elyntegration

Grid Integrated Multi Megawatt High Pressure Alkaline
Electrolysers for Energy Applications

Assessment of the regulatory framework and end-user/customer

DELIVERABLE 2.1

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Content

Figures

Tables

1 EXECUTIVE SUMMARY

The research and innovation project “Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications” (ELYntegration) is focused on the design and engineering of a robust, flexible, efficient and cost-competitive electrolyser. To meet technical and economical requirements, a commercial deployment of an electrolyser has to take into account a lot of steps. This deliverable focused on the clarification of the end-user’s requirements in the areas grid connection, regulatory framework and grid services.

The deliverable shows that the technical requirements of grid disturbances are not to be seen as critical and solutions for grid disturbance issues are state of the art. Furthermore the deliverable presents that the national regulatory frameworks affect the price elements. Therefore, the possible business models have to be investigated in each county individually. For example, in Germany it is necessary to consider possible exemptions for electrolysers from use of system charges, RES subsidy surcharge and the electricity tax. Finally, the deliverable investigates if grid services could be a business model for electrolysers. Depending on the service, the electrolyser design has to consider these additional technical requirements such as ramping abilities.

2 OBJECTIVES

The research and innovation project “Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications” is focused on the design and engineering of a robust, flexible, efficient and cost-competitive single stack Multi Megawatt High Pressure Alkaline Water Electrolysis (hereafter referred to as electrolyser). To meet technical and economical requirements, a commercial deployment of an electrolyser has to take into account following key steps:

- Clarify the end-user requirements and potential business models
- Define technical specifications of future electrolysers so that its exploitation can provide financial incomes
- Reduce electrolyser costs of Ownership and achieve highly competitive CAPEX

This deliverable focuses the first part of the first point: The Assessment of the regulatory framework and end-user/customer. Even the analysis of this part represents a complex challenge. The second part of the first point and the other points are later edited by other work packages of this project and published in future Deliverables.

From the simple perspective from an electricity grid, an electrolyser is a customer who uses the grid to consume electricity. For the connection the grid operator defines a technical framework.

Furthermore, the European Electricity Markets are liberalised. This means that the electricity networks have to be independent companies. Due to the natural monopoly of electricity grids, they are regulated by government agencies. Therefore, the connection tariffs for electrolysers are affected by the regulatory framework. This affects in further steps the potential of possible business models. Thus, this deliverable considers the technical framework and the regulatory framework.

The electricity world is more and more dominated by intermittent renewable energy sources (wind and solar). Today scenarios with a surplus of electricity generation rarely occur, but in the near future and distant future the probability for these scenarios increases. Therefore, the electricity grid needs additional consumption or Energy Storage Systems (ESS). For example, an electrolyser could provide this consumption as a grid service. Also other grid services are imaginable. As the grid operators have to pay for grid services, the technical requirements to provide grid services are also important for the evaluation of potential business models.

Therefore, this deliverable works on three areas and has to formulate the associated objectives:

- Grid connection
- Regulatory framework
- Grid services

2.1 Grid Connection

The first objective is the grid connection. This analyses the standards for electricity grid connections. The first important question is of course where to connect an electrolyser with a consumption of almost 10 MW electricity. Which voltage level is necessary or which voltage level is expected? As the voltage level is fixed, the deliverable analyses the technical framework. Especially the question, what grid disturbances by customer facilities have to be considered?

2.2 Regulatory Framework

The regulatory framework influences the connection tariffs. For example the grid charges or subsidies for renewable energies or ESS could be different from country to country, or even inexistent in the case of the subsidies. Therefore, the main question is, which cost has to be expected in which country? The answer to this question is very important for the identification of business models in the next steps of the project.

2.3 Grid Services

As grid services could be useful or necessary for grid operators in the near or distant future, electrolyser could participate and provide some kind of services. As this also could be a potential business model, the deliverable analyses the technical requirements for grid services. Especially the question, which extra requirements have to be met to provide grid services as an additional business model?

3 DESCRIPTION OF WORK

As chapter 2 introduces, this deliverable has three objectives:

- Grid connection
- Regulatory framework
- Grid services

Therefore, this chapter analyses the three objectives.

3.1 Grid Connection

When assessing all requirements needed to pave the way for the future deployment of electrolysers, an essential part are technical requirements that electrolysers need to fulfil for grid connection. At first, it needs to be determined to which voltage level an electrolyser of several megawatt is most likely to be connected. This enables to identify which kind of system operator is to be contacted for grid connection and thus which technical requirements apply. Technical requirements for end users are mainly connected to limitations on the effect of grid disturbances. After a short overview on the relevant grid codes, end user requirements for reducing grid disturbances like rapid voltage changes, flicker, harmonics, voltage phase unbalances, commutation notches, audio-frequency centralised ripple control and grid voltage drops are addressed. For each grid disturbance, an assessment on its relevance for the grid connection of electrolysers is undertaken and it is analysed to what extent these requirements might impose critical challenges for grid connection. Appropriate countermeasures are presented. Finally, reactive power compensation requirements are depicted.

3.1.1 Voltage level

The voltage level to which the electrolyser is to be connected is essential. Apart from determining which grid operator has to be approached for a request of grid connection, it defines which technical requirements for grid connection apply. The costs for grid connection and use of system charges are also dependent on the voltage level (see section 3.2.2). Consequently, the voltage level is relevant for the efficiency of business models.

The grid connection point of a new customer and therefore its voltage level is determined individually by the grid operator based on the grid impedance at the junction point, the maximum power and the type of the customer. Table 1 shows reference values for the connection voltage level in dependence of the maximum power of a customer exemplary for grid operators Westnetz GmbH and Unión Fenosa Distribución respectively Red Eléctrica de España (REE). Westnetz GmbH is the largest German distribution grid operator supplying more than 7 million people with electricity [1] [1]. Unión Fenosa is a Spanish distribution grid operator, that together with Iberdrola Distribución, Endesa Distribución, HC Energía and E.ON Distribución España are the main Spanish DSOs that supply electricity to more than 95% of the population. Red Eléctrica de España is the Spanish transmission grid operator. The other grid operators within Germany and Spain use similar reference values.

The aim of this project is the development of an electrolyser with a maximum power of 9.2 MW. The electrolyser is therefore to be connected either to the medium voltage grid or directly to a high voltage/medium voltage substation. Therefore, the assessment of grid connection is concentrated on the medium voltage level in this Deliverable.

Connection voltage level	**Maximum annual power**	
	Westnetz GmbH	Unión Fenosa & REE
Low voltage grid	< 85 kVA	50 kVA
Medium voltage/low voltage substation	< 200 kVA	50 kVA – 450 kVA
Medium voltage grid	200 kVA – 5.5 MVA	250 kVA – 10 MVA
High voltage/medium voltage substation	3 MVA – 15 MVA	1 MVA – 12 MVA
High voltage grid	Individual specification	> 10 MVA

Table 1. Example of DSO classification of connection power ranges to voltage level [1] [2]

3.1.2 Grid disturbances in general

Customer facilities impose disturbances on the power system to which they are connected. In order to limit these disturbances to an appropriate level, grid operators establish technical requirements. The end user has fulfilled these requirements. Otherwise, the operator of the customer facility has to take countermeasures.

On European level, the grid codes on electromagnetic compatibility IEC 61000-3-3 [3], IEC 61000-3-6 [4] and IEC 61000-3-7 [5] formulate emission limits for the connection of distorting and fluctuating installations to medium and high voltage power systems. National grid codes are generally aligned with these European grid codes. The guideline “Technical Conditions for Connection to the medium-voltage network” by the German Association of Energy and Water Industries (BDEW) is used as a reference for German distribution grid operators [6]. Since the BDEW guideline is not binding, each grid operator is allowed to adapt the specifications to their own needs. Spanish guidelines are defined in case of the distribution grids by the Spanish distribution grid operators individually. However, their specifications are similar. REE as transmission grid operator in Spain is responsible for the management of the connexion to the high voltage grid (400 kV and 220 kV, and 220 kV, 132 kV and 66 kV in the insular grid system). The guideline for the connection to the high voltage power grid (>220 kV) is the “Guía descriptiva del procedimiento de conexión a la red” [7].

The following sections depict and analyse the relevant grid whether they are critical for an electrolyser as a customer facility.

3.1.3 Rapid Voltage Changes

Strong and fast load changes within seconds lead to rapid voltage changes at the connection point. These often occur during switch-on of large motors, welding sets and electric arc furnaces. According to German grid codes, the maximum permissible rapid voltage change is 2 % of the rated voltage [6], within Spain the limit is set to 7 % of the rated voltage [8].

Since for electrolysers no strong and fast load changes occur, rapid voltage changes do not impose critical restrictions for electrolysers. Therefore, the corresponding grid codes for rapid voltage changes are not relevant for the design of the grid connection of electrolysers.

3.1.4 Flicker

Flicker phenomena are characterised by voltage fluctuations with certain frequencies and large enough amplitudes leading to visible fluctuating lighting densities for electric lamps. In order to reduce the impairment of illumination, grid connection codes prescribe limits for maximum admissible flicker strengths by customer facilities. The flicker strength is defined as a value that expresses the susceptibility of the human eye for luminosity variation of a 60 W lamp with tungsten wire as a result of voltage variations.

Since flicker reduction by use of compensating condensers is state of the art, this technical requirement is not critical for grid connection of electrolysers. When designing the grid connection for electrolysers, appropriate compensation devices need to be included.

3.1.5 Harmonics

Due to the switching characteristic of power electronic converters, customer facilities with power electronic equipment inject harmonic currents at the grid connection point inducing harmonic voltages within the grid. These harmonic voltages are seen at each connection point of the grid and impair the sinusoidal waveform with the fundamental frequency of 50 Hz. Figure 1 shows an exemplary voltage waveform impaired by harmonics of third and fifth order. In order to reduce the impairment of the phase voltages, the grid codes define upper limits for the harmonic current injection per customer facility.

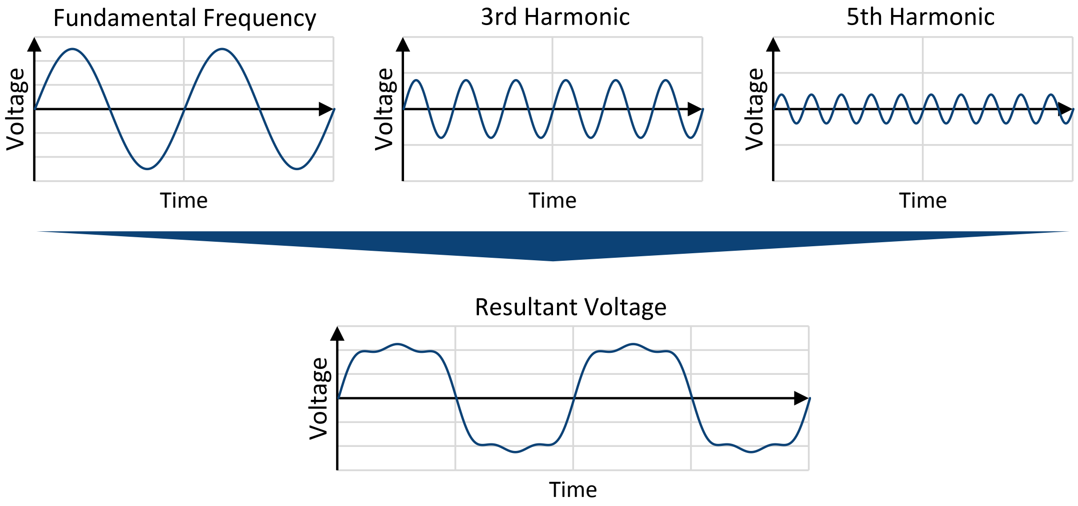

Figure 1. Schematic display of harmonic distortion of phase voltage

Due to their power electronics interface, electrolysers impose harmonics on the power system and compliance of harmonic current injection limits need to be observed and assured. Countermeasures such as higher-pulse switching mode of the voltage source converter based power electronic interface and appropriate applications filtering the harmonics are available and state of the art. When planning the grid connection for electrolysers, these countermeasures need to be considered.

3.1.6 Voltage phase Unbalances

Within a three-phase power system, the voltages of all three phases should ideally be symmetrical. That means that the voltage of each phase should have the same magnitude and the angle between two phase voltages should always be 120 degrees. A deviation from these symmetrical conditions is called voltage phase unbalance.

Voltage phase unbalances are caused by single-phase or asymmetrical three-phase loads. Typical loads with these characteristics are customer facilities like induction furnaces, arc furnaces and welding machines. The grid codes define upper limits for the resultant degree of unbalance by each customer facility.

Since electrolysers with a maximum power consumption of several megawatt are equipped with a three-phase power electronic connection, voltage phase unbalances are not critical for the grid connection of electrolysers.

3.1.7 Commutation Notches

Commutation notches are characterized by abrupt and large voltage drops for a fraction of line frequency cycle. These notches occur for line-commutated converters due to the switching of its thyristors. During the commutation process all thyristors of both commutating phases are conducting thus shorting both phase voltages through the line reactance. This results in abrupt voltage deviations from the sinusoidal waveform of the standard 50 Hz power system frequency during the commutation intervals. Figure 2 shows schematically the AC voltage of one phase of a three-phase, full-bridge, six-pulse converter for two line frequency cycles.

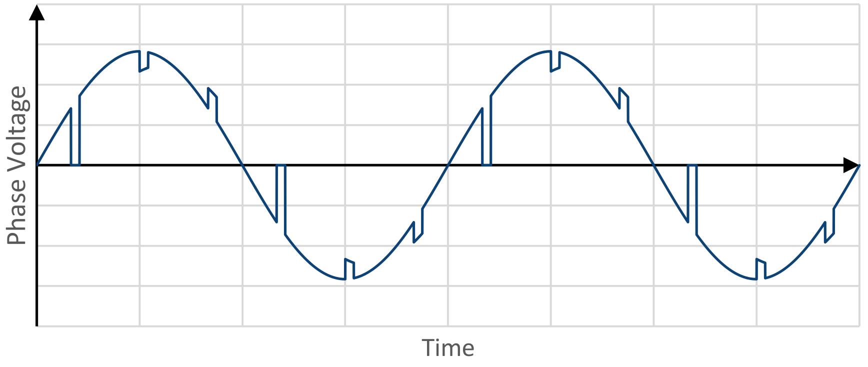

Figure 2. Schematic display of commutation notches for a three-phase line-commutated converter topologies [9]

As electrolysers are usually connected to the grid via a voltage source based power electronic converter, commutation notches do not occur for electrolyser applications. The corresponding grid codes are therefore only relevant for grid connection of electrolysers if line-commutated power electronic interfaces are used.

3.1.8 Audio-Frequency Centralised Ripple-Control

Several distribution grid operators within Europe use audio-frequency centralised ripple control in order to control loads and generating units connected to their grid. One example is the switching of streetlamps at morning and evening. As communication path, the existing electricity grid is used. Within this concept, a control signal with a higher-frequency than the standard 50 Hz is superimposed. Loads and generating units are equipped with receivers that filter out these control signals. The consumption respectively the feed-in are adapted accordingly.

In case a distribution grid operator uses audio-frequency centralised ripple control, according to the grid codes he is allowed to prescribe measures to be taken by the customer in order to avoid impairment of the control signals. The customer is obliged to design its filter applications accordingly.

Due to the power electronic converter for grid connection of electrolysers, filter applications need to be installed. Improper impairment of audio-frequency centralised ripple control by these filter applications needs to be addressed. However, countermeasures are state of the art. Therefore, these countermeasures are to be included in the design and planning process of the grid connection of electrolysers.

3.1.9 Grid Voltage Drop

A grid voltage drop is defined as sudden decrease in tension (between 90 % and 1 % of rated voltage) followed by its reset after a short period of time (10 ms to 1 min). These grid voltage drops are usually caused by grid disturbances like short circuits, e.g. in cases when a branch of a tree touches a high voltage line resulting in an arc discharge.

For the connection of electrolysers to the grid, its power electronic interface must be able to deal with these grid voltage drops without any damage.

3.1.10 Reactive Power Compensation

Reactive power compensation of customer facilities is needed in order to prevent an improper impairment of the voltage profile by the customer facility within the grid. Within Germany, the grid code allows the displacement factor $\cos(\varphi)$ of a customer facility to be between 0.9 inductive and 0.9 capacitive. Distribution grid operators are allowed to introduce stricter limits for their grids. In case displacement factors outside these limits occur, countermeasures like compensation devices need to be implemented. Within Spain, no strict limits for the displacement factor of customer facilities are defined. Spanish distribution grid operators introduce a supplement cost depending on the value of displacement factor for all customer facilities with power consumption larger than 15 kW [10].

For the grid connection of electrolysers, requirements for reactive power compensation are easily met due to the voltage source converter design of the power electronic interface.

3.1.11 Interim Conclusion

Multi megawatt electrolysers are most likely to be connected to medium voltage level or directly to the high voltage/medium voltage substations. For the grid connection, grid codes of medium and high voltage level apply. Technical requirements concerning the restriction of grid disturbances are not expected to be critical. Because of its load behaviour, rapid voltage changes are no critical restrictions for an electrolyser. The same applies to voltage phase unbalances and commutation notches due to its three-phase grid connection via voltage source converter. For all other technical requirements being relevant, appropriate countermeasures exist and are state of the art due to the switching characteristics of the power electronic interface. Due to the voltage source converter characteristic of the power electronics interface, the reactive power can be set independently from the active power consumption of the electrolyser thus enabling a reactive power compensation in accordance with all grid codes.

3.2 Regulatory Framework

The electrolyser has to pay the electricity price. This has a substantial influence on the expenditure of the electrolyser operator and therefore impacts the efficiency of possible business models crucially. Therefore, an overview of the composition of consumer prices for electricity is given at first. After that, it is presented under which conditions electrolysers can be exempted from certain price elements like use of system charges, RES subsidy surcharge and electricity tax.

3.2.1 Composition of Consumer Price of Electricity

For the consumption of electric energy, electrolysers have to pay an electricity price that is usually significantly higher than the wholesale price determined at the electricity markets. Apart from the wholesale price, other components of the electricity price to be paid by the electrolyser are charges for sales, for grid usage and grid connection as well as taxes and other charges.

Figure 3 gives an overview of the elements of the final electricity price seen by end users. The costs for energy and supply are covered by a wholesale and a retail component. The wholesale price results from the marginal price of generation plants that are in operation, which consist mainly of operational expenditures e.g. for fuel. The wholesale price is determined at the spot markets by clearing processes at the different European energy exchanges. The retail element covers costs related to the sale of energy products to end users like domestic consumers and industrial consumers. The transmission and distribution grid cost elements (use of system charges) include infrastructure costs, system services, grid losses and other charges. In addition to energy and supply and network costs, the consumer has to pay taxes and levies. These can be broken down into general taxes to be paid in order to finance the general public budget like value added tax (VAT) and levies and charges that are earmarked to certain energy or other policy measures like environmental taxes [11].

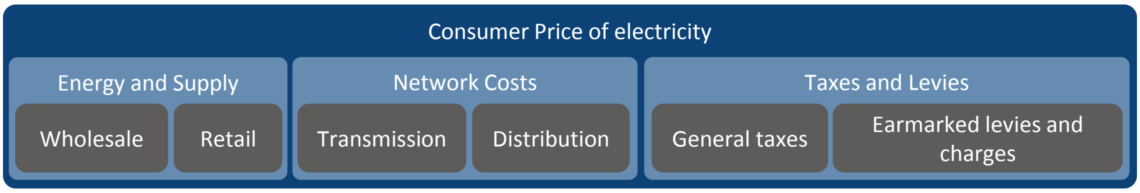

Figure 3. Electricity price elements for end users [11]

The height of the different price elements differ within Europe depending on the regulatory framework of each country. The Statistical Office of the European Communities (Eurostat) collets data on industrial and domestic end-user prices according to directive 2008/92/EC for each member of the European country broken down into its different elements [12]. Figure 4 depicts the average price components seen by domestic consumers with a yearly consumption between 2.5 MWh and 5.0 MWh for selected European countries for year 2014.

Due to the increasing harmonization of European internal energy markets, the difference between the wholesale prices is moderate. However, based on individual national regulatory frameworks, the amount and height of additional price elements to be paid by end users differ significantly for the examined countries. The resulting overall electricity price for domestic consumers shows not only significant differences within Europe but is also considerably higher than the wholesale price. Within Germany and Italy, the difference between end user price and wholesale price is highest. Here, domestic consumers pay a price nine times higher than the wholesale market price. In countries with a low spread between end user and wholesale price like in Poland, the price for domestic consumers is still three times higher than the wholesale price.

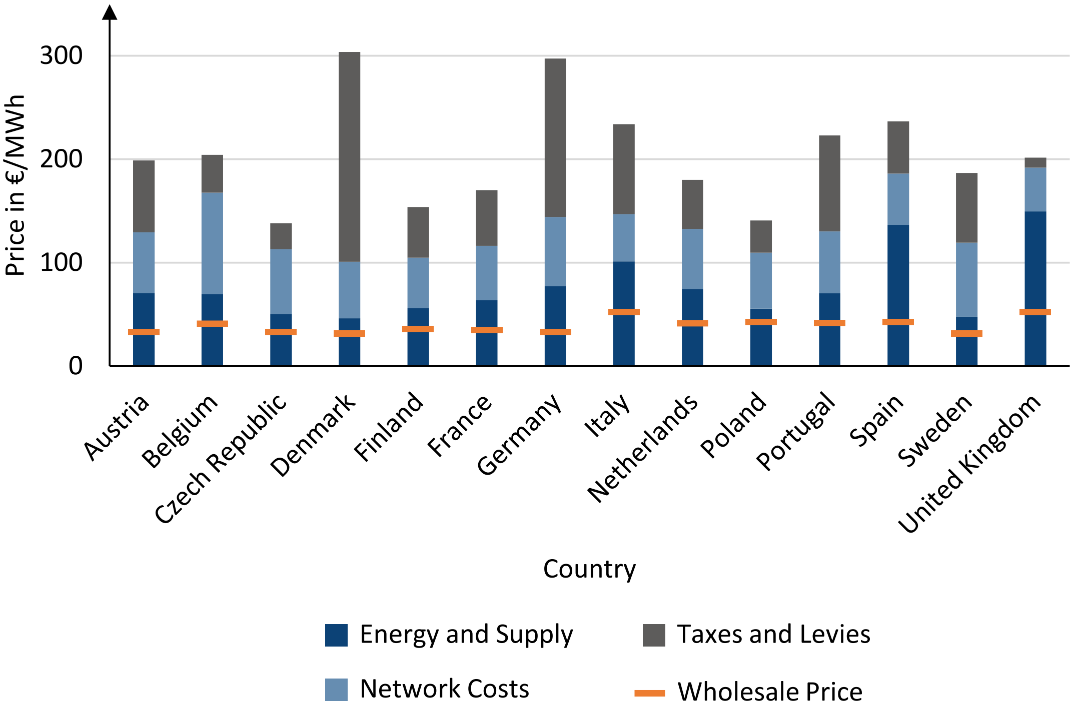

Figure 4: Average electricity prices and their break down into components for domestic consumers (2.5 MWh – 5.0 MWh) in 2014 by country [13] [14] [15] [16]

Figure 5 depicts the average price components seen by industrial consumers with a yearly consumption between 20 MWh and 500 MWh for selected European countries for year 2014. A comparison with electricity prices for domestic consumers (Figure 4) shows that industrial consumers generally face lower end user prices than domestic consumers. Figure 6 depicts the average price components for industrial consumers with a yearly consumption between 20 GWh and 70 GWh. It can be seen that industrial consumers with this consumption face even lower end user prices. This is mainly due to reduced network costs and the retail prices.

The strategic goal of ELYntegration project is the design of a multi megawatt electrolyser. Assuming an electrolyser size of 10 MW and full load hours of at least 2,000 hours per year results in a yearly consumption of at least 20 GWh. Consequently, for such an electrolyser design end user price components depicted in Figure 6 are most likely to be relevant.

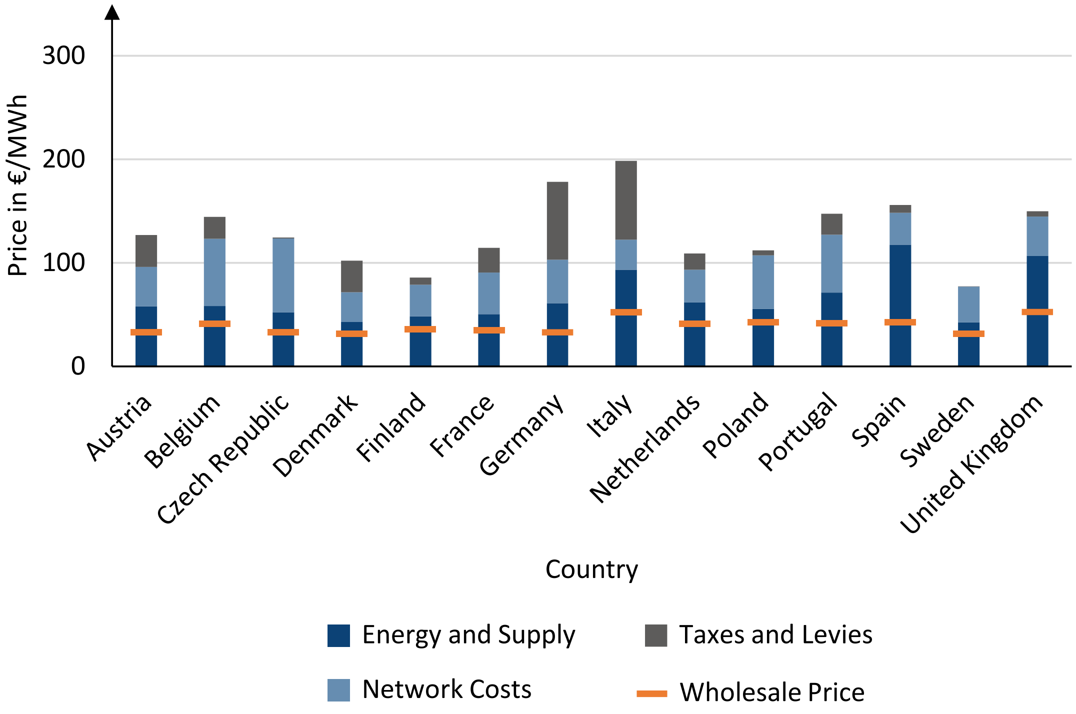

Figure 5: Average electricity prices and their break down into components for industrial consumers (20 MWh – 500 MWh) in 2014 by country [13] [14] [15] [16]

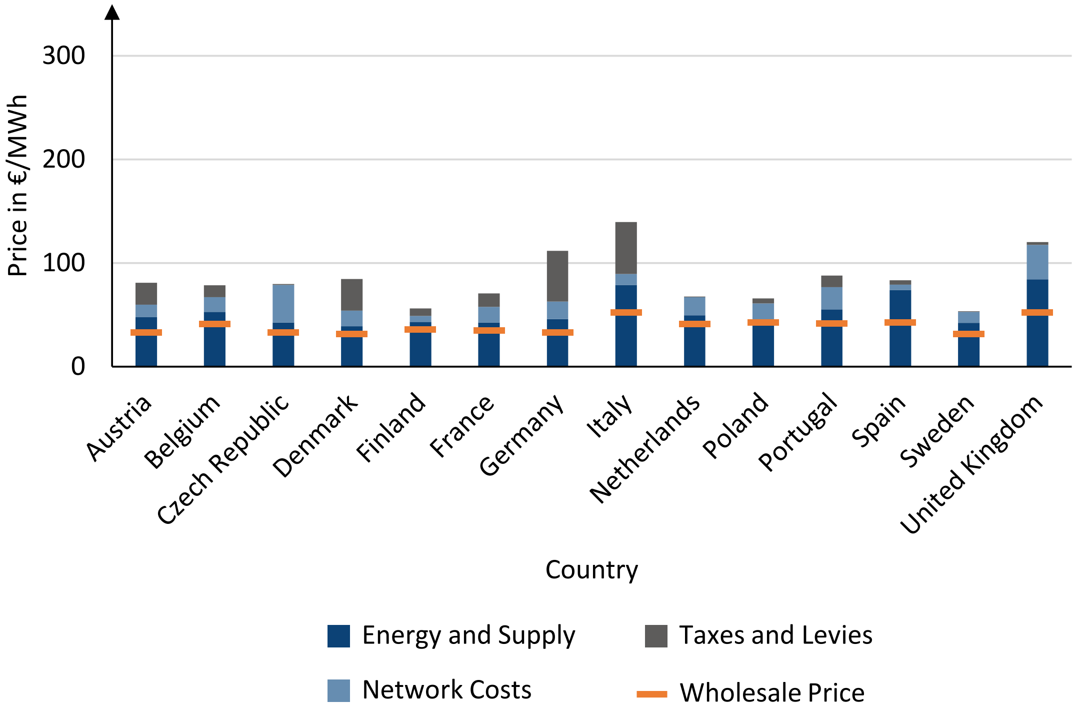

Figure 6: Average electricity prices and their break down into components for industrial consumers (20 GWh – 70 GWh) in 2014 by country [13] [14] [15] [16]

Since the height of end user prices is highly relevant for the efficiency of potential business models for an electrolyser, for a proper evaluation not only the wholesale price of each country has to be taken into account but also the regulatory framework differentiated by country. High taxes and levies or use of system charges are expected to have a negative impact on the economic efficiency. Within some countries, electrolysers are exempted from certain taxes or charges. Therefore, it is necessary to clarify in which countries and to what extent a reduction of the end user price is to be expected for electrolysers. The definition of electrolysers as an industrial consumer instead of a domestic consumer may also reduce the end user price.

3.2.2 Use of System Charges

The use of system charges covers the costs for operating and maintaining a safe and reliable transmission and distribution system. They are paid by the end users to the transmission and distribution system operators who have to take appropriate measures within grid expansion planning (e.g. new power lines) as well as operation planning (e.g. redispatch) to secure a safe and reliable system. Within most European countries, these charges are independent of the geographical distance between power injection and consumption. The height of the charges depends on the grid area as well as the voltage level to which the end user is connected.

Figure 7 shows the use of system charges for end users with a registered power measurement exemplarily for the German distribution grid operator Westnetz GmbH. According to § 12 StromNZV, this applies for all end users with an annual consumption of electrical energy of more than 100 MWh. The use of system charges are divided into a price for the maximum power consumption of the end user and price for the annual consumed energy. The height of power and energy price is dependent on the full load hours and the voltage level for grid connection. Independent of the full load hours, all end users face lower prices for both power and energy with a higher voltage level.

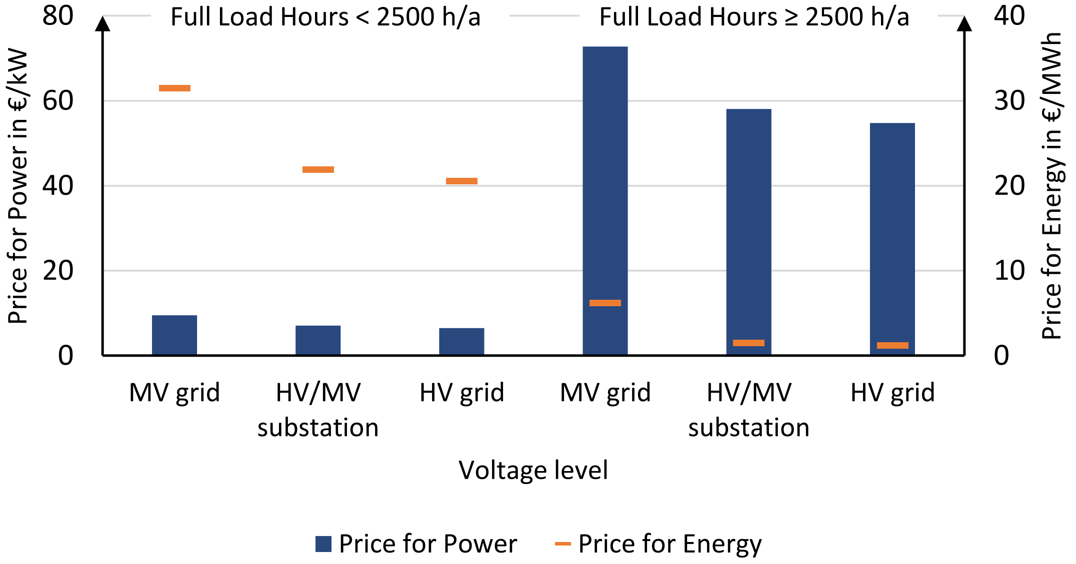

Figure 7. Use of system charges for end users with registered power measurement [17]

Especially the increased share of renewable energy sources in the power system has a mayor influence on the network costs. A suitable operation of electrolysers as a storage unit for electrical energy can loosen the stress of the transmission and distribution grid induced by the feed-in of renewable energy sources. Consequently, electrolysers can reduce the need for grid expansion respectively operation planning measures and thus reduce the network costs.

Therefore, within Germany, electrolysers are exempted from use of system charges under specific circumstances. The conditions for an exemption are defined within the Energy Industry Act (§ 118 EnWG). Electrolysers that are installed within the period between 04.08.2011 and 04.08.2026 are exempted from use of system charges for a period of 20 years. The legal position on the question if the exemption from use of system charges also includes the exemption from other charges that are defined as an additional charge on top of the use of system charges is still unclear. This includes the apportionment for combined heat and power (§ 9 KWKG), the apportionment for liability of offshore wind power plants (§ 17 EnWG), the concession fee and the apportionment according to § 19 StromNEV.

Within other European countries, e.g. in Spain, there is no distinction between electrolysers and regular consumers. An exemption from use of system charges is therefore currently not possible.

3.2.3 RES Subsidy Surcharge

Within Germany, the RES subsidy surcharge is an apportionment for the promotion of the exploitation of renewable energy sources to be paid through the end user price for electricity. This surcharge is specified within the Renewable Energy Law (§ 61 EEG). As storage units for electrical energy, electrolysers are exempted from the RES subsidy surcharge if the electrolyser hydrogen or methane is used for storage purposes only and used temporally delayed for feed-in into the electric grid (§ 60 EEG). Electrolysers are also exempted from the subsidy charge if the electrolyser is located within the vicinity of RES power plants and the supply of electricity is done without usage of the public transmission or distribution grid.

Within other European countries, subsidy surcharges also apply for all electric energy storage systems. Therefore, electrolysers are currently not exempted from the RES subsidy surcharge.

3.2.4 Electricity Tax

The electricity tax was originally introduced in Germany in order to increase the electricity price for consumers aiming at a reduction of electric energy consumption. Exemptions for electrolysers from this tax are regulated within the electricity tax law (StromStG). According to § 9 StromStG, storage units are exempted from the electricity tax if the electric energy consumed by the storage unit is supplied by RES power plants or the consumption is connected to RES power plants within close vicinity of the storage unit and the rated power of the storage unit is less than 2 MW. The electricity tax is also not applied, if the unit is used solely for storage purposes and the stored energy is fed into the electric grid temporally delayed. According to § 9 StromStG, electrolysers are additionally exempted from the electricity tax in case of industrial consumers.

Within other European countries, in terms of electricity tax there is currently no special treatment for energy storage systems and electrolysers are not exempted.

3.2.5 Interim Conclusion

For the determination and evaluation of potential business models, the electricity price for the electrolyser is essential. It is therefore not sufficient to investigate the wholesale price determined at the electricity markets since the end user prices can be up to nine times higher due to payments for supply, use of system charges and taxes and levies. These price elements are highly dependent on the national regulatory framework. Consequently, the end user prices within European countries differ significantly. The efficiency of potential business models for electrolysers is therefore not only dependent on the wholesale prices but also on the regulatory framework in each country. For Germany, it is necessary to consider possible exemptions for electrolysers from user of system charges, RES subsidy surcharge and the electricity tax. Within other European countries, there are currently no exemptions for electrolysers available.

3.3 Grid services

In order to maintain a stable and reliable system operation, transmission system operators provide grid services which include frequency stability through control reserve and grid congestion management such as redispatch. Furthermore, distribution system operators account for a stable distribution grid operation, which as well relies on grid services. Transmission system operators and distribution system operators represent possible customers for electrolyser applications if the electrolyser can comply with requirements during operation. Those applications may include different types of control reserve, substitution for redispatch interventions and possibly services for stabilising distribution grids. In order to assess the suitability of electrolysers for different services, regulatory and technical requirements will be analysed in the following sections. Besides an overview of different possible commitments, an analysis of the specific situation in Germany and further details about requirements in Spain and other important European countries is conducted.

3.3.1 Control Reserve

Frequency deviations are balanced by control reserve, which means that suitable technical units provide positive and negative reserve by raising or lowering their generation or consumption when necessary. The following section gives an overview of the different types of control reserve in Europe. The detailed conditions in national reserve markets decide whether a participation is possible for electrolysers. Thus, the current situation with details about electrolyser and consumer participation and details about activation requirements are analysed as well as an outlook to possible future market developments is given. A more detailed analysis of technical requirements for providing control reserve is provided in sections 3.3.2 and 3.3.3.

Current Situation

The European control areas are currently structured by national policies, which differ in their market design. Overall, the reserve market can be divided into four common types of control reserve, which correspond in their functions but show differences in their precise arrangement for example in activation time. Figure 8 shows the succession of the different types of control reserves, which are consecutively activated after a disturbance.

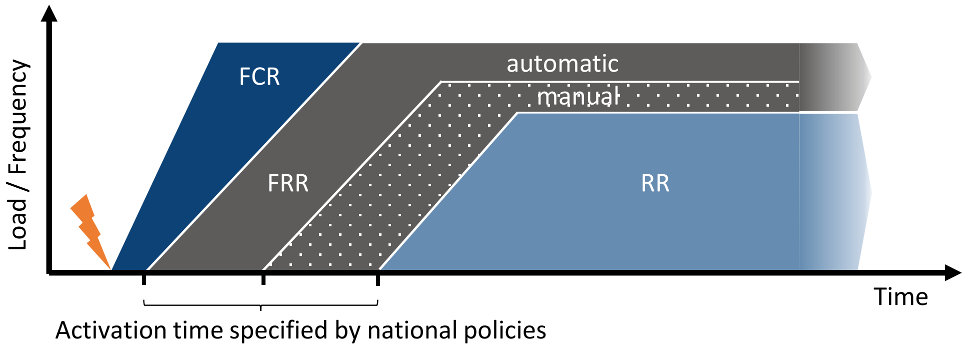

Figure 8. Consecutive activation of different types of control reserve

The Frequency Containment Reserve (FCR) is used for balancing within seconds. In Germany for example, the required activation time is below 30 s [18]. This means that Frequency Containment Reserve requires a very fast reacting reserve, usually a spinning reserve, which then is not suitable for provision by electrolysers. Subsequently, the automatic Frequency Restoration Reserve (aFRR) follows, which is used for automatic short term balancing of frequency deviations, then followed by the manual Frequency Restoration Reserve (mFRR), which is manually activated if deviations are continuing. Furthermore, some countries contract the Replacement Reserve (RR), which follows in order to replace capacities if an outage is continuing further on. In Germany, the automatic Frequency Restoration Reserve has to be fully activated within 5 minutes, and manual Frequency Restoration Reserve has an activation time of 15 minutes [18]. Both might be suitable business models, so prequalification requirements will be analysed later on. Activation times for other European countries are summarised in Table 2. The Spanish market for example is similarly arranged with three types of control reserve with a lot of identical properties. While the Frequency Containment Reserve and the manual Frequency Restoration Reserve require the same activation time as in Germany, the automatic Frequency Restoration Reserve has to be activated within 30 s [19, 20]. This ramping requirement might pose an obstacle for the technical suitability of electrolysers. From a technical view, the manual Frequency Restoration Reserve might be provided by electrolysers in Spain.

Besides technical requirements, the regulatory side plays an important role for electrolyser market participation. For the commitment of electrolysers in reserve markets, it is crucial that the market is opened to electricity customers. Consumer participation is considered in terms of demand response policies. The objective of promoting demand response is mentioned within the European Network Codes [21] and the European Commission’s Energy Union Communication [22], but so far some European countries fail to acknowledge and accept the technological field in control reserve markets.

Table 2 provides a review of European countries in terms of acceptance of demand response in reserve markets, the acceptance of aggregated loads and details about activation times for countries which accept electrolysers for reserve markets.

Country	Notation	Participation	Participation by agg. loads	Activation time	Tenders
Austria, Germany, Switzerland	FCR	✓	✓	30 s	weekly
	aFRR	✓	✓	5 min	weekly
	mFRR	✓	✓	15 min	4 hours
	RR	-	-	-	-
Belgium	FCR	✓*	✓*	15 - 30 s	annual
	aFRR	✗	✗	-	
	mFRR	✓*	✓*	3 - 15 min	
	RR	✗	✗	-	
Denmark	FCR	✓	✓	30 - 150 s	N/A
	aFRR	✓	✓	15 min	N/A
	mFRR	✓	✓	N/A	N/A
	RR	✓	✓	N/A	N/A
Finland	FCR	✓	✓	inst. - 3 min	annual
	aFRR	✓	✓	2 min	annual
	mFRR	✓	✓	15 min	N/A
	RR	✓	✓	15 min	N/A
France	FCR	✓	✓	< 30 s	flexible
	aFRR	✓	✓	< 15 min	
	mFRR	✓	✓	13 min	
	RR	✓	✓	30 min - 2 hrs	
Great Britain	FCR	✓	✓	2 s	flexible but long-term (e.g. daily weekday participation)
	aFRR	✓	✓	2 min	
	mFRR	-	-	-	
	RR	✓	✓	2- 4 hours	
Ireland, Italy, Poland, Spain	FCR	✗	✗	-	-
	aFRR	✗	✗	-	
	mFRR	✗	✗	-	
	RR	✗	✗	-	
Netherlands	FCR	✗	✗	-	
	aFRR	✓	✗	N/A	annual
	mFRR	✓	✗	N/A	voluntary bids
	RR	-	-	-	-
Norway	FCR	✓	✓	5 - 30 s	hourly, weekly
	aFRR	✓	✓	2 min	weekly
	mFRR	✓	✓	15 min	weekly, seasonal
	RR	✗	✗	-	-
Slovenia	FCR	✓	✗	N/A	annual
	aFRR	✓	✗	N/A	
	mFRR	✓	✓	15 min	
	RR	-	-	-	
Sweden	FCR	✓	✓	5 s - 3 min	daily
	aFRR	✓	✓	2 min	weekly
	mFRR	✓	✓	15 min	hourly
	RR	✓	✓	15 min	yearly

* partially accepted

✓	Demand Response accepted	✗	Demand response not accepted
-	Reserve does not apply	N/A	Information not available

Table 2. Demand response and activation time for control reserve in European countries [18, 19, 20, 23]

As of now, countries that accept consumers and thus electrolysers as participants are Austria, Denmark, Finland, France, Germany, Great Britain, Switzerland and Sweden. Countries that accept demand response for selected types of control reserve are Belgium, the Netherlands, Norway and Slovenia. Not accepted as control market bidders are electrolysers in Ireland, Italy, Poland and Spain [23]. The acceptance of aggregated loads indicates whether small units can participate in markets by pooling arrangements if they fail to reach required minimum lots on their own. For example, in Germany the minimum lot is +/- 1 MW for Frequency Control Reserve and 5 MW for Frequency Restoration Reserve [18]. Further influence on market participation of electrolysers has the length of tenders, as short tenders allow flexibility in business models with electrolysers dispatch reacting to electricity prices. They will be analysed in the following sections.

Future Development

The development of control reserve specifications in the next years is relevant for the identification of end-user requirements, as electrolysers should meet required specifications during their entire operating period of several years. To some extent, future developments can be derived from recent trends.

In Europe, harmonisation efforts by European transmission system operators are made, which aim to share balancing resources between countries and to develop cross border balancing markets [24, 25]. In consideration of these efforts, homogenous types of control reserve might develop in the future. So far, a definite time frame for the development and detailed design of control reserve specifications cannot be distinctly defined. Thus, national developments may be used to indicate recent trends.

In Germany, time frames, tenders and minimum lots for different control reserve types have undergone considerable changes. Within the last few years, the reduction of minimum lots, the acceptance of pooling of units for reaching minimum lots with small units, as well as the acceptance of electricity customers as bidders are recent developments that opened the markets to new participants. Furthermore, the time frame for which procurement is conducted has become shorter. The two types of Frequency Restoration Reserve used to be procured every half year until the release of the Transmission Code 2007, currently it is a daily procedure for automatic Frequency Restoration Reserve and a weekly procedure for manual Frequency Restoration Reserve [18]. The same tendency can be observed for shortened tenders [26]. Those tendencies are likely to proceed in the future, leading to even shorter time frames and tenders and opening markets to multiple participants. In Spain on the other hand, the acceptance of electricity customers such as electrolysers as bidders on control reserve markets is currently the main obstacle for establishing new business models in that field and the future development is not yet foreseeable. Currently the national power system is over capacitated, with high shares of manageable power plants based on natural gas operating less than 1000 hours per year, and with an inadequate regulatory framework to promote renewable energies. With this context the necessity to increase the power reserve is limited and pumped heat electrical storage seems to be a good solution in the short term. A change in the politics with renewable energies in Spain can change the situation in the mid-term.

To summarize, the developments in Europe are currently not on the same level and national distinctions are still a decisive factor. With increasing harmonisation, short tenders and open markets for electricity customers, a market participation of electrolysers would become easier. Still, countries should be carefully chosen for electrolyser placement because a few markets do not promise the development of accepting electrolysers for reserve control, e.g. Spain. However, a possible market harmonisation with a decrease of differences between European countries as well as short tenders and open and connected markets would also imply a reduction of demand and balancing costs and an enhancement of security of supply. For electrolysers, this would result in a higher competition, lower prices on reserve markets and lower contribution margins.

3.3.2 Automatic Frequency Restoration Reserve

As automatic Frequency Restoration Reserve may identify as a possible future business model for electrolysers, the technical requirements for market participation are further analysed.

Generally, the prequalification procedure ensures the technical suitability of technical units and the security of supply. Only successfully prequalified units are approved to participate in the control power market. In order to examine the prequalification process in further detail, an exemplary analysis of the German prequalification procedure is conducted in the following. It is to be expected that the procedure is generally related in other European countries, but differences occur in detailed specifications. For example, an important technical feature which differs depending on the country is the ramping ability. For European countries which accept demand response, it can be derived for different types of control reserve from activation times as shown in Table 2.

The main prerequisites for participation in any German control reserve market can be divided into technical and organisational requirements and requirements for instrumentation and control. The most important technical requirements are summarized in Table 3.

General ramping requirement	at least 2 % of nominal power per minute
Technical reliability	> 95 %
Activation and control	automatic activation online by TSO or pooling operator
Tender	one week
Operating mode	Regulation not explicit, possibly continuous synchronization for entire tender
Activation time	< 5 min

Table 3. Technical requirements for automatic Frequency Restoration Reserve in Germany [18]

It is generally required that the units participating as automatic Frequency Restoration Reserve have a ramping ability of at least 2 % of nominal power and that units can be automatically activated online by the transmission system operator or the pooling provider. A technical reliability of at least 95 % is required, which has to be verified for the time period of the tender [18].

Concerning the operating mode, the regulatory instructions are not explicit for electrolysers, as regulation distinguishes between thermal and hydraulic units and electrolysers can't be clearly assigned to one of the two categories. Generally, technical units have to remain synchronized to the grid for the entire time of the tender, which is one week, in order to ensure provision of services. For hydraulic units, an exemption is possible if the ramping ability is at least 2 % of the nominal power per second and the power ramp time is below 5 minutes [18]. If a continuous operation is required, this amounts to an exclusion of electrolysers as market participants, because with current prices, a week long continuous electricity procurement without price consideration would lead to high deficits.

The activation time of 5 minutes refers to the time in which the full prequalified power needs to be available in both power directions. For evidence, an operation schedule as exemplary displayed in Figure 9 has to be completed.

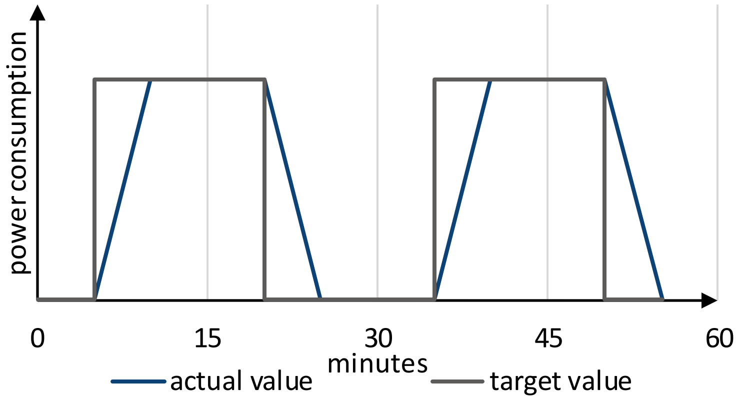

Figure 9. Ramping protocol for automatic Frequency Restoration Reserve in Germany [18]

The operation protocol proves that the unit is able to ramp up to maximal prequalified power within 5 minutes, maintain power for a given amount of time and ramp down to initial power within 5 minutes. A possible delay time of the unit, displayed in Figure 10, is included within the ramping time. This test has to be successfully completed twice within one hour. During the test, a brief overshoot of at most 5 % of the target value but at most 5 MW is permitted. The performance has to be reproducible. [18]

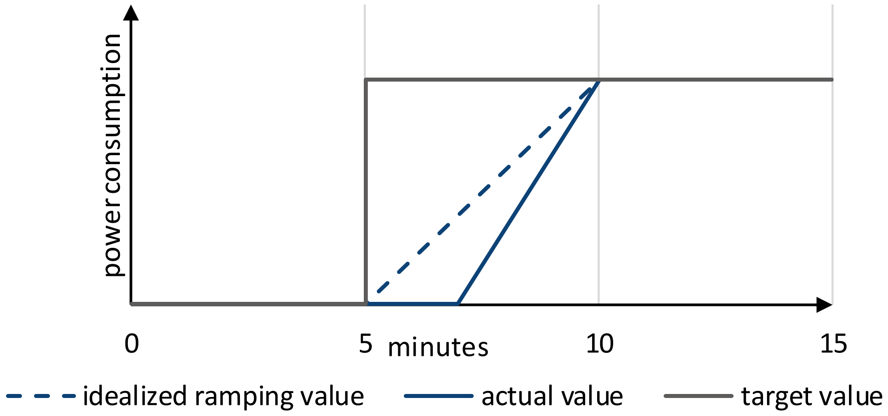

Figure 10. Accepted delay time for automatic Restoration Reserve in Germany [18]

Technical requirements furthermore include grid connection specifications, with state that no technical units that are affected by grid restrictions can be prequalified and that if the unit is not connected to the transmission grid, the respective distribution system operator has to sign an agreement for the provision of reserve control. [18]

Concerning instrumentation and control, requirements for automatic Frequency Restoration Reserve are comparatively high, because the automatic activation and online observation is conducted. This includes a redundant data connection, point-to-point-connection, a control cycle time of at most 4 seconds, a telecontrol protocol and a spontaneous transmission of reports. The transmitted technical data contains the actual generation and operating point of each unit, desired value and actual value of control power at the time, status information (on/off) and upper and lower limits of the control power range. [18]

On an organisational level, if pooling is conducted, the pooling provider verifies the qualification of the pool for providing the respective reserve in addition to the prequalification tests for the technical suitability for individual units. Furthermore, confirmations e.g. of compliance with directives for reserve control by the supplier of a balancing group and by the operator have to be supplied. [18]

In summary, the technical suitability of electrolysers for providing automatic Frequency Restoration Reserve has to be proven during a prequalification procedure. The most important technical requirement concerns ramping abilities. Control power has to be fully available within 2 to 5 minutes, sometimes 15 minutes depending on the considered country. Furthermore, automatic control by reserve operators is mandatory, which leads to extensive requirements for instrumentation and control.

3.3.3 Manual Frequency Restoration Reserve

Manual Frequency Restoration Reserve requires lower ramping abilities, typically around 15 minutes. The prequalification procedure generally follows the same process as for automatic Frequency Restoration Reserve. For that reason, only main differences in requirements are specified in the following with focus being on the German regulations in order to give a specific example. Requirements concerning organisational requirements, pooling and grid connection do not differ from automatic Frequency Restoration Reserve.

Table 4 lists the technical requirement for manual Frequency Restoration Reserve. As the notation suggests, manual Frequency Restoration Reserve prequalification only demands manual activation done via telephone so online controllability is not necessary. For instrumentation and control, this implies lower requirements so that no detailed connection specification but only the transmission of information such as actual generation, provided control power, desired value of control power and actual value of control power and status information is listed [18].

General ramping requirement	no general requirement
Activation and control	manual activation by telephone
Tender	4 hours
Operating mode	no requirement of continuous synchronization
Activation time	< 15 min
Technical reliability	> 100 %

Table 4. Technical requirements for manual Frequency Restoration Reserve in Germany [18]

Tenders for manual Frequency Restoration Reserve are 4 hours, so a lot shorter than tenders for automatic Frequency Restoration Reserve [18]. Short tenders enable a flexible market participation for bidders so their commitment may react for example to spot market prices. Also, as the activation time is longer on this market, units are not required to react as quickly as for automatic Frequency Restoration Reserve. This implies that there is no general requirement for general ramping speed or for continuous synchronization for the time of the tender. The activation time is set at < 15 minutes for full availability of the reserve power output. For evidence, an operational protocol as in Figure 11 has to be submitted that proves that ramping was successfully completed twice within two hours. The technical reliability of mFRR units is required to be 100 %, it can be ensured by pooling bids [18].

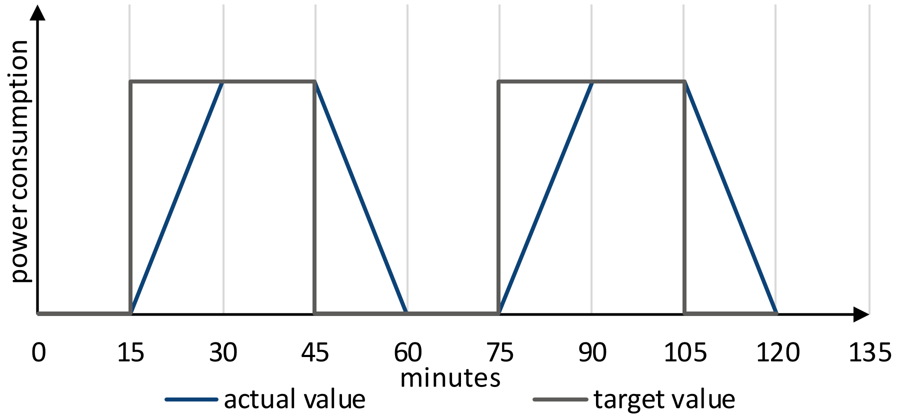

Figure 11. Operational protocol for automatic Frequency Restoration Reserve in Germany [18]

To conclude, a successful prequalification for manual Frequency Restoration Reserve requires lower technical abilities from electrolysers, because activation times are longer with around 15 minutes and thus lower ramping abilities are necessary. Also, a manual activation of the electrolyser is intended so requirements for instrumentation and control are modest.

3.3.4 Distribution Grid Services

Distribution grid services may be a possible electrolyser application. Electrolysers can be used for relieving distribution grid congestions which happen with an increased frequency due to higher infeed by renewables energy systems. Depending on the future development, even an extensive application of storage units such as electrolysers in distribution grids might be possible if this proves to be an economically efficient option. However, the application of electrolysers in distribution grids is a fairly new development and it isn’t established within policies or regulations yet. Thus, definite technical requirements by distribution system operators couldn’t be identified, as well as there is no regulated compensation established.

Generally, a flexible operation is essential for effective smoothing of feed-in peaks that cause congestions. Thus, a high tolerance for a flexible mode of operation and good ramping characteristics are necessary for successfully providing distribution grid services.

3.3.5 Interim Conclusion

Grid services present different options as possible business models for electrolysers. Opportunities may be in transmission grid services and distribution grid services. Both are regulated on national levels, so individual regulations in European countries have to be taken into consideration. For the provision of control reserve as a transmission grid service, technical requirements such as ramping abilities have to be considered for assessing the technical suitability of electrolysers. From that aspect, automatic and manual Frequency Restoration Reserve present promising markets. In order to participate in those markets, countries have to accept electrolysers as consumers as market participants. This is not yet given in all European countries. Another transmission grid service option for electrolysers is redispatch. There, no explicitly defined technical requirements exist, but a flexible operation ability is necessary. Distribution grid services aren't commonly established yet, so no strictly defined requirements exist, but again a flexible operation will be obligatory in order to complete the task of congestion reliefs.

4 CONCLUSIONS

The research and innovation project “Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications” is focused on the design and engineering of a robust, flexible, efficient and cost-competitive electrolyser. To meet technical and economical requirements, a commercial deployment of an electrolyser has to take into account a lot of steps. This deliverable focused the clarification of the end-user’s requirements.

From the simple perspective from an electricity grid, an electrolyser is a customer who uses the grid to consume electricity and has to meet a technical framework from the grid operator. Furthermore the regulatory framework affects the end-user requirements. Especially, in case of new business models.

Therefore, this deliverable worked on three areas:

- Grid connection
- Regulatory framework
- Grid services

For the grid connection, technical requirements concerning the restriction of grid disturbances are not expected to be critical. Because of its load behaviour rapid voltage changes and due to its three-phase grid connection via voltage source converter voltage phase unbalances and commutation notches are no critical restrictions for an electrolyser. For all other technical requirements being relevant due to the switching characteristics of the power electronic interface appropriate countermeasures exist and are state of the art. Due to the voltage source converter characteristic of the power electronics interface, the reactive power can be set independently from the active power consumption of the electrolyser thus enabling a reactive power compensation in accordance with all grid codes.

The electricity end user price for the electrolyser is essential. The individual price elements are highly dependent on the national regulatory framework. Consequently, the end user prices within European countries differ significantly. The efficiency of potential business models for electrolysers is therefore not only dependent on the wholesale prices but also on the regulatory framework in each country. For example, in Germany it is necessary to consider possible exemptions for electrolysers from use of system charges, RES subsidy surcharge and the electricity tax.

Additional, business models may be in transmission grid services and distribution grid services. Both are regulated on national levels, so individual regulations in European countries have to be taken into consideration. For the provision control reserve as a transmission grid service, technical requirements such as ramping abilities have to be considered for assessing the technical suitability of electrolysers. From that aspect, automatic and manual Frequency Restoration Reserve presents promising markets. In order to participate in those markets, countries have to accept electrolysers as consumers as market participants. Another transmission grid service option for electrolysers is redispatch or distribution grid services. There are no strictly defined requirements, yet.

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