzers is not considered to fall under the P2G approach, even if the use of a nuclear power plant could produce hydrogen without any CO_2 emissions