H2FUTURE

Green Hydrogen

Deliverable D2.2

Specifications of Pilot Test 2 / Use Case 2

v1.0

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Revision History

Version	Date	Author / Reviewer	Notes
0.1	28/04/2017	K. Zach, R. Zauner	First draft version
0.2	22/06/2017	K. Scheffer	Review of first draft version
1.0	26/06/2017	K. Zach	Final version incl. alignment of KPI definitions to the wording agreed upon in Deliverable D2.8

Executive Summary

Work Package 2 (WP2) of the H2FUTURE project has the objective to detail the aims and execution of the individual use cases / pilot tests and the quasi-commercial operation phase, which are performed in WP8 at a later stage of the project.

This document, deliverable D2.2, details the specifications for use case / pilot test 2 - continuous operation 24/7 with maximized hydrogen production to determine potential degradation or power limitations. The aim of this use case is to quantify key performance indicators (KPIs) related to the availability, efficiency and hydrogen production of the electrolyser system during continuous operation of the facility in order to determine the technical abilities and behaviour of the electrolyser system.

In order to facilitate the development of the use case / pilot test specifications a common methodology based on the use case collection method (cf. Smart Grid Coordination Group at EC level) has been used, which is briefly introduced in chapter 2.

The filled-out use case template for use case / pilot test 2, which contains the general narrative description, KPIs, sequence diagram, etc., can be found in chapter 3.

Table of Contents

1 Introduction

1.1 The H2FUTURE Project

As part of the H2FUTURE project a 6 MW polymer electrolyte membrane (PEM) electrolysis system will be installed at a steelworks in Linz, Austria. After the pilot plant has been commissioned, the electrolyser is operated for a 26-month demonstration period, which is split into five pilot tests and quasi-commercial operation. The aim of the demonstration is to show that the PEM electrolyser is able to produce green hydrogen from renewable electricity while using timely power price opportunities and to provide grid services (i.e. ancillary services) in order to attract additional revenue.

Subsequently, replicability of the experimental results on a larger scale in EU28 for the steel industry and other hydrogen-intensive industries is studied during the project. Finally, policy and regulatory recommendations are made in order to facilitate deployment in the steel and fertilizer industry, with low CO_2 hydrogen streams also being provided by electrolysing units using renewable electricity.

1.2 Scope of the Document

Work Package 2 (WP2) of the H2FUTURE project has the objective to detail the aims and execution of the individual use cases / pilot tests and the quasi-commercial operation phase, which are performed in WP8 at a later stage of the project. Further on, in order to validate the commercial exploitation of the PEM electrolyser, to analyse the operational impacts and the deployment conditions of the resulting innovations, key performance indicators (KPIs), which are monitored during the demonstration, are also detailed in WP2. For each use case / pilot test specification (D2.1 – D2.5), for the specification of the quasi-commercial operation (D2.6), for the final technical review (D2.7) and for the monitored KPIs separate documents will be created in WP2.

This document, deliverable D2.2, details the specifications for use case / pilot test 2 - continuous operation 24/7 with maximized hydrogen production to determine potential degradation or power limitations. The aim of this use case is to quantify the following KPIs during continuous operation of the facility:

- Reliability and availability of the facility
- Instabilities or power limitations of the facility and of each of its subunits
- (Electric) system efficiency of the facility
- Hydrogen production, etc.

Together with the use case / pilot test 1 – stress tests – this use case 2 determines the technical abilities and behaviour of the electrolyser system. They serve as basis for the following use cases, which are related to business opportunities and commercial operation.

In chapter 2 of this document a brief introduction to the use case methodology and the use case template for WP2 is given. The filled out use case template is then provided in chapter 3.

1.3 Notations, Abbreviations and Acronyms

AC	Alternate Current
DC	Direct Current
EC	European Commission
EU	European Union
HHV	Higher Heating Value
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
KPI	Key Performance Indicator
PEM	Polymer Electrolyte Membrane / Proton Exchange Membrane
WP	Work Package

Table 1: Acronyms list

2 Use Case Methodology

2.1 Introduction to Use Cases

In order to facilitate the development of the use case / pilot test specifications a common methodology based on the use case collection method (cf. Smart Grid Coordination Group at EC level) has been used.

Use cases were initially developed and used within the scope of software engineering, and their application has been gradually extended to cover business process modelling. This methodology has extensively been used within the power supply industry for smart grid standardisation purposes by international and European standardisation organisations and projects, such as International Electrotechnical Commission (IEC), M/490 Smart Grid Coordination Group, EPRI Electricity Power Research Institute and National Institute of Standards and Technology (NIST).

In general, use cases describe in textual format how several actors interact within a given system to achieve goals, and the associated requirements. IEC 62559-2 defines a use case as "*a specification of a set of actions performed by a system which yields an observable result that is of value for one or more actors or other stakeholders of the system*". Use cases must capture all of the functional requirements of a given system (business process or function), and part of its non-functional requirements (performance, security, or interoperability for instance), not based on specific technologies, products or solutions.

The targets of actors can be of different levels, i.e. business or functional, and use cases can be of different levels of detail (very high-level or very specific, related to the task the user of a system may perform) accordingly. Business processes and the related requirements can be described in business use cases, while functions or sub-functions supporting the business processes and their associated requirements can be detailed in system use cases.

2.2 Use Case Template

For the H2FUTURE use cases a template based on the IEC 62559-2 (IEC, 2015) and the DISCERN project (OFFIS, 2013) has been used. This structured format for use case descriptions helps to describe, compare and administer use cases in a consistent way.

The use case template contains the following main information, structured in separate sections and tables:

- Administrative information (version management)
- Description of the use case (general narrative description, KPIs, use case conditions, etc.)
- Diagram(s) of the use case (e.g. sequence diagram)
- Technical details (actor description, references, etc.)
- Step-by-step analysis of the use case
- Information exchanged and requirements

The system use case developed within task WP2.2 of the H2FUTURE project is described in the following section of the document.

3 Use Case / Pilot Test 2

1 *Description of the use case*

1.1 *Name of use case*

Use case identification		
ID	***Area / Domain(s)/ Zone(s)***	***Name of use case***
UC2	Customer Premises / Process, Field, Station, Operation	Continuous Operation 24/7 with maximized Hydrogen Production

1.2 *Version management*

Version management				
Version No.	***Date***	***Name of author(s)***	***Changes***	***Approval status***
0.1	04/04/2017	K. Zach, R. Zauner	First Draft	
0.2	11/04/2017	K. Zach	Second Draft incl. comments from WP2 workshop	
0.3	24/05/2017	K. Zach	Graphic for definition of electrolyser aggregation levels included	
1.0	26/06/2017	K. Zach	Adaption of KPIs	

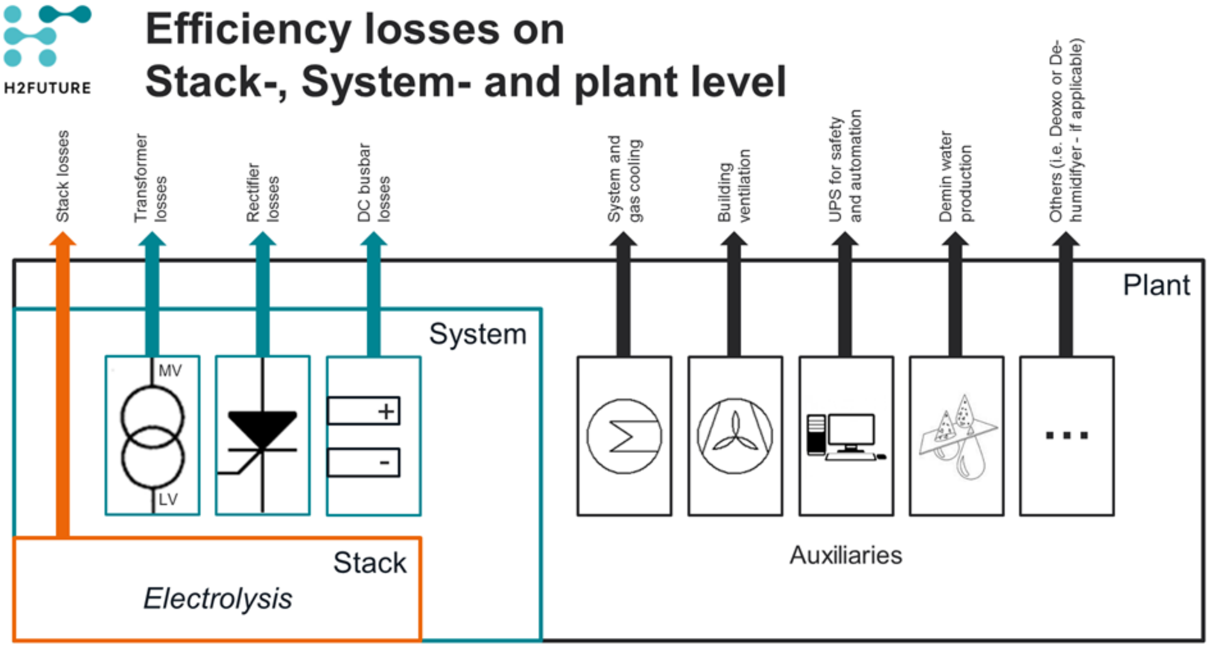
1.3 *Scope and objectives of use case*

Scope and objectives of use case	
Scope	Continuous operation 24/7 of the electrolyser with maximized hydrogen production to determine potential degradation or power limitations
Objective(s)	Quantify the reliability and availability of the facility and other KPIs of the electrolyser
Related business case(s)	Base for any related business case

1.4 *Narrative of Use Case*

Narrative of use case
Short description
This Use Case describes the continuous operation 24/7 and monitoring of the electrolyser with maximized hydrogen production to determine potential degradation or power limitations.
Complete description
This Use Case describes the continuous operation of the electrolyser for at least one week (24/7) with continuous maximized hydrogen production at nominal production capacity of the electrolyzer. System and performance monitoring ensures that potential degradation of the electrolyser or power limitations of the facility and each of its subunits can be detected and analysed. In this use case only the SCADA system of the electrolyser, which controls and monitors the electrolyser, and the electrolyser itself are directly involved. Additional Intelligent Electronic Devices (IED) could be used to determine additional technical parameters of the facility and its subunits. The Key Performance Indicators (KPIs)/parameters determined are specified in section 1.5 below. For the calculation of these KPIs and the following description of the use case the term “electrolyser” or “system” comprises the following subunits: • Electrolyser stack (SILYZER 300), • Transformer / rectifier and For some KPIs also the energy consumption of auxiliary systems is included, these are: • Water pumps • Demineralized water refinement • Uninterruptable power supply • Building ventilation • Lighting

The electrolyser system and these auxiliary systems together form the “electrolyser plant”. So, in total there are three different levels of aggregation, which are (i) stack level, (ii) system level and (iii) plant level. The definition of these levels is shown in the graphic below. The electrolyser plant level includes any and all components which are directly or indirectly connected to the electrolyser and which consume (additional) energy due to the existence of the electrolyser.



Note that this use case is not related to a specific business case, but rather to functions as an advanced test for the systems overall performance.

1.5 Key performance indicators (KPI)

ID	Name	Description	Reference to mentioned use case objectives
1	Time-based availability of the electrolysis plant	Availability of the electrolyser plant in the considered operating period relative to the planned operating time, excluding the duration of planned maintenance = $(t_{OT\_planned} - t_{D\_plant}) / t_{OT\_planned} *100$ [%], with $t_{OT\_planned}$ is the planned operating time and t_{D_plant} is the unplanned downtime of the electrolyser plant in the operating period due to any failure of the stacks, power conversion or auxiliaries systems	
2	Time-based availability of the stack modules	Availability of the stacks in the considered operating period relative to the planned operating time excluding the duration of planned maintenance = $(t_{OT\_planned} -t_{D\_stack}) / t_{OT\_planned} * 100$ [%] with t_{D_stack} is the downtime due to failure of a stack module, and $t_{OT\_planned}$ is the planned operating time in the considered operating period	
3	Time-based availability of the system	Availability of the electrolyser system in the considered operating period relative to the planned operating time, excluding the duration of planned maintenance = $(t_{OT\_planned} -t_D) / t_{OT\_planned} * 100$ [%] with t_{D_system} is the unplanned downtime due to any failure of the electrolyser system, and $t_{OT\_planned}$ is the planned operating time in	

		the considered operating period	
4	Production-based availability	Availability based on the lost H_2 production = ($m_{planned}$ – m_{actual}) / $m_{planned}$ * 100 [%] m_{actual} … actual hydrogen production in the testing period [kg] $m_{planned}$ … planned hydrogen production in the testing period [kg]	
5	Specific system electrical input	The specific system electrical input equals the hydrogen specific energy content in HHV (e.g. 39.4 kWh/kg at 25°C) divided by the electrolyser system efficiency	
6	System electrical efficiency with maximised hydrogen production	The efficiency on system level, at nominal load operation, of the use of AC electric energy to split liquid water into gaseous hydrogen and oxygen relative to the HHV hydrogen energy content (e.g. 39.4 kWh/kg at 25°C). The efficiency is determined using stack efficiency multiplied with the measured efficiency of the AC/DC conversion including losses on medium voltage transformer.	
7	Specific stack electrical input	The specific stack electrical input equals the hydrogen specific energy content in HHV (e.g. 39.4 kWh/kg at 25°C) divided by the stack efficiency at nominal hydrogen production.	
8	Stack electrical efficiency with maximised hydrogen production	The efficiency on stack level, at nominal load operation, of the use of DC electric energy to split liquid water into gaseous hydrogen and oxygen relative to the HHV hydrogen energy content (e.g. 39.4 kWh/kg at 25°C). This is calculated using the thermoneutral voltage and the actual stack voltage – considering 1% losses from recombination. For example, at 25°C it would be calculated using the following formula: $= \frac{1{,}48\ V \times number\ of\ cells}{Stack\ voltage} - 1\%.$	
9	Specific plant electrical input	The energy consumption for H_2 production equals the hydrogen specific energy content in HHV (e.g. 39.4 kWh/kg at 25°C) divided by the electrolyser plant efficiency	
10	Plant electrical efficiency with maximised hydrogen production	The efficiency on electrolyser plant level, at nominal load operation, is determined under consideration of additional losses caused by auxiliary systems (i.e. system cooling, gas treatment, building ventilation, demin water production, provision of uninterruptible power for safety, control & automation systems)	
11	Average hydrogen production	Average hydrogen output of the system [kg/h] in a specified operating period = total power consumption on DC level multiplied by the stack electrical efficiency, and divided by the specific energy content of hydrogen in HHV and the total number of operating hours in the specified operating period. Alternatively, the average hydrogen output of the system in a specified operating period can be calculated from the stack current hours and related operating hours, considering production losses of 1% due to recombination: average production rate=	

		number of cells ×stack current hours [Ah] ÷operating hours ×0,03761 [g/Ah]×99%	
12	Average oxygen production	Average oxygen production of the system [kg/h] will be determined by directly measuring the flow of oxygen after cooling. This oxygen measurement can be used as a cross check for the hydrogen production rate.	
13	Efficiency degradation	The efficiency degradation of the stack(s) determined as increase in cell voltage averaged over the cells of the stacks(s) divided by the number of operating hours in a specified period [μV/h]. Nominal hydrogen production level will be used as a reference point for calculating the voltage degradation rate.	
14	Efficiency degradation per 1000h	Increase in cell voltage averaged over the cells of the stack(s) after every thousand hours the electrolyser system has been in operation = (1.48 * (1 / $V_{t=0}$ – 1 / V_t) *100%) / (t / 1000), where $V_{t=0}$ is the initial cell voltage, V_t is the cell voltage after an operating time t measured in hours. The efficiency degradation is the absolute decrease of the stack efficiency; i.e. the decrease in efficiency in percent point. Nominal hydrogen production level will be used as a reference point for calculating the voltage degradation rate.	
15	External power limitation (time)	The electrolyser plant's power consumption is limited due to external events (e.g. in the electricity grid) = (t_{OP}-t_L) / t_{OP} * 100 [%] t_L … time of limitation t_{OP} … operating period	
16	Plant power limitation (time)	The electrolyser plant's power consumption is limited due to electrolyser plant events = (t_{OP} - t_L) / t_{OP} * 100 [%] t_L … time of limitation t_{OP} … operating period	
17	External power limitation (power)	The electrolyser plant's power consumption is limited due to external events (e.g. in the electricity grid) = (P_L * t_L) / (P_R * t_{OP}) * 100 [%] P_L … power limitation P_R … rated power t_L … time period of power limitation t_{OP}… operating period	
18	Plant power limitation (power)	The electrolyser plant's power consumption is limited due to electrolyser plant events = (P_L * t_L) / (P_R * t_{OP}) * 100 [%] P_L … power limitation P_R … rated power t_L … time period of power limitation t_{OP}… operating period	
19	Availability unplanned and planned	Availability of the electrolyser plant in the considered operating period relative to the total operating period = (t_{OT_total} - $t_{D\_plant\ u\&p}$) / t_{OT_total} * 100 [%], with t_{OT_total} is the total operating period and $t_{D\_plant\ u\&p}$ is the planned and unplanned downtime of the electrolyser plant in the operating period due to any failure of the stacks, power conversion or auxiliaries systems and maintenance	

1.6 Use case conditions

Use case conditions
Assumptions
Prerequisites
Electrolyser and infrastructure components are installed, commissioned and ready for operation
Permission to operate the electrolyser has been granted
Electrical energy is available with required amount

1.7 Further information to the use case for classification / mapping

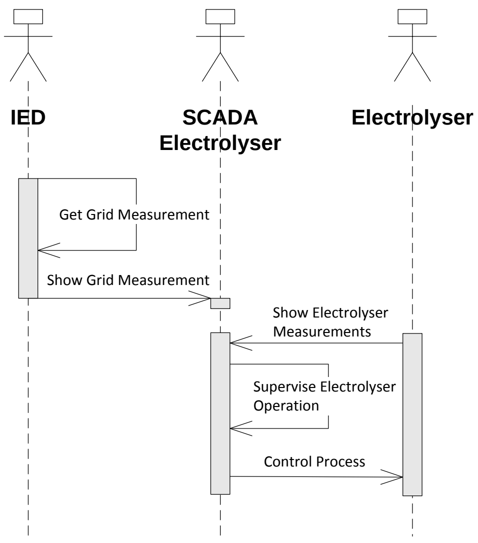
Classification information
Relation to other use cases
Use case of the WP2.2 of H2FUTURE
Level of depth
Individual Use Case
Prioritisation
Implemented in demo
Generic, regional or national relation
Austria
Nature of the use case
Technical
Further keywords for classification
Continuous operation, degradation, electrolyser

1.8 General remarks

General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping		**Group description**	
Process/Field/Station actors		Actors in Process, Field, Station levels	
Actor name	**Actor type**	**Actor description**	*Further information specific to this use case*
Electrolyser	Component	An electrolyser is a technology allowing to convert electricity into hydrogen (and oxygen). It consists of electrolyser stacks (several electrolyser cells stacked to a larger unit) and the transformer rectifier system providing the electrical power	
Intelligent Electronic Device (IED)	Component	Any device incorporating one or more processors with the capability to receive or send data/control from or to an external source (e.g., electronic multifunction meters, digital relays, controllers)	In this Use Case, the IED collects power measurements from the AC grid and sends them to the SCADA of the electrolyser
SCADA Electrolyser	Application	Supervisory control and data acquisition – an industrial control system to control and monitor a process and to gather process data. A SCADA consists of programmable logic controllers and human-machine interface computers with SCADA software. The SCADA system directly interacts with devices such as valves, pumps, sensors, actors and so on	In this use case the SCADA controls the electrolyser process and sets the DC power input for the electrolyser stack

3.2 References

References						
No.	**References Type**	**Reference**	**Status**	**Impact on use case**	**Originator / organisation**	**Link**

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	**Scenario name**	**Scenario description**	**Primary actor**	**Triggering event**	**Pre-condition**	**Post-condition**
1	Monitoring	IED measures the power consumption of the electrolyser	IED	periodically	SCADA is running and data connection is established	
2	Control	SCADA sends control commands to the electrolyser in order to change its power consumption	SCADA Electro-lyser	periodically	SCADA is running and the electrolyser system is running or ready to start.	Electrolyser adepts its power consumption according to the control commands

4.2 Steps – Scenarios

Scenario name:		No. 1 – Monitoring						
Step No.	*Event*	*Name of process/ activity*	*Description of process/ activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
1	Periodically	Get grid measurement	IED performs measurement of local grid	INTERNAL OPERATION	IED	IED	G_M	
2	Periodically	Show grid measurement to SCADA	IED sends measurements to SCADA	SHOW	IED	SCADA Electrolyser	G_M	
Scenario name:		**No. 2 – Control**						
Step No.	*Event*	*Name of process/ activity*	*Description of process/ activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
1	Periodically	Show electrolyser measurement to SCADA	Electrolyser sends measurements to SCADA	SHOW	Electrolyser	SCADA Electrolyser	E_M	
2	Periodically	Supervise electrolyser operation	SCADA keeps electrolyser consumption at constant level (rated power)	INTERNAL OPERATION	SCADA Electrolyser	SCADA Electrolyser		
3	Periodically	Control process	SCADA sends set point to the electrolyser system	CHANGE	SCADA Electrolyser	Electrolyser	SP_V	

5 Information exchanged

Information exchanged			
Information exchanged, ID	*Name of information*	*Description of information exchanged*	*Requirement, R-IDs*
G_M	Grid Measurement	Measurement of the power consumed by the transformer-rectifier system of the electrolyser	
E_M	Electrolyser Measurement	Measurement indicating the DC current consumption of the electrolyser which is then used to calculate the hydrogen production	
SP_V	Set-Point Value	Set-point for controlling the hydrogen production of the electrolyser	

6 Requirements (optional)

Requirements (optional)		
Categories ID	**Category name for requirements**	**Category description**
Requirement R-ID	**Requirement name**	**Requirement description**

7 Common terms and definitions

Common terms and definitions	
Term	**Definition**

8 Custom information (optional)

Custom information (optional)

4 References

4.1 Project Documents of H2FUTURE

D2.1 Specifications of Pilot Test 1 / Use Case 1

D2.2 Specifications of Pilot Test 2 / Use Case 2

D2.3 Specifications of Pilot Test 3 / Use Case 3

D2.4 Specifications of Pilot Test 4 / Use Case 4

D2.5 Specifications of Pilot Test 5 / Use Case 5

D2.6 Specifications of quasi-commercial Operation

D2.7 Specifications of Final Tests

D2.8 KPIs to monitor the Demonstrations and perform the Exploitation Tasks

4.2 External Documents

International Electrotechnical Commission (IEC) (2015): IEC 62559-2 "Use case methodology – Part 2: Definition of the templates for use cases, actor list and requirements list", 2015

OFFIS (2013): “Architecture templates and guidelines”, deliverable D1.3 of the DISCERN project, available at https://www.discern.eu/project_output/deliverables.html, 2013