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Long-term power-to-gas potential from wind and solar power: A country analysis for Italy

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ABSTRACT

Challenges related to variability of renewable energy sources (RES) recently arose in many countries and several solutions based on energy storage were proposed; among them, a promising option is Power-to-Gas (P2G), able to recover excess and unbalanced electrical energy. In this work, an assessment of long-term P2G potential is performed on a country scale, based on the analysis of electrical system historical data series, rescaled in order to consider the evolution of load and installed wind and solar capacity. In a long-term perspective, it is assumed the complete exploitation of the technical potential of the RES, which represents an upper deployment boundary with current technology. Once satisfied the electric load, residual energy to the P2G system and hydrogen production are calculated on a hourly basis; P2G installed capacity is a consequence of the assumed target on minimum operation on a yearly basis. The Italian case is analyzed, evidencing that the recovered excess energy from RES could substitute nearly 5% of current natural gas consumption or about 7% of national fuel consumption when used for hydrogen mobility. A range of options and a sensitivity analysis on assumptions is presented, showing scenarios with up to 200 GW of installed RES and a 50% additional load with respect to current one. In addition, the extension of the model to a zonal grid structure evidences the impact of transmission lines saturation that may increase gas production up to 50%. Results are compared with the German case, considered in a previous work, evidencing differences due to the diverse energy production mix.

Introduction

Renewable energy share is continuously increasing in most industrialized countries, allowing environmentally friendly power production but entailing growing issues in power grids management [1,2]. The reliable integration of renewable sources of electricity is complex, partly because it implies changes in the vitally important activity of electricity provision, and partly because some renewable energy technologies pose additional challenges. Many works assess the possibility and the implications of a totally renewable energy system [2,3]. However, well before a complete transition to renewables, increasing the RES fraction to high penetration levels - as foreseen by environmental policies - arises many issues. A reference target is for instance set in the IEA Energy Technology Perspectives for 2050 [4,5], where the share of renewables is forecasted at 57÷71% of the global electricity

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List of acronyms

CAES	Compressed Air Energy Storage
EES	Electric Energy Storage
HES	Hydrogen-base Energy Storage
P2G	Power-to-Gas
PHS	Pumped-Hydro Energy Storage
RES	Renewable Energy Sources
TSO	Transmission System Operator

production, mostly relying on wind and solar power, if the international community will pursue a strong CO_2 emissions reduction policy ("*2DS*" and "*2DS-HiRen*" scenarios). Such a large amount of installed non-dispatchable RES capacity tends to cause a strong mismatch between electricity production and load, yielding issues for the management of RES energy lack or excess. A first option to cope with such issues is the adoption of a more flexible generation system involving traditional technologies with improved start-up and load following capabilities, able to compensate for sudden RES production changes. According to this viewpoint, more and more flexible combined cycle power plants are being developed and deployed by the power industry [6,7] and a higher number of simple cycle gas turbines might be introduced in the generation park, alone or in association with innovative systems [8,9]. Anyway, this solution is not able to recover excess energy. The second alternative are energy storage systems (ES), currently strongly developed in several countries [10–15], but with few options for very large peak shaving (GWh scale) capability. Among them, pumped-hydro storage (PHS) plants and compressed air energy storage plants (CAES) are feasible solution for peak shaving and excess energy recovery, due to the possibility of handling both large power and energy capacities. However, the possibility to install these technologies is limited by the geographical location and availability of attractive sites, as well as by environmental impact and social acceptance issues. Moreover, they are capital-intensive investments with a low modularity. Another research field involves hydrogen-based energy storage systems (HES), adopting electrolysis devices, which are nowadays considered a promising solution to support PHS and CAES for large scale energy storage [10,16,17]. An advantage of hydrogen technologies (and Synthetic Natural Gas ones) is the capacity of storing large amount of energy for long time, contributing also to manage load and production variability and grid frequency control. Usually, HES make use of Power-to-Gas (P2G) conversion systems (nominally, electrolysers) that convert excess or low cost electric energy in hydrogen heating value; in recent times, this terminology was extended and refers to the technologies aimed to convert renewable energy in hydrogen, for mobility, industrial applications, synthetic fuel production or reconversion to electricity (Power-to-Power). In addition to long-term storage and excess energy recovery, fast response electrochemical devices can also provide ancillary services (i.e. frequency and voltage control), resulting in positive effects on the grid and additional revenues for the P2G system [18]. The general concept of Power-to-Gas and its possible integration in the energy system is outlined in Fig. 1, while a review of possible process chains of different P2G paths, including different transformation technologies, the optional methanation step, distribution options and geological storage options as well as end-user applications can be found in Ref. [19].

P2G devices are modular, allowing the installation of new capacity with gradual investment, and compatible with a geographically distributed deployment, concentrated on the locations where issues of grid balancing are stronger. Drawbacks are mainly related with high specific costs and still uncertain lifetime under strongly unsteady operation; nevertheless, the foreseen evolution in next years could solve such issues and allow HES to contribute to the solution of the challenges posed by high renewable scenarios.

In this work, distributed electrolysis system (or Power-to-Gas, P2G) is supposed to be integrated in the electrical system of a country in order to shave peaks of wind and solar production that exceed the simultaneous load. The time horizon is very long (e.g. 2050) in order to investigate the effects of a high penetration of RES and the presence of large quantities of excess energy to be stored. The final use of the produced hydrogen (natural gas substitution for thermal purposes, industrial feedstock or fuel for mobility) is not specifically addressed, but compared with the expected size of the different energy sectors. After a brief presentation of the general methodology, the case of Italy is analyzed in order to verify the potential of P2G technology in the foreseen scenarios, approaching the problem from the point of view of the global system. A comparison with case of Germany – a country where a great deal of effort has been put in last years in developing and demonstrate P2G technologies – is then setup on the same basis. The comparison allows to evidence differences due to the diverse potential of RES and structure of the energy grids as well as in the reachable target application of this technology.

Long-term analysis concept

This work focuses on future energy systems where RES installed capacity is -at least to some extent- higher than the minimum electric load, with the possibility of a frequent full load coverage by non-dispatchable energy sources. The timeframe will be frequently addressed making reference to the year 2050, which is set as representative of a long-term time horizon. In this scenario, the goal is the assessment of P2G systems impact on this type of energy system and the estimation of the amount of hydrogen generated through P2G, whose final use could be primarily in the mobility field (feeding fuel cell electric vehicles) or related to industrial and thermal sectors. The long-term time horizon makes extremely difficult an estimation of the installed capacities of both conventional and innovative technologies, since they depend on the evolution of economics, politics, regulatory policies and technology improvements along several decades – a matter which can hardly be foreseen. Many studies defining future 'scenarios' related to this topic are periodically published and updated as a support to policy makers (such as IEA Energy Perspectives [4]) by international and governmental agencies. In this work, rather than relying on the combination of a specific economic, political and technologic scenario, a