VALUATION OF HARNESSING FLEXIBILITY FROM DECENTRALIZED WATER ELECTROLYSIS SYSTEMS FOR THE DSO

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ABSTRACT

A recent call for projects related to the development of new hydrogen applications and infrastructure in France has revealed renewed interests of city authorities and regions for water electrolysis technologies in order to achieve their energy transition goals. By taking into account the expected business models of these very flexible systems, the cost of providing flexibility services to the distribution system operator was studied for three types of hydrogen infrastructures connected to the electricity distribution grid. The contractual framework was divided into a multi-year commitment contract and a day-ahead activation contract. The calculations of the average costs for the flexibility provision to the DSO reflect these two parts.

INTRODUCTION

A recent call for projects [1] related to the development of new hydrogen applications and infrastructure in France has revealed the renewed interest of city authorities and regions for water electrolysis technologies in order to achieve their energy transition goals, whether to reduce greenhouse gas emissions of local industries and transportation sectors or to improve the integration of renewable into the electricity grids via power-to-hydrogen systems.

During a private workshop in 2016 with industrial members of the AFHyPAC association (Association Française pour l'Hydrogène et les Piles à Combustible), three key trends for the next five years were highlighted:

1. Recent and upcoming water electrolysis systems are expected to be very flexible loads capable of providing large modulations of their electricity demand in a few seconds [2].
2. The primary downstream markets for water electrolysis are segments where hydrogen selling prices are the highest, namely mobility applications (fuel cell electric vehicles noted FCEV) and traditional industry customers (where hydrogen is used as a chemical input).
3. Water electrolysis systems can be considered as flexible loads since H_2 can be stored in tanks and used when needed. This flexibility could provide multiple services (for instance primary reserve, voltage regulation, and other flexibility services etc.) to many stakeholders in the electricity market, whether in the transmission or distribution grid [3,4].

This study models the business models of three different configurations of water electrolysis systems connected on the electricity distribution grid, and evaluates the costs when these systems provide two types of flexibility services to the distribution system operator (DSO).

CONSIDERED MODELS OF WATER ELECTROLYSIS SYSTEMS

Vanhoudt et al.[5] studied in detail the expected business model of a large-scale water electrolysis site connected to the electricity distribution grid as well as the natural gas transmission grid. In this model, the electrolysis system was able to

- serve a regional network of hydrogen refuelling stations with an increase in hydrogen demand over the span of 10 years,
- optimize its electricity purchases on the market,
- provide ancillary services, and
- inject an optimized amount of hydrogen into the natural gas grid.

In that study, the water electrolysis system could reach an Internal Revenue Rate of about 4% provided that the site was eligible to favourable grid tariffs and that the hydrogen injected into the natural gas grid was eligible to a 90€/MWh regulated injection tariff and to "renewable H_2" certificates. Figure 1 illustrates the evolution of costs and revenues over a ten year span for this system.

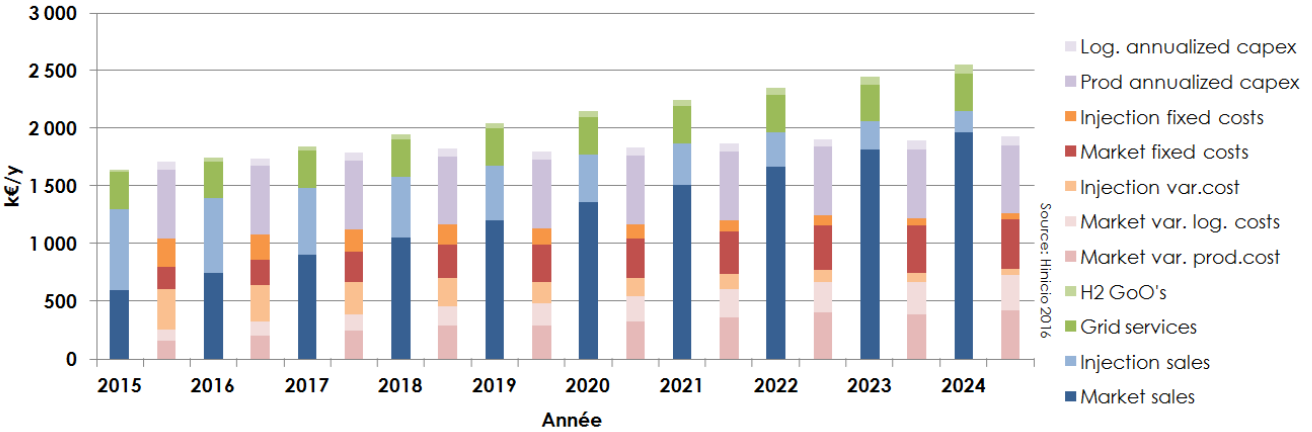

Figure 1. Evolution of annualized revenues (blue and green bars) and costs (purple and red bars) of a 2 MW "semi-centralized water electrolysis "regional" site per [5]. The revenues include sales of the hydrogen on the energy markets and injected in the gas grid, the electricity grid services and "renewable hydrogen" certificates (H2 GoO in the figure). The costs include annualized fixed costs for the logistics and production assets, the fixed and variable costs.

The current study adapted this business model approach for three models of water electrolysis systems:

1. a 2 MW regional (semi-centralised) water electrolysis system dedicated to provide hydrogen to refuelling stations (HRS) around a 50 km radius supplying a maximum of 200 full-power FCEV per day, each using 5 kg of H_2 per day,
2. an 1 MW system dedicated to one on-site HRS providing hydrogen to a captive fleet of maximum 25 fuel cell electric buses, each using 20 kg of H_2 per day,
3. a 400 kW system dedicated to one on-site HRS providing hydrogen to a captive fleet of maximum 200 light-utility battery electric vehicles fitted with a fuel cell range extender, as proposed by Symbio Fuel Cell for the Renault Kangoo LUV [6], each using 1 kg of H_2 per day.

The modelled systems are equipped with PEM electrolyser stacks, with 66% efficiency and able to provide a power consumption surge of 200% of a nominal capacity during 30 minutes [7]. This feature is used to double the capacity made available on the primary reserve markets, such that a 1 MW system has a power range of [0; 2 MW] and can therefore provide a symmetrical primary reserve of 1 MW even when operating at nominal capacity.

The business model takes into account

- The capital expenses for the water electrolyser, the compression system, the hydrogen storage system, communication interfaces, power conversion systems, and, for the first case, the fleet of transport trucks and the gas grid injection system ;
- The operational expenses for the water used, the electricity purchased on SPOT markets (EPEX Spot prices for year 2014), the electricity grid fees, overall operations and maintenance costs, and for, the first case, the cost of fuel for the fleet of trucks;
- The revenues from the H2 supply to the fleet of vehicles (hypothesis of contractual price of 8€/kg of H_2 at the point of delivery, i.e. excluding HRS costs), providing primary reserve to the French TSO RTE (capacity revenues of 18€/MW/h, this can represent up to 20% of total revenues), and, for the first case, the revenues for injecting gas into the natural gas transport grid (hypothesis of a gas injection tariff of 90 €/MWh, in line with the existing bio-methane injection tariff).

The costs associated to the HRS are not included in this business model, for two reasons:

1. a HRS does not provide flexibility itself, and
2. a HRS could be owned and operated by another stakeholder (and so not necessary the water electrolysis system owner).
3. However, the end-client's on-site storage is included, as a standard practice in the hydrogen merchant market.

In the first case, the water electrolysis site is sized to meet expected hydrogen demand for mobility use at the tenth year of the modelling period, with a progressive increase of the share of hydrogen production dedicated to mobility use from 25% the first year to 100% the tenth year. The remaining available capacity is used to produce hydrogen to be injected in the natural gas transport grid. The resulting water electrolyser capacity factor is about 88% over ten years.

In the other two cases, the sites are not expected to be connected to the natural gas transport grid because of site location constraints (inner-city). The capacity factor of the water electrolyser rises progressively from 25% the first year to 100% the tenth year, following the progressive increase of hydrogen demand for mobility uses.

PROPOSED STRUCTURE OF FLEXIBILITY SERVICE CONTRACTS

Based on the fast response of water electrolysis systems [7] and the expected business model aforementioned, it was found that, mainly, two types of flexibility services could be provided to the DSO:

1. "commitment of reduced consumption", on the one hand, could be useful for the DSO when a local peak in the electricity demand leads to a temporary network congestion ;
2. "commitment of forced consumption", on the other hand, could be useful for the DSO when a local peak in electricity injection on the grid (for example from non-dispatchable distributed renewable energy resources), during a period of low local demand leads also to a temporary network congestion.

Voltage regulation did not seem of principal interest for this study, as new technical specifications for grid connections of power conversion systems could be a cheaper and simpler alternative.

While the electrolysers are connected to the medium voltage (1 and 2 MW systems) or low voltage grids (400kW system), there is a strong competition between provision of flexibility to the TSO on the one hand through primary reserve markets and to the DSO on the other. Moreover, today, there are no markets in France to provide flexibility to DSOs.

This competition can be mostly avoided if the DSO's contractual framework for flexibility includes a commitment period of several years combined with day-ahead scheduling for activation. In this study, the proposed contractual framework between the electrolysis site and the DSO was structured in two parts:

1. **A commitment contract** specifying the nature of the flexibility service (commitment of reduced consumption or forced consumption), the length of the contract (5 years in this study), the expected time slots in the day and days in the year, the maximum available power capacity of flexibility (60% of nominal power in this study), the maximum number of activation hours per year ;
2. **An activation contract** specifying when the site will be contacted prior to the activation (at least one day-ahead to reduce competition with primary reserve market), the requested flexible power capacity, the time of activation and the requested duration.

The valuation of the flexibility calculates the cost for the water electrolysis site to deliver the flexibility services to the DSO with the following assumptions:

- The commitment of reduced consumption is set to be activated between 19h and 21h, when national peaks of electricity demand is most likely to occur in France;
- The commitment of forced consumption is set to be activated between 00h and 05h, when national demand for electricity is usually low in France;
- The activation duration (in hours) of the flexibility capacity is modulated during the year with 60% of committed hours during winter, 40% of committed hours during spring and autumn, and 20% of committed hours during summer;
- The maximum capacity of available flexibility takes into account the operational constraints to deliver hydrogen to mobility uses.

MAIN RESULTS

The technico-economical study found that the main drivers of costs are

1. reduced revenues from primary reserve (as a result of competition between services),
2. reduced revenues due to the reduction of volumes of hydrogen injected into the natural gas grid (for the first case), and
3. sub-optimal electricity procurements relative to the standard business model.

Secondary drivers of costs include the increased capital expenses and maintenance costs.

By taking into account the structure of the used contractual framework, the cost for water electrolysis site to provide flexibility service to the DSO has been broken down into two different components: the average fixed costs, related to the commitment component over a period of 5 years, range from 9 €/MW/h to 36 €/MW/h ;

- the average variable costs, related to the activation component on a day-ahead basis, range from 0 €/MWh to 7 €/MWh.

The cost structure is summarized in figure 2.

More precisely, the cost of a forced consumption commitment in the first case is close to zero, due to the high capacity factor of the electrolyser. In the other two cases, the cost of activating a reduced consumption commitment is close to zero when the activation time slot occurs when the electrolyser is not scheduled to produce hydrogen, especially in the first years of operations. On average for the second and third cases, the costs of activating both types of flexibilities are driven mainly by the sub-optimal electricity procurements relative to the initial business model.

Configuration	Type of service	Services to DSO: Elec. Cpty. (MW)	Com. (Nb hours over contr. duration)	Call (Nb hours over contr. duration)	Contr. length (years)	Use (over contract duration): % Mobility	% Inject.	% Total	Costs: Com. €/MW/h	Com. €/yr/MW	Call €/MWh	Call €/yr/MW
Semi-centralised configuration	Limited consumption commitment - 1a	2,0	5 475	2 025	5	38%	50%	88%	35,6	197 000	7,3	7 090
Semi-centralised configuration	Limited consumption commitment- 1b	2,0	21 900	8 100	20	67%	21%	88%	34,2	931 000	6,7	2 835
Semi-centralised configuration	Consumption commitment-2a	2,0	9 125	3 540	5	38%	50%	88%	31,4	283 000	0,0	0,0
Distributed configuration	Limited consumption commitment- - 4a (**bus**)	1,0	5 475	2 025	5	41%	NA	41%	17,4	95 000	1,3	2 630
Distributed configuration	Limited consumption commitment- - 4b (**RE FCV**)	0,4	5 475	2 025	5	39%	NA	39%	9,2	50 000	1,1	7 425

Figure 2. Synthesis of cost structure of the flexibility services to the DSO calculated for the commitment (com. in the figure) and activation (call in the figure) components, over the length of the contract and averaged per year and per MW/h or per MWh.

CONCLUSION

By starting from the expected business models of water electrolysis system dedicated to the hydrogen supply for mobility applications, the study modelled the cost for the site to provide two types of flexibility services to the DSO: a commitment of consumption reduction or a commitment of forced consumption.

In order to reduce the costs associated with the competition with TSO primary reserve markets, the contractual framework with the DSO has two components : a multi-year commitment contract reserving the capacity for set hours and days in the year and an activation contract enabling the modalities for the DSO to activate the flexibility at least one-day ahead.

The costs were calculated for three types of systems connected with powers ranging from 400kW to 2MW, and were broken down into two components:

- the fixed costs, related to the commitment component over a period of 5 years, range from 9 €/MW/h to 36 €/MW/h ;
- the variable costs, related to the activation component on a day-ahead basis, range from 0 €/MWh to 7 €/MWh.

The study shows that the activation cost can be close to zero when the DSO activates a commitment of forced consumption when the water electrolysis site would have been operating at nominal capacity, or when the DSO activates a commitment of consumption reduction when the system would not be scheduled to operate. Such situations could lead to free-rider risks, if the contract between the DSO and the water electrolysis system has set an activation price unrelated to the inherent cost of the requested activation. This could be alleviated if the DSO were able to check the next day's planned operations programme of the water electrolysis site before requesting the activation of a flexibility service.

The study also highlighted the competition between the TSO primary reserve market and the DSO flexibility services for very flexible systems. Beyond the proposed contractual framework, the competition could be further reduced if the primary reserve market would allow asymmetric capacity proposals.

Provided the business model is well-known, this valuation method could be applied to other flexible systems such as electricity storage systems and fleets of electric vehicles.

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