Renewable and Sustainable Energy Reviews 92 (2018) 794–806

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

# Applications of power to gas technologies in emerging electrical systems

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ARTICLE INFO

*Keywords:*
Power to Gas
Energy system
Electrolyser
Electricity distribution
Generation
Transmission
Review

ABSTRACT

The energy sector is undergoing substantial changes in order to promote better efficiency, increase the use of renewable energy, reduce emissions and effectively deploy technologies to trade off costs and benefits One emerging solution is the application of the Power-to-Gas technology, which can be used for different purposes. In recent years, Power-to-Gas has been studied to understand the role it could play in the electrical system. This paper has the aims of analysing the existing literature about the Power-to-Gas technology in detail, by considering some solutions that have a direct impact on the electrical system (in particular electrolyser and $CO_2$ production) and applications in the different sectors of the electricity value chain (i.e., generation, transmission, distribution and utilisation). This paper sets out the conceptual aspects that are necessary to include Power-to-Gas facilities in a more comprehensive analysis framework of the operation of the electrical system in various sectors. Some perspectives concerning new Power-to-Gas applications are also presented for each sector, and some promising aspects that are expected to play a relevant role in the future technical and economic evolution of electrical systems are discussed.

## 1. Introduction

In recent years, the increase in the capacity of renewable energy sources (RES), together with the need to reduce the carbon emissions [1], have encouraged researchers to investigate new methodologies that could be used to fully exploit the production of RES to supply the energy system. Some studies have even been aimed at creating a 100% RES supplied energy system [2], and in particular a 100% RES-based electrical system [3].

A few years ago, after the nuclear accident that occurred at Fukushima in Japan, the German government announced the so-called "Energiewende" [4]. This term indicates the transition from a carbon-based energy system to a low-carbon energy system, with the aim of dismissing the nuclear energy plants still operating in the country. The presence of wind farms in the north of Germany, together with the presence of massive load in the south, created the conditions for the introduction of a proper means of energy transportation from north to south. However, as the construction of new overhead lines is often not accepted by the general public, novel methods have to be applied. Since there is already a gas network spread over all the industrialised countries in Europe, it could be used for energy storage, and the gas could represent an energy vector that could be used to exploit the potential of RES.

In this context, one of the main challenges is the necessity of introducing more flexibility to the existing bulk system in order to reduce RES curtailment as much as possible [5–7]. The Power to Gas (P2G) option represents a suitable solution for the long-term storage of the electricity produced by RES-based plants [8]. P2G is able to add more flexibility to the electrical system, and it allows the electrical system to be coupled to other energy systems, such as heating districts [9] and transport systems [10]. The idea of producing Synthetic Natural Gas (SNG) to store electricity was first introduced by Long in 1978 [11]. He described the possibility of converting electricity into gas (feeding the public gas network) and of obtaining enough electricity to satisfy the load peak. Several pilot and demonstration sites were installed throughout the world, thus demonstrating the great interest in this technology [12].

Gas and electricity are linked by means of both the P2G and the Gas-to-Power facility, i.e., Combined-Cycle Gas Turbine (CCGT) power plants and Open-Cycle Gas Turbine (OCGT) power plants. An example of the potential paths and connections is shown in Fig. 1. In the figure, the blue lines represent the *gas* vector, which can be provided to the

*Abbreviations:* CAES, Compressed Air Energy Storage; CC, Carbon Capture; CCGT, Combined-Cycle Gas Turbine; *HHV*, Higher Heating Value; HV, High Voltage; HVDC, High Voltage Direct Current; *LHV*, Lower Heating Value; LV, Low Voltage; MV, Medium Voltage; NG, Natural Gas; OCGT, Open Cycle Gas Turbine; OLTC, On-Load Tap Changer; P2G, Power-to-Gas; PEM, Proton Exchange Membrane, or Polymer Electrolyte Membrane; PHES, Pumped Hydroelectric Energy Storage; PV, Photovoltaic; RES, Renewable Energy Sources; SNG, Synthetic Natural Gas; SOEC, Solid Oxide Electrolysis

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https://doi.org/10.1016/j.rser.2018.04.072
Received 27 January 2017; Received in revised form 5 March 2018; Accepted 14 April 2018

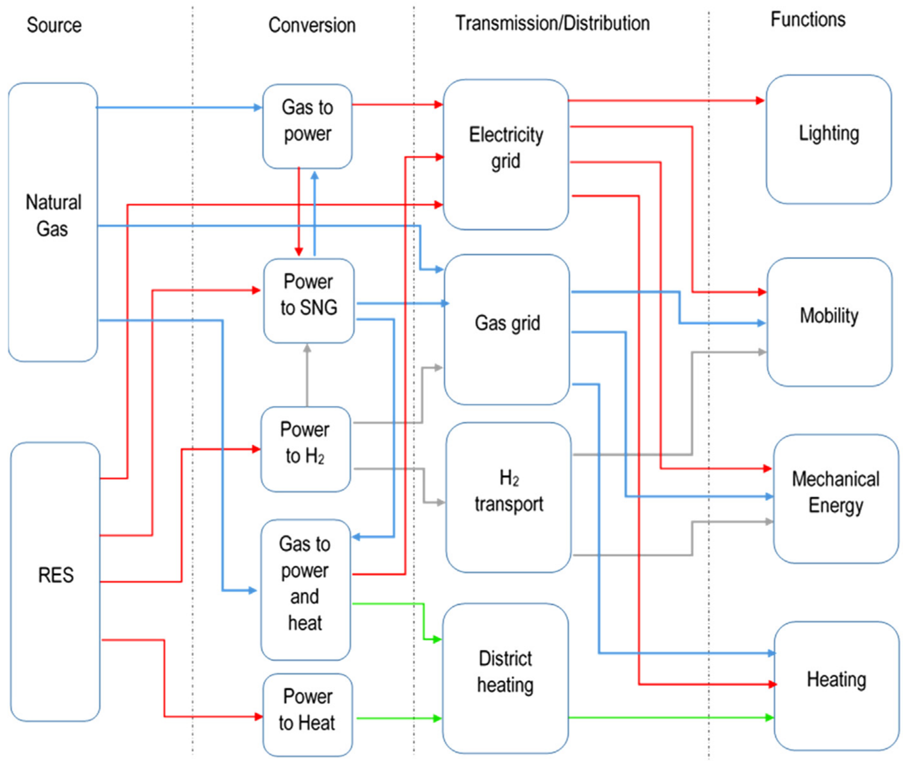


**Fig. 1.** Energy paths involving different vectors (i.e., electricity, natural gas, $H_2$ and heat).

customer as it is (for heating and mobility), or converted into electricity, heat or mechanical energy. The red lines represent the *electricity* vector, which is usually provided directly to the customers, but could be converted into either gas (SNG or $H_2$) or heat. The green lines represent the *heat* vector, which can be produced from both electricity and gas, and can be distributed by means of a district heating system. Finally, the grey lines represent the possible distribution of $H_2$, which can be used in the mobility sector, converted into mechanical energy and heat, or used as an element for the production of SNG. The link between $H_2$ and SNG means that the production of SNG could be made directly from $H_2$ stored in tanks (for example, for small power plants to SNG ones), without the need of including an electrolyser in the same plant. Further possible connections (such as the production of $H_2$ from gas and applying processes such as steam reforming) have not been highlighted in the figure for the sake of clarity. P2G in fact represents a significant new entry, which shows a growing integration within the multi-energy generation framework [13].

This paper has focused on the analysis of the *electrical* aspects of P2G. As such, for the sake of completeness, a brief presentation of the structure of the electrical system is provided. The structure of an electrical system is traditionally divided into four sectors (Fig. 2) that form an electricity production to utilisation value chain:

- Generation: this sector includes all the power plants necessary to produce the energy necessary to supply the sum of load and system losses. The power plants can be divided into two categories: dispatchable and non-dispatchable. The term dispatchable indicates all the controllable generators (i.e., with fossil, hydro and nuclear primary sources), while the term non-dispatchable indicates all the plants with non-controllable generators, including RES-based plants. The presence of a larger and larger share of non-dispatchable units is making the operation of the entire system more complicated [14], for a number of reasons, including a lack of controllability, the possible ownership by different entities with non-coordinated operation plans, a larger uncertainty in the outputs provided by these units (especially due to the uncertainty of the ambient variables in RES-based units), and exacerbation of the dynamic issues in the case of large disturbances due to the lower inertia of units with converter-based interface with the network.
- Transmission system: this is composed of High Voltage (HV) lines and represents the backbone of the entire electrical system. It guarantees the transfer of electricity over long distances. It is operated through a meshed structure to allow a high security level in the case of faults, with the possibility of excluding the faulted component and redistributing the power flows in the systems,

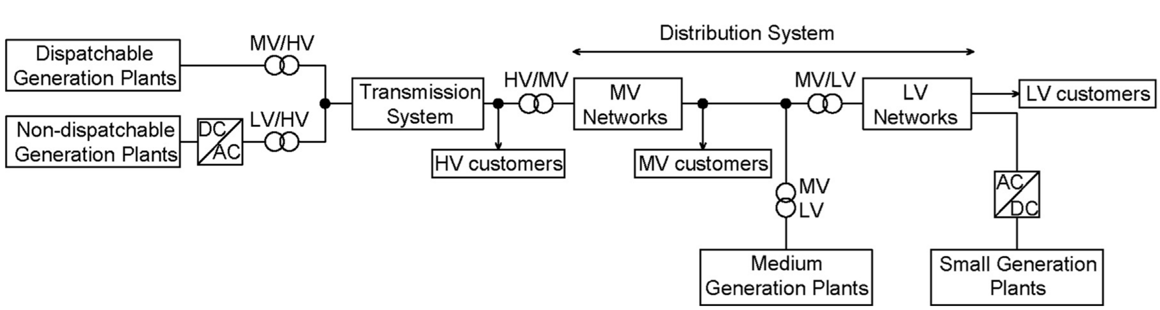


**Fig. 2.** The four typical sectors that make up the electricity value chain.