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Energy Procedia 105 (2017) 4569 – 4574

Energy Procedia

1+The 8th International Conference on Applied Energy – ICAE2016

Opportunities of Power-to-Gas technology

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Abstract

This paper presents an overview of power-to-gas technologies by describing the potential, the type of technologies and the challenges that are to be faced in order to introduce them in the energy system of large areas where large shares of renewable energy have been introduced or are planned to be introduced. When large electrical grids have too large a share of intermittent renewables, there is a strong need of energy storage to balance the supply and demand with time and to avoid curtailment of renewable energy power plants.

At the same time, energy storage is fundamental in small or remote grids, where the demand may be strongly different form the supply of energy during the day and during the year. In those cases reaching large shares of renewable power plants may be impossible without energy storage systems.

Another important aspect that has to be studied in order to introduce energy storage systems on small or large grids, is the flexibility of operation of all power plants connected with the grid.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: energy storage; power-to-gas; hydrogen; renowable energy sources;

1. Introduction

Energy markets in the EU have faced very important transformations after the decision about the 2020 climate and energy package [1]. One of the long-term strategies to decrease the emissions from fossil fuels, is based on switching from conventional to renewable energy sources. Renewable sources, like wind, solar or hydro power plants produce “free” and zero-emission energy. Unfortunately, their production programs are very difficult to predict and may cause energy fluctuations in the grid. Despite the problems they raise, they are considered the energy sources of the future.

The problems mentioned above can be solved by storing energy when the supply exceeds the demand and using it when the demand is larger than the supply. Energy can be stored in different forms and the proper choice of storage facility depends on different factors such as location, performance (efficiency, energy density, etc.) or costs [2]. In this paper, a variety of power-to-gas technologies (PtG) will be presented and discussed.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.982

Power-to-gas technology is a technological chain which converts the excess electricity into a gaseous fuel, such as hydrogen or methane. Its big advantage is that it can perform different roles in energy system. It can be used not only as an energy storage technology, but also as an instrument for balancing electric and gas networks. Due to the possibility of converting one energy vector into another, PtG systems can facilitate the distribution of energy among different systems and can contribute to decrease in greenhouse gases emissions as hydrogen and methane produced in PtG are considered to be clean gases. Furthermore, it increases the energy security of the system.

Nomenclature

CCU carbon capture and utilization

PEM proton exchange membrane

PtG power-to-gas

RES renewable energy sources

2. Power to gas technologies

The primary step of a power-to-gas technology is the conversion of excess energy into hydrogen via water electrolysis process. This mechanism differs from conventional energy storage systems, in which electric energy is absorbed and released. Gas is a very good energy carrier for storage as it can be easily stored for a long period of time, without the loss of its content [3]. It also has more applications than other energy vectors. Naturally, hydrogen can be used to reproduce electric energy, if used, for example, in a fuel cell. Furthermore, it can be used as a vehicle fuel or raw material for chemical industry.

The process of hydrogen production is carried by water electrolyzer. The conversion efficiency of RES into hydrogen is in the range 54-77%. There are three types of electrolysers: alkaline, proton exchange membrane (PEM) and high-temperature electrolyser. The basic characteristics of each type are shown in Table 1.

Table 1. Characteristic of alkaline, PEM and high-temperature electrolyzer

	Alkaline electrolyzer	PEM electrolyzer	High-Temperature electrolyzer
Electrolyte	Aqueous alkaline solution (KOH or NaOH)	solid polymer	yttria-stabilized zirconium oxide
Operation temperature	60-80°C	50-80°C	700-1000°C
Operation pressure	<30 bar	<30 bar	
Efficiency	65-75%	50-70%	70%
Part-load range	20-40%	0-10%	
Advantages	Most mature technology	Ability to operate in part-load and overload conditions	Can be used with high temperature heat sources like nuclear or geothermal power
Disadvantages	Relatively low current density		Need of constant operation

3. System designs

3.1 On-grid power-to-gas system

On-grid renewable system is one, which is connected to a large or national grid. In such system power-to-gas is supplied directly by renewable sources or by power network. Its main function is storage of excess electricity. In on-grid design, it also creates synergy between power and works as a balancing technology for better energy management.

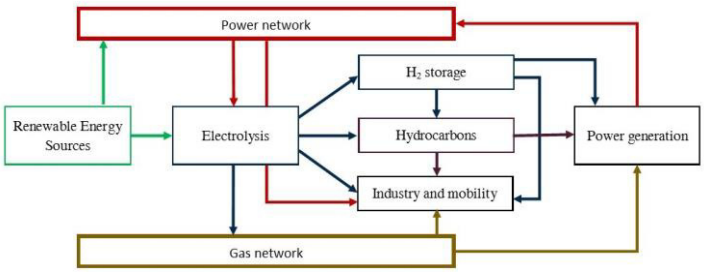

Fig. 1. On-grid power-to-gas system scheme

In large grids, a power-to-gas system can be arranged in different modules. Simple chain incorporates renewable energy source; such as wind or sun; electrolyzer and hydrogen storage technology (gas tank or gas network). Thereafter hydrogen can be used to produce hydrocarbons such as methane or methanol, or can be used in mobility or industry sector. In Figure 1 a scheme of on-grid system with power-to-gas technologies is presented. The scheme is limited to electricity – gas system interactions. In reality the power-to-gas system could also incorporate heat systems and CO_2 market.

3.2 Off-grid power-to-gas system

Off-grid systems are designed to provide electricity in places where connection with large or national grids is impossible. In such systems energy is generated by renewable energy sources. Such systems have two main applications: they incorporate energy obtained from “clean” power plants, situated in remote places, or provide electricity for communities, who do not have access to it. Access to electricity gives new possibilities for development. With energy, not only the quality of life increases, but also the possibility of creating new jobs. The working hours of existing shops and workshops can be extended giving its owners and employees the possibility to increase their income and promote investment. In times of rapid population growth in developing countries the access to electricity is an important issue.

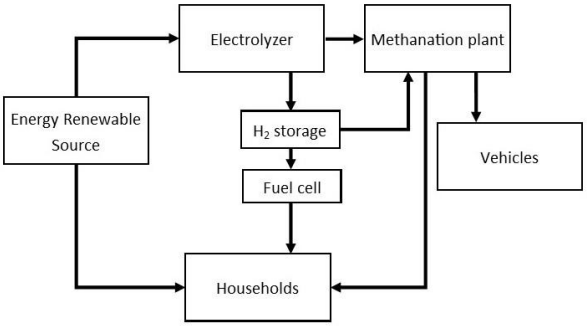

Fig. 2. Off-grid power-to-gas system scheme

In networks, which are supplied only by intermittent energy sources emerges the necessity of implementing a prevention system. In such system energy storage is necessary for providing uninterrupted access to electricity. In most mini-grid systems batteries are used for storing electricity. In our opinion, a much better solution would be utilization of multitasking role of power-to-gas systems. It would provide long and efficient storage and in case of grid expansion also flexibility and balancing. Another advantage of PtG over other technologies is the possibility of producing gas. Introducing an additional energy carrier opens further opportunities. Hydrocarbons can be used as gas for cooking or as a fuel for vehicles, which can be beneficial for the local community. The exemplary scheme of mini-grid power-to-gas system is presented in Figure 2.

4. Challenges

Power-to-gas technology is in its development stage. The research in this topic is going into two directions. The first one is improving parameters of particular modules like electrolyzer, storage tanks or methanation plants. The second field of research is focused on the behavior of power-to-gas in the system. The main challenges which need to be further explored and which can contribute to deployment of the technology to the market are:

- Requirement to establish the appropriate policy framework for power-to-gas technology as the system balancing technology [4].
- Lack of precise data as the PtG technology is currently unavailable. This results in uncertainties in PtG modelling and it is impossible to obtain reliable results [5].
- Requirement of case study analyses, including economic and social analyses for implementation of PtG system in mini-grids.
- Precisely designed smart management system for PtG with IT network for high effectiveness.

5. Opportunities

5.1. Integration of renewable energy sources in the existing energy system

Power-to-gas systems can be used in a large energy system, when the percentage of load output of renewable sources is high. In such system, load balancing with conventional power sources can be difficult, while a power-to-gas system provides more flexibility. It can also prevent the curtailment of renewable sources during periods of high supply and low demand. Qadrdan at al. in [6] investigated the possibility of utilization of excess electricity produced from wind farms to produce hydrogen. The model

they have created for that purpose showed that in case of Great Britain, the operation of power-to-gas system can reduce wind curtailment during high wind periods up to 62% (during low demand day). Another research on solar systems done in Bavaria (Germany) shows that 370 MW_e of PtG capacity can capture 30% of excess solar power. The authors predict that the utilization of power-to-gas systems will increase in time as the installed solar power capacity will increase [4].

5.2. Provision of flexibility to energy system

A flexible energy system is one, which is able to maintain continuous operation even during large and rapid changes in supply and demand. So far, balancing of the energy system lies on the supply side. There are actions taken for increasing the flexibility of demand side by implementing smart technologies, but still supply side needs improvement [7]. The advantage of power-to-gas systems in case of flexibility is its fast time of response, which takes from seconds to minutes, depending on the electrolysis technology. PtG can also increase flexibility of the system with significant share of renewable energy.

Power-to-gas system integrates all energy sectors: electricity, gas, heat and even CO_2 market in one synergic system. In such configurations, the balance would not only lie between the supply and demand side, but also among different networks.

5.3. Contribution to emission reduction targets in energy sectors

For obtaining hydrocarbons via chemical reaction, the addition of carbon dioxide is necessary. This can be a good opportunity to use the CO_2 recovered by carbon capture and utilization (CCU) technologies, which are being developed all over the world to mitigate increasing air pollution. The idea of CCU is to capture the harmful gas before it gets to the atmosphere. The research on possibilities of utilization of captured CO_2 to produce methane via power-to-gas processes were investigated by Reiter [8]. Furthermore, production and use of fuels obtained via PtG can contribute to emission reduction [3].

5.4. Contribution to increase sustainability in sectors, like the industry and the mobility sector

Hydrogen produced from renewable sources can contribute to development of clean-mobility sector. Hydrogen, intrinsically, can be used as a fuel, likewise it can be used as raw source for production of other compounds such as ethanol or methane. Schiebahn at al. in [9] claims that renewable hydrogen has the potential to become an economical fuel, since the fuel cell vehicles have high efficiency, what makes hydrogen competitive to gasoline. The costs of hydrogen produced from photovoltaic technology are estimated at 5.78 $/kg to 23.27$/kg, whereas from wind energy range from 2.27 $/kg to 6.77 $/kg [10].

6. Discussion and Conclusions

In the time of necessary energy systems transformation, there is need for new technologies, which will solve arising problems of increasing share of intermittent sources in the system. As presented in the paper power-to-gas can be the solution. For its faster implementation, more effort shout be put to design the scenarios for PtG role in the system. Likewise, there is need for development of economic and political background.

Power-to-gas is a technology, which could contribute to development of more efficient and flexible energy systems. In our opinion it can contribute to faster transformation of energy systems towards sustainability, which is the main European, energy strategy goal. Furthermore, hydrogen produced from power-to-gas system can promote development of fuel cell vehicles market. That is why in our opinion more effort should be put on modelling PtG role in the system.

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Biography

Anna Lewandowska-Bernat is a PhD student in the Department of Energy, Systems, Territory, and Construction Engineering at University of Pisa. Her research is focused on sustainable energy systems including: smart grids, energy management, energy storage systems, particularly power-to-gas systems.