FEASIBILITY ANALYSIS OF THE POWER-TO-GAS CONCEPT IN THE FUTURE SWISS POWER SYSTEM

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Abstract

This paper presents a qualitative and quantitative feasibility analysis of the Power-to-Gas (PtG) technology in the future Swiss power grid which will be characterized by a significant share of intermittent renewable energy sources. The focus is placed on establishing a resolution to effectively integrate renewable energy sources (RES) into Swiss power grid through energy storage systems including pumped hydro storage (PHS) and PtG, which is commonly known to offer the advantage of a long-term storage over other storage options. The resolution will be presented through the analysis of designed scenarios that reflect the current and future energy profile of Switzerland, and will utilize the strength of a model predictive controller (MPC) with respect to the optimized dispatch of storage capacity including the existing PHS and the proposed PtG plants in addition thereto.

Keywords: Integration of Renewable Energy Sources, Long-Term Storage, Power-to-Gas, Pumped Hydro Storage, Model Predictive Control, Excess Energy, Grid Expansion.

1 Introduction

After the disaster of the nuclear power plant in Fukushima, Japan, in 2011, the Swiss federal government decided to abandon the nuclear energy, which currently amounts to about 35% of the total electricity supply of the nation. The existing plants will be decommissioned as soon as they reach the operational limits and there will be no new installations of nuclear power plants. The deficit in the production of electricity as a result of the decision and other sweeping changes in the international energy arena will lead to major changes in the Swiss energy system. For this reason, the Swiss Federal government developed the Energy Strategy 2050 which is a long term plan based on a step-by-step guidance to reach this ambitious goal [1].

In order to fill the gap in electricity production after the phase-out of the nuclear energy, renewable energy sources 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 TWh, PV will make up a fifth of Switzerland energy production [2]. In addition to PV, wind power will fill up the energy gap with a share of 4.3 TWh. The share of renewable energy sources (RES) will increase to make up 24.2 TWh by 2050, which amounts to be about 40% of the gross electricity production.

An important aspect of the RES to be considered—mainly energy from solar and wind—is their intermittency and unpredictability. Also they are not quite aligned with the load most of the time. There are hours when the generation clearly exceeds demand and there are also periods in which RES generation is not sufficient to cover the load [3]. High share of the excess energy, which is defined as the generated energy, can add a considerable uncertainty to the supply of electricity which could threaten the power balance and thus the stability and reliability of the Swiss electric power system [4]. For excess energy production due to PV and wind, there are three possible options for balancing the power grid, including:

1. Storing the excess energy in storage systems such as batteries, pumped hydro storage (PHS), PtG or thermal storages;
2. Curtailing energy production;
3. Exporting the excess energy.

Focus of the effort of this paper is to investigate how PtG technology might be able to contribute to integrating renewables in the future Swiss power system by providing additional storage capacity along with active power curtailment.

The structure of the paper is as follows. Section 2 introduces the principal concept of PtG and Swiss power system and PHS. Section 3 presents simulations, in which PtG serves as an additional storage in the Swiss power grid in future. Section 4 describes results of the simulation and discussion surrounding PtG as an additional storage. Then Section 5 summarizes the results of this paper and discusses ideas for future research.

2 Technology Analysis

2.1 Power-to-Gas

The principal concept of PtG is to transform electrical energy via electrolysis into gases, which in turn can be stored in gaseous chemical storages. The electrical energy is used
to produce hydrogen ($H_2$) and oxygen ($O_2$) from water. The concept can be expanded with an optional process step—the methanation process—which needs a source of carbon dioxide ($CO_2$) to produce methane ($CH_4$) out of $H_2$ and $CO_2$. The produced $H_2$ or $CH_4$ has various areas which it can be used such as: Mobility sector and chemistry industry or it can be used to feed directly into the gas network [5]. Figure 1 displays the concept of $PtG$ with all the different stages to produce $H_2$ or $CH_4$. The produced $H_2$ will be stored in tanks. However, the $H_2$ storage tank would rather serve as a buffer, and the stored $H_2$ will be delivered to the consumers in an appropriate time.

2.2 Power system and PHS in Switzerland

Switzerland’s current energy system has many features that put it in a comfortable position from an energy storage perspective. Most notably, the country has a large installed base of hydropower and pumped hydro storage facilities: Approximately 59% Switzerland’s current energy production comes from hydropower.

Pumped hydro storage (PHS) is currently the most established technology for providing control energy in the electric power system. Electricity is converted to potential energy by pumping water to higher altitudes. When electricity is needed, the water is released from the reservoir, and the potential energy is again converted to electricity by hydro turbines. The efficiency of this storage technology ranges between 70-85% which is comparatively high [6].

As far as energy storage technologies in Switzerland are concerned, PHS is a well-developed and widely applied technology, with its use limited by site limitations. The existing pumped power capacity and storage capacity in Switzerland in 2010 are 1.8 GW and 50 GWh, respectively [4]. Up to 4GW of additional pumped power capacity is planned to be added by the time-period of 2020-25 [7] and the pumped storage capacity is estimated to be 200 GWh [8].

3 Simulation of Power-to-Gas as an Additional Storage

3.1 Approach

The goal of this simulation is to illustrate the extent of the excess energy in light of one of the BFE scenarios [2] and the possible role of Power-to-Gas technology with respect to the excess energy. To evaluate the role of $PtG$ plants in the Swiss power grid, a simulation will be constructed by treating the Swiss power grid as a single node, consisting of power generators including hydropower generation, conventional generation, and RES, energy storages including PHS and $PtG$ plants, and consumers, as shown in Figure 2.

![Fig. 2: Swiss power grid represented as a single node.](image)

3.2 Simulations

In order to demonstrate the feasibility of $PtG$ for integrating the renewable energy generation through $PtG$ technology at the Swiss grid level, three scenarios are established for simulation. For the simulations Switzerland is treated as a single node as shown in Figure 2.

3.3 Scenario 1

For this simulation, the energy model of Switzerland in the year 2050 was constructed based on Swiss Federal Office of Energy (BFE) Energy Strategy 2050 report, conducted by the consultancy Prognos [2], especially in accordance with BFE New Energy Policy (NEP) scenario, Option NEP C/E. As shown in Figure 3, input data was constructed with the statistical data compiled and provided by BFE in [9]. Also PV and wind data are reconstructed based on measurement data from MeteoSwiss [10]. In accordance with BFE New Energy Policy (NEP) scenario, Option NEP C/E [2], the parameters of electricity production and consumption are as follows: Total
It is to be noted that all the losses are neglected for this simulation. For this scenario, the energy flow model as shown in Figure 2 is established as follows:

a. The generations \( (P_g) \) supply energy to the consumers \( (P_L) \), contribute to charge the PHS \( (P_e) \) and transform energy into hydrogen \( (P_{2g}) \):

\[
P_g(i) = P_{g0}(i) + P_e(i) + P_{2g}(i),
\]

where \( P_{g0}(i) \) consists of all the energies produced according to the parameters defined in the Scenario 1, at time instant \( i = 1, 2, \ldots, 35040 \).

b. The PHS absorbs power from the generation \( (P_L) \) and provides power to the consumers \( (P_d) \):

\[
P_{PHS}(i) = P_c(i) - P_d(i)
\]

c. The total power consumption \( (P_L) \) is equal to the contribution from the generation \( (P_g) \) and the power stored on the PHS system \( (P_d) \):

\[
P_L(i) = P_{g0}(i) + P_d(i)
\]

d. By Kirchoff’s law, the sum of currents (and thus the sum of active powers) injected in a node has to be equal to zero:

\[
0 = P_g(i) + P_{PHS}(i)P_L(i) - P_{PtG}(i)
\]

e. When the energy production is greater than the consumption, the excess power is present:

\[
P_{ex}(i) = P_g(i) - P_L(i) > 0
\]

f. If the excess energy is less than or equal to an epsilon (\( \epsilon = 5GW \) in this case), the power will be absorbed by the PHS. If the excess power exceeds this value the power will be absorbed by the PtG plant:

\[
P_{ex}(i) \leq \epsilon \text{ and } P_c(i) \leq P_{ex}(i)
\]

\[
P_{ex}(i) > \epsilon \text{ and } P_{PtG}(i) \leq P_{ex}(i)
\]

The results are shown in Figure 6, where (a) shows the yearly profile of energy production and consumption; (b) shows charge and discharge of energy in PHS, and excess energy to be stored in PtG; in (c) sum of Excess energy stored in PtG and the state of charge (SOC) of PHS are depicted. The excess energy captured by the PtG plant is 606 hours over the whole year.

3.4 Scenario 2

In this scenario, a model predictive controller (MPC) is used to optimally fill the energy gap with the excess energy. Also the excess energy is more than the existing storage, which is the PHS, in this case, the energy will be stored in the PtG plants.
In this simulation, the MPC model in the scenario 2 will be repeated with curtailed PV production. In other words, the PV was curtailed to see its influence on the grid and the implemented PtG plant. The PV curtailment was set at 35%, resulting in 5% loss of the annual PV energy yield. The results show that the excess energy captured by the PtG amounts to 1.26 TWh. It is also calculated that the runtime of the PtG plant is 495 hours over the whole year.

4 Results and Discussion

4.1 PtG for Integrating excess energy

As indicated in the above simulation, additional storage capacity might be required due to the amount of the excess energy expected in year 2050. However, building new pumped hydro-power plants or even increasing the capacity of the existing plants will probably be politically difficult. PtG plants can contribute to solving this problem. One major advantage of the power-to-gas technology is that it needs less space than a pumped hydro storage plant to store energy [6].

In Scenario 2 of the above simulation, the excess energy, which is not integrated into grid, amounts to about 1.63 TWh, which can be converted to hydrogen or methane. According to the average efficiency of electrolysis of 65.5% and methanation of 49.5% [11], the produced hydrogen and methane amount to 1050 GWh and 792 GWh, respectively. Based on the lower heating values of hydrogen, 33.33 kWh/kg, and methane, 13.9 kWh/kg [12], 3.14 × 10^7 kg of hydrogen and 5.7 × 10^7 kg of methane are produced, respectively. In scenario 3, the excess energy is 1.26 TWh, for which the produced hydrogen and methane amount to 825 GWh (or 2.47 × 10^7 kg) and 624 GWh (4.49 × 10^7 kg), respectively.

4.2 PHS for integrating the excess energy

The simulations executed above indicate that additional storage is required to integrate the excess energy projected in 2050. This might create difficulties in the Swiss grid. First, although PHS is a well-developed and widely applied technology, the erection of new PHS facilities is generally difficult due to commonly low public acceptance of infrastructure projects affecting the overall appearance of the landscape [6]. Second, most of the PV generation will be connected to the local distribution grids (Grid level 7). If the PV energy is stored in PHS plants, which are connected to Grid level 1, the energy has to be transported via all the grid levels. This may result in the need for grid expansions. If the PV energy is stored near the site of generation, grid losses can be reduced and investments for grid expansions can be avoided [8].

4.3 PtG as long-term storage

In references including [4], Power-to-Gas is categorized as a large-scale storage, which maintains power capacity ranges from 100 to 1,000 MW for durations of up to months. It is commonly known that methane can be stored in the natural gas network for months at a time, including pipeline and gas storage. In case of Switzerland, the gas network consists of 16,591 km of pipeline, including transport network (2,220 km) and distribution network (14,371 km), and 116 public filling stations offering natural gas [13]. This gas network could be utilized to transport the PtG produced gas and to store it to a certain extent. When it comes to storing the gas, especially on a long-term basis, however, there is a storage capacity of about 4.8 million cubic meters in Switzerland [14]. In comparison, there are 48 underground storage facilities in Germany with a total volume of 20 billion cubic meters, which can be classified into 26 storage caverns and 22 pore storage reservoirs. The pore reservoirs are used to cover a basic load. The cavern storages are used to compensate the peak loads of gas consumption [15]. Considering the fact that the annual gas demand in Switzerland is 3,682 million cubic meter [16], which is equivalent to about 10 million cubic meter per day, the Switzerland gas storage capacity can sustain its demand for about a half day long. The natural gas demand is expected to be reduced until year 2050 in accordance with the scenario NEP, option C/E in 2050 [2]. Therefore, significant amount of investment is expected to be made in the natural gas storage in order to establish a long-term storage in its own premises in relation to the Power-to-Gas technology.

5 Summary and outlook

Through simulations based on the data and scenarios set forth in light of Energy Strategy 2050, which was initiated by the Swiss Federal government, this paper illustrated that PtG will play a significant role in the effective integration of RES into the future Swiss power grid. This paper estimated the amount
of the projected excess energy in future by treating Switzerland as a single node. Then a PtG plant was demonstrated in combination with PHS in handling the excess energy. The paper also established the requirements for implementing PtG as a long-term storage in Switzerland. The authors plan to further investigate feasibility of PtG concept in Switzerland, which will be treated as multi-node system, thereby placing the focus on sizing and siting of the PtG plants.

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References


