Techno-economic assessment of a coupled battery PEM electrolyzer system

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This paper aims at providing the results of a techno-economic analysis related to the integration of a battery on a PEM electrolyzer operating under intermittent PV power supply conditions.

Keywords : PEM electrolyzer, intermittency, sizing, battery, techno-economic assessment.

1. INTRODUCTION

The integration of renewable energy sources in the operation of current electrolysis systems is of growing interest given the major contribution it brings towards the energy transition. However, the literature has brought to light the impacts that an intermittent operation could have on the system key performance indicators [1] such as the efficiency [2][3], durability [4] and other aspects inherently linked to the dynamic operation of electrolyzers, i.e. the load-following capacity, response time etc. Several studies from current literature have shown that intermittent operation could both increase the system specific consumption and affects the electrochemical performance and physico-properties of the stacks over time. In order to counterbalance these impacts, an approach can rely on the integration of a battery to the overall electrolyzer operation. At first glance, this latter would bring a twofold asset regarding intermittency issues: on the one hand, smoothening out the intermittent events of a given load profile to a constant setpoint over time, and on the other hand, redistributing the surplus production to the electrolyzer when the setpoint is higher than the system maximal size. Thus, smoothening out an intermittent power profile could both increase the load factor of the electrolyzer over its operation time, and therefore, increase the hydrogen production, and also to overcome intermittency issues on system performance. However, the implementation of this strategy requires to know to what extent it is profitable to store the surplus of production, i.e. if the surplus production recovered counterbalances the additional costs and operational complexity that the integration of a battery brings to the global system operation. For this purpose, a short analysis aimed at assessing the techno-economic impacts that a coupled battery-electrolyzer system when supplied with an intermittent may have on the overall system performances is presented in this paper. An annual PV profile from a 95 MW plant located in Madrid (Spain) has been generated from JRC public databases [7]. The input PV data have been oversized in order to generate a surplus of production to be valued during the operation of the system. The aim of this study was to recover all the electricity produced by the PV plant by integrating a battery. Besides, it should be noted that this analysis is applied to a simplified scenario taking into account a number of assumptions described in the remainder of this paper.

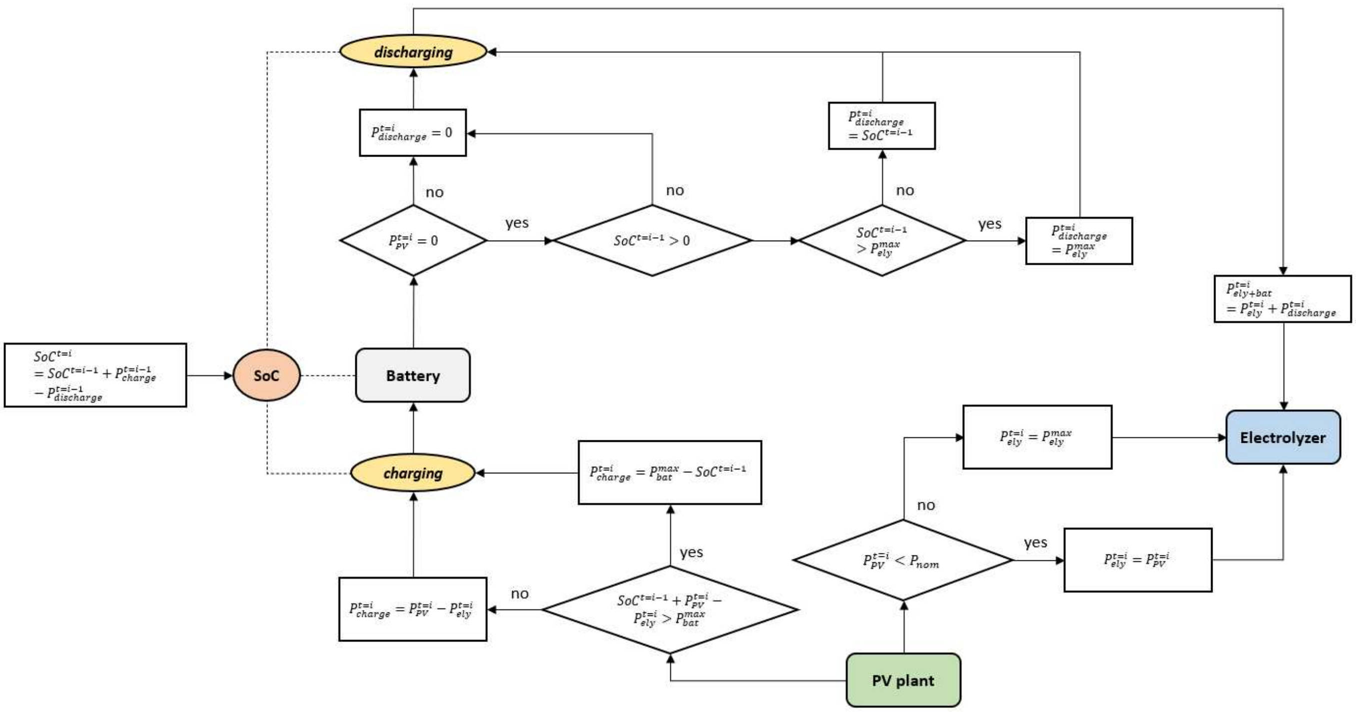

Figure 1: Flow chart of the considered system

2. DESCRIPTION OF THE STUDIED SYSTEM

The electrolyzer is a PEM 8-stack system receiving a maximal power capacity of 20 MW. The proposed scenario aims at smoothing the intermittent events coming from the PV power profile to an overall setpoint close to the maximal power capacity of the electrolyzer. The sizing of the coupled battery-electrolyzer system is essentially based on the definition of the sizing assumptions applied to the four following variables at each time step: the electrolyzer power $P_{ely}^{t=i}$, the power charging the battery $P_{charge}^{t=i}$, the power discharge to the electrolyzer $P_{discharge}^{t=i}$ and the battery state of charge $SoC^{t=i}$.

- Definition of the conditions for $P_{ely}^{t=i}$:

At time i, if the PV power $P_{PV}^{t=i}$ is higher than the maximal electrolyzer capacity P_{ely}^{max}, then the power received by the electrolyzer $P_{ely}^{t=i}$ is equal to the maximal electrolyzer capacity P_{ely}^{max}. Otherwise, $P_{ely}^{t=i}$ is equal to $P_{PV}^{t=i}$.

- Definition of the conditions for $P_{charge}^{t=i}$:

At time i, if $P_{PV}^{t=i} - P_{ely}^{t=i} + SoC^{t=i-1}$ exceeds the maximum battery capacity P_{bat}^{max}, then $P_{charge}^{t=i}$ is equal to $P_{bat}^{max} - SoC^{t=i-1}$. Otherwise, $P_{charge}^{t=i}$ is equal to $P_{PV}^{t=i} - P_{ely}^{t=i}$.

- Definition of the conditions for $P_{discharge}^{t=i}$:

At time i, if there is no PV production (i.e. $P_{PV}^{t=i} = 0$) and if the battery at time i-1 is loaded (i.e. $SoC^{t=i-1} > 0$) at a power higher to the electrolyzer maximal capacity (i.e. $SoC^{t=i-1} > P_{ely}^{max}$) then $P_{discharge}^{t=i}$ is equal to the maximal electrolyzer capacity (i.e. $P_{discharge}^{t=i} = P_{ely}^{max}$). Otherwise, $P_{discharge}^{t=i}$ is equal to 0 (i.e. $P_{discharge}^{t=i} = 0$).

- Definition of the conditions for $SoC^{t=i}$:

At time i, the battery state of charge $SoC^{t=i}$ is defined as the sum of the battery state of charge $SoC^{t=i-1}$ at time i-1 and the input $P_{charge}^{t=i}$ and output $P_{discharge}^{t=i}$ power at time i.

The interconnection of the conditions previously described is depicted in the flowchart, Figure 1.

3. METHODOLOGY

In order to assess the techno-economic relevance of the studied scenario, a comparative study based on the calculation of the Levelized Cost of Hydrogen (LCOH) is conducted for the two following case studies:

- Single operation of the electrolyzer;
- Integration of a battery into the electrolyzer.

The LCOH is defined as follows:

$$\text{LCOH } (€/\text{kg}) = \frac{(\text{ CAPEX . AF }) + \text{OPEX} + \text{ Utility expenditures}}{\text{Hydrogen Production}}$$

and the utilization factor AF as:

$$\text{AF } (\%) = \frac{\text{r . } (1+\text{r})^{\text{N}}}{(1+\text{r})^{\text{N}} - 1}$$

with:

- CAPEX (€): the investment expenditures over the plant lifetime;
- OPEX (€): the annual operation and maintenance expenditures;
- Utility expenditures (€): the annual generated electricity cost;
- Hydrogen Production (kg): the annual hydrogen production;
- r: the discount rate.

The total CAPEX generated by an electrolyzer over a year of operation can be defined as follows:

$$\text{CAPEX } (€) = \left(\text{CAPEX}_{\text{installation}}\left(\frac{€}{\text{MW}}\right) * \text{P}_{\text{ely}}^{\text{max}}(\text{MW}) * \text{AF}\right) + \left(\text{CAPEX}_{\text{installation}}\left(\frac{€}{\text{MW}}\right) * \text{P}_{\text{ely}}^{\text{max}}(\text{MW}) * 40\% * \frac{1}{(1+\text{r})^{\text{N}_{\text{stack}}+1}}\right)$$

with:

- $\text{P}_{\text{ely}}^{\text{max}}$: the maximal power capacity of the electrolyzer;
- N_{stack} : the number of stacks composing the overall system.

The total OPEX generated over the year of operation has been rated at 3% of the total cost of installation, according to the following equation:

$$\text{OPEX } (€) = 3\% * \text{CAPEX}_{\text{installation}}\left(\frac{€}{\text{MW}}\right) * \text{P}_{\text{ely}}^{\text{max}}(\text{MW})$$

The total cost related to electricity consumption is assessed as follows:

$$\text{Utility expenditures } (€) = \text{specific consumption}\left(\frac{\text{kWh}}{\text{kgH}_2}\right) * \text{amount of H}_2 \text{ produced } (\text{kgH}_2) * \text{electricity cost}\left(\frac{€}{\text{kWh}}\right)$$

The amount of hydrogen produced at the end of the year of operation can be defined as the ratio between the total input power received by the system over the year of operation and the specific consumption at nominal conditions:

$$\text{amount of H}_2 \text{ produced } (\text{kgH}_2) = \frac{\int_{\text{t=0h}}^{\text{t=8761h}} \text{P}_{\text{ely}}\, \text{dt } (\text{MWh})}{\text{specific consumption}\left(\frac{\text{MWh}}{\text{kg}_{\text{H2}}}\right)}$$

The LCOH calculation based on the previous equation has been performed on a number of simplifying assumptions related to the sizing of the electrolyzer and the battery. The main ones can be summarized as follows:

- The costs related to the integration of the battery were included into the overall system CAPEX;
- Only the CAPEX has been considered for the calculation of the battery cost;
- The OPEX and H_2 production are the same each year;
- The replacement of the stack over the whole project lifetime has not been taken into account. Besides, it should be mentioned that the integration of the battery could extend the overall lifetime and this last statement has not been evaluated in this study;
- The performance degradation of the battery over the system operation has not been considered.

Considering the PV profile and the assumptions taken for the sizing of the electrolyzer, a total of 74 MW of surplus to be stored has been obtained. From this result, the sizing of the battery has been defined. Furthermore, the calculation of the additional equivalent cost generated by the integration of the battery is based on the projected data for the costs of battery systems in 2020 provided by the National Renewable Energy Laboratory (NREL) [8], according to the following equation:

$$\text{Cost battery } (€) = \int_{\text{t=0h}}^{\text{t=8761h}} \text{P}_{\text{ely}}\, \text{dt } (\text{kWh}) * \left(\text{energy cost}\left(\frac{€}{\text{kWh}}\right) + \frac{\text{power cost}\left(\frac{€}{\text{kW}}\right)}{\text{duration (h)}}\right)$$

Considering that the electrolyzer operates around 10 hours per day, a 14-hour battery operating time has been chosen so that the electrolyzer can run full time without interruption during each day.

The parameters and assumptions considered in this study are summarized in Table 1.

Table 1: Techno-economic parameters used in this study

Parameter	Value	Unit
Size of the electrolyzer	20	MW
Specific consumption electrolyzer	50	kWh/kgH_2
CAPEX_installation	1500	€/kW
OPEX	3% CAPEX	€/kW
Discount rate	8	%
Utilization factor	40	%
Electricity cost	50	€/kWh
Size of the battery	75	MW
Plant lifetime	20	Years
Energy cost battery	255	€/kWh
Power cost battery	230	€/kW
Battery operating time	14	h

4. RESULTS

The total amount of produced hydrogen for both considered cases is depicted in Figure 2. As suggested, integrating the battery with the electrolyzer more than doubles the hydrogen produced over the year, compared with the case of a single operating electrolyzer. In addition to smoothing out intermittent events and thus reducing the associated impacts on the performances of the electrolyzer, this indicates that integrating a battery allows the electrolyzer to operate at a higher load factor, thus optimizing its production throughout the year, which was obviously a foreseeable outcome.

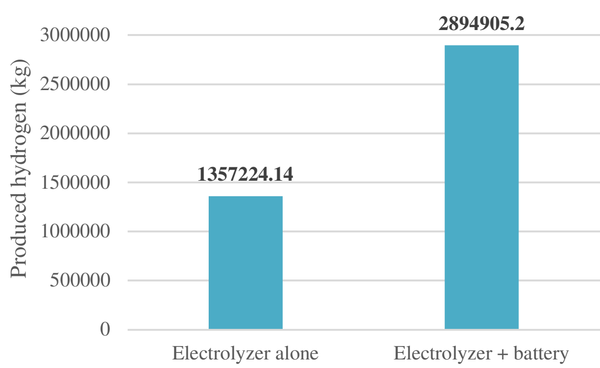

Figure 2: Total produced hydrogen during the year of operation

Figure 3 shows that a LCOH of 4.72 €/kg is reached when the electrolyzer operates alone. The LCOH rises up to 34.16 €/kg when a battery is integrated to the system. As expected, the gain in hydrogen production during the year is not sufficient to offset the additional cost generated by the battery.

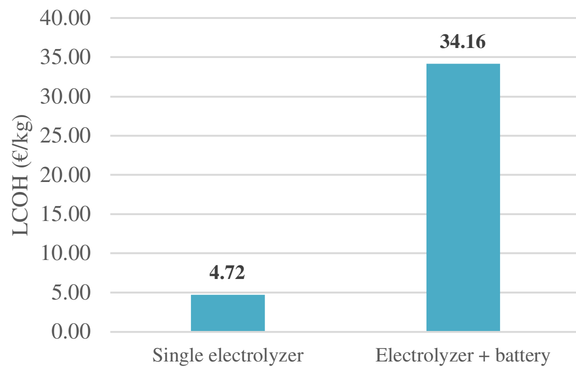

Figure 3: LCOH for the three described case scenarios

As depicted in Figure 4, the breakdown of the total cost induced by the integrated battery-electrolyzer system shows that 89% of the total cost comes from the battery, justifying the very high LCOH observed for this case scenario while only 4% of the total cost is directly linked to the electrolyzer and 7% for the consumed electricity.

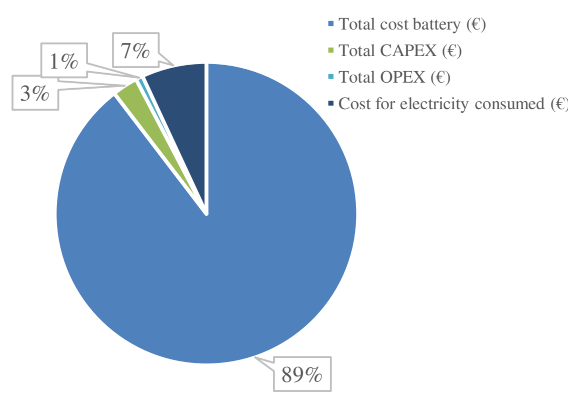

Figure 4: Breakdown of the total cost

5. CONCLUSIONS

In this study, the additional cost induced by the integration of a battery into the operation of a 20 MW PEM electrolyzer system has been estimated. The gap appears very high compared to the expected gain. However, it should be reminded that the problem described in this paper is a simplified analysis of a much more complex case study. Thus, some factors, such as the energy management strategy, the optimization of the sizing of the different components and the ageing of the electrolyzer, could be further investigated for a fair comparison.

6. REFERENCES

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