B1402

Application of Water Electrolysers in the Swiss Balancing Service Markets

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Abstract

The Swiss balancing service markets support explicit demand side response where industrial installations and micro-units participate as virtual power plants, opening the market to new technologies such as water electrolysers. A research program supported by the Swiss Federal Office of Energy SFOE and the Association of Swiss Electricity Companies VSE analyses the market situation and identifies requirements, opportunities and obstacles for suppliers of balancing services in the Swiss markets.

The article starts with the characterization of the Swiss balancing service markets, then considers the conclusions relevant to water electrolysers and quantifies the financial contribution of balancing energy to the business case. It concludes with an outlook about the FCH research project *Standardized qualifying tests of electrolysers for grid services* QualyGridS, where the considerations are extended to the balancing energy markets of the European member states.

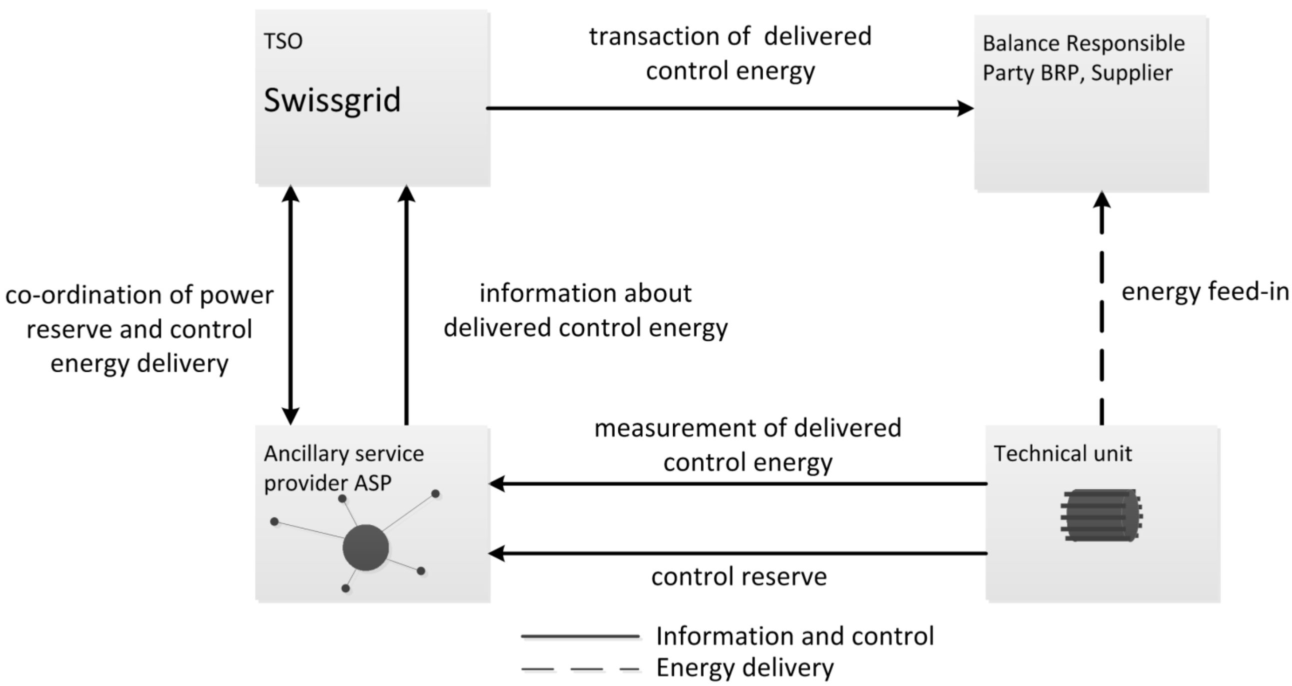

Figure 1: Aggregator model implemented in Switzerland (illustration based on [5])

Introduction

Swissgrid as the Swiss transmission system operator (TSO) procures balancing services from independent ancillary service providers (ASP, Figure 1) through auctions. According to the ENTSO-E three stage control concept [2] Swissgrid procures primary control reserve (PCR), secondary control reserve (SCR) and tertiary control reserve (TCR) [3]. All these services are provided by flexible technical units, which are power generators or loads prequalified for the provision of balancing energy.
It is possible to aggregate geographically distributed technical units in the grid levels 5 (50KV) and 7 (400V) in order to build a virtual power plant. This enables smaller flexible technical units such as water electrolysers to also contribute to the balancing energy markets, reducing the TSO's dependency on hydrological conditions, and offering additional earnings to the operators of water electrolysers.
The article explains the logic of the Swiss balancing service markets in section 1. It especially discusses the specifics of the Swiss balancing service products and highlights the interaction between the TSO, the ASP and the technical units, describing the bidding and power reservation, the energy delivery and the settlement processes. Special attention is paid to the aggregator model, which paves the path towards integration of smaller technical units in virtual power plants. Section 2 considers the market logic from the perspective of water electrolysers operated as technical units in the balancing service markets. It considers an abstract model of a water electrolyser providing SCR and TCR. Possible hurdles and constraints to the market entrance are discussed as well as the value generated, respectively for SCR and TCR.

Abbreviations

ASP	Ancillary service provider
BRP	Balance responsible party
PCR	Primary control reserve (frequency containment reserve FCR)
SCR	Secondary control reserve (automated frequency restoration response aFRR)
TCR	Tertiary control reserve (manual frequency restoration response mFRR and replacement reserve RR)
TSO	Transmission system operator

1. The Swiss balancing service markets

Swissgrid procures balancing services from ASPs, based on non-discriminatory, transparent and market-oriented criteria. Within the synchronous integrated electrical grid in Europe the process of balancing generation and consumption at any given point in time is realised by a three-step process, making use of PCR, SCR and TCR products, which differ with regard to their technical als well as commercial characteristics. As an example for PCR there is no remuneration for the requested energy whereas for the SCR and TCR the requested energy is remunerated. For the remainder of this text we will focus on SCR and TCR, which are commercially more attractive for the operation of water electrolysers.

Demand side response integration through aggregation

When providing balancing services different entities are involved. The relevant entities are the technical unit, the supplier of energy or the balance responsible party (BRP) respectively as well as the ASP (Figure 1). The ENTSO-E document "Market Design for Demand Side Response" proposes different models for demand side response integration in electricity markets [4]. Switzerland implements the central settlement model, which supports the settlement of energy from technical units in balance groups outside the ASP's own balance group. The corresponding aggregator model [5] was developed by the electricity branch of Switzerland as illustrated in Figure 1. It allows a balance group neutral extension of an ASP portfolio.

Use cases

The following use cases are particularly relevant for the owner of a technical unit:

Bidding and power reservation

To ensure grid stability, Swissgrid tenders SCR and TCR with different tender periods:

- Six daily 4 hour blocks and one week products are tendered for TCR.
- One week product is tendered for SCR.

Taking the tendering calendar into consideration, prequalified ASPs are requested to bid to Swissgrid. A bid is characterized by a combination of quantity and the associated control reserve price. The following describes the different process steps [7]:

1. Swissgrid tenders the required control reserve (approximate amount is published).
2. The technical unit updates the ASP regarding its availability. The technical unit informs the ASP by phone or electronically if it is available. Differing from one ASP to another, the lead time is around 2 days for daily products and 1.5 weeks for the week product. ASPs typically expect the unit availability to be >99% for the period offered.
3. The ASP aggregates different technical units and bids to Swissgrid.
4. Swissgrid informs the ASP if the bid was accepted. (TCR: 2 days in advance for daily products, 1 week in advance for week products (usually on Tuesdays); SCR: 1 week in advance (usually on Tuesdays; the exact dates are published by Swissgrid in the tender calendar.))
5. Technical units are informed by the ASP whether their bid has been accepted.

For TCR, the activation is as per the merit order list of all the energy bids (4-hour blocks). The ASP can influence the frequency of activation by changing the energy price. The energy price can be changed till one hour before the start of the 4-hour block. For SCR, the activation is pro-rata. All ASPs which were successful in the SCR auction get the secondary control signal from Swissgrid. The ASP can in turn define a merit order list within its SCR portfolio to decide the order of activation of technical units. Thus:

6. For TCR: provide a price for the energy bid if the energy price needs to be changed (determines the merit order of dispatch).
7. The technical unit confirms its availability to the ASP.
8. The ASP sends schedules to Swissgird till D-1 17 which contains information about which technical units are withholding the power.

Energy delivery

In case of control reserve activation, the so-called control energy (positive or negative) is delivered. Swissgrid informs the ASPs in real time, which in turn notify their technical units. For secondary control energy, the technical units are dispatched automatically. If tertiary control energy is required, the ASP is informed by e-mail and phone. The activation of the control reserve then happens within a minimum of 15 minutes. The following describes the different process steps [7]:

1. Swissgrid activates the control reserve from the ASP.
2. The ASP distributes the control reserve activation request amongst the aggregated technical units.
3. Positive control energy is realised by a reduction of electricity consumption or an increase of electricity generation of technical units during the activation period. Negative control energy is realised by an increase of electricity consumption or a reduction of electricity generation of technical units during the activation period.

4. The technical unit delivers monitoring data via the ASP to Swissgrid (automatic, 10s values for TCR and SCR).

On the next working day, the ASP must send Swissgrid schedules with the amount of energy actually activated. These schedules have a resolution of 15 minutes and include the information about the balance group and supplier in which the control energy was activated. Swissgrid exchanges correction schedules with the ASP and the BRPs involved, based on the information from the ASP.

Measurement of the energy activated is explained in the following paragraph. For conventional power plants or larger loads which work according to a schedule, the delivered control energy is calculated as the deviation of the actual power value from the schedule (Figure 2). The time interval for the schedules for control energy is 15 minutes.

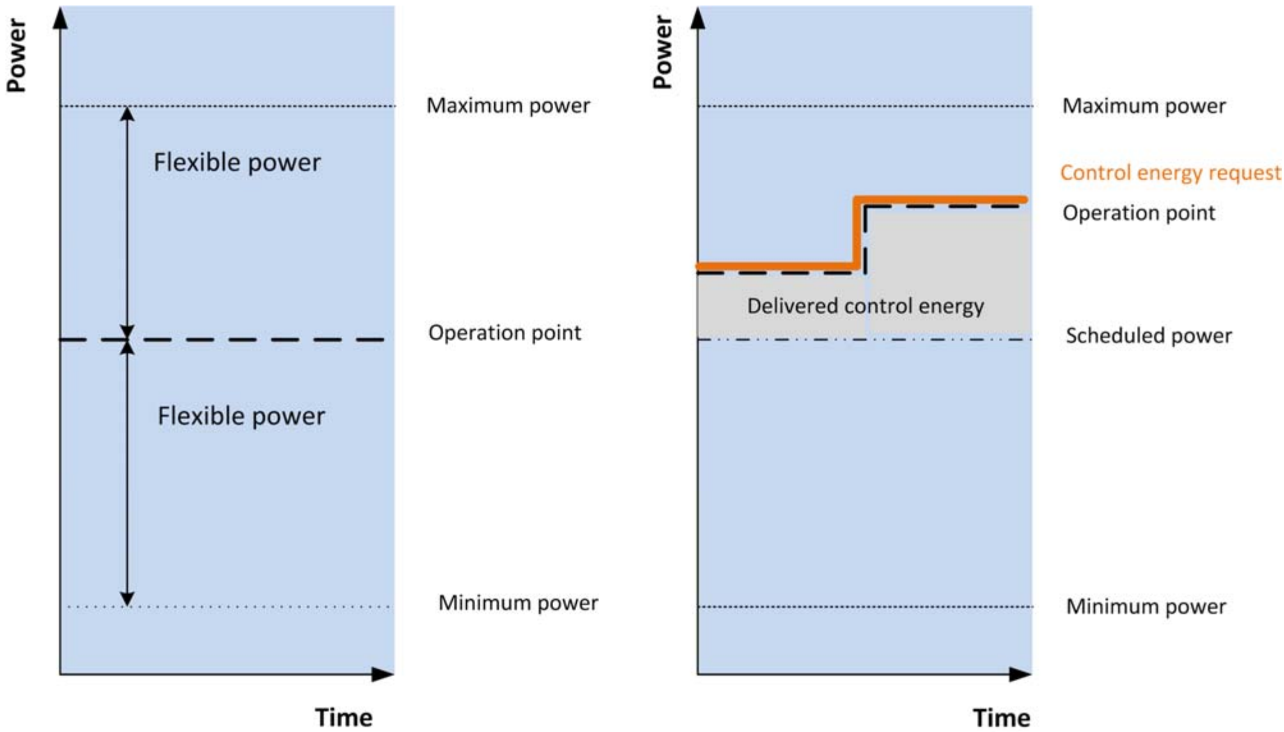

Figure 2: Determination of delivered control energy from technical units which work according to a schedule

For technical units which do not have a schedule a baseline method has been developed in the aggregator working group which is illustrated in Figure 3. The effective delivered control energy corresponds to the energy that was delivered in excess to or lesser than the energy before the start of the control energy activation. Ideally this corresponds exactly to the requested amount. Decisive is the last measured value of power before the control energy activation at T_*begin* as well as the measured value of power after T_*begin*, P_*high*. P_*high* is fixed for the duration of the activation while P_*activated* may change during the course of the activation depending on how the technical unit is reacting. Ideally P_*high* and P_*activated* are equal for the entire duration of the activation as shown in Figure 3. The power values P_*high* and P_*activated* are the reference levels for determining the control energy. If P_*high* is less than P_ *activated* then P_ *activated* becomes the upper reference level.

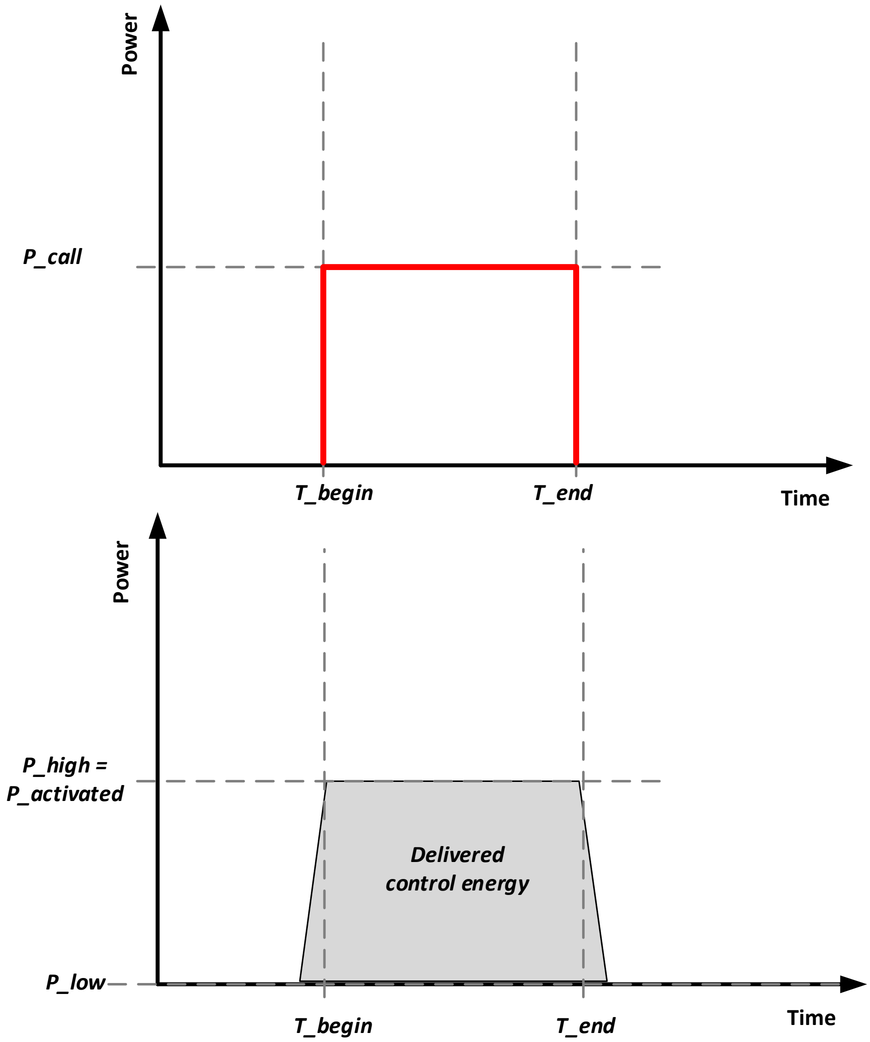

Figure 3: Determination of delivered control energy from one technical unit. In this example the requested energy is activated and deactivated without delay

Settlement

The settlement process is identical for both SCR and TCR and is independent from positive or negative control power. The control reserve is remunerated based on the control reserve price.

The remuneration for control reserve is simple and can be broken down into two steps:

1. Remuneration of the ASPs based on the tenders for control reserve.
2. Remuneration of the technical unit bases on the contractual terms with its ASP.

Positive control energy is remunerated as follows [7]:

1. Between supplier and technical unit, excess production or reduced consumption is dealt with as defined by the energy delivery contract between the two parties.
2. Swissgrid remunerates the BRP for the delivered control energy according to the SwissIX tariff. Swissgrid corrects the operating schedule of the BRP to avoid balance energy being falsely allocated.
3. Swissgrid remunerates the ASP for the delivered control energy, subtracting the payment to the BRP.
4. The ASP remunerates the technical unit according to the aggregated reserves contract between ASP and technical unit.

For negative control energy, the remuneration process works as follows:

1. Between supplier and technical unit, reduced generation or increased consumption is dealt with as defined by the energy delivery contract between the two parties.
2. The BRP remunerates Swissgrid for the delivered control energy according to the SwissIX tariff. Swissgrid corrects the operating schedule of the BRP to avoid balance energy being falsely allocated.
3. Swissgrid pays the ASP the amount received from the BRP minus the control energy price.
4. The ASP remunerates the technical unit according to the aggregated reserves contract between ASP and technical unit.

2. Application of water electrolysers in the SCR and TCR markets

In [6] the Swiss TSO specifies the requirements for technical units to participate in the balancing service markets. Aggregation of units in virtual power plants provides a solution for the minimum power requirement. With regard to water electrolyser the relevant electrical parameters are given in Figure 4 and Table 1. The model values (which we consider as at least being close to typical values) given in Table 1 by far fulfill the technical requirements for the SCR, as well as for the less stringent TCR.

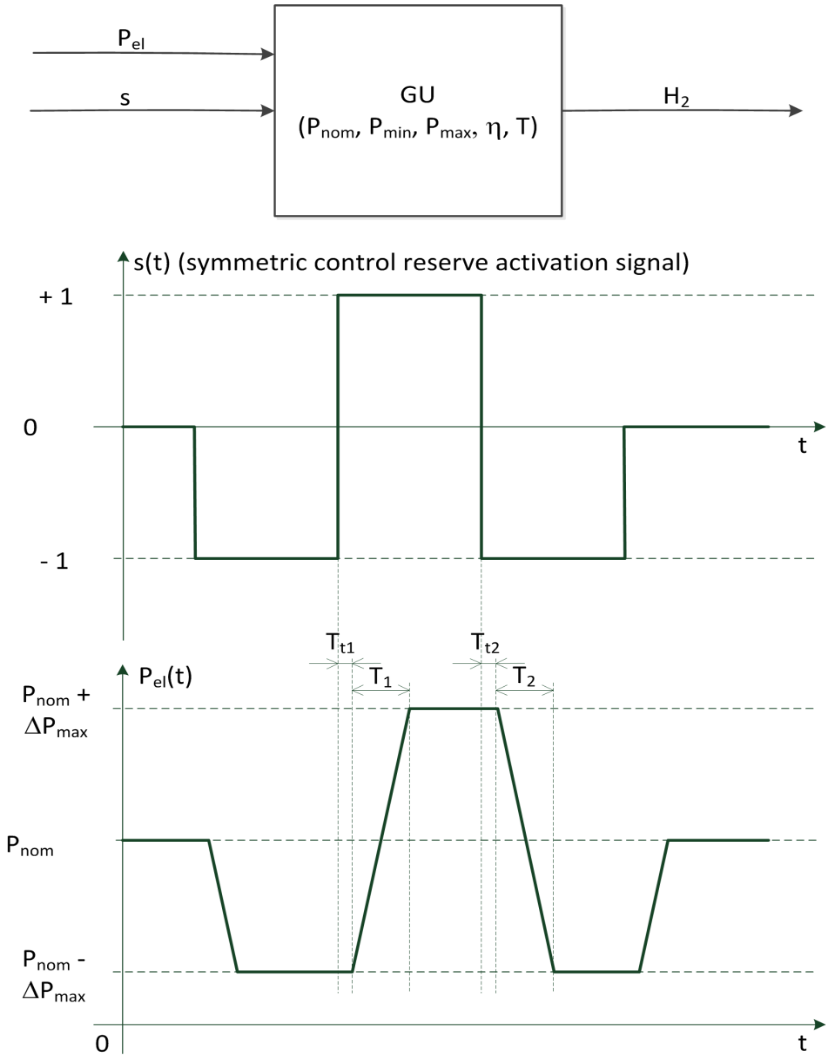

Figure 4: Simplified model of a water electrolyser applied to the SCR and TCR markets. The water electrolyser is considered as a technical unit with the inputs P_{el} (electrical power) and s (control reserve activation signal). Other inputs are considered irrelelvant in our context. Considered parameters of the water electrolyser are defined in Table 1. Furthermore SCR and TCR operation require online monitoring of P_{el} (10s values), offline

monitoring (10s values for TCR and 2s values for SCR) and a remotly controllable activation signal s(t).

Table 1: Parameters relevant to the operation of a model water electrolyser in the SCR and TCR markets.

Parameter	***Variable***	***Model value***	***Swiss TSO requirement (SCR)***
Electrical power consumption	P_{el}		
Nominal electrical power	$P_{el} = P_{nom}$	1MW	
Power flexibility offered to the ASP	ΔP_{max} (symmetric, i.e. $P_{nom} - \Delta P_{max} \leq P_{el} \leq P_{nom} + \Delta P_{max}$)	0.6 * Pnom	≥ 5MW (for the ASP portfolio)
Ramp up dead time	T_{t1}	$T_{t1} \approx 0$ (supplier data)	< 20s
Ramp down dead time	T_{t2}	$T_{t2} \approx 0$ (supplier data)	< 20s
Ramp up time	T_1	$T_1 < 100$ms (supplier data)	< 75s (simplified)
Ramp down time	T_2	$T_2 < 100$ms (supplier data)	< 75s (simplified)

Possible hurdles and constraints

The water electrolyser operator needs to consider a number of possible challenges and factors when setting up a participation in the SCR and TCR markets. Cost factors associated with providing control reserve can be found in Table 2. Even though margins in the SCR are generally higher than for TCR products, water electrolyser operators may favor the latter as it provides the opportunity to set control energy prices independently, covering operational- and opportunity cost.

Table 2: Cost factors to be considered (adapted from [7])

Criterion	***Description***
Subsidies	Do control reserve activations cause losses in subsidies?
Loss of production	Does control reserve activation cause a reduction in production volume, which cannot be made up for at a later point in time?
Loss of profit due to trading	Is it likely to experience loss of profit on other energy trading platforms due to reserve control activation?
Cost associated to operational dynamics	Does additional cost occur due to reserve control activation (e.g. additional wear and tear)?
Quality cost	Does additional cost occur to provide a predefined quality level?
Stand-by cost	Does control reserve activation lead to cost associated with e.g. human resources or resource consumption to maintain a certain operation temperature?
Energy cost	Does control reserve activation lead to additional energy cost, i.e. due to efficiency decrease?
Power peaks	Does control reserve activation cause additional power peaks? Peak loads can occur during control reserve activation if units are required to ramp up. The tariffs for peak loads are managed by the grid operator. The tariffs can vary significantly between different grid operators.

Investment	Is investment required in order to join the control reserve market (e.g. control system, communication system, remote control, testing)?

Furthermore provision of control reserve can lead to additional risks for water electrolyser operators, as summarized in Table 3.

Table 3: Risk factors to be considered (adapted from [7])

Criterion	***Description***
Penalties	Can contract-based penalties be inflicted (e.g. due to missed production goals)?
Liability / Follow-up cost	Can the water electrolyser operator be made liable for damages caused to third parties? Can customers be lost due to e.g. delivery delays?
Reliability of operation	How reliable is the equipment in case of control reserve operations? Retrofits of technical units and adaptations of the unit control can lead to initial difficulties during the commissioning of new operating modes.
Further relevant risks / PESTEL	Are there further relevant risks associated with the political, economical, sociological, technical, legal and ecological environment known?

Table 4 lists factors to be considered during the evalution of the potential of a water electrolyser for the provision of control reserve. The first seven criteria deal with the controllability of production. The remaining criteria focus on the quality of the electric power.

Table 4: Factors determining the control reserve potential (adapted from [7])

Criterion	**Description**
Operating hours / control reserve period	Over which period is a certain operating state held constant (e.g. from daily 07.30 until 17.30)?
Regularity / operating scheme	Are there regularities in the operation of a unit in case it does not run 24/7 (e.g. annually, monthly, weekly, daily)? How many operating hours occur annually and are there maintenance periods scheduled during the year?
Buffers / storage size	How large is the storage for the hydrogen produced? What time span can be compensated with that storage? Can the production be resumed at a later point in time? If yes, what is the maximum delay period?
Delivery period	What are the delivery periods for the hyrogen produced?
Planning security of production	How well can the operation be scheduled? How long in advance can the schedule be set up? How well can the operation schedule be adhered?
Remote controllability	Is remote control of the unit possible? Is the control process already automated?
Deterministic, controllable power	How large is the non-stochastic, controllable electrical power, which can be considered for providing control reserves?

Value contribution of water electrolysers to the SCR and TCR markets

Possible operation schemes of water electrolysers as participants in virtual power plants are manifold. The ASP is responsible for the operation of the pool of technical units, and is free to decide on the activation scheme. In particular the ASP may build a merit order list placing units with higher operation and opportunity cost towards the end of the list.

In order to determine the value of flexibility a water electrolyser can provide in the Swiss SCR and TCR markets, we consider two typical business cases as examples: once a water electrolyser operated with the parameters given in Table 5 for SCR, and once a water electrolyser operated with the parameters given in Table 6 for positive TCR.

Table 5: Cost factors of the model water electrolyser offering SCR

Parameter	Name	Value	Comment
Control reserve product		SCR	
ASP operation scheme		Linear	No merit order within the unit pool
Nominal electrical power	P_{nom}	1MW	Before compensation for η_{red}
Power flexibility offered to the ASP	ΔP_{max}	600kW	Symmetric
Bid price			
Annual hours offered	T_{offer}	8'000h	Hours offered to the market
Annual hours called	T_{call}	7'864h	Hours awarded, maximising the product of price and quantity
Average efficiency reduction due to control reserve provision	η_{red}	3%	Average efficiency reduction during calls. Example value
Weighted average cost of capital	WACC	5% p.a.	Examle value
ASP primium of the income from the SCR business	ASP prime	20%	Estimate based on experience; for control reserve and energy
Initial cost: installation and commissioning of water electrolyser base configuration with P_{nom}	I_{00}	2'000'000CHF	Example value
Initial cost: CR specific functionality connection and commissioning	I_{01}	5'000CHF	Support the control signal and provide 2s metering values; estimate based on experience
Compensation for η_{red}: Increased unit size and increased annual energy consumption	P_{nom2} E_{Loss}	$(1+\eta_{red})*P_{nom}$ $\eta_{red}*P_{nom}*T_{call}$	Compensation of losses by increasing P_{nom}, which implies higher initial cost and higher average energy consumption
Energy tariff	c_E	43.82CHF/MWh	40.30€/MWh, SwissIX average 2015, day ahead base [11]. 1€=1.0875CHF (2015-12-31)
Grid connection configuration		Own consumption	No grid tariffs, fees or power peak tariffs apply if the water electrolyser is at the same location as the power generator
Administrative effort		1'000CHF p.a.	Estimate based on experience

Table 6: Cost factors of the model water electrolyser offering positive TCR (week)

Parameter	Name	Value	Comment
Control reserve product		Positive TCR (week)	On-demand power reduction
ASP operation scheme		Merit order	According to control energy price
Nominal electrical power	P_{nom}	1MW	Before compensation for positive TCR call losses
Power flexibility offered to the ASP	ΔP_{max}	600kW	Asymmetric
Annual hours offered,	T_{R_offer}	8'000h	Control reserve hours offered

Parameter	Name	Value	Comment
control reserve			
Annual hours called, control reserve	T_{R_call}	4’633h	Control reserve hours awarded, maximising the product of price and quantity
Annual hours called, control energy	T_{E_call}	60h	Example value. For 2015 this results in an average control energy price of 188.6CHF/MWh, which approximately maximises the revenue [9]
Average efficiency reduction due to control reserve provision	η_{red}	6%	Efficiency reduction during calls, where the water electrolyser operates at the max. control level. Example value
Weighted average cost of capital	WACC	5% p.a.	Examle value
ASP primium of the income from the TCR business	ASP prime	20%	Estimate based on experience; for control reserve and energy
Initial cost: installation and commissioning of water electrolyser base configuration with P_{nom}	I_{00}	2’000’000CHF	Example value
Initial cost: CR specific functionality connection and commissioning	I_{01}	5’000CHF	Support the control signal and provide 2s metering values; upper limit experience value
Compensation for positive TCR call losses: Increased unit size and increased annual energy consumption	P_{nom2} E_{Loss}	$P_{nom} + \Delta P_{max}/(1-\eta_{red})*T_{E\ call}/T_{R\ offer}$ $(P_{nom2}-\Delta P_{max})*T_{E\_call}*\eta_{red}$	Compensation of losses by increasing P_{nom}, which implies higher initial cost and higher average energy consumption
Energy tariff	c_E	43.82CHF/MWh	40.30€/MWh, SwissIX average 2015, day ahead base [11]. 1€=1.0875CHF (2015-12-31)
Grid connection configuration		Own consumption	No grid tariffs, fees or power peak tariffs apply if the water electrolyser is at the same location as the power generator
Administrative effort		1’000CHF p.a.	Estimate based on experience

Making use of the toolset in [9] the offered control reserve prices are calculated ex post, such that the revenue on the control reserve market is maximized, where it’s assumed that the control reserve is offered at constant prices throughout the year. This explains why the annual hours awarded (T_{call}, T_{R_call}) are below the annual hours offered (T_{offer}, T_{R_offer}). Calculations are done from the investor’s point of view: it’s assumed that a potential reduction in hydrogen production due to the balancing service activities needs to be compensated through an increase of the nominal power P_{nom} of the water electrolyser unit. This explains why the investment of the two cases in Figure 5 differ, and why hydrogen prices don’t show up in the calculations.

In the SCR case the water electrolyser delivers symmetrical control energy for more than T_{call} = 7’864 hours per year. During this time we account for an average efficiency reduction η_{red} of 3%, which is compensated by an increment of nominal power by about

2.9% = η_{red} * T_{call}/T_{offer}, leading to corrresponding initial cost. The assumed value of η_{red} bases on unpublished data from equipment providers and considers the fact that the Swissgrid control signal s(t) (Figure 4) for SCR is proportional to the grid frequency deviation, which means that most time the water electrolyser is operated at power levels with small efficiency reductions. At the same time the efficiency reduction leads to inefficient use of energy provided, which is considered as energy losses adding E_{Loss} * c_E = CHF10'339 to the annual operation cost.
In the TCR case the water electrolyser delivers asymmetrical control energy for T_{E_call} = 60 hours per year only. Although the efficiency reduction during the call times is much higher (η_{red} = 6%, TCR calls are at full amplitude), the very short call time T_{E_call} limits the impact on hydrogen losses. Again losses are compensated by increasing the nominal power of the water electrolyser and are considered as energy losses in the annual operation cost calculation.
The result of the two business case examples is shown in Figure 5. The case postive TRL (week) profits from the fact that control energy can be offered in a separate auction at a fairly good price. On the other hand, SRL (symmetric) achieves better reserve prices. Both cases suffers from a productivity reduction, leading to higher initial and operational cost in order to compensate for the reduction in the hydrogen production efficiency.

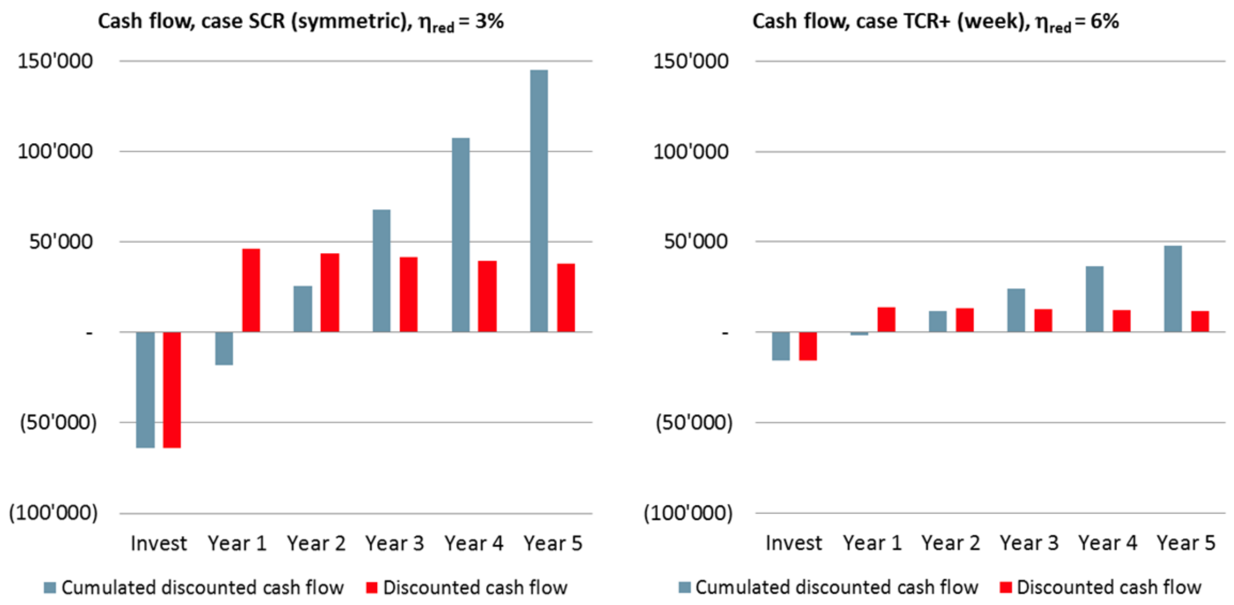

Figure 5: Cash flow of SCR and positive TCR (week) cases as defined in Tables 5 and 6, based on 2015 prices of the Swiss SCR and TCR markets. The examples are calculated with the toolset given in [9] at constant control reserve bid prices (for SCR and positive TCR) and constant energy bid prices (for positive TCR)

The relative impact of different factors on the 5-year results for SCR and positive TCR is shown in Figure 6. For SCR, changes in annual operation hours and efficiency reduction have the strongest impact. For positive TCR (week) the impact of annual operation hours clearly exceeds the other effects because the energy bid price is set very high, reducing the annual operation hours for control energy to as little as 60h (which is near the optimal operation point for this case). Due to the fact that losses in hydrogen production are compensated through an increase in the nominal power of the unit, the impacts of hydrogen price and hydrogen production volume are not seen.

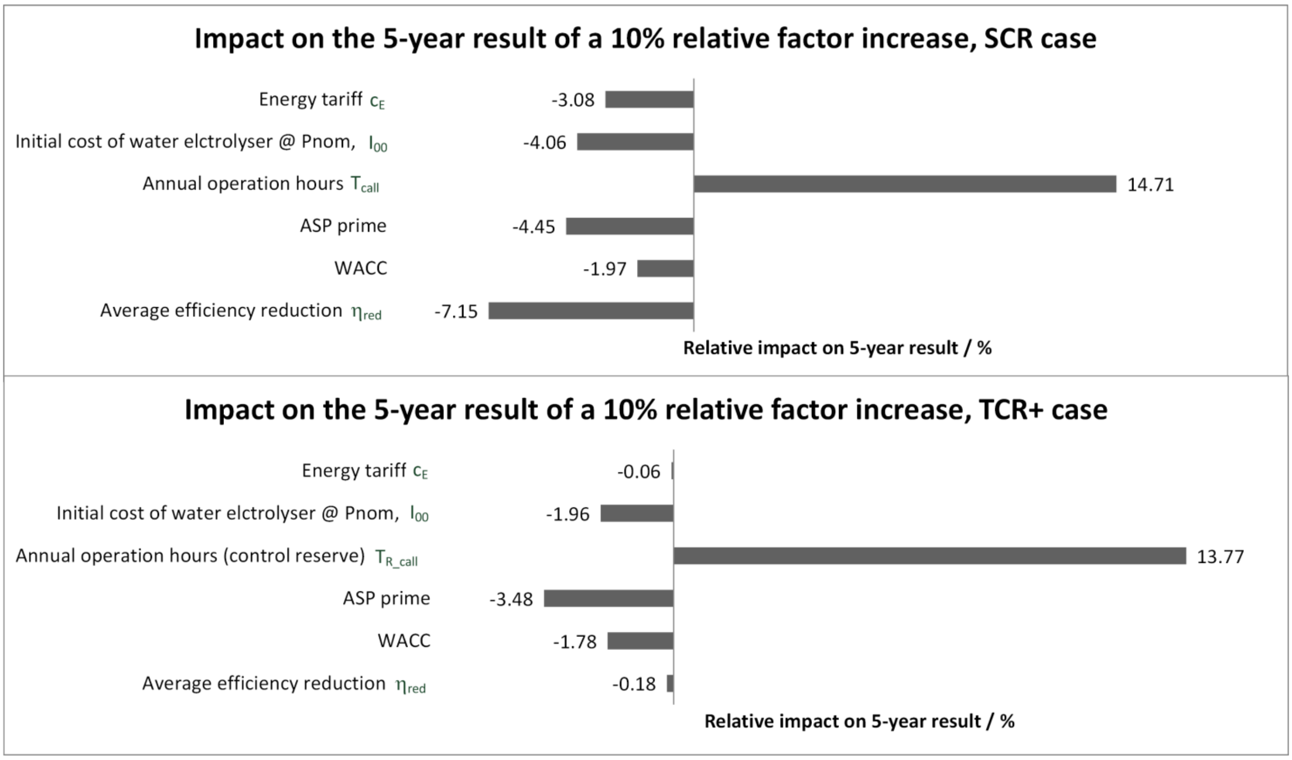

Figure 6: Sensitivity of cost factors on the 5-year result of water electrolysers applied to the business case examples according to Table 5 for SCR, and Table 6 for positive TCR (week)

4. Conclusion

Technical units such as water electrolysers can profitably contribute to the Swiss balancing service markets, making use of the aggregator model. As in the TCR case the units can participate on the market with very few hours of control energy delivery, factors such as energy tariff and efficiency reduction are of minor relevance. On the other hand, the more profitable SCR case is limited by exactly these factors if the ASP directly forwards the TSO's call signal, which means the water electrolyser permanently operates outside its optimal operation point. The calculations base on a general model of water electrolysers. The conditions of specific water electrolyser products may differ. These as well as other European markets will further be evaluated in the course of the FCH research project *Standardized qualifying tests of electrolysers for grid services* QualyGridS. There a consortium of three product suppliers and seven institutions address technical and commercial issues of the application of different types of water electrolysers to the grid service markets for different European states.

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