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Power-To-Gas Concept for Integration of Increased Photovoltaic Generation into the Distribution

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Abstract

According to the Energy Strategy 2050 set forth by the Swiss federal government, Photovoltaic (PV) energy shall make up one fifth of the nation's total energy production in 2050. Such a drastic expansion rate of PV and the resulting excess energy thereof can lead to so-called reverse power flow in the low voltage (LV) grid as demonstrated in previous studies. Power-to-Gas (PtG) represents a suitable storage solution to resolve the situation by absorbing the excess PV energy. This paper presents a qualitative and quantitative feasibility analysis of the PtG technology in the future Swiss LV grid. For this purpose, PtG is integrated in simulation into the grid for absorbing the excess PV energy while producing hydrogen. This hydrogen is assumed to be sold in the mobility sector. Three different operational scenarios are established with respect to the input energy source to the PtG plant, including the excess PV energy, curtailed PV excess energy and PV excess energy plus the energy from the grid. Summing up the results, it can be concluded that the PtG plant is still far from economically viable even though significant improvement can be accomplished to the hydrogen production costs by adopting the active PV curtailment and by purchasing additional energy from the grid. The future study to be undertaken by the authors, with respect to economical viability of the PtG, will include other sources of value, including production of methane as main product, production of oxygen and heat as by-products, and provision of services such as biogas upgrading, frequency regulation and voltage.

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Keywords: Power-to-Gas; Renewable energy; Distribution grid; Excess energy; Energy storage; Gas grid

1. Introduction

After the disaster of the nuclear power plant in Fukushima, Japan, in 2011, the Swiss federal government decided

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to abandon the nuclear energy, which currently amounts to about 35% of the total electricity supply of the nation. According to the Energy Strategy 2050 subsequently set forth by the Swiss federal government, the deficit in the production of electricity as a result of this decision and other sweeping changes in the international energy arena will lead to major changes in the Swiss energy system. In order to fill the gap in electricity production after the phase-out of the nuclear energy, renewable energy sources (RES) represent the only possibility for Switzerland to produce self-reliant and CO2-emission free energy. With a share of 20% of the entire electric energy consumption, which equals 11 TWhel, Photovoltaic (PV) energy shall make up a fifth of Switzerland energy production [1].

As demonstrated in the already implanted systems around the world, PV represents a fluctuating energy source due to its innate dependency on diurnal, seasonal, and meteorological variations. These characteristics are anticipated to cause significant challenges to the existing electricity network. A previous study [2] was performed to illustrate the impact of the increased PV production in the low voltage (LV) grid in in a Zürich area by simulating the load flow through Powerfactory from DIgSILENT. The characteristics of the urban area are depicted in Table 1.

Table 1 Characteristics of the urban area

Description	Value
Maximum active power load	0.675 MW
Yearly load energy consumption	2.95 GWh
Maximum PV power	2.096 MWp
Yearly PV energy production	2.453 GWh

The result of the load flow analysis of the study is illustrated in Figure 1, in which the reverse power flow is anticipated beyond the maximum 630 kVA, causing problems characterized as voltage violation, line and transformer overloading, and N-1 violation.

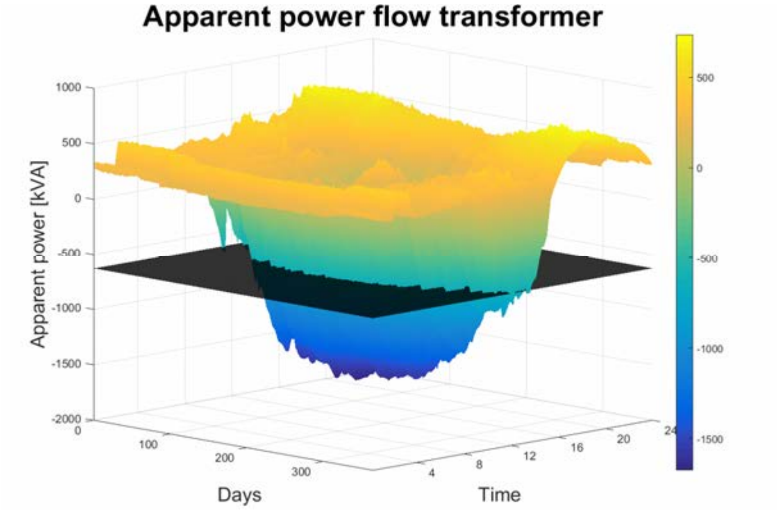


Figure 1. 3-dimensional plot of a transformer power flow of the case under consideration. For the z axis values, the area below the black plane indicates the reverse power flow, which occurs when the energy flows form the LV level to the MV level through the transformer

In order to prevent the existing electricity network form such violations, energy storage systems (ESS) will play an important role in the future. To operate the transformers in a safe range, for example, the previous study [2] indicated that a Battery Energy Storage System (BESS) is required to have a nominal power of 1.004 MW and a nominal capacity of 6.457 MWh. However, the size of the BESS seems unrealistic to implement, considering the fact that it is nine times bigger than the largest one that exists currently in Switzerland, in order to resolve an issue at such a LV level.

Alternatively, PtG represents another suitable storage solution for absorbing the excess PV energy production in the LV grid in future. The goal of study presented in this paper is to analyze the feasibility of a PtG plant in light of the previous study [2]. The results of the simulations shall give the insights concerning the technical as well as economical feasibility of the integration of PtG into the existing electricity network.

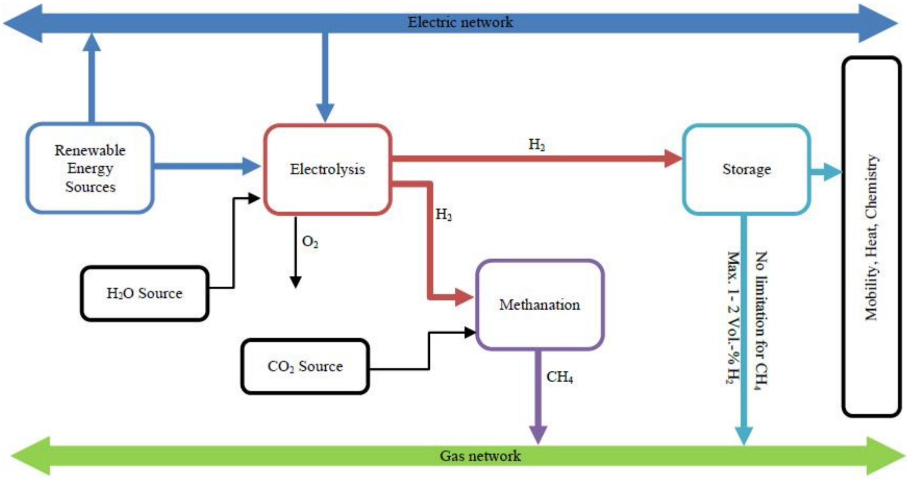


Figure 2. Concept of Power-to-Gas (PtG)

2. Methodology

2.1. PtG technology

The principal concept of PtG is to transform electrical energy via electrolysis into gas, which in turn can be stored in in a gaseous chemical storage. As shown in Figure 2, the electrical energy is used to produce hydrogen (H2) and oxygen (O2) from water. The concept can be expanded with an optional process step- the methanation process- which needs a source of carbon dioxide (CO2) to produce methane (CH4) out of H2 and CO2. The produced H2 or CH4 can be applied to various areas such as mobility sector, heat generation, and chemistry industry. Alternatively, it can be fed directly into the gas network [3]. Figure 2 shows that the concept of PtG with all the different stages to produce H2 or CH4. Produced H2 will be stored in tanks. However, the tanks would rather serve as a buffer, and the stored H2 will be delivered to the consumers at an appropriate time. Or it can be fed into and stored in the existing gas network.

There are mainly 3 different types of electrolysis including Alkaline Electrolysis (AEL), Polymer Electrolyte Membrane Electrolysis (PEM), and high temperature electrolysis of steam or solid Oxide Electrolysis (HTES or SOEL). Due to the ability of a dynamic operation [4], the PEM electrolysis is considered as the most suitable for absorbing the fluctuating production of PV. Only PEM electrolysis is therefore considered for the study of this paper.

2.2. Simulation layout

The data of the load flow analysis from the previous case [2] was applied to conduct necessary simulations as shown in Figure 3. The PV generation profile is generated based on the mean production rate of 288 PV plants located near Zürich. This data has been provided by Elektrizitätswerk der Stadt Zürich (ewz), a utility company in Zürich.

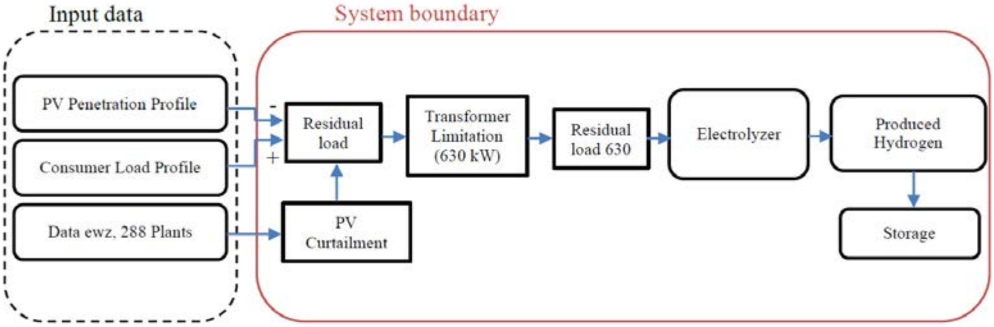


Figure 3. Simulation layout and input data

2.3. Simulation paramenter

Table 2 shows all the applied parameters which are applied to conduct the simulation. All the used parameters with the corresponding reference can be found in this table.

Table 2 Used parameters for the simulation with the corresponding reference

Electrolyzer parameters		**Reference**
Efficiency including storage	63 %	[5]
Investment calculation parameters		**Reference**
Lifetime of the power plant	25 years	Assumed
Interest rate	5 %	Assumed
CAPEX of electrolyzer	2000 CHF/kW	[4]
Yearly operation costs	4 % of CAPEX	[4]
Costs for delivery and construction	10 % of CAPEX	[4]
Energy curtailment price	0.219 CHF/kWh	[6]
Energy price for additional energy	0.2 CHF/kWh	[7]
Tank costs	990 CHF/kg	[8]

2.4. Simulation scenarios

Technical and economical feasibility of the integration of PtG into the existing LV grid of the above-mentioned case was conducted by establishing and simulating the following scenarios with respect to the input energy source tothe PtG plant, including the excess PV energy, curtailed PV excess energy, and PV excess energy plus the energy from grid as summarized in Table 3. For each scenario, a tank dimensioning was carried out in order to estimate the resulting tank costs. The hydrogen is compressed up to 200 bar and the tank is emptied 3 times a week. Then the unit production cost of hydrogen, CHF/kg, is calculated and compared for each scenario.

Table 3. Simulation scenarios of this study

Scenario 1	Scenario 2	Scenario 3
• All PV excess is applied to PtG plant • Impact of maximum PV excess is examined	• Curtailed PV excess is applied to PtG plant. • Optimal curtailment calculated • Examine the effect upon investment costs and thus production costs	• In addition to PV excess , applied to PtG plant is additional energy purchased from the grid, during the winter months, mainly from November to February, and off-peak hours between 7 PM and 7 AM • Boost capacity factor (CF)

3. Results

The results of the simulation with the three scenarios are shown in Table 4, Figure 4, and Figure 5. When the use of the PtG plant is restricted solely to absorb the PV excess energy, for example, the theoretical H2 production cost amounts to 27.8 CHF/kg. Adopting PV curtailment up to 37 % leads to decreasing the investment costs by 30 % while the energy losses are negligible, in other words approximately 2 % of the yearly PV production. With the curtailment, the H2 production cost decreases to 24.5 CHF/kg. Moreover, further improvement of the production cost has been accomplished by purchasing additional energy from the grid for the operation of the PtG plant. This process demonstrates the importance of the so-called high capacity factor (CF) of the plant. In other words, the PtG operating hours can be increased from 499 to 623 hours by applying the curtailment. With the purchase of additional energy, the operating hours operating hours are increased up to 2074 hours while reducing the hydrogen production costs down to 15.7 CHF/kg.

Table 4. Summary of results of the simulation of this study

Scenario 1	Scenario 2	Scenario 3
Max. power flow 1044 kW Operating hours 499 h Storage size 19.42 m^3 (200 bar)	Max. power flow 733 kW (30 % reduction) Optimal curtailment 37 % 2 % PV energy loss due to curtailment Operating hours 623 h Storage size 17.11 m^3 (200 bar)	Max. power flow 733 kW (30 % reduction) Operating hours 2074 h Storage size 32.7 m^3 (200bar) Additional energy 1.06 GWH

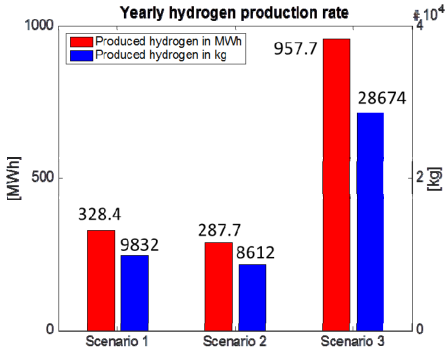


Figure 3. Yearly hydrogen production rate

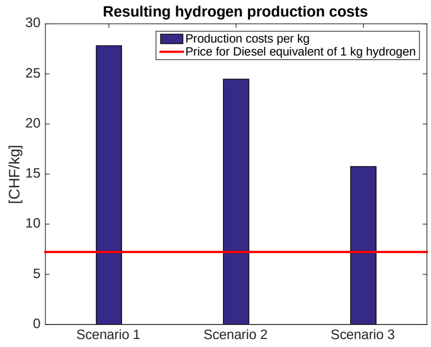
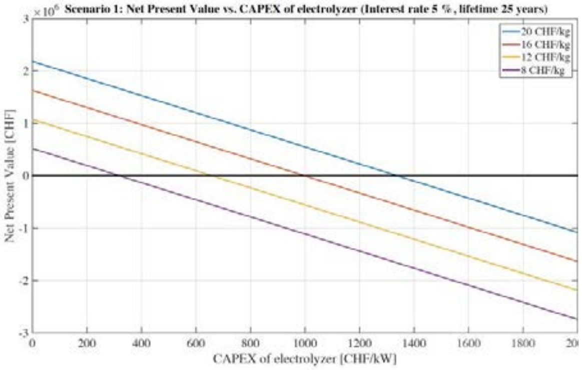


Figure 4. Hydrogen production cost, CHF/kg

4. Discussion

As shown in Figure 5, the benchmark for competitive hydrogen selling price is around 7.23 CHF/kg, which was calculated based on the actual market price of 1.52 CHF/l diesel and an assumed fuel reduction of 30 % compared to conventional vehicles. This actual market price can be considered as relatively low since the price decreased almost by a fifth in the beginning of this year [9]. It is displayed that the hydrogen production cost for all the scenarios is higher than the competitive hydrogen selling price (7.23 CHF/kg).

A realistic price setting for coming years can be assumed between 1.7 CHF/l and 2.1 CHF/l, which corresponds with a price range of 8 CHF/kg to 10 CHF/kg for the hydrogen. The sensitivity analysis showed that the CAPEX of the electrolyzer should be approximately 300 CHF/kW to 500 CHF/kW in scenario 1 (Figure 6) and in scenario 2 250 CHF/kW to 450 CHF/kW (Figure 7). The analysis shows that scenario 2 is only beneficial compared to scenario 1 when the hydrogen selling price is higher than 12 CHF/kg and the CAPEX is higher than 650 CHF/kW. However, below this circumstances the additional costs for the curtailed energy has a negative influence and it is beneficial to use the full PV energy excess. Both cases seem beyond reachable distance in the near future. Regarding scenario 3 it can be noted that at a certain CAPEX the price for the additional energy (set to 0.2 CHF/kWh) starts to have a negative influence on the overall results (Figure 8) and the purchase of additional energy makes sense only when the hydrogen can be sold at approximately 15 CHF/kg or higher.



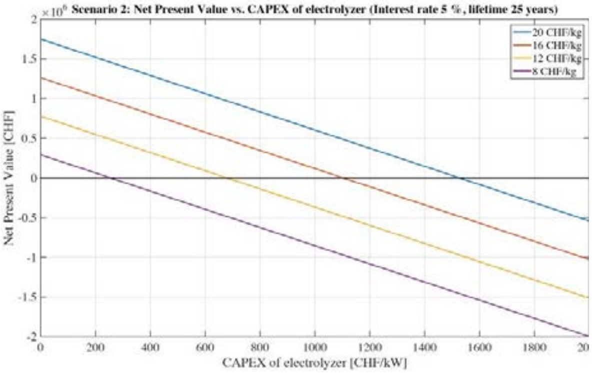


Figure 5. Net Present Value vs. CAPEX of electrolyzer with different hydrogen selling prices for scenario 1

Figure 6. Net Present Value vs. CAPEX of electrolyzer with different hydrogen selling prices for scenario 2

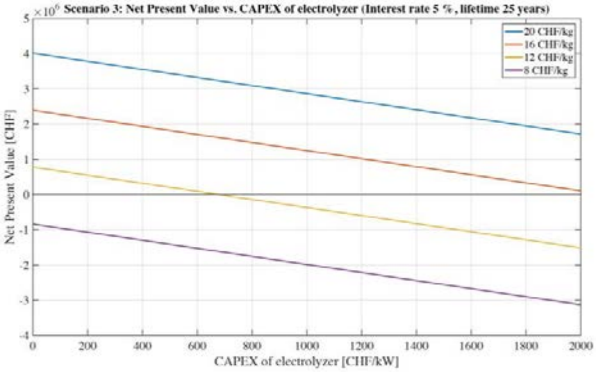


Figure 7. Net Present Value vs. CAPEX of electrolyzer with different hydrogen selling prices for scenario 3

5. Conclusions

Summing up the results, it is concluded that the PtG plant is far from being economically viable under the current economical factors including the investment cost (CAPEX) for electrolyzer, the electricity cost purchased from the grid, and the hydrogen selling price. Therefore future study with respect to feasibility of the PtG plant will be extended toinclude other sources of value, including production of methane as main product, production of oxygen and heat as by-products, and provision of services such as biogas upgrading, frequency regulation and voltage control in order to make the PtG system economically viable [10]. For example, participating in the ancillary service will provide the owner of the PtG plant with an additional income. In this case the PtG plant would be used as a controllable load upon request of Distribution System Operators (DSOs). The BESS installed by a utility company near Zürich, for example, generates 200’000 CHF a year with a controllable load of 1 MW [11]. This fact demonstrates the attractiveness to provide the ancillary service to the grid. The feasibility of the PtG to fulfill this task and other services has to yet be evaluated and is a subject of further study by the authors.

6. Acknowledgements

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