POWER-TO-GAS IN AN ELECTRICITY MARKET DOMINATED BY RENEWABLES

Charlotte van Leeuwen, University of Groningen, +31(0)503637163, c.van.leeuwen@rug.nl
Machiel Mulder, University of Groningen, +31(0)631035729, machiel.mulder@rug.nl

Overview

Electricity will increasingly be generated with renewable energy sources such as wind and sun. As wind and solar power are related to weather conditions, generation from these sources is highly fluctuating from time to time and cannot be predicted with 100% accuracy. Because the electricity system needs to be in balance at all times, an increase in renewable power generation consequently requires more flexibility within the system. Conventional fossil fuel power plants are currently the main providers of flexibility in many electricity systems, but in future systems with high shares of renewables these plants will be less available or not available anymore at all. Such systems will therefore have a large demand for flexibility from other sources.

Power-to-gas (PtG) is one option that could provide flexibility in a renewable energy dominated power system. In PtG, electricity is used to split water into hydrogen and oxygen with an electrolyser. The hydrogen can be stored and used later to regenerate electricity, whereby PtG thus serves as an electricity storage technology. Alternatively, the produced hydrogen can be used in the industrial or mobility sector. In this case, PtG is not an electricity storage technology but it can be a demand side response technology that also offers flexibility to the power system.

Methods

In our paper we investigate to what extent PtG is a feasible option for providing flexibility to the power system as a demand side response technology. We analyse the market conditions (i.e. the electricity prices) under which PtG is able to operate economically. This means that we analyse the maximum electricity price a PtG plant operator is willing to pay in case the investment in the plant is already made (short-term) as well as when the operator still needs to make the investment (long-term). Next, we explore the feasibility of these maximum prices.

To determine the willingness-to-pay (WTP) for electricity, we assess all costs and revenues of PtG plants. The short-term WTP for electricity determines the number of operating hours in a year and depends on the costs of water, the revenues of the hydrogen and the efficiency of the plant. The long-term WTP for electricity depends on all costs and revenues of the PtG plant, including CAPEX and OPEX. The burden of these costs is spread over the total volume of hydrogen that is produced during the lifetime of the plant (for CAPEX) or during the year (for OPEX). The long-term WTP for electricity therefore depends on the yearly full load hours of the plant and is not a single number but a functional relationship.

Because PtG is still in an early development state, there are no widely accepted values for most of the cost and revenue parameters. In addition to a base case, we defined an upside and downside boundary for all parameters based on literature sources. The boundaries are used to illustrate the effect of the uncertainty in the parameters on the business case of PtG. We compare the WTP for electricity with current market prices, using recent (2013 – 2017) data from the day-ahead (DA) and intraday (ID) markets of four western-Europen countries (DE, FR, NL and DK) with different power system characteristics in terms of power generation portfolio, interconnection and market design. Data are taken from (Bloomberg LP, 2017; EPEX SPOT, 2017; Nord Pool, 2017).

After evaluating PtG under current market conditions, we assess the future business case of PtG. The technology is still in the development phase and it is expected that electrolysers will become more efficient and significantly cheaper in the near future (e.g. (Bertuccioli et al., 2014). We assess the potential developments that influence the WTP for electricity and also explore the future development of electricity prices.

Results

Taking into account our base case assumptions for the cost and revenue parameters of PtG, the short-term WTP for electricity was found to be 21.06 €/MWh. To put this value in perspective we determined the amount of hours in a year that the price was below this WTP in the different countries and years. Under the most favourable current market conditions – represented by Denmark 2015 – the electricity price was below the short-term WTP for 38.3% of the time (Table 1), meaning that the plant would be able to operate for 38% of the time at most. Under average current western-European market conditions – represented by Denmark 2013 – the plant would be able to buy electricity only during 6% of the time (Table 1).

In the long-term, the WTP for electricity was found to be negative for all operating hours in the base case. Even under the upside boundary assumptions for the cost and revenue parameters, the PtG plant needs to run for many hours during the year at very low prices that do not currently exist in western-Europe. These findings are in line with other studies that investigated the profitability of PtG plants under current market conditions (e.g. (Baumann et al., 2013; Jørgensen and Ropenus, 2008; Mansilla et al., 2013).

Three future effects in the cost and revenue parameters were identified that would increase the WTP for electricity: a higher efficiency, lower CAPEX and higher hydrogen selling price. The influence of these effects on the short-term WTP for electricity is given in Table 1. Lower CAPEX has no effect on the short-term but was found to be crucial on the long-term. With the three future effects combined, a long-term profitable business case was found under the most favourable current market conditions as represented by the electricity price profiles of Germany and Denmark in the years 2015 and 2016. In other years and countries, however, the electricity price was still not sufficiently low during a sufficient amount of hours in the year.

Table 1: The short-term WTP in the base case and under three different future effects.

	Base case	Higher efficiency	Lower CAPEX	Higher H_2 selling price	All changes together
CAPEX electrolyser system (€/kW_{el})	1250	1250	500	1250	500
Efficiency electrolyser (% HHV)	67%	75%	67%	67%	75%
Hydrogen selling price (€/kg)	1.25	1.25	1.25	2.25	2.25
Short-term WTP for electricity (€/MWh)	21.06	23.57	21.06	38.07	42.62
Share of DK1 2013 below this price (%)	6.0%	7.1%	6.0%	56.5%	73.8%
Share of DK1 2015 below this price (%)	38.3%	49.4%	38.3%	91.1%	94.1%

The future electricity prices in Europe will be determined by the layout of the whole power system in the region, including both power generation and power consumption portfolios and interconnection between countries. PtG plants might be able profit from negative and low electricity prices in the short-term but it can be expected that power systems will eventually adapt to the new circumstances. If electricity becomes available at very low prices during many hours of the year, flexible power consumers (including PtG plants) will start a competition for the cheap electricity, thereby increasing the price up to their WTP (Brunner, 2014). Large-scale application of PtG plants will ultimately change the optimal power generation portfolio (Green et al., 2011).

Conclusions

Current market conditions do not result into profitable business cases for PtG plants in which all investment costs can be covered. A combination of higher hydrogen revenues, lower CAPEX and a higher efficiency leads to a profitable long-term business case when assuming the lowest recently observed electricity prices. For large-scale investments to come off the ground, however, the electricity price must be structurally lower than the long-term WTP. Future prices are hard to predict but will depend on the overall layout of the whole power system in a region.

References

Baumann, C., Schuster, R., Moser, A., 2013. Economic potential of power-to-gas energy storages, in:. Presented at the 2013 10th International Conference on the European Energy Market (EEM 2013), IEEE, pp. 1–6. doi:10.1109/EEM.2013.6607315

Bertuccioli, L., Chan, A., Hart, D., Lehner, F., Madden, B., 2014. Development of Water Electrolysis in the European Union. Fuel Cells and Hydrogen Joint Undertaking.

Bloomberg LP, 2017. Electricity prices.

Brunner, C., 2014. Changes in electricity spot price formation in Germany caused by a high share of renewable energies. Energy 5, 45–64. doi:10.1007/s12667-013-0084-2

EPEX SPOT (Ed.), 2017. EPEXSPOT. EPEX SPOT. URL http://www.epexspot.com/en/ (accessed 12.8.17).

Green, R., Hu, H., Vasilakos, N., 2011. Turning the wind into hydrogen: The long-run impact on electricity prices and generating capacity. Energy Policy 39, 3992–3998. doi:10.1016/j.enpol.2010.11.007

Jørgensen, C., Ropenus, S., 2008. Production price of hydrogen from grid connected electrolysis in a power market with high wind penetration. International Journal of Hydrogen Energy 33, 5335–5344. doi:10.1016/j.ijhydene.2008.06.037

Mansilla, C., Louyrette, J., Albou, S., Bourasseau, C., 2013. Economic competitiveness of off-peak hydrogen production today – A European comparison. Energy 55, 996–1001. doi:10.1016/j.energy.2013.03.022

Nord Pool (Ed.), 2017. Nord Pool group. Nord Pool. URL https://www.nordpoolgroup.com/ (accessed 12.8.17).