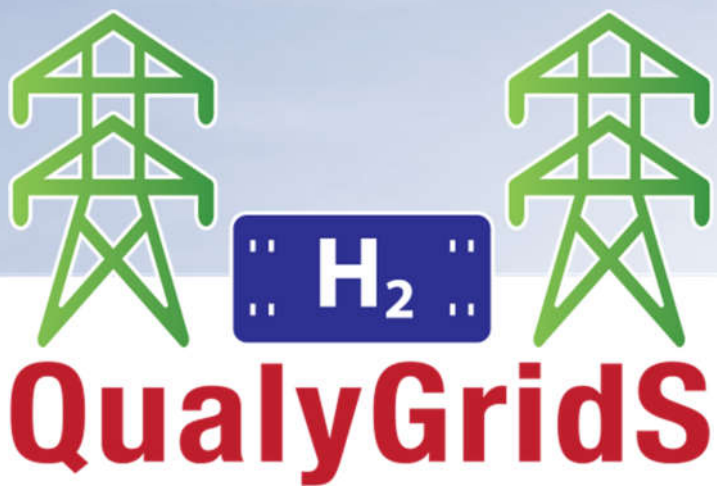

Deliverable Report

Updated KPIs for electrolysers performing grid services

(D2.2)

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Abbreviations and Indices

Abbreviation	Explanation
KPI	Key Performance Indicator
PPI	Primary performance indicator
SPI	Secondary performance indicator
MAWP	Multi Annual Work Plan

1 Summary

This report investigates the performance indicators for electrolysers performing grid services as defined in the testing protocols and derived from the economic analysis in the project QualyGridS. It selects the three primary performance indicators that determine if or if not an electrolyser can do the most relevant electricity grid services. It then compares these primary performance indicators to the KPIs defined by FCH-JU in their MAWP and makes a link between the primary performance indicators for grid services and the FCH-JU KPIs. Target numbers for the primary performance indicators are given and primary performance indicators that cannot be derived from the FCH-JU KIPs are identified.
These are the primary performance indicators of electrolysers for grid services suggested by QualyGridS: (Table 1)

PPI	Description	Target value	Related FCH-JU KPI
1	Dynamics: Ramp duration for step power change t_{full}	10 (30)* sec	KPI 5: H_2 production electrolysis, hot start from min to max power. Target 2 sec
2a	Stability in constant power sections in %:	<5%	No corresponding KPI
2b	Ramp precision: percentage of data points outside the defined range	0-5%	No corresponding KPI
3	Reliability	>99%	No corresponding KPI

* 10 seconds are only needed for one specialized service in the Nordic grids. In most cases 30 sec is enough if also the requirements in FCR second test are fulfilled.

2 Introduction

The currently valid KPIs for electrolysers as published in the MAWP 2014-2020 involve energy consumption, CAPEX and efficiency degradation. Optional targets consider operating flexibility and cold/hot startup times to reach maximum power. Also indicators describing and quantifying flexibility and/or reactivity, such as:

- Operating range: 0 – 200% of nominal power
- Ramping time from minimum to maximum power: < 2 seconds
- Ramping time from maximum to minimum power: < 2 seconds
- Cold start time (from 0 to minimum power): < 30 seconds

are defined. Based on the protocols from Task 2.1 and the experimental validation in WP 3 and WP 4 these indicators will be reviewed. Updated KPIs are provided by the consortium and needed new indicators are suggested in order to reflect the requirements for MW scale electrolysers best.

3 The Background

Key Performance indicators relevant for electrolysers were defined by FCH2-JU in their Multi-Annual-workplan[9]:

[9] *http://www.fch.europa.eu/sites/default/files/FCH2%20JU%20-%20Multi%20Annual%20Work%20Plan%20-%20MAWP%20(ID%20623483).pdf*

Table 2 State-of-the-art and future targets for Hydrogen production from renewable electricity for energy storage and grid balancing from MAWP2014-2020 (* corrected for 30 bar hydrogen output pressure)

No.	KPI description	State-of the-art 2012	2017	2020	2023
KPI 1	H_2 production electrolysis, energy consumption (kWh/kg)@rated power*	57-60 @ 100 kg/d	55 @ 500 kg/d	52 @ 1000+ kg/d	50 @ 1000+ kg/d
KPI 2	H_2 production electrolysis, CAPEX @ rated power including ancillary equipments and commissioning	8.0 M€/(t/d)	3.7 M€/(t/d)	2.0 M€/(t/d)	1.5 M€/(t/d)
KPI 3	H_2 production electrolysis, efficiency degradation @ rated power and considering 8000 h operation / year	2% - 4% / year	2% / year	1.5% / year	<1% / year
KPI 4	H_2 production electrolysis, flexibility with the degradation < 2% year (refer to KPI 3)	5% - 100% of nominal power	5%-150% of nominal power	0% – 200% of nominal power	0% - 300% of nominal power
KPI 5	H_2 production electrolysis, hot start from min to max power (refer to KPI 4)	1 minute	10 sec	2 sec	< 1 sec
	H_2 production electrolysis, cold start	5 minutes	2 minutes	30 sec	10 sec

Besides these more electrolyser properties are classified as KPI in the annual data collection by FCH-JU. These are

- catalysts, catalyst loading, catalyst loading per Watt
- stack CAPEX per kW, system CAPEX
- minimal current density,

4 Deliverable within the Project QualyGridS

This deliverable summarizes the work of Task 2.4 Extracting KPIs and considering the context of previously defined KPIs.

The deliverable is submitted with quite some delay as compared to the project plan. However in the testing protocols, especially the second draft testing protocols D2.4 performance indicators as derived from the tests and relevant for grid services as well as their target values have already been suggested. However to finally define performance indicators as relevant for grid services the experimental validation of the second draft of testing protocols and the economic evaluation in the project had to be waited for. This report is now delivered at the end of the project taking all the learnings in the project into account.

5 KPIs

In this report KPIs that are relevant for electrolysers in the normal electrolyser operation, usually constantly producing hydrogen for a given application will not be considered. These are of course also relevant for electrolysers performing grid services because still the primary purpose of the electrolyser is to produce hydrogen for a given application. Grid services are only the secondary purpose that will change the performance profile and add some additional revenues for the operator. Examples of KPIs relevant for normal electrolyser operation and still relevant for grid service operation is
KPI1 Energy consumption (kWh/kg)@rated power
KPI3 Efficiency degradation @ rated power and considering 8000 h operation / year

5.1 Performance indicators as suggested in QualyGridS report D2.4

Summarizing the test evaluations of all tests D2.4[10] achieves the following performance indicator. The method of how to do the measurements, the data evaluation of single tests and the aggregation of test results into performance indicators is described in detail in D2.4.
Also for the grid service performance indicators of D2.4 Table 3 gives the relation to FCH-JU KPIs. However most of these parameters have only approximate correspondence or they are related to more than one FCH-JU KPI together.

Table 3: Grid service performance indicators from D2.4 and their corresponding KPIs from FCH-JU

Technical grid service Performance indicators	How determine from these tests	Target value	Related FCH-JU KPIs
Dynamics: Ramp duration for step power change t_{full}	→maximum of all values t_{full} determined in the different protocols	10 sec	KPI 5: H_2 production electrolysis, hot start from min to max power. Target 2 sec
Stability constant power section in %:	→ (maximum of all values Δ_{max} in the different protocols)/(capacity P_{up}-P_{low}) *100	<5%	No corresponding KPI
Initial response time	→from FCR protocol, time from power change request to the system leaving its original power level continuously	<1.5 sec	No corresponding KPI
Ramp precision: percentage of data points outside the defined range	→ maximum of (Percentage of data points outside the range for the ramps) for all tests	0-5%	No corresponding KPI
Power capacity	→ minimum (P_{up}-P_{low}) for all tests	>1MW	KPI4 Flexibility with the degradation < 2% year (refer to KPI 3). Target 0-200% of nominal power

[10] QualyGridS Deliverable report D2.4 is a confidential report. Few updates from this report were made and then published as the QualyGridS document “Finalized Testing protocol” DOI: https://doi.org/10.5281/zenodo.3937273

			multiplied by nominal power (not a KPI)
Reliability	Percentage of all tests following these protocols that were completed as described	>99%	

Furthermore the section “Basic characterisation” names a list of performance indicators of electrolysers as basic characterisation of an electrolyser and helping to decide which grid service testing protocol should be applied. In table 4 these are opposed to FCH-JU KPIs where there is a correspondence.

Table 4: Values basic characterization as given in D2.4 and corresponding FCH-JU KPIs

Basic characterisation performance indicators	Related FCH-JU KPIs
Cold Start Time to Nominal Power: t_{cold}	KPI 5b: cold start, target 30 sec
Start-up time from Standby State to Nominal Electrical Power Input: $t_{start,standby}$	KPI 5a: hot start from min to max power. Target 2 se
Average Electrical Power Input of the system in Standby State and in cold standby state: $P_{standby.}$ and $P_{cold\ standby.}$	
The average Electrical Power Input of the system at maximum power level $P_{max\ system}$	KPI 4: flexibility with the degradation < 2% year, target 0-200% nominal power
The average Electrical Power Input of the system at 0 or minimum hydrogen output continuously operable: $P_{min\ system}$	
The Total Response Time Minimum Power to Maximum Power $t_{min→max}$	
The Total Response Time Maximum Power to Minimum Power $t_{max→min}$	
The Total Response Time Nominal Power to Maximum Power $t_{nom→max}$	
The Total Response Time Maximum Power to Nominal Power $t_{max→nom}$	
The duration time of maximum power t_{max}	
Time from nominal to standby state: $t_{down\_to\_standby}$	
Time between reaching standby state and reaching the subsequent Nominal Power state $t_{down→up}$	

With their relevance for grid services these values will be grouped in primary, secondary and tertiary performance indicators for electrolysers performing grid services:

5.2 Performance indicators based on economic evaluation D6.4

QualyGridS deliverable D6.4 described in detail the economic situation and impact on operating strategy for electrolysers performing grid services. It also performed sensitivity studies. From this report the following two performance indicators turn out to be relevant, besides, as said before, those values that are also important for the business case of an electrolyser producing hydrogen normally at its nominal power. Target values are difficult to indicate at this stage.

Table 5: Economic performance indicators

Economic grid service Performance indicators	Target value	Related FCH-JU KPIs
CAPEX rel. Maximum power		Stack CAPEX per kW or System CAPEX + KPI4 flexibility with the degradation < 2% year target 0-200% of nominal power
Efficiency at minimum power respectively , energy consumption (kWh/kg)@minimum power		No correspondence

5.3 Suggestion for KPIs for electrolysers performing grid services and relation to FCH-JU KPIs

To differentiate between FCH-JU KPIs and KPIs as relevant for grid services we name the latter ones defined by our project "**Primary Performance Indicators**" PPI. Primary performance indicators are those that are prerequisites for performing grid services. An electrolyser not fulfilling these requirements will not be able to perform all the considered grid services in all considered countries in Europe. However it might still be permitted for some services in some countries.

PPI	Description	Target value	Related FCH-JU KPI
1	Dynamics: Ramp duration for step power change t_{full}	10 (30)* sec	KPI 5: H_2 production electrolysis, hot start from min to max power. Target 2 sec

* 10 seconds are only needed for one specialized service in the Nordic grids. In most cases 30 sec is enough if also the requirements in FCR second test are fulfilled.

PPI1 and KPI5 are very closely related. Possibly the starting power for the PPI ramp is not from minimum power as in the KPI but somewhat above. The target value for PPI1 is less challenging than for KPI5. Most likely in the definition of KPI5 it was assumed that electrolysers are immediately connected to renewable power sources that would request such high dynamics. In the grid services as seen from today's perspective as relevant for electrolysers the less challenging target value for dynamics is sufficient. Most grid services require the less challenging target value of 30 sec for PPI1. Only the service FCR-D from the Nordic zone requires that fast reaction.

PPI	Description	Target value	Related FCH-JU KPI
2a	Stability in constant power sections in %:	<5%	No corresponding KPI

2b	Ramp precision: percentage of data points outside the defined range	0-5%	No corresponding KPI

Both PPIs are closely related because they describe the precision of power control of electrolyser systems. This is primarily related to the power input into the rectifier, however preferentially also the total system power should obey a good stability. In the FCH-JU KPIs there is no corresponding term.

PPI	Description	Target value	Related FCH-JU KPI
3	Reliability	>99%	No corresponding KPI

When being called for grid services the device must perform the requested power change with a high reliability without issues of malfunction of the system. Definition of reliability is somewhat difficult and can normally only be done in long test series. D2.4 tries a definition on how to achieve the value from the measurements. The FCH-JU list of KPIs does not define a corresponding indicator.

Secondary performance indicators (SPI):
In this group are those performance indicators that should be achieved by the system especially to be economically successful or are requirements in few countries but are not essential for doing the grid services.

SPI	Description	Target value	Related FCH-JU KPI
1	Power capacity	>1MW	KPI4 Flexibility with the degradation < 2% year (refer to KPI 3). Target 0-200% of nominal power Multiplied with Nominal Power (not a KPI)

The economic analysis highlighted there is a potential interest to have the possibility to operate WE over its nominal capacity; that could open more opportunities to participate in grid services. If WE is used over nominal power on regular basis and if maximum power is much higher than nominal power (operating range 0-200%), that implies some adjustments on the system that will have an influence on the costs. The system CAPEX must reflect these effects.

SPI	Description	Target value	Related FCH-JU KPI
2	Total system costs CAPEX rel. Maximum power of the system	<<900 €/kW	Stack CAPEX per kW or System CAPEX + KPI4 flexibility with the degradation < 2% year target 0-200% of nominal power multiplied by Nominal Power (not a KPI)

PPI 3 and PPI 4 are closely related, however the PPI4 is more relevant for deciding if the electrolyser must be operated with the maximum number of operating hours or if other aspects like good adaptation to the requested grid service power profiles get dominant.

SPI	Description	Target value	Related FCH-JU KPI
3	Initial response time →from FCR protocol	<1.5 sec	No corresponding KPI

The initial response time is the time it takes from the moment the request of power change comes to the moment that the system leaves its original power level continuously. The requirements on this vary between the countries. Some require it strictly, some have it as a recommendation with the ramp points being reached on time being the strict requirements. Therefore this requirements should be respected but it could be in the future that there will be relieves on the target value.

SPI	Description	Target value	Related FCH-JU KPI
4	Efficiency at minimum hydrogen production respectively power consumption in standby mode	No target defined, high efficiency or low power consumption	No corresponding KPI

If an electrolyser wants to run negative control power services only, this can mean that it will be operating in a low power mode for long time only rarely being called to increase power. For the business case it is important that the efficiency at this power level (when it is a hydrogen producing power level) will be high; or if it is a standby mode then the power consumption in this mode should be low.

The other performance indicators determined in the tests are certainly good to know to be able to decide about the way to use the system but they are not essential for grid services.

6 Conclusions

Running the QualyGridS testing protocols and doing the data evaluation the primary performance indicators relevant for grid services can be evaluated. With grid services evolving with time the exact target values might change but it can be expected that more or less these requirements will remain.