INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 3748–3761

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Techno-economic implications of the electrolyser technology and size for power-to-gas systems

*David Parra**, *Martin K. Patel*

Energy Efficiency Group, Institute for Environmental Sciences and Forel Institute, University of Geneva, Boulevard Carl-Vogt 66, 1205, Genève, Switzerland

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form
23 December 2015
Accepted 23 December 2015
Available online 25 January 2016

Keywords:
Power to gas
Alkaline electrolyser
PEM electrolyser
Energy storage
Techno-economic analysis
Value proposition

ABSTRACT

Power-to-gas (P2G) is a modular technology which offers several benefits to different types of networks and sectors while playing the role of mid-term and long-term energy storage. The core element of a P2G plant is the electrolyser which transforms low cost and/or renewable electricity into hydrogen. A thorough analysis of the implications of selecting an electrolyser technology (namely alkaline or PEM) and scale is key for understanding the performance and economic benefits of P2G plants generating hydrogen or methane.

In this study, a dynamic P2G model accounting for electrolyser ageing is presented following a bottom-up approach in which the electrolyser cell is modelled by means of its polarisation curve. This model allows to determine the performance, levelised cost and value of P2G plants purchasing electricity and selling gas in the wholesale market, depending on the system configuration under the Swiss regulatory context. The results indicate that technical and economic benefits increase with the electrolyser rating but those improvements are more marked for systems on the kW scale while levelling off for the MW scale. Higher capacity factors (by approximately 11%) are needed for PEM electrolysers compared to alkaline electrolysers in order to minimise the levelised cost.

Introduction

In addition to energy efficiency use, the deployment of renewable energy (RE) technologies is a key solution to reduce carbon dioxide emissions while making world economies less dependent on fossil fuels. Approximately 18% of the global final energy consumption was generated from renewable energy (RE) sources in 2013 of which 9% came from traditional biomass [1]. However, the installed RE capacity has increased exponentially since the beginning of this century and wind (on-shore and off-shore) and solar PV capacities grew by 47 GW and 40 GW respectively in 2014 [2,3]. For electricity, RE accounted for more than 22% of the global generation in 2014 and it is expected to grow by 45% between 2013 and 2020, reaching approximately 7300 TWh [3,4]. Hydropower contributed to more than 85% of the total RE mix in 2012 and it will continue to be the main RE source in the coming years [5].

According to these data, the RE technologies which penetration is growing faster (namely wind and solar PV) are converted into electricity and the electrical network is utilised to transport variable RE generation to the demand load centres. In fact, RE only accounts for 2% and 13% of the total transport and heating needs respectively at the moment [6,7]. However,

* *Corresponding author.*
E-mail address: David.Parra@unige.ch (D. Parra).
http://dx.doi.org/10.1016/j.ijhydene.2015.12.160

the production of heat, mainly for industry (46% of the total heat production) and buildings (49% of the total heat production), accounts for more than 50% of global final energy consumption [7] whereas the transport sector consumed the 28% in 2012 [8]. These data translate to 33% and 22% of global (energy-related) CO_2 emissions respectively [9]. Against this background, alternative energy conversion systems and energy storage technologies which make use of RE electricity are urgently required to decarbonise the heat and transport sectors [10]. Some example are heat pumps for heating and electric-drive-vehicles (using battery and fuel cell technology) for the transport sector.

The power-to-gas (P2G) technology offer the possibility of converting electricity into gas with the two main options being: (a) power-to-hydrogen (P2H) and (b) power-to-methane (P2M). In addition to an electrolyser system, the latter option requires a methanation reactor to generate methane using hydrogen and carbon dioxide as reactants. Two different electrolysis technologies, alkaline and polymer electrolyte membrane (PEM), are mainly utilised in different pilot and first commercial plants worldwide [11]. Both technologies are classified as low temperature electrolysis since the typical maximum operational temperature is lower than 100°C [12]. High temperature electrolysis by means of solid oxide electrolysers has the potential of increasing the efficiency but it is still in the R&D phase and considerable development is still required [13].

The temperature level in addition to the materials utilised to manufacture the electrolyser cell stack determine the main characteristics of alkaline and PEM electrolysers. Alkaline electrolysis is the most mature technology and has been widely used for industrial applications due to its durability, maturity and relatively low cost [14]. The anode and cathode are usually made of nickel-plated steel and steel respectively and the electrolyte consists of aqueous potassium hydroxide. Main traditional downsides include the potential environmental risk due to use of highly caustic electrolyte, limited pressure generation up to 30 bar and limited operational load range [12], the latter restricting its coupling with RE generators due to their intrinsic variable output. However, it has been recently claimed by alkaline manufacturers that new designs allow variable operation ranging from 5% to 100% of the nominal capacity, increasing the hydrogen generation effectively and starting from cold within seconds and minutes respectively [13].

Alternatively, PEM electrolysis is based on proton conductive polymer electrolytes. This type of membrane offers a better impermeability for gases enabling PEM electrolysers to handle variable load operation including very low partial operation (5%). Enhanced ramping capability, cold starting times in the minute range and high pressure hydrogen generation (potentially up to 100 bar) are other key features of PEM electrolysers [15]. In conventional PEM electrolysers, platinum alloys (e.g., platinum/ruthenium and platinum/iridium) and platinum, despite their high initial cost, are used as a catalyst for the anode and cathode respectively, the former reaction being more sluggish [16]. The use of these materials has important disadvantages in comparison with alkaline electrolysers such as higher investment cost and lower durability.

Previous techno-economic studies on P2G

Some previous reports which focused on P2G technology only performed a qualitative technology assessment based on previous literature and expert opinion [14,17]. The performance, durability and cost of different options including the electrolyser (alkaline versus PEM), gas production (P2H versus P2M) and CO_2 source for the methanation reactor (power plants, industry, atmosphere and biomass) were compared in qualitative and quantitative terms. The main applications for the generated gas were also described, namely the natural gas network and mobility. Most previous studies also introduced a P2G model in order to perform a techno-economic assessment under different boundary conditions and related input data, these studies being the focus of this literature review.

M. Jentsch et al. optimised the P2G capacity and its spatial distribution for a 85% German RE scenario [18]. It was concluded that a combination of P2G and power-to-heat minimised the variable cost of the German energy system with increasing penetration of RE and that the P2G fleet should be installed in the north of Germany next to the wind generation plants. S. Schiebahn et al. compared three different P2G scenarios: P2H and P2M for injection into the natural gas infrastructure and P2H for the transport sector in Germany [15]. The economically most attractive case was found for P2H for mobility (saving the cost of the methanation reactor) due to the high gasoline costs (0.08 EUR/kWh_t before taxes) and highly efficient fuel cell electric-drive-vehicles. Another recent P2G report quantified the technical potential and economic performance of P2G for Switzerland including a Montecarlo approach in order to model the uncertainty inherent to some input data including the electrolyser and methanation reactor efficiencies and capital costs [19]. The availability of carbon dioxide and the maximum volume of hydrogen to be injected into the natural gas network were recognised as the two main limitations for the implementation of P2M and P2H respectively in Switzerland. For the Spanish energy system, F. Gutierrez-Martín et al. utilised a dynamic alkaline electrolyser model to determine the optimal capacity and operation strategy of a fleet of electrolysers using electricity purchased at low wholesale prices [20]. It was concluded that hydrogen generation is economically viable for 58 TWh/year of surplus power generation (equivalent to 23.1% of the national demand) at 0.025 EUR/kWh. Finally, a report commissioned by the "EU Fuel Cells and Hydrogen Joint Undertaking" applied a comprehensive techno-economic model on P2H which was utilised with five different European electricity markets, two different energy supplies (RE generator of grid-connected electrolyser), and two types of electrolysers (alkaline and PEM) [13]. It was concluded that today the strategy for electrolysers is to operate them at high load factors and to provide balancing services which ensures good utilisation of the capital asset.

While offering interesting insights regarding the required installed capacity for a given scenario, cost and revenue of P2G plants for different applications, all studies mentioned above calculated the economic benefits based on static values including durability and/or efficiency i.e., dynamics of electrolyser performance and electrolyser degradation were not