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Economic evaluation of hybrid off-shore wind power and hydrogen storage system

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ABSTRACT

This research evaluates the economics of a hybrid power plant consisting of an off-shore wind power farm and a hydrogen production-storage system in the French region Pays de la Loire. It evaluates the concept of H2 mix-usage power-to-X, where X stands for the energy product that hydrogen can substitute such as gas, petrol and electricity. Results show that a complex H2 mix-usage design would increase investment cost in too many infrastructure components and would significantly decrease the profits. Resizing the project would result in providing two energy products only, such as power-to-power and power-to-gas or alternatively power-to-mobility and power-to-gas services. Hydrogen production costs of selected projects would range between 4 and 13 €/kg of H2 as a function of the application type, of oil and gas prices and of expectations of a further reduction in the electrolyser and fuel cell investment costs.

Introduction

The development of hydrogen production and storage has emerged worldwide with the increasing prices of oil and gas, with renewable energy deployment and concerns over the security of energy supply. Moreover, clean hydrogen could reduce carbon emissions, in substitution to coal, gas and oil, and could reduce the local pollution from road traffic as well [1]. Hydrogen could support the integration of intermittent renewables, by avoiding power curtailment, electricity grid congestion and by improving the system reliability in remote areas [2,3].

In Europe, the Fuel Cells and Hydrogen Joint Technology Initiative has been launched in 2008 as a public private partnership aiming to accelerate the market introduction of hydrogen technologies by supporting research, development and demonstration activities.[1] Among European Union Member States, Germany, Spain, UK and France have developed various pilot plants of hydrogen production and storage; for an international review of hydrogen pilot plants see Gahleitner [4]. In France, the national Association for Hydrogen and Fuel Cells has been created in 1998 for supporting the development of hydrogen technologies and fuel cells.[2] At a regional level, in the French region Pays de la Loire, the initiative *Mission Hydrogène* has been launched since 2005 several demonstrator projects on hydrogen uses for marine and fluvial applications.[3]

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[1] http://www.fch-ju.eu/.

[2] http://www.afhypac.org/fr/accueil.

[3] http://www.mh2.fr/en/.

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Hydrogen can be used to produce electricity (power-to-power), it can be injected into a natural gas pipeline network (power-to-gas), it can fuel natural gas power plants or the production of second generation biofuels (power-to-fuel), and it can be used as a fuel in transportation (power-to-mobility). This research develops the concept of power-to-X and evaluates to what extent revenue sources could increase from multiple hydrogen usage on different energy market segments.

The research on the economics of hydrogen shows different perspectives for the market development, based on different cost ranges. The overall cost of hydrogen includes the hydrogen conditioning, compression, storage and distribution. Hydrogen technologies have high investment costs and also high energy losses during power to hydrogen and hydrogen to power conversions. Moreover, when combined with intermittent renewables, the technical lifetime of the electrolyser could be further reduced [5].

The hydrogen cost varies from 5 €/kg to 30 €/kg of H2 as a function of the size of the equipment. A large-scale hydrogen plant could reduce this cost at 3 €/kg of H2 produced for an electricity cost of 40 €/MWh [6]. The most important cost part is the fixed cost of investment. As for variable costs, the most important component of the production chain could be the cost of the electricity input.

This research investigates the case where the power used to generate the hydrogen comes from renewable energy and it is infed at zero cost. The case study consists into a contractual arrangement which is hybrid system-specific, where the two wind and hydrogen operators share their costs and benefits. The economic evaluation is based on the optimal operation of wind power and hydrogen production by means of a dynamic operational optimization model which maximizes revenues from several energy markets. A set of technological and economic constraints apply, from both demand and supply sides. The demand for hydrogen is estimated by assuming that hydrogen substitutes for primary and secondary energy sources, such as natural gas, electricity and fuel for marine and road transportation. On the supply side, the wind flow constraints the power generation used for the hydrogen production. At equilibrium, the issue is to constantly match the intermittency of the wind power with the continuous demand for hydrogen in the case of fixed commitment with refuelling stations for cars and fishing vessels.

The paper is organized as follows. The section Study case describes the study case and the database, the section Methodology details the model and the section Result analysis discusses results and policy implications. The concluding remarks show under what conditions hydrogen storage may be viable as a future investment option to help managing systems with intermittent renewable generation and to substitute scarce and carbon-emitting fuels such as gas and oil.

Study case

Description of the infrastructure

Within its National Renewable Energy Action Plan, France has committed to achieve a 23% share of the energy generated by renewables in its final energy consumption by 2020 [7]. Among energies from marine sources, off-shore wind power will represent around 6000 MW to be installed off the French coast.

The study case considers an off-shore wind power farm installed in the area of Saint-Nazaire, a French region with large off-shore wind potential and no grid interconnections to other countries. The base case assumes the large-scale deployment of off-shore wind turbines of 1 GW by 2030, and the development of hydrogen fuel cells as a technical support to the wind power integration. This is a hypothetical project where a storage facility is built close to the offshore wind farm that is connected to the rest of the power system via a dedicated transmission line. The study investigates the design of the wind-storage-transmission system such as to reduce the wind power curtailment occurring because of limited grid line capacity. The power can be transmitted to the grid by either the wind plant or the storage-fuel cell component of the hybrid plant (see Fig. 1). During periods with no wind, the power needed to produce the hydrogen could be withdrawn from the grid.

One of the current challenges is to supply electrolysers with power from intermittent energy sources, in particular when the power supply is below its idling threshold, e.g. 25% of the rated power [8]. Fell et al. [9] have demonstrated that a pressurized alkaline electrolyser and wind energy system can improve the ability to capture the fast variations in wind power production with a quick response time (<1s) and a broad operational range (10%–100%). In front of massive deployment of hydrogen and wind or solar power farms, there is a need to develop appropriate control strategies such that the electrolysers achieve full dynamic range of rated power.

There are several technological options for providing electrolytic hydrogen, such as the alkaline electrolysis, the polymer electrolyte membrane electrolysis, the alkaline polymer electrolyte water electrolysis, or the solid oxide electrolysis. They each have advantages and drawbacks making the integration of large scale off-shore wind energy challenging [10]. The alkaline electrolyte is a well mature technology and the most extended at a commercial level worldwide, while the polymer electrolysis would respond more quickly to the power input and thus being suitable to support intermittent energy integration. However more research is needed to develop these technologies, to enhance their durability and to further reduce costs.

In this paper it is assumed that a polymer electrolyte is coupled with the off-shore wind energy source and that by 2030 the system achieves full range of rated power. Two compressors are used, one of 200 bar pressure for power-to-power provision, and one compressor of 700 bars for the power-to-mobility application.

Compressed hydrogen is supplied to the gas network or to the storage tanks adapted to each pressure type (200 bars and 700 bars). The auxiliary equipment includes also a fuel cell for the electricity generation which will be supplied to the local grid. Efficiency rates are reported in Table 2 along with the investment cost of the components.

Wind power potential

The wind farm consists of more than 160 *Haliade*™150-6 *MW* turbines with a total installed capacity of 1000 MW. The