EFC19075

SIZING OF INTEGRATED SOLAR PHOTOVOLTAIC AND ELECTROLYSIS SYSTEMS FOR CLEAN HYDROGEN PRODUCTION

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Abstract - **This work presents a method to design an optimised system that combines electrolysers and solar photovoltaic panels for sustainable hydrogen production. Given the daily and seasonal variations of the electricity output vs. a stable hydrogen demand, power exchange to/from the electric grid and hydrogen storage systems are considered. The aim is to determine the optimal size of the PV field, the electrolyser, and the storage, for a given hydrogen demand, by minimising the cost of the hydrogen produced.**

Index Terms - **Electrolysis; Hydrogen; Integration; Solar PV.**

I. Nomenclature

EL	Electrolyser
PV	Photovoltaic

II. Introduction

Hydrogen is a key enabling element of the energy transition. As a flexible carbon-free energy vector, it offers a strong sector coupling potential thanks to the multiplicity of end uses (e.g., industry, mobility, natural gas admixture). When produced from renewable sources, it also enables a fully sustainable energy supply chain, increasingly attractive thanks to recent improvements in electrolyser performance.

A number of applications is likely to introduce stable, if not constant, hydrogen demands along the year, e.g., industrial facilities aiming at a zero-carbon supply chain ('green chemistry') or hydrogen vehicle refuelling stations that are increasingly required to offer 'green hydrogen'.

This work presents a sizing method to design a system that combines electrolysers and solar photovoltaic (PV) panels for a sustainable hydrogen production, focusing on the small scale.

III. System configuration and operation

The study integrates an intermittent power generation technology (solar PV) with a flexible hydrogen production device (electrolyser, EL) and a hydrogen storage system.

The analysis considers a year-long hourly electricity generation profile of the solar PV plant and simulates the electrolyser operation with the aim of guaranteeing the required demand. The annual hydrogen demand drives the required PV and electrolysis capacities, whereas the hydrogen delivery to the consumer is critical for storage sizing.

A. Hydrogen production from solar PV

Given the electricity generation time series, the amount of energy that can be transformed into hydrogen varies when the ratio of EL and PV nominal capacities ($P_{nom,EL}/P_{nom,PV}$) changes. Fig. 1 illustrates the interaction between the plants, with a nominal capacity ratio equal to 0.25, in two typical days with high and low irradiance. When the PV power output is comprised between the minimum load and the nominal capacity of the electrolyser, the latter absorbs the entire generation. When the PV output is larger than the electrolyser capacity, the surplus is directed to the power grid. The same happens when PV generation is below the electrolyser minimum load.

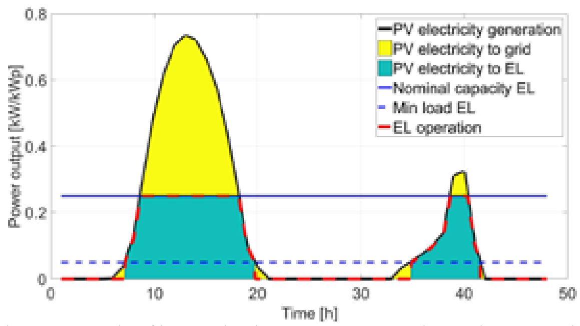

Fig. 1. Example of integration between PV generation and EL operation.

If the system is not required to provide 100% hydrogen production from PV, the electrolyser can absorb electricity from the grid at any time to satisfy the production needs (except for moments of PV-driven nominal operation and by respecting the minimum load constraint).

Year-long time series of PV power generation are taken from the European PV-GIS database [1] for the selected location, considering state-of-the-art PV panels. The system sizing assumes perfect scaling of electricity generation with the installed capacity.

B. *Hydrogen storage for annual management*

The electrolyser and the PV field are sized to comply with the cumulative annual demand. However, the fluctuations of solar energy during the year determine an unbalanced hydrogen production during summer and winter which imposes the need for hydrogen storage. Hydrogen storage is assumed in the form of conventional high-pressure metallic tanks (200 bar).

IV. CALCULATIONS AND RESULTS

Calculations are performed for the case of a hydrogen demand of 100 kg_{H2}/d (36.5 ton_{H2}/y), considering a location in northern Italy. Economic assumptions reflect short-term projections: 700 €/kW_p for PV, 900 €/kW_{el} for EL, 500 €/kg_{H2} for storage tanks [2].

As long as only PV panels and electrolysers are considered (without storage), the possibility to guarantee the cumulated production on annual basis depends on their installed capacities and on the solar radiation profile. At small installed capacities, only a limited fraction of hydrogen comes from PV electricity. This is shown by the black contour lines in Fig. 2 and Fig. 3, which represent the fraction of electricity coming from PV with respect to the total amount needed. The investment cost increases linearly with the installed capacities of PV and EL. The lowest-capital-cost configuration for 100% cumulated renewable H_2 has an investment cost of 2.2 M€ and features nearly 1.0 MW_{el} of EL and 1.8 MW_p of PV.

When considering the annual operation and requiring the plant to deliver the same quantity of hydrogen each day of the year, inter-seasonal storage becomes mandatory. Fig. 2 shows the required H_2 storage capacity (colour scale) as a function of electrolyser capacity and PV rated power. The storage capacity increases massively when the PV fraction is high and the oversizing is limited (i.e., cases close to the black line '1'). The minimum assumed storage size is 700 kg_{H2} (1-week demand).

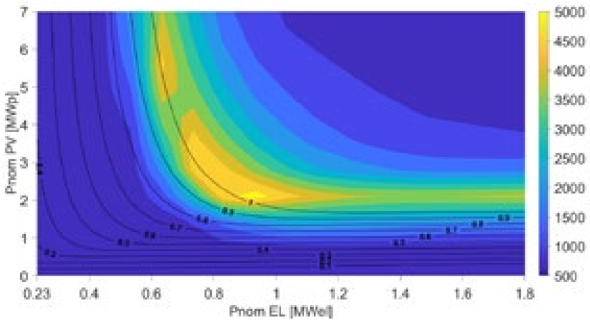

Fig. 2. Contour plot of hydrogen storage capacity, as function of electrolyser and PV rated power. The black lines represent the fraction of electricity generated by the PV field.

Consequently, the investment cost of the complete system shows a different and more complex structure, as depicted in Fig. 3. Due to its high specific cost, the large storage capacity required near the black line '1' increases the total system costs, while the optimal configuration is shifted to an oversized system where ~1.3 MW_{el} of EL are coupled to ~2.8 MW_p of PV and ~2 ton_{H2} of storage (black dot), for a total investment cost of about 4.2 M€. Hence, the presence of the storage almost doubles the cost from the optimal PV+EL configuration.

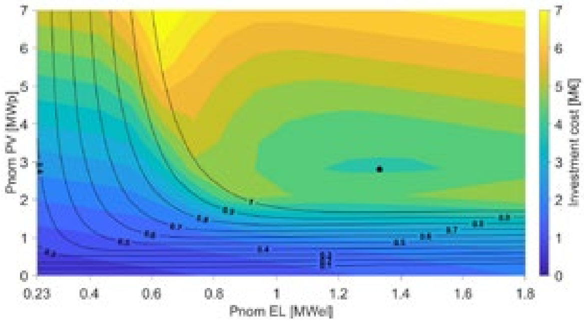

Fig. 3. Contour plot of total investment cost (PV+EL+storage), as function of electrolyser and PV rated power. The black lines represent the fraction of electricity generated by the PV field.

Based on the investment cost and on the annual energy balances of the system (PV generation, electrolyser operation, exchange with the grid), it is possible to determine the hydrogen specific cost. OPEXs are assumed as 1-2%/y of CAPEX, depending on the technology; the discount rate is set to 6%. Table I reports the system sizing that results from the optimisation with a 'minimum H_2 cost' objective. The injection of surplus electricity into the electric grid is calculated with a baseline selling price of 60 €/MWh_{el} (today's Italian average) and compared with a 20% reduction (48 €/MWh_{el}), which is likely to occur in the medium term, when more and more new solar plants will all aim to sell electricity in the central hours of the day. The lowest hydrogen cost is predicted at higher electricity value with a system featuring a large PV capacity, where the revenues are sustained by electricity sales rather than by hydrogen production (note that 7 MW_p is the assumed upper boundary of PV capacity for the solver).

TABLE I
SYSTEM CONFIGURATION AND H_2 COST AT VARIOUS CONDITIONS

Sold electricity value	PV [MW_p]	EL [MW_{el}]	Storage [kg_{H2}]	Investment cost [M€]	H_2 cost [€/kg_{H2}]	PV coverage fraction
60 €/MWh_{el}	7.0	0.4	700	5.6	5.84	75%
	7.0	0.9	1104	6.3	6.29	100%
48 €/MWh_{el}	2.8	0.5	738	2.8	8.08	76%
	4.9	1.1	1137	5.0	9.46	100%

V. CONCLUSIONS

The analysis shows that hydrogen can be generated at costs in the range of 5.8 to 9.5 €/kg_{H2} depending on electricity cost assumptions and PV coverage fractions, influencing also the required storage size. Additional work will investigate effects of adopting different electrolysis and storage technologies.

REFERENCES

[1] JRC, PV-GIS, https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.

[2] FCH2JU, Addendum to the Multi-Annual Work Plan 2014-2020, 2018.