



Open test suite for interoperability validation V2.0

Deliverable D3.2

29/08/2019



This project has received funding
from the European Union's Horizon 2020
research and innovation programme under
grant agreement n°731289

ID & Title :	Open test suite for interoperability validation		
Version :	V2.0	Number of pages :	67
Short Description			
This deliverable presents the methodology and analysis along with the resulted test suite for the interoperability validation.			
Revision history			
Version	Date	Modification's nature	Authors
V0.1	08.11.2018	Draft version sent to the TC for review	Friederich Kupzog, Marco Cupelli, Olivier Genest, Jawad Kazmi, Mihai Calin, Amir Ahmadifar, Fabien Berthomé, Milica Savic, Vincent Maury
V1.0	21.12.2018	First version, submitted to the EC	Friederich Kupzog, Marco Cupelli, Olivier Genest, Jawad Kazmi, Mihai Calin, Amir Ahmadifar, Fabien Berthomé, Milica Savic, Vincent Maury
V1.1	31.05.2019	FR analysis and its internal GWP3 review	Friederich Kupzog, Marco Cupelli, Olivier Genest, Jawad Kazmi, Mihai Calin, Amir Ahmadifar, Fabien Berthomé, Milica Savic, Vincent Maury
V2.0	29.08.2019	Updated version Submitted to the EC	Jawad Kazmi
Accessibility			
<input checked="" type="checkbox"/> Public	<input type="checkbox"/> Consortium + EC	<input type="checkbox"/> Restricted to a specific group + EC	<input type="checkbox"/> Confidential + EC
Owner/Main responsible			
Name(s)	Function	Company	Visa
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Reviewer(s): company name(s)			
Company			
Enedis, Avacon, CEZ Distribuce, E.ON, Enexis, RWTH, TRIALOG, AIT			
Approver(s): company name(s)			
Company			
Enedis, Avacon, CEZ Distribuce, E.ON, Enexis, RWTH			
Work Package ID	GWP3	Task ID	3.2

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EXECUTIVE SUMMARY

The EU project InterFlex is aiming to address the challenges of the Distribution System Operator in modernizing their systems and business models in order to be able to support the integration of distributed renewable energy sources into the energy mix.

The activities in the GWP3 are dedicated to the impact and deployment analysis with a strong focus on the interoperability of the innovative solutions proposed in the five demonstrations. As part of these activities the demonstration and showcase of interoperability and interchangeability of the employed solutions in a laboratory setting. This requires a detailed analysis of the UCs from all the demonstrators.

This document describes the methods, analysis and the resulting recommendations for an Open Test Suite (OTS) for the inseparability validation. InterFlex is a large project covering 18 UCs for the six demonstrators, in 5 countries. Each of these UCs is implementing an innovative solution for exploring the ways a DSO can activate the flexibility sources with possibly a different implementation strategy (upper/lower-bound etc.) and/or implementation technology. The UCs are focusing on different business cases and implementing different ICT architectures for implementing them. Such a diversity, on one hand, is good in showing the different possibilities but poses a big challenge in finding the common ICT pattern/practices easily. Such identified common ICT patterns can be a valuable contribution to the EU or international standard body or, in this specific case (GWP3) to an OTS.

To handle such diversity, a well-crafted methodology is needed. Such a methodology ideally should not be too far away from the processes already in use so that it may not further complicate the process by requiring a new set of skills for its application. On the other hand, it should be able to do a detailed analysis at different levels so that the results are more acceptable. Keeping these guidelines in mind, a detailed methodology that is both in line with the project and able to perform analysis at three different levels is proposed. It is an extension to the (Step 3. of the) well-known process model proposed by the Sustainable Process Working Group under EU Mandate M/490. The steps added are helpful in finding the common pattern that can later be utilized for developing the OTS and recommendations for standard bodies.

A detailed treatment of the proposed methodology along with its applications on all 18 UCs at three different levels (UC, demonstrator and project) are presented. The analysis resulted in identifying 13 CPs that have been employed by the DSOs for activating the flexibility sources in all six demonstrations. These patterns are further classified into five Super Category (SC) (voltage, frequency, congestion, support and hard to test in a laboratory). Such classification is aimed at combining the similar patterns along with their suitability and effectiveness for a laboratory validation. The common patterns falling into the first three SCs are further considered for developing first the validation designs and later a laboratory setup.

The resulting three SCs are forming the core requirement for any electrical flexibility usage in a European power system context: a device or resource offering electrical flexibility should be technically able to provide the flexibility at least for one, ideally for all three of these SCs.

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LIST OF ACRONYMS

InterFlex	Interactions between automated energy systems and flexibilities brought by energy market players
SGAM	Smart Grid Architecture Model
SCADA	Supervisory Control And Data Acquisition
PV	Photovoltaics
EV	Electric Vehicle
DSO	Distribution System Operator
DER	Distributed Energy Resources
LV	Low Voltage
MV	Medium Voltage
CPO	Charge Point Operator
RES	Renewable Energy Sources
SGH	Smart Grid Hub
EU	European Union
SG	Smart Grid
AMI	Advanced Metering Infrastructure
RESS	Residential Energy Storage Systems
BEMS	Building Energy Management System
EMS	Energy Management System
SoS	System-of-Systems
M/490	EU Mandate M/490
CZ	Czech Republic
DE	Germany
FR	France
SE	Sweden
NL	Netherlands
IEC 62559	IEC 62559 - Use case methodology
GWP	InterFlex General Work Package
SC	Super Category
CP	Common Pattern
OTS	Open Test Suite
IoT	Internet of Things
HIL	Hardware In Loop
PHIL	Power Hardware In Loop
CHIL	Controller Hardware In Loop

1 INTRODUCTION

The European Union (EU) Project Interactions between automated energy systems and flexibilities brought by energy market players (InterFlex) is a response to the Horizon 2020 Call for proposals, LCE-02-2016 (“Demonstration of smart grid, storage and system integration technologies with increasing share of renewable: distribution system”).

This Call addresses the challenges of the distribution system operators in modernizing their systems and business models in order to be able to support the integration of distributed renewable energy sources into the energy mix. Within this context, the LCE-02-2016 Call promotes the development of technologies with a high TRL (technology readiness level) into a higher one.

InterFlex explores pathways to adapt and modernize the electric distribution system in line with the objectives of the 2020 and 2030 climate-energy packages of the European Commission. Six demonstration projects are conducted in five EU Member States (Czech Republic, France, Germany, the Netherlands and Sweden) in order to provide deep insights into the market and development potential of the orientations that were given by the call for proposals, i.e., demand-response, smart grid, storage and energy system integration.

With Enedis as the global coordinator and CEZ Distribuce as the technical director, InterFlex relies on a set of innovative use cases. Six industrial-scale demonstrators are being set up in the participating European countries. Figure 1.1 shows a map identifying the demo site around the Europe.

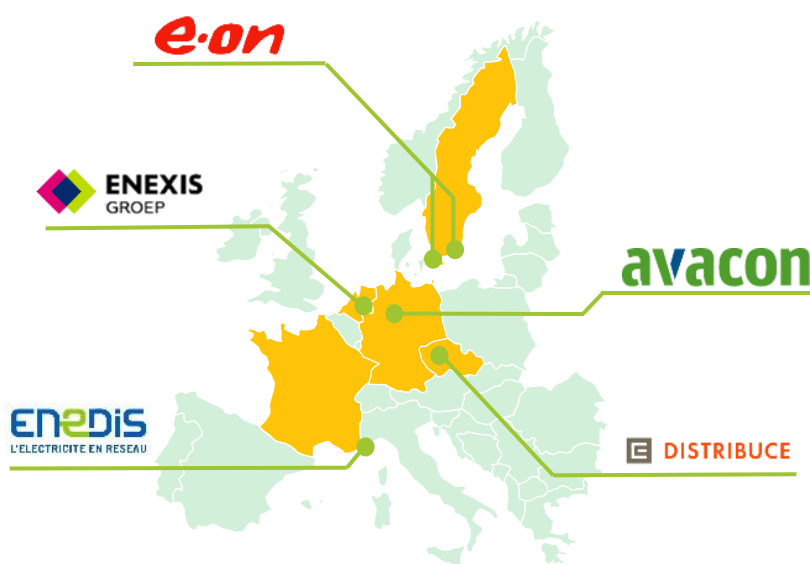


Figure 1.1: The map identifies the demo sites in the context of this project.

Through these demonstration showcases, the InterFlex will assess how the integration of the new solutions can lead to a local energy optimization. Technically speaking, the success of these demonstrations requires that some of the new solutions, which are today at TRLs 5-7, are further developed reaching TRLs 7-9 to be deployed in real-life conditions.

1.1 Scope of the document

The scope of this document is to present the analysis, used methodology and resulting recommendations for the Open Test Suite (OTS) of the 18 UCs from the six InterFlex demonstrators.

1.2 Objectives

The objectives of this work is to derive an Open Test Suite (OTS) for the interoperability validation for the five demonstrations in the InterFlex project. For this purpose, all the 18 UCs from the five demonstrators were analyzed from the interoperability perspective using the novel envisioned methodology. Upper-bound and lower-bound validation designs along with corresponding laboratory setups were proposed. These setups can be later implemented in a laboratory setting to perform the interoperability validation.

1.3 Motivation

The project InterFlex is a large EU project with six demonstration sites in five countries around Europe. As depicted in the Figure 1.3, it is aiming at “*validating the enabling role of the DSO in calling for the flexibility sources*”. The six demonstrations sites in Germany, France, the Netherlands, Sweden and Czech Republic are defined with eighteen (18) Use Cases (UCs) that demonstrate the innovative solutions divided into different *clusters*. In these UCs the goal is to test these innovative solutions for activating the flexibility sources at the Distribution System Operator (DSO) level. However, these solutions are using different implementation strategies and technologies to achieve the same goal - activating the interoperability sources. Such diversity at the implementation level, poses a challenge and it would be too difficult to come up with recommended practices. An immediate consequence for InterFlex in this case is that it would be difficult to propose an OTS that can then be used for interoperability validation in a laboratory settings. This challenge can be overcome by deriving a well-defined methodology that when applied to the UCs, could be able to find the common patterns and eventually leads to a test suite.

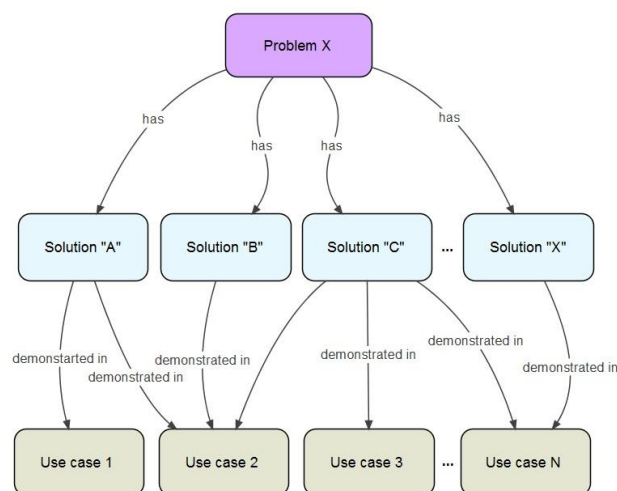


Figure 1.2: Find the common patterns that can be inoperable.

This fact is further explained with the graphics in Figure 1.2. The need for such a methodology is realized and one is developed for this task. An import aspect of the proposed methodology is that it's an extensions to a well-known methodology proposed by the Sustainable Process Working Group under EU Mandate M/490 that has been used in the project already. This means that the proposed methodology is very well in line with the project InterFlex.

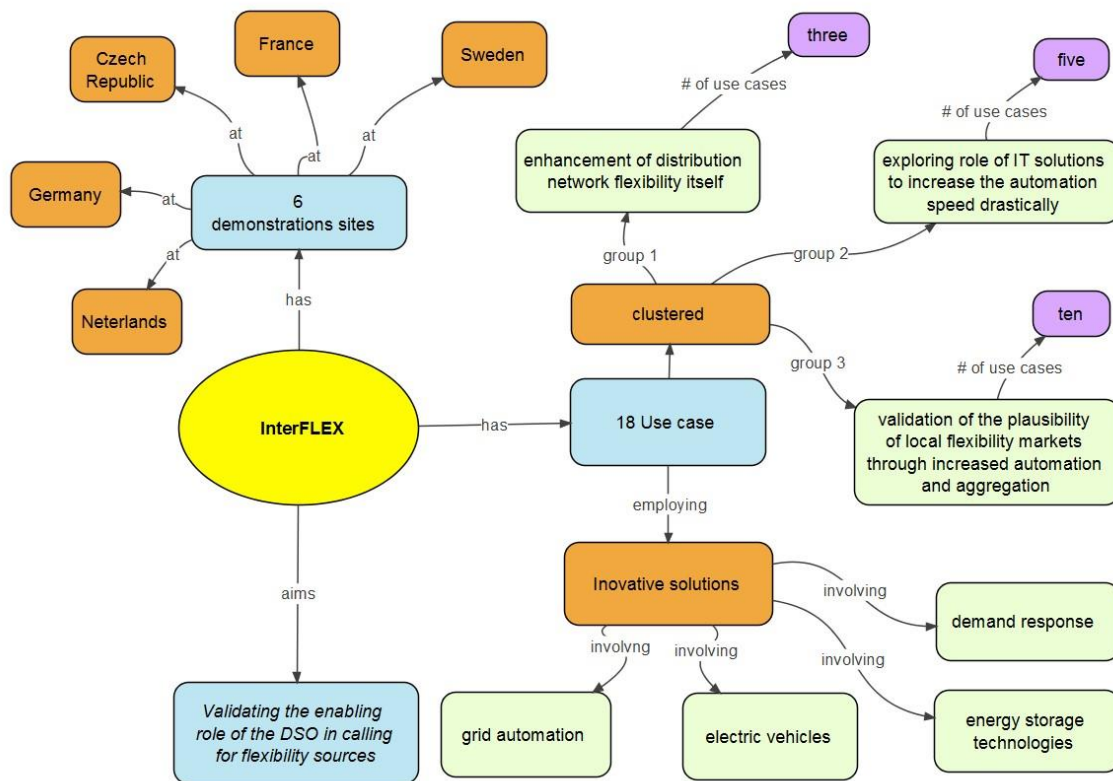


Figure 1.3: InterFlex summary.

1.4 Deliverable Organization

The rest of this deliverable is organized into 4 further chapters. Next chapter (Chapter 2) presents the proposed methodology which is an extension to the well-known methodology proposed by the Sustainable Process Working Group under EU Mandate M/490. Later, Chapter 3, presents the analysis using the proposed methodology, first at the individual and then at the aggregated level for all the 18 UCs from the six demonstration sites. Further, in Chapter 4 the upper- and lower-bound validation design, laboratory setups and next steps are presented. Chapter 5 concludes this deliverable with listing the important findings.

2 METHODOLOGY

This chapter presents the methodology proposed as an extension to the well-known process-model proposed by the Sustainable Process Working Group under EU Mandate M/490. The methodology is aimed at finding the Common Pattern (CP)s that can be used to develop the Open Test Suite (OTS) and/or generate recommendations for the standardization bodies at the EU level. The proposed methodology will be used to analyze the 18 InterFlex UCs from six demonstrators. The expected outcome when applying this methodology is finding the Common Pattern that are employed by the participating DSOs for activating the flexibility sources. These CPs can then be used when developing the OTS. With to develop an OTS for the interoperability validation in a laboratory settings. The chapter starts with discussing the aim of this study in Section 2.1. Next, it provides a context/background for understanding the bases of the proposed methodology in the Section 2.2. The Section 2.3 describes the type of input that is available from the mentioned 18 UCs. A detailed description of the proposed extension is described in the Section 2.4. This chapter concludes with presenting the expectations from applying the methodology to the available input.

2.1 Aim of the study

The aim of this study is investigate and derive a compatible methodology (as close as possible to existing standardized/well-known methodologies) that can be used to analyze the demonstration UCs in the context of InterFlex and develop the test cases for the purpose of interoperability validation in a laboratory settings. This study reports the approach that is employed on 18 UCs from six different demonstrators in InterFlex. ICT architectures are analysed at three different levels (UC, demonstrator and aggregated) to allow for a systematic deduction of CPs in the solutions for the flexibility provision.

2.2 Background

Due to emergence of modern energy systems (Smart Grids) as interconnected systems, it is becoming more and more complex to design, develop and validate such systems. These are now multi-domain System-of-Systems (SoS) and can no longer be modelled as one big monolithic system. The individual sub-systems exposes interfaces at different domain and system levels. These interfaces are then needed to be integrated with the participating sub-systems. Such integration is a challenging task and requires a well-thought-over methodology [2] otherwise the complexity would multiply further. There have been recent effort at the EU level under the Mandate M/490. Two major outcomes from the working groups under the mandate are the UC management (Sustainable Process Working Group) and reference architecture model (Reference Architecture Working Group) [3].

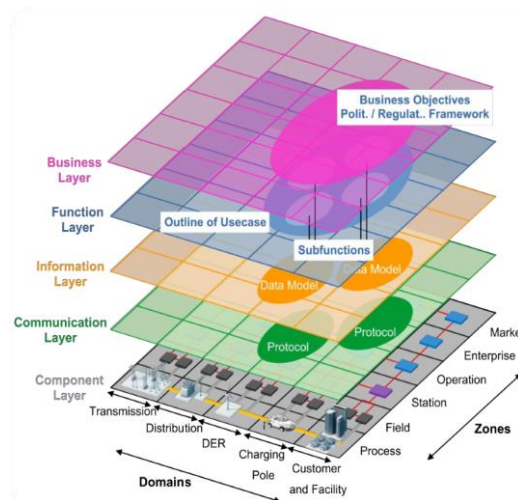


Figure 2.1: The Smart Grid Architecture Model (SGAM).

For Smart Grid, the IEC 62559 family of standards provides a UC template in addition to related concepts and guides for the UC management. The template provided in IEC 62559[4] can be used to describe a UC with all the relevant details that are understandable across domains. The other major outcome from M/490 is from Reference Architecture Working Group in the form of an architecture model called the Smart Grid Architecture Model (SGAM) that provides a holistic viewpoint for SG architecture. It consists of a visualization, concepts and methods for mapping the UC information in a structured way. It is usually visualized (Figure 2.1) as a cube with five interoperability layers and the SGAM Smart Grid Planes. Each of the interoperability layer (business, function, information, communication and component) is providing high-level architecture information. The SGAM Smart Grid Planes are organized in domains (generation, transmission, distribution, and DER) and zones (Process, field, station, operation, enterprise and market).

The Sustainable Process Working Group further proposed a generic system engineering process-model that can be adopted for defining innovations for SoS (e.g. Smart Grids) functionalities [1]. The model is depicted in the Figure 2.2. It is a 4 steps process where findings are first converted into UCs and stored in a repository. These UCs are then mapped to SGAM. Steps 3 and 4 are the analysis of identifying the requirements and finding the gaps that eventually leads to the expected outcome. Adapting such an approach is very helpful in many respects including the share of information on a common understanding making the experience sharing easy. Another worth mentioning advantage is the highly details knowledge availability in when following such process-models. Realizing these advantages, InterFlex has also adopted this process-model as a common methodology for UC collection and method adoption by all the partners [5]. IEC 62559 and SGAM are utilized extensively in *Step 1* and *Step 2* is this adapted process.

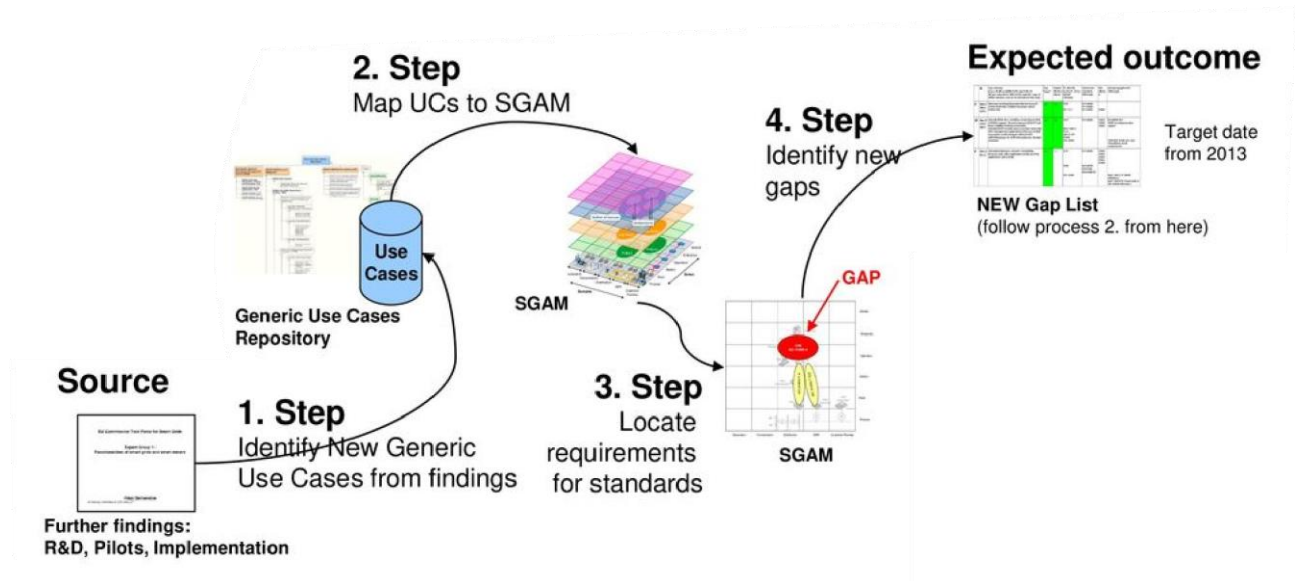


Figure 2.2: System engineering process proposed by the Sustainable Process Working Group working under EU Mandate M/490 for crating and formalizing the complex systems (SoS.) [1]

2.3 Input Material

The analysis is based on detailed documentation of UCs available in the form of IEC 62559 templates for respective architectures developed within the individual demonstrators. These UC descriptions are converted to the SGAM where it is represented in five inseparability layers along with domains and zones. The resulting SGAM harmonized models contain a lot of information that is then used as input for this task. All five layer are considered as input. To show as an example of the level and representation of the information Figure 2.3 shows the Communication and Information layers for the Czech UC CZ.1.

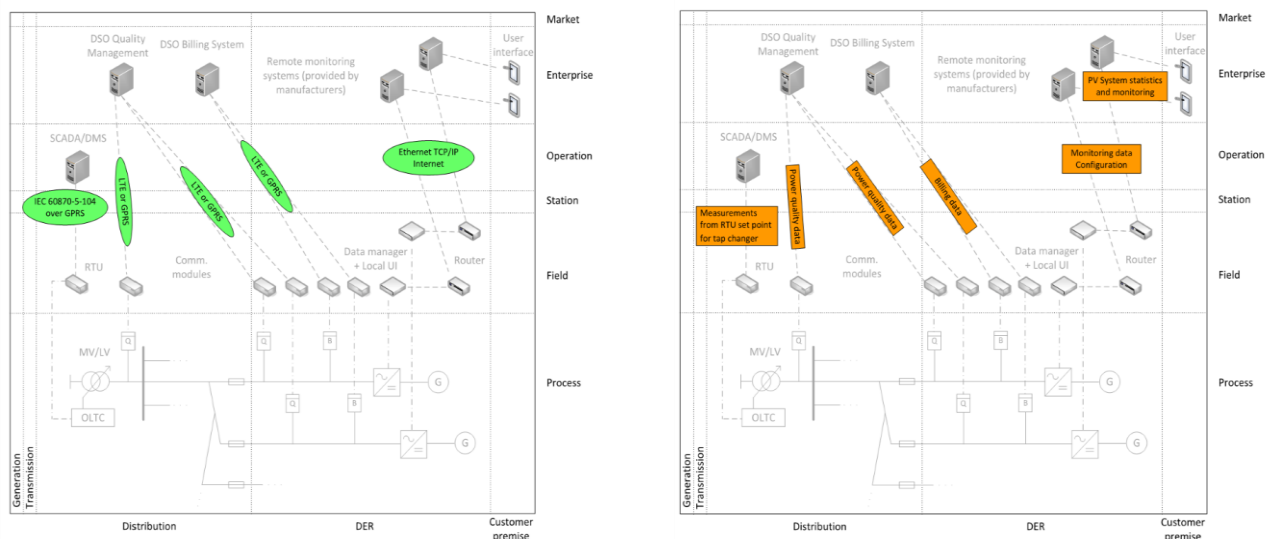


Figure 2.3: Example SGAM Communication (a) and Information (b) layers for one of the input UCs.

2.4 The Methodology

InterFlex is a large project with 18 UCs for its six demonstrations. Each of these UCs is implementing an innovative solution for exploring the ways a DSO can activate the flexibility sources with possibly a different implementation strategy (upper/lower-bound etc.) and/or implementation technology. Such a diversity, on one hand, is good in showing the different possibilities but on the other hand, poses a big challenge in finding the common pattern/practices easily. Such identified common patterns can be a valuable contribution to the EU or international standard body or, in this specific case (GWP3) to an OTS.

To handle such diversity, a well-crafted methodology is needed. Such a methodology ideally must not be too far away from the processes already in use so that it may not further complicate the process by requiring a new set of skills for its application. On the other hand, it should be able to do a detailed analysis at different levels so that the results are more acceptable. Keeping these guidelines in mind, a detailed methodology that is both in line with the project and able to perform analysis at three different levels is proposed. It is inspected as an extension to a well-known process-model (see Figure 2.2). It's a 4 steps process where findings are first converted into UCs and stored in a repository. These UCs are then mapped to SGAM. Steps 3 and 4 are the analysis of identifying the requirements and finding the gaps that eventually leads to the expected outcome. Adapting such an approach is very helpful in many respects including the share of information on a common understanding making the experience sharing easy. Another worth mentioning advantage is the highly details knowledge availability in when following such process-models. Realizing these advantages, InterFlex has also adopted this process-model as a common methodology for UC collection and method adoption by all the partners [5]. IEC 62559 and SGAM are utilized extensively in *Step 1* and *Step 2* is this adapted process.

The proposed methodology is an extension to the (Step 3. of the) this process-model. The additional steps are proposed to find the Common Pattern (CP) added to find the CPs that can later be utilized for developing the OTS and recommendations for standard bodies.

2.4.1 Design Rationale

The design rationale for the proposed methodology is that demonstration UCs are implementing innovative solutions for achieving the same objective i.e. flexibility provision but there is a huge diversity in the ICT implementation strategies and technologies. An Open Test Suite (OTS) for interoperability validation of such solutions can only be developed once the ICT architectures from all the involved UCs in the six demonstrators are analysed to find CPs. This identified CPs are further needed to be suitable for the laboratory validation that requires performing another round of analysis activity. Another likely outcome of the identified CPs is a submission of recommendations to the standardization bodies.

To perform such an analysis, a set of inputs and an analysis method is needed. The input is chosen to be the detailed UC descriptions developed by each demonstrator as part of the project and the SGAM harmonization of these UCs.

The analysis methodology ideally must not be too far away from the well-known process in use so that it may not further complicate the its applications by requiring a new set of skills. On the other hand, it should be able to do a detailed analysis at different levels so that the results are more acceptable. Figure 2.4 depicts the design rationale in a very simplified way.

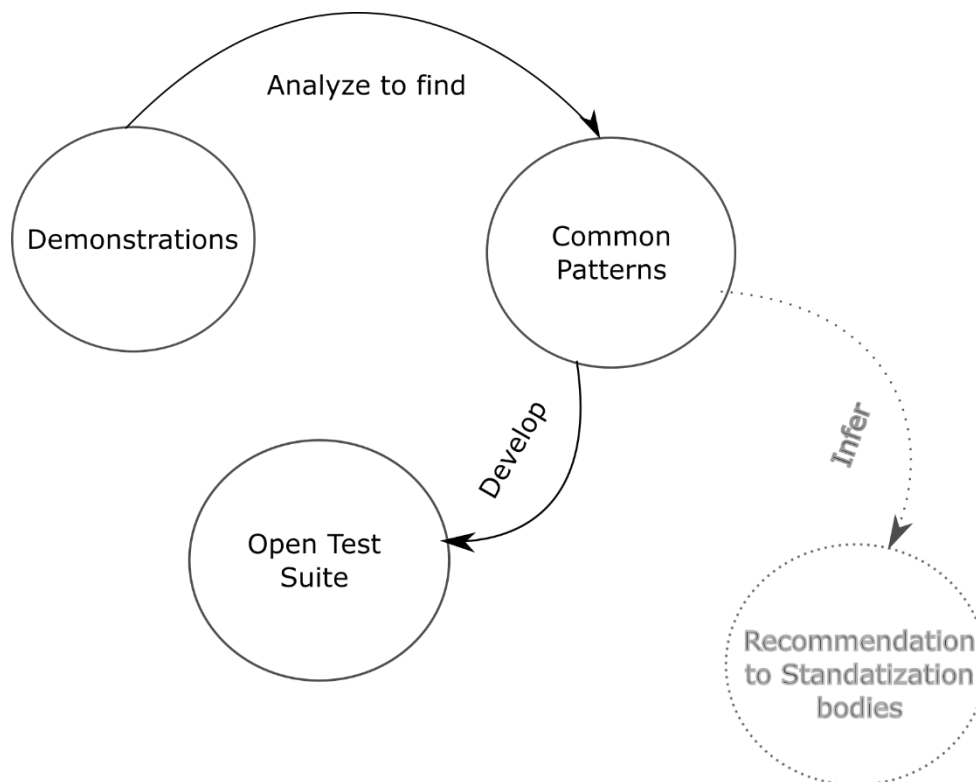


Figure 2.4: The design rationale for the proposed methodology

2.4.2 Detailed Description

The proposed methodology is presented in the Figure 2.5. As can be seen in the figure, it is an extension to the EU Mandate M/490 process-model that was introduced in Figure 2.2 before. There are three additional (3.1, 3.2, and 3.3) steps extending the 3. Step of the original process. Now each extended step is described below.

Extended step 1

In the first step of the extended methodology is to perform the first round of analysis on the available input. This input contains the detailed UC descriptions in the form of IEC 62559 templates and their corresponding harmonization to the SGAM. This step is designed to transform the input SGAMs to a mapping shown in Figure 2.6.

This analysis is performed at three different levels. At first all 18 UCs are individually analyzed and input SGAMs are mapped to a hierarchical structure composed of multiple concepts. These concepts and the corresponding SGAM layers it is extracted are summaries in the Table 2.1. As seen in the Figure 2.6b, these concept are represented as a “tree” with “Aim” as the root node. The elements of the tree also have cordiality relationships which is mostly a 1-to-many (1:M) relationship. For example “Aim” and “Objectives”, “Categories” and “Services”, “Services” and “Functions”, and “Functions” and “Implementations” all

have a 1-to-many (1:M) relationship. The colors of the node are representing the color of the SGAM layer where the node belongs. Another view of the proposed methodology is presented in the Figure 2.6a where the same concepts are mapped on to a pyramid. The first three layers of the pyramid are representing the first four layers of the SGAM, while the fourth layer of the pyramid has encapsulated the 3.2. and 3.3. Step of the proposed methodology.

The mapping in this step is not automatic and is performed by analyzing the UC detailed description and the corresponding SGAM mappings. The concepts used to represent the mappings are, to some extent, self-explanatory. Once the mapping is done for all the UCs individually, the UCs are analyzed together at the demonstrator level and later at the project level. The outcome of this step is the emergence of the CPs that can then be analyzed in the next steps.

Table 2.1: Description of the concepts used in the methodology (Step 3.1.).

Concept	Definition	SGAM Layer
Aim	The major focus of the UC.	Business
Objectives	The High-level goals of the UC	Business
Categories	The Features of the UC (the Common Pattern(CP))	Function
Services	The major steps of achieving an objective in the UC	Function
Functions	The detailed steps for providing a service in the UC	ICT
Implementation	The implementation details like data models, protocols, encoding etc. in the UC for implementation a function	Information

Extended step 2

In this step two functions are performed. First, the CPs identified in the previous step can be extracted at the three different level. However, for this task only the CPs at the project level analysis would be needed. Second, a laboratory suitability analysis/test can be specified to select only the CPs that can be validated in the laboratory. The outcome of this step would be set of CPs are can be validated in a laboratory settings.

Extended step 3

The third and the last step is developing the validation design and validation setup recommendations for the OTS on the basis of the analysis performed at different layers and for different purpose. The outcome of this setup would be the validation designs that can be further developed into the validation setup.

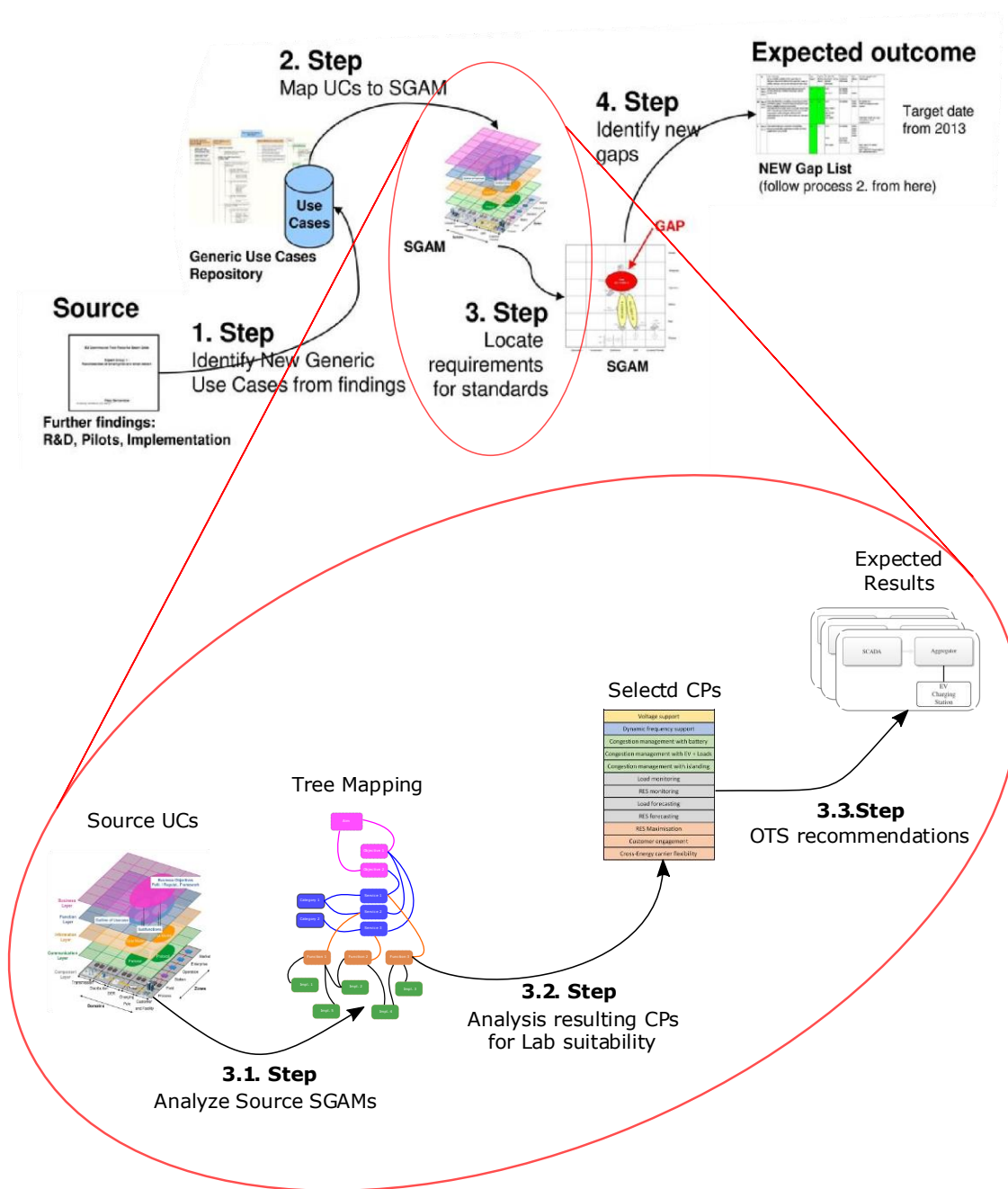
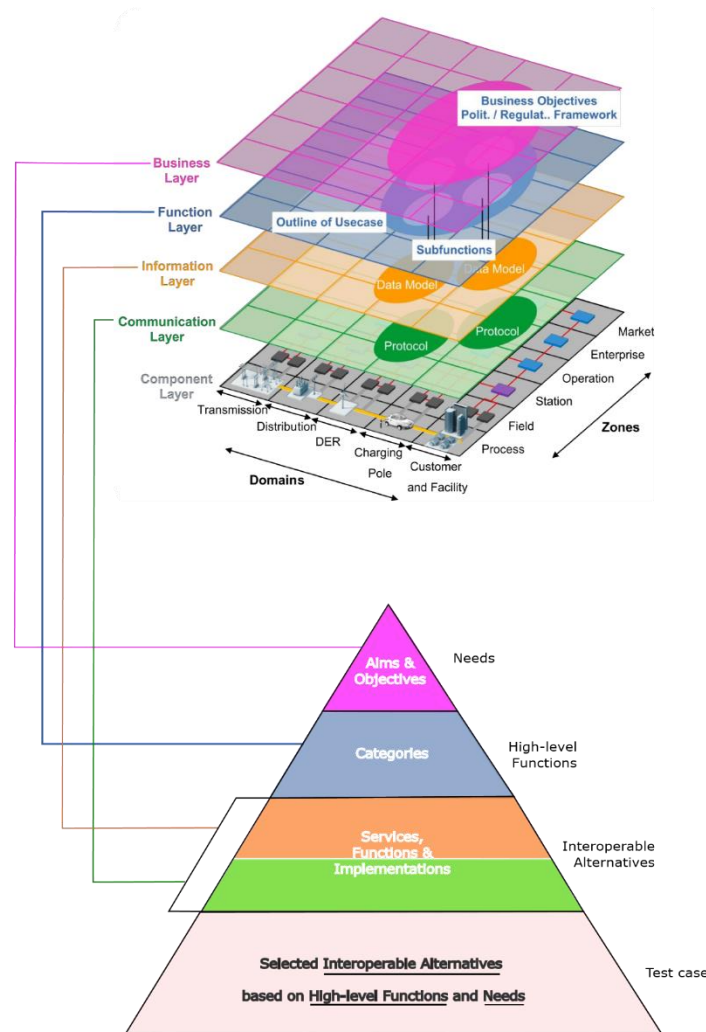
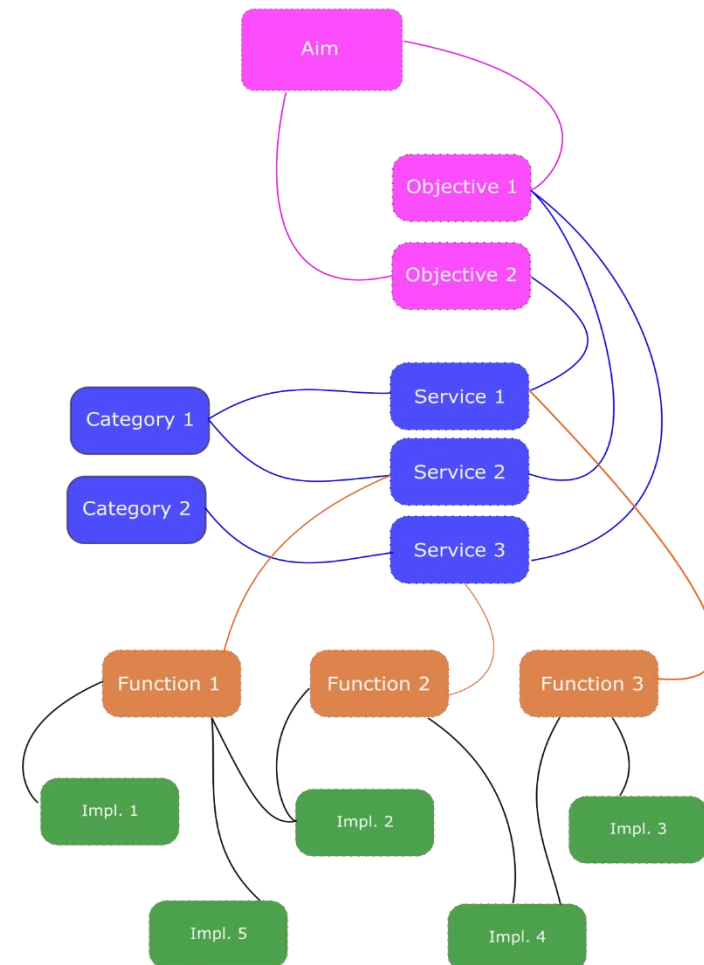


Figure 2.5: The proposed methodology which extends the 3. Step of the EU mandate M490s Sustainable Process Working Group



(a) The proposed methodology represented as a direct mapping from the input SGAMs to the final outcome (OTS).



(b) The "tree" mapping used in 3.1. Step of the proposed methodology.

Figure 2.6: Representation of the mapping from the input SGAM (a) and explanation of the mapping in 3.1. Step

2.5 Expected Output

The expected output from the application of the proposed methodology to all the 18 UCs of the six demonstrators constitutes a set of recommendations for an OTS. In *3.1. Step*, the analysis at three different layers (UC, demonstrator and project) provides a systematic way of extracting CPs from the input available in the form of detailed UC descriptions and corresponding SGAMs. The CPs extracted at this step are then used as input for *3.2. Step* to do a laboratory suitability analysis and then to select the CPs that should be considered for the OTS. The *3.3. Step* helps in providing the recommendation for a validation design.

3 ANALYSIS

Previous chapter has described the proposed extension as the methodology for finding the CPs that are being employed in all the six demonstrations by the DSO for activating the flexibility sources. This chapter will present the analysis as an application of this methodology. The analysis is done at three different levels. Section 3.1 presents the analysis at the UC and demonstrator level while Section 3.2 shows the analysis at the project level. Section 3.3 concludes the chapter by summarizing the analysis at three levels.

Table 3.1: Listing of the 18 UCs from the six demonstrators in the InterFlex project

S#	UC ID	Objective
Czech Demonstrator		
1	CZ1	Increase DER hosting capacity of LV distribution networks by smart PV inverters
2	CZ2	Increase DER hosting capacity in MV networks by volt-var control
3	CZ3	Smart EV charging
4	CZ4	Smart energy storage
French Demonstrator		
5	FR1	Automatic Islanding
6	FR2	Multi-service approach for centralized storage systems
7	FR3	Local flexibility mechanism
German Demonstrator		
8	DE1	Feed In Management
9	DE2	Demand Side Management
10	DE3	Ancillary Services
Dutch Demonstrator		
11	NL1	Improve grid flexibility using Smart Storage Unit
12	NL2	Improve grid flexibility using Electric Vehicle
13	NL3	Usability of an integrated flex market
Swedish Demonstrator n°1		
14	SE1	Use of DSR to optimize DSO operation by exploiting the interaction with different energy carriers
15	SE2	Optimal use of a large heat pump asset providing the district heating grid with heat and electricity flexibility for grid management purposes
Swedish Demonstrator n°2		
16	SE3	Technical management of a grid-connected Local Energy System that can run in an islanded mode with 100% renewable generation
17	SE4	Micro Grid Customer Flexibility facilitated by a peer to peer market platform and enabled by Demand Side Response Programs
18	SE5	Increased ability to observe and steer the operations of a micro-grid in response to distribution network constraints

3.1 Individual UC and Demonstrator Analysis

This section is dedicated to describing analysis first at the individual UC level and later at the demonstrator level. For this purpose, this section is divided into five sub-sections presenting first a summary of the demonstrator and all its UCs and then two further sub-sections present individual UC analysis and the analysis at the demonstrator level respectively.

3.1.1 Czech Demonstrator

The Czech demonstration (GWP6) is managed by ČEZ Distribuce, a. s.¹, a leading ISO 9001 compliant DSO, and is defined with four UCs. This demonstration is located in several areas in Czech Republic where ČEZ Distribuce operates its distribution networks. Among the major focuses are the implementation of solutions which are not so far usual in distribution systems but which have a strong potential for future roll out. The solutions being tested are designed to cover the most urgent challenges of DSOs - increasing DER hosting capacity, EV charging stations implementation and energy storage. Beyond the technical developments, it also aims to propose grid codes and standards updates (if any) in order to secure future smoother integration of selected smart grid solutions.

A summary of these four UCs is shown in the Table 3.1 while a short description (summarized/adopted from [5], [6] and [7]), of the individual UCs is presented below:

- The UC CZ.1 - “*Distributed Energy Resources (DER) hosting capacity of Low Voltage (LV) distribution networks by combining smart Photovoltaics (PV) inverter functions*”, is aiming at demonstrating how the combination of new smart PV inverter functions Q(U) and P(U) under real operating conditions within LV distribution networks can increase the DER hosting capacity. A successful demonstration requires appropriate conditions for testing roof PV systems using smart PV inverters (fulfilling the EN 50438 ed.2 standard) installed massively under pre-selected 2 MV/LV secondary substations. Two areas with different typologies but high penetration of PV systems are needed. Crucial tasks for this UC are the recruitment of customers within the selected areas, the installation of PV systems with smart PV inverters and the delivery of technical operational data and results from the PV inverter monitoring systems with the customer’s consent.
- The UC CZ.2 - “*Increase the DER hosting capacity in Medium Voltage (MV) distribution network by volt-var control*”, integrates the selected DER connected to MV networks into volt-var control system. The selected DER connected to MV networks are integrated into volt-var control system (PV: 1.1MW, bio-gas station: 1.25MW, wind: 4.6MW). The DSO can send required voltage set points from its SCADA to DER unit, which then react and regulate at the required voltage set points (thanks to reactive power generation/consumption. For this volt-var control strategy, an existing DER over 100kW with communication capabilities towards the DSO dispatching control system (SCADA) is used.
- The focus of the UCs CZ.3 - “*Smart EV charging*” is to test the influence of smart EV charging stations functions to show their potential for increasing the network flexibility through improved EV charging stations implementation into the distribution networks (services to the distribution network), and optimizing the future EV charging stations

¹ <https://www.cezdistribuce.cz/>

implementation to prevent from power quality issues and to contribute to the system stability and flexibility without reduction of customer comfort. The Smart functions to be tested (first in a laboratory then in the field) are partial active power curtailment of EV charging in case of under frequency or under voltage in the DS and partial remote active power curtailment from DSO SCADA in case of emergency.

- While, the CZ.4 - “*Smart energy storage*” tests the influence of using the Residential Energy Storage Systems (RESS) on the PV peak shaving in LV distribution network and assesses the potential of grid-connected energy storage systems for increasing the flexibility by providing grid services. The smart energy storage functions which are going to be tested are limited to active power injection in case of DSO request, and active power injection in case of under frequency or under voltage in the distribution network. Testing the influence of RESS on solar peak shaving helps determining how these systems affect the power quality and how they contribute to avoiding congestion in the distribution network.

3.1.1.1 Individual UC analysis

Analyzing the input SGAM for the individual UC in Czech demonstration using the Step 3.1. of the extend methodology resulted into Figure 3.1 for UC CZ.1, Figure 3.2 for UC CZ.2, Figure 3.3 for UC CZ.3 and Figure 3.4 for UC CZ.4. In each of these figure, the analysis has identified different CPs.

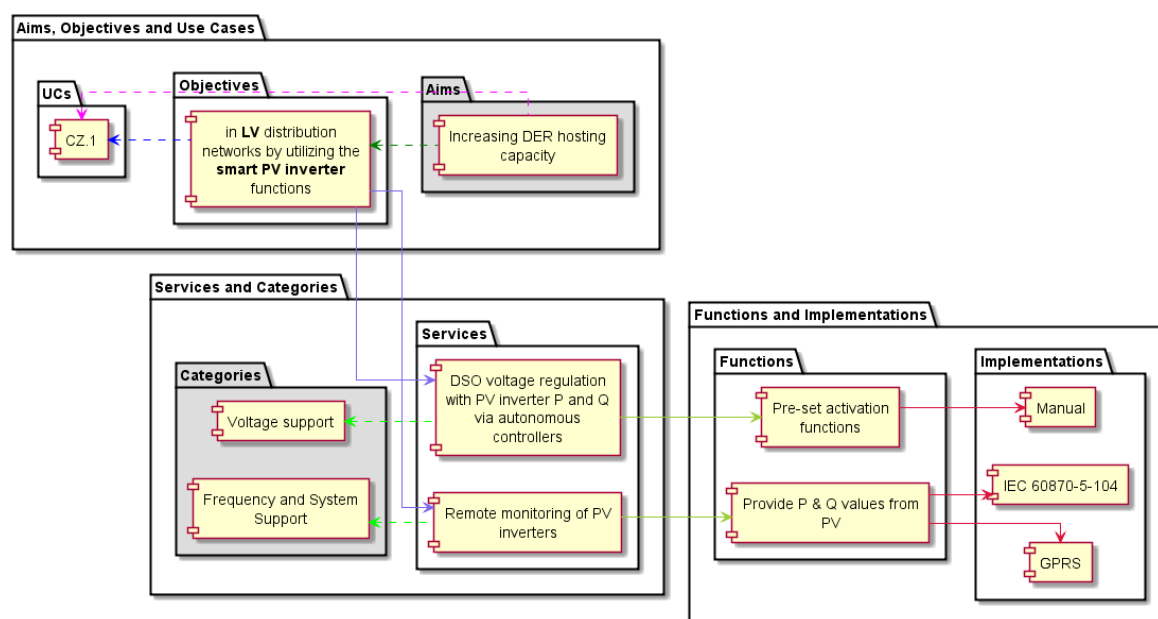


Figure 3.1: Analysis for the Czech Demo UC CZ 1

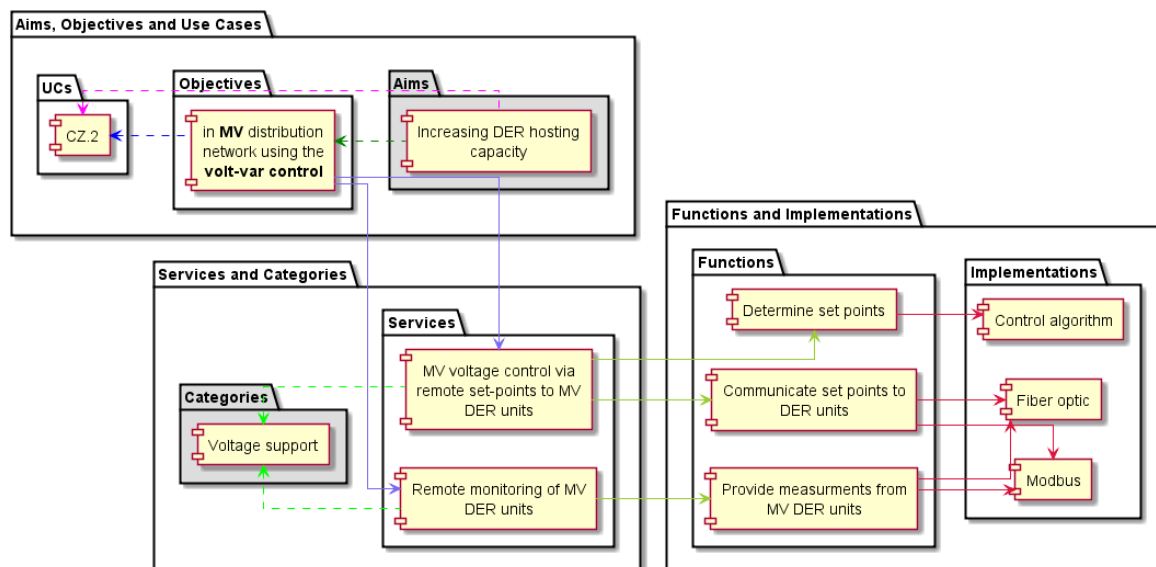


Figure 3.2: Analysis for the Czech Demo UC CZ 2

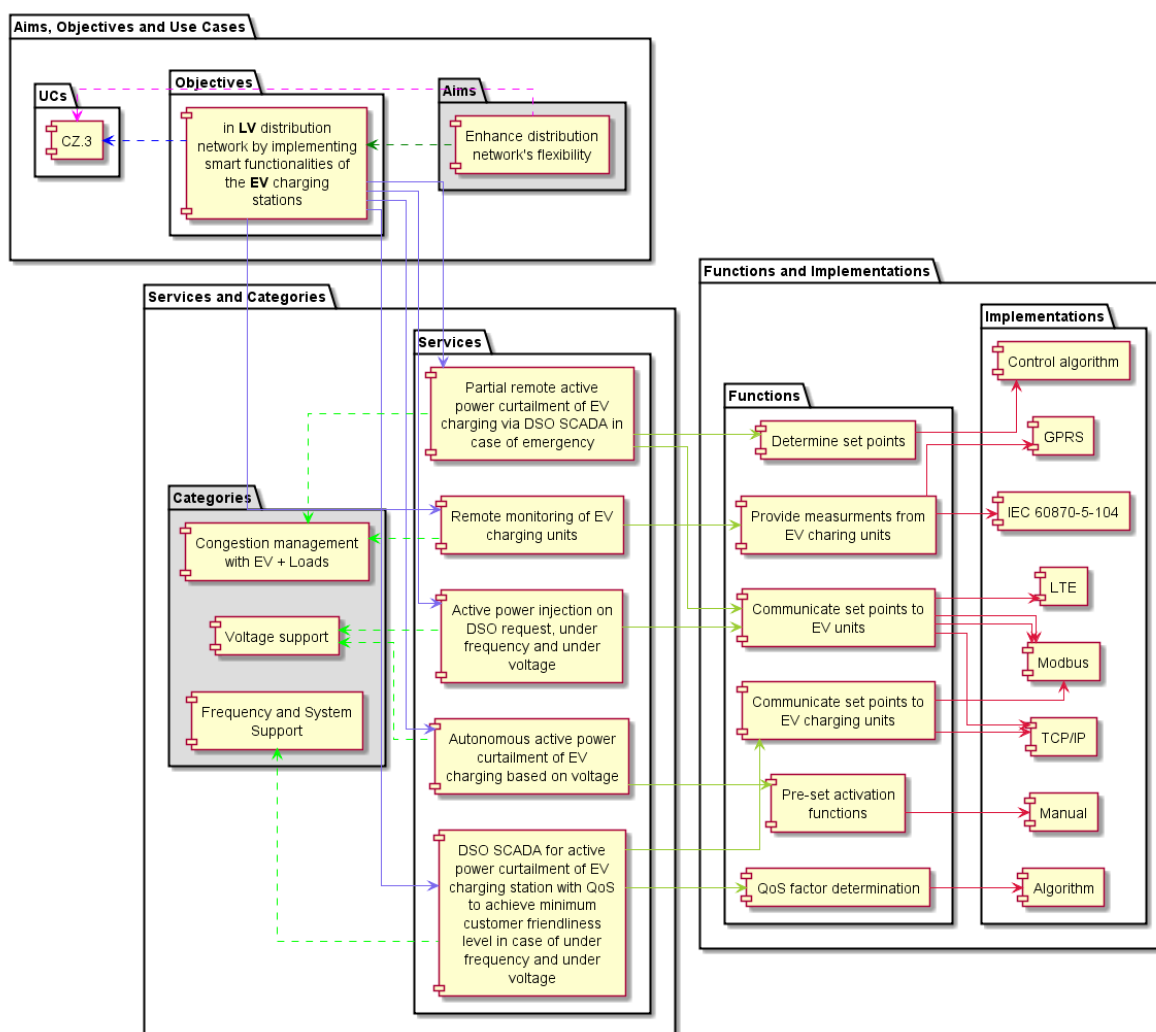


Figure 3.3: Analysis for the Czech Demo UC CZ.3

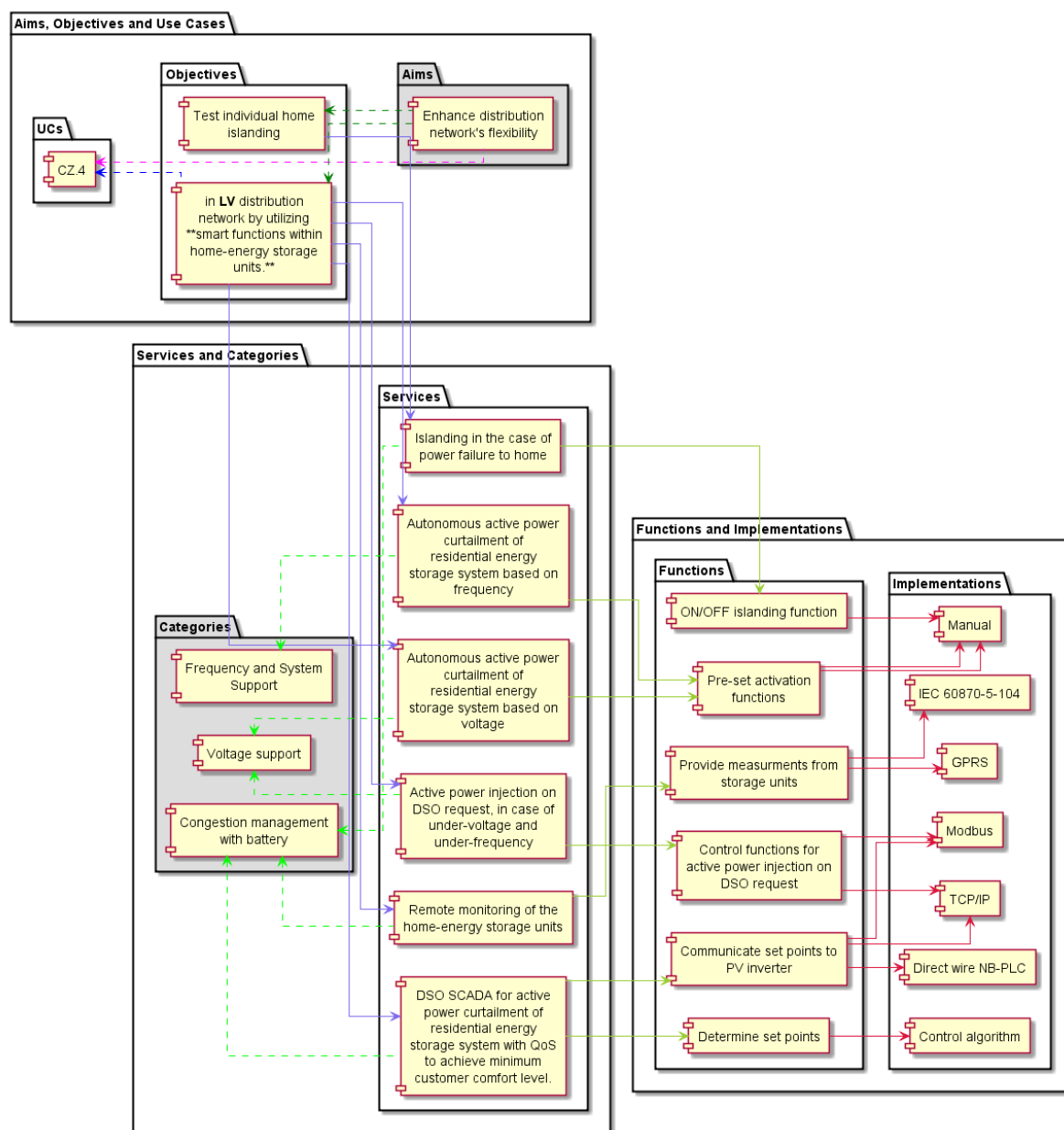


Figure 3.4: Analysis for the Czech Demo UC CZ.4

3.1.1.2 Analysis at the demonstrator level

The Figure 3.5 shows the mapping diagram when the analysis is performed for the all the UCs for the Czech demonstrator (CZ.1, CZ.2, CZ.3 & CZ.4) combined together. Looking at this aggregated demonstrator analysis diagram, it can be seen the analysis has found five CPs of services that are common to all the four UCs.

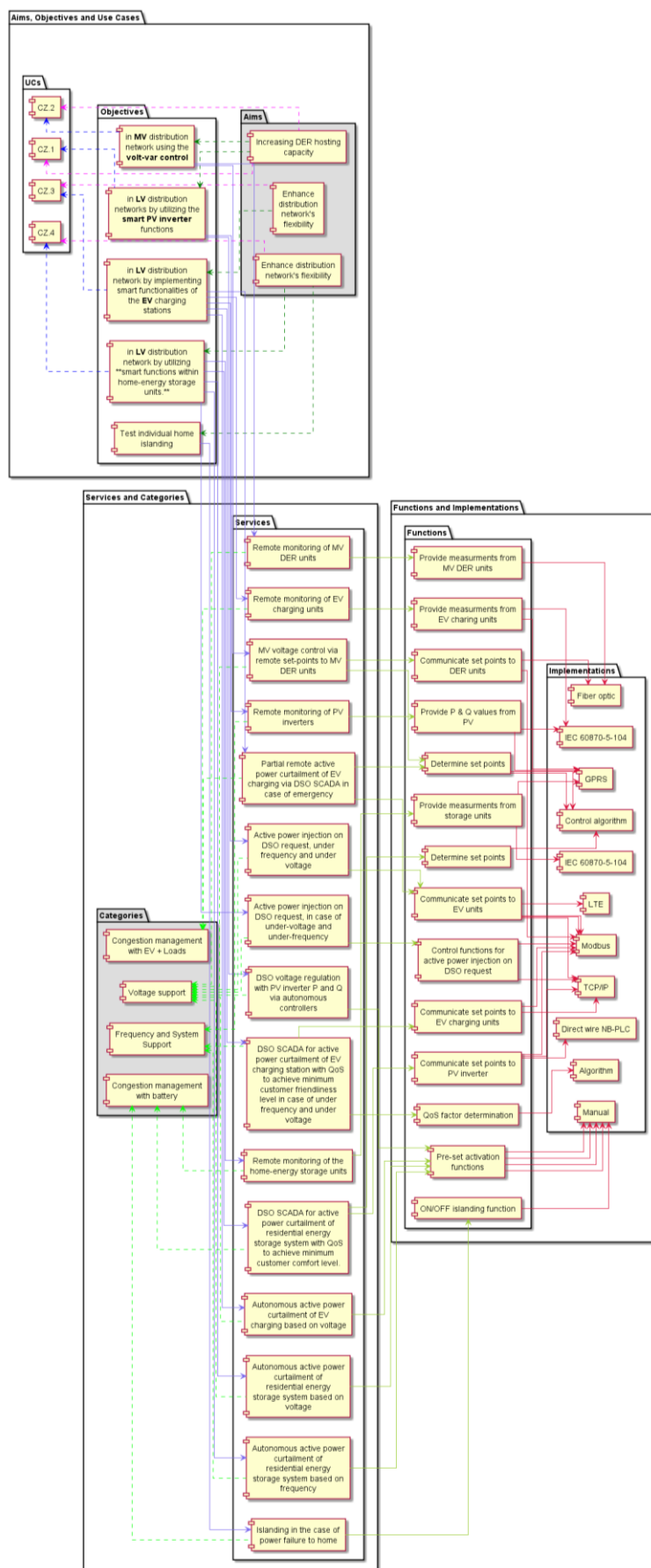


Figure 3.5: Analysis for the Czech demonstrator.

3.1.2 French Demonstrator

The French demonstration (GWP9) is named “Nice Smart Valley”² and managed by Enedis³, a leading DSO managing the public electricity distribution network for 95% of continental France.

A summary of the UCs is shown in the Table 3.1 while a short description (summarized/adopted from [5], [14] and [7]) of the individual UCs is presented below:

- The first UC FR.1 implements an innovative automatic islanding solution. It is described as *“an alternative to grid reconfiguration, (where) DSOs can provide a continuous supply of electrical energy to customers, thanks to electricity storage assets operated by the DSO”*. The UC is dedicated to the islanding of a portion of the distribution grid using local resources. It includes emergency islanding (fault on the MV distribution grid), planned islanding (for maintenance works on the MV distribution grid). It is to be noted that islanding operations are conducted for resilience reasons, following a possible incident or failure on the upstream power line (submarine cable). Those incidents are simulated during the demonstration phase. The islanding operation is remotely controlled, on-demand from the regional control room.
- The second UC FR.2 - *“Multi-service approach for centralized storage systems”*, is dedicated to the multi-service approach for grid-connected storage systems. It is investigating ways by which the DSOs could integrate large-scale storage volume and enable multi-service electricity storage operated by storage aggregators or the DSOs themselves. It is mainly focused on a multi-service approach for centralized storage systems that should be more efficient and visible for the DSO (data analysis can be easily done).
- The third UC FR.3 - *“Innovative flexibilities can be aggregated and bid either on a local DSO mechanism to reduce local grid constraints or on national market to ensure global stability”* is dedicated to the use of flexibility managed by aggregators for the need of the DSO, using a local flexibility system. It creates and manages a local flexibility mechanism involving electric vehicles, hot water storage tanks, energy storage system, hybrid boilers (gas/electric) and combined heat/power system. Furthermore, this UC uses a forecast system to manage the flexibility.

The following areas have been chosen to test these use cases:

- The demonstration site for islanding purpose is Lerins Islands, an archipelago of several islands, in the south of Cannes City, France. The islands are supplied by an autotransformer in Cannes through a single submarine cable of 10 kV of nominal voltage. Today, there is no “N-1” configuration that can supply the customers on these islands in case of a loss of the submarine cable. In Nice Smart Valley, islanding the Lerins Islands will allow an autonomous operation of the islands in case of grid’s maintenance or incident on the upstream grid. There are 56 customers connected to the LV grid on the islands who get their power supply from 5 secondary substations.
- The demonstration sites for centralized storage systems are both on the Lerins islands (see above) and in Carros, a city of ~12,000 inhabitants located next to Nice. One of Carros’ secondary substations presents interest to install a storage system to maximize the self-consumption rate as there are 400 kWp of installed photovoltaic panels. ENGIE

² <http://nice-smartvalley.com/gb/>

³ <https://www.enedis.fr/>

aims at optimizing the use of central storage assets on different value pockets (national market, self-consumption, islanding, etc.)

- The idea of this use case is to assess how the flexibility requested by the DSO from aggregators can solve the constraints on different grid topologies and customers typologies. The following areas⁴ have been chosen through simulation results:
 - Isola is a rural mountain village where a ski station is located and connected to the MV grid. A few grid constraints may appear during the night - in winter season - in case of an equipment loss at HV level.
 - Guillaumes is a rural mountain village where several constraints may appear during the night - in winter season - in case of a loss of an HV or MV equipment.
 - Carros is a city near Nice with a lot of industrial customers. A few constraints may appear at midday in summer, in case of a loss of an HV/MV transformer.

The western district of Nice is a very urban area that has been added to the demonstration areas to increase the scope of the typology of grid and customers.

3.1.2.1 Analysis at UC level

In the case of individual UC analysis in the French demonstrator, the resultant mappings from the analysis are shown as Figure 3.6 for UC FR.1, Figure 3.7 for UC FR.2 and Figure 3.8 for UC FR.3. As can be seen in these figures there are at most three CPs per UC.

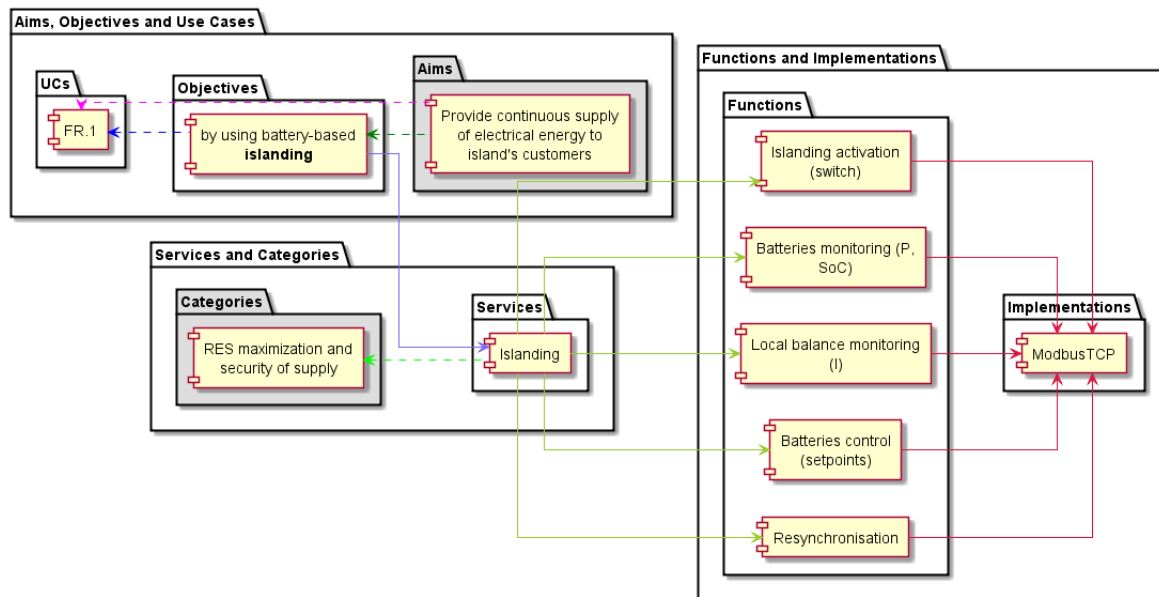


Figure 3.6: Analysis for the French Demo UC FR.1

⁴ See D9.1 for more details on the areas.

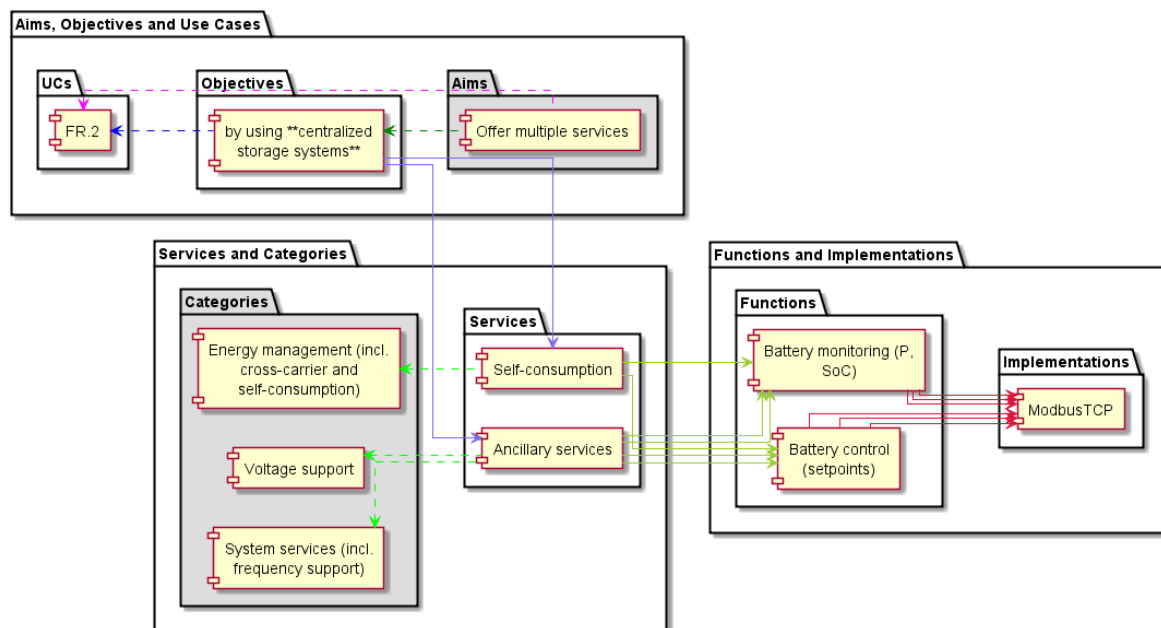


Figure 3.7: Analysis for the French Demo UC FR.2

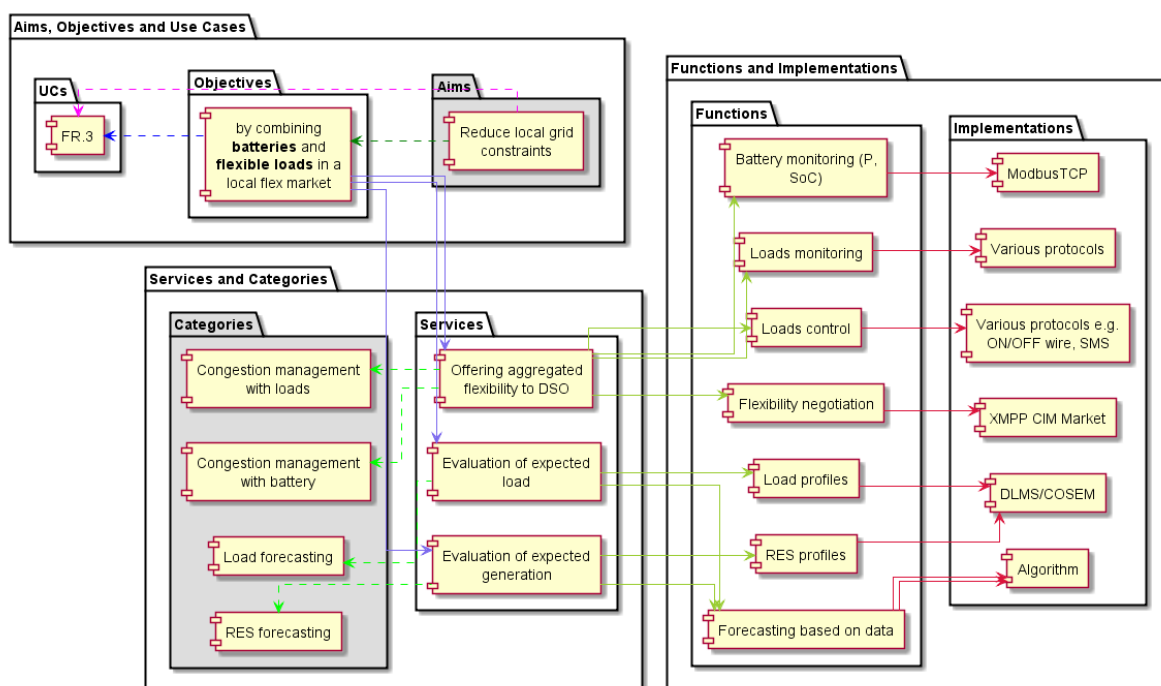


Figure 3.8: Analysis for the French Demo UC FR.3

3.1.2.1 Analysis at the demonstrator level

The Figure 3.9 shows the resultant analysis diagram when the analysis is performed at the demonstrator level for all the three (FR.1, FR.2, FR.3) UCs for the French demonstrator.

Looking at the aggregated analysis diagram, it can be seen the analysis has found three CPs for all the UCs in the demonstration.

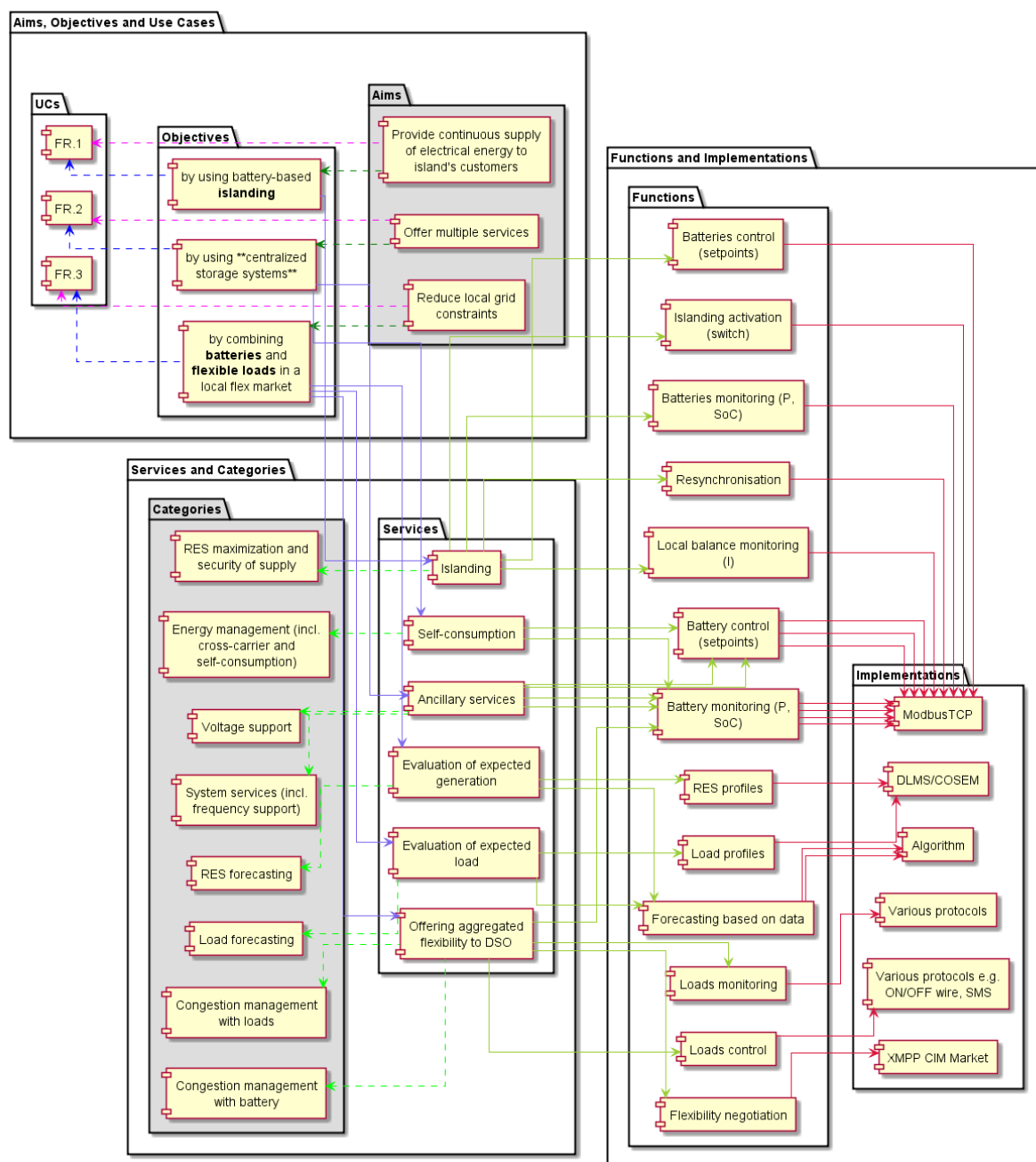


Figure 3.9: Analysis for the French demonstrator.

3.1.3 German Demonstrator

The German demonstration (GWP5) is managed by Avacon AG⁵, “one of the largest regional network operators and infrastructure service providers in Germany”. Avacon AG has developed a prototype of an intelligent device the Smart Grid Hub (SGH) (see [9] for more details) that can work with any Advanced Metering Infrastructure (AMI) while complying with

⁵ <https://www.avacon.de>

EU recommendations. The SGH, according to [9], *“is part of an integrated concept to enable the grid control centre of a DSO to access and directly control small scale flexibilities of any type in response to violations of technical grid constraints or even external market signals.”* It acts as an aggregation and enables DSO to monitor, measure and control small scale flexibilities offered by residential customers. The SGH is located within the grid control SCADA environment and communicates with customer’s devices via the AMI as set out by the Federal Agency for Cyber Security in Germany. It monitors the state of local small-scale generators via an AMI which transmits power, voltage, and current at the customer’s premises. Combined with data from the grid control center about the state of the grid the SGH can forecast and recognize impending or existing violations of technical limits and control and curtail the momentary feed-in of local generators to such an extent, that all technical limits will be respected at all times. It also determines the curtailment strategy in such a way that the number of generators affected and the total volume of energy curtailed remains the minimum necessary to keep the grid within technical limits. In this demonstration, Avacon AG is testing SGH by connecting the AMI in 200 households among its selected customers. The three UC being tested are focused on feed-in management, ancillary service provision, and demand response. A summary of these three UCs is shown in the Table 3.1 while a short description (summarized/adopted from [5], [9], [10] and [7]) of the individual UCs is presented below:

- In the UC DE.1 - *“Controlling small RES units”*, SGH decides which Renewable Energy Sources (RES) units should be controlled based on the field measurements and intelligence.
- In the UC DE.2 - *“Ancillary services provided by generation, consumption and storage devices”*, the signals coming from the aggregation of generation, consumption, and storage devices are coordinated with other signals such as curtailment and demand response signals.
- In the UC DE.3 - *“Distributed sources of flexibility within the distribution grid”*, demand response signals coming from different market participants are aggregated in the SGH according to the least intervention possible. Battery storage and cross-sectional technologies such as E-mobility and electrical heating systems provide flexibility for the distribution grid.

3.1.3.1 Analysis at UC level

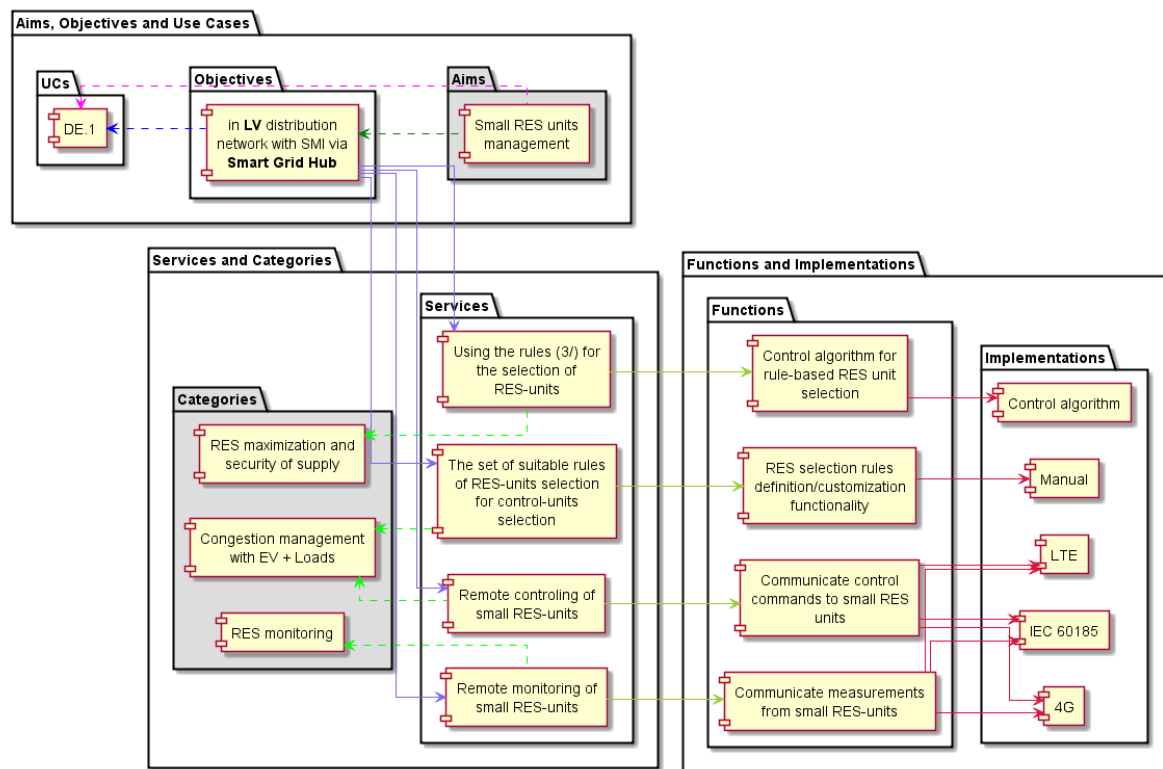


Figure 3.10: Analysis for the German Demo UC DE.1

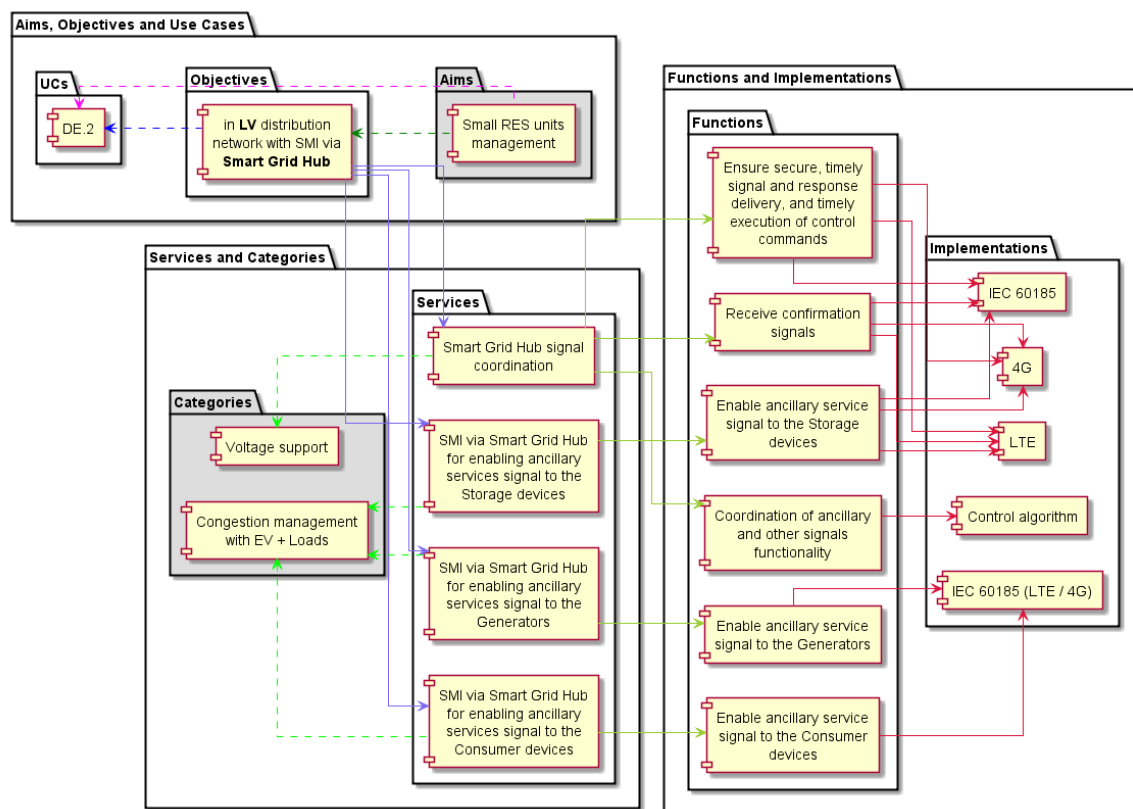


Figure 3.11: Analysis for the German Demo UC DE.2.

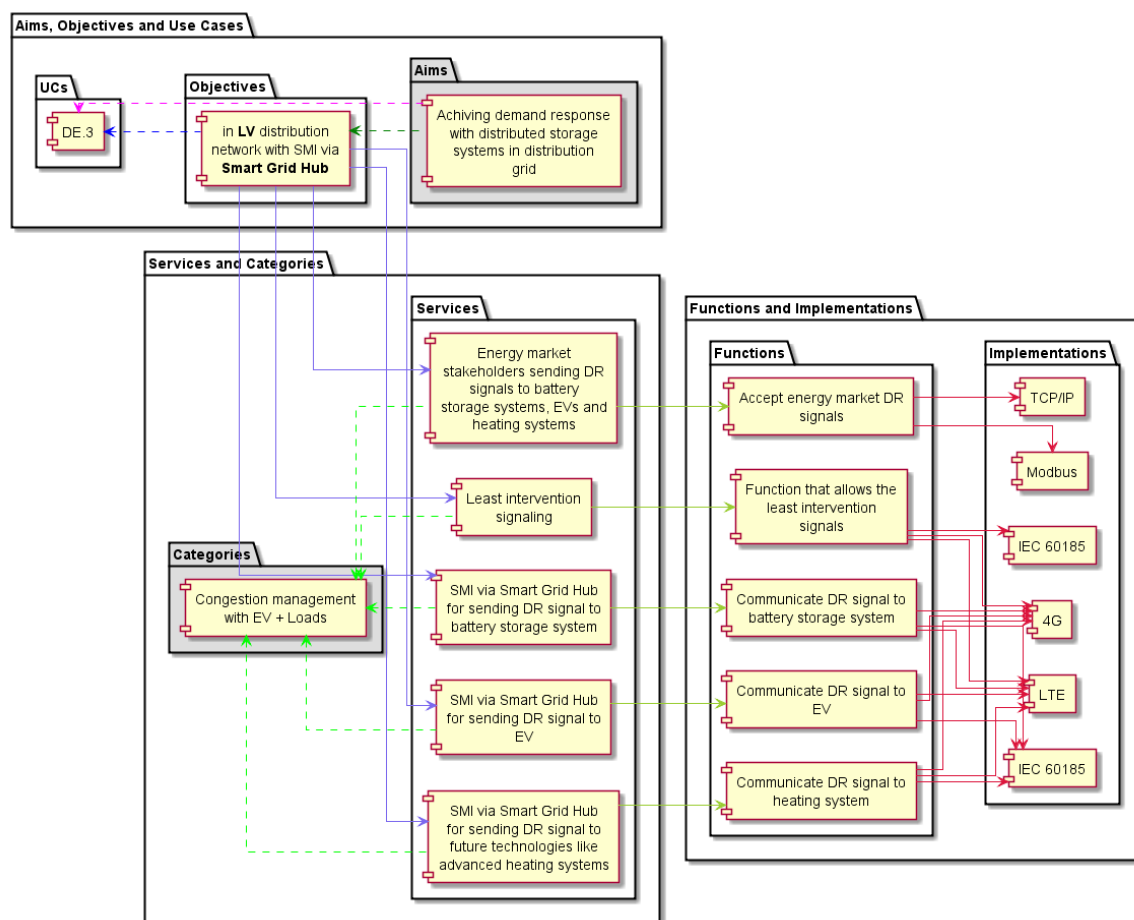


Figure 3.12: Analysis for the German Demo UC DE.3.

3.1.3.2 Analysis at the demonstrator level

The Figure 3.13 shows the resultant analysis diagram when the analysis is performed at the demonstrator level for all the three (DE.1, DE.2, DE.3) UCs for the German demonstrator. Looking at the aggregated analysis diagram, it can be seen the analysis has found three CPs for all the UCs in the demonstration.

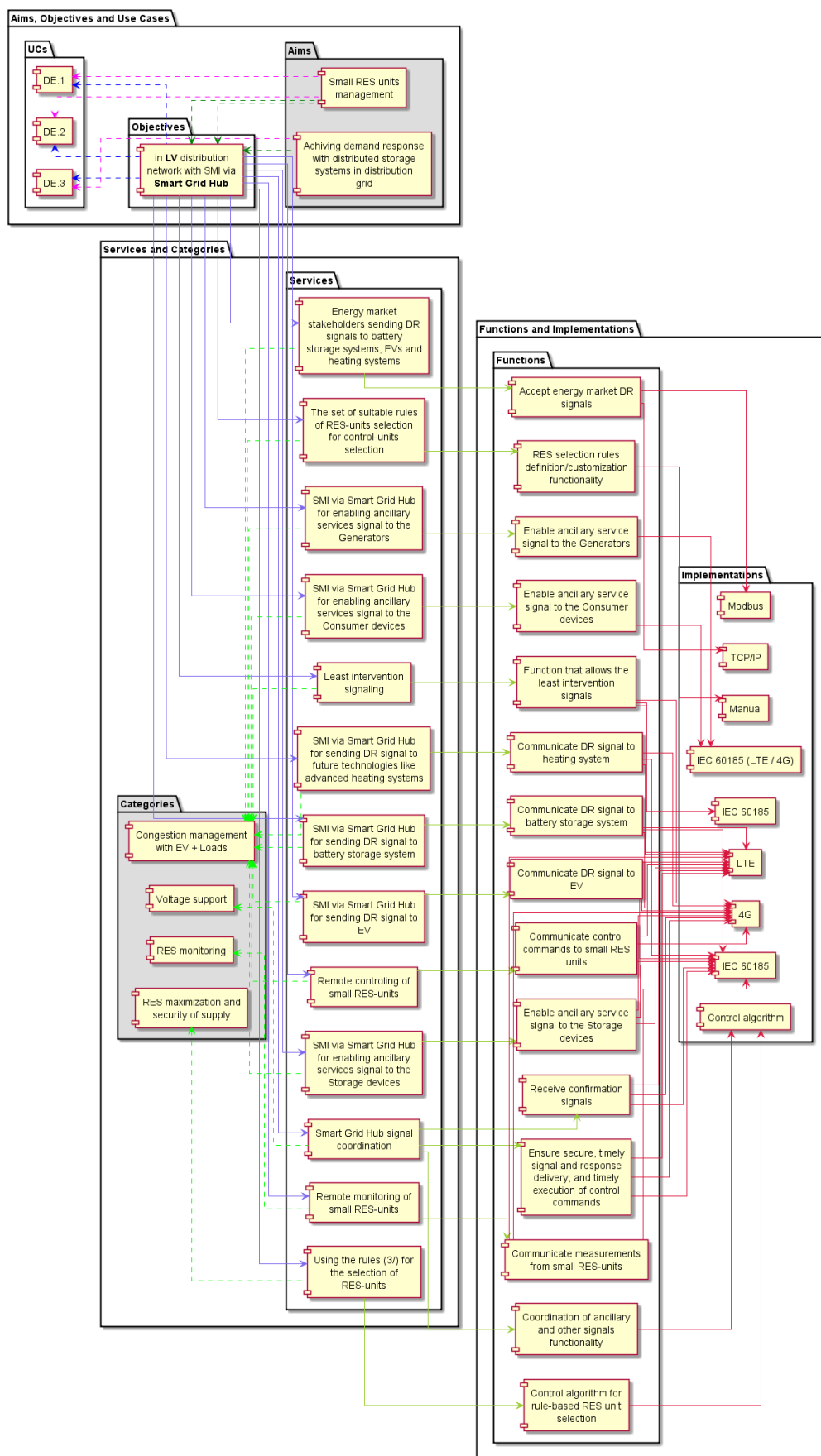


Figure 3.13: Analysis for the German demonstrator.

3.1.4 Dutch Demonstrator

The Dutch demonstration (GWP7) is managed by Enexis⁶, a regional distribution system operator distributing electricity and gas to 2.7 million and 2.3 million customers respectively in the provinces of Groningen, Drenthe, Overijssel, Noord-Brabant and Limburg in the Netherlands. For this demonstration, the site is located at Strijp-S at Eindhoven city in the south of the Netherlands. It is addressing similar challenges as GWP6 by providing merit orders for flexibility coming from local generation and consumption and where load areas may vary dynamically. This demonstration has three systems and mechanism innovative UCs that are being tested on the operational, enterprise and market levels to investigate the provision of ancillary services to the distribution grid via a flexibility market [11].

A summary of these three UCs is shown in the Table 3.1 while a short description (summarized/adopted from [5], [11] and [7]) of the individual UC is presented below:

- By implementing UC NL.1 - *“Enabling ancillary services, congestion management, and voltage support for PV integration using centralized, grid-connected storage systems which improve grid observability of prosumers, while promoting batteries in a multi-service approach”*, Enexis and the involved aggregators test and validate the application of a smart storage unit for congestion management, energy trading / portfolio management through spot market, imbalance market, and/or ancillary service provision, power quality improvement & voltage control upon request from the DSO.
- The UC NL.2 - *“Enabling the optimal activation of all available local flexibilities, using interactions between the DSO and the Charge Point Operator (CPO) in the role of aggregator using the local installed EVSE’s for congestion management and voltage control”* focused on testing and validating a technical framework for realizing DSO requested flexibility from EVs in order to prove the concept and develop knowledge on the applicability and the future scalability of the concept. Additionally, it provides an in-depth understanding on how flexibility can be managed between DSOs and multiple aggregators and how the required systems should interact. Yet another benefit is the validation of the maturity (and shortcomings) of communication chain and its protocols, so that recommendations could be made to the relevant standardization bodies.
- The UC NL.3 - *“Validating technically, economically and contractually the usability of an integrated flex market based on a combination of static battery storage and EV”*. This demonstrator is strongly focusing on a flexibility aggregator approach and its interplay with the DSO.

⁶ <https://www.enexis.nl/>

3.1.4.1 Analysis at UC level

In the case of individual UCs analysis in the Dutch demonstrator, the resultant mappings from the analysis are shown as Figure 3.14 for UC NL.1, Figure 3.15 for UC NL.2 and Figure 3.16 for UC NL.3. As can be seen in these, figures there are at most three CPs per UC.

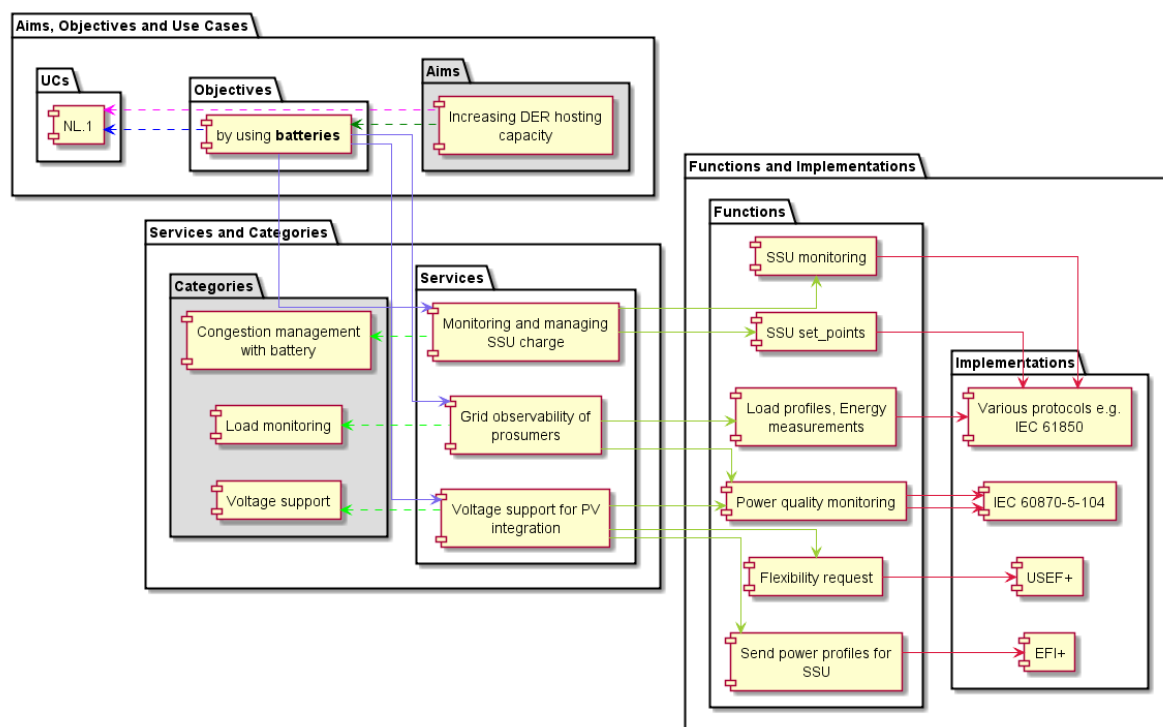


Figure 3.14: Analysis for the Dutch Demo UC NL.1.

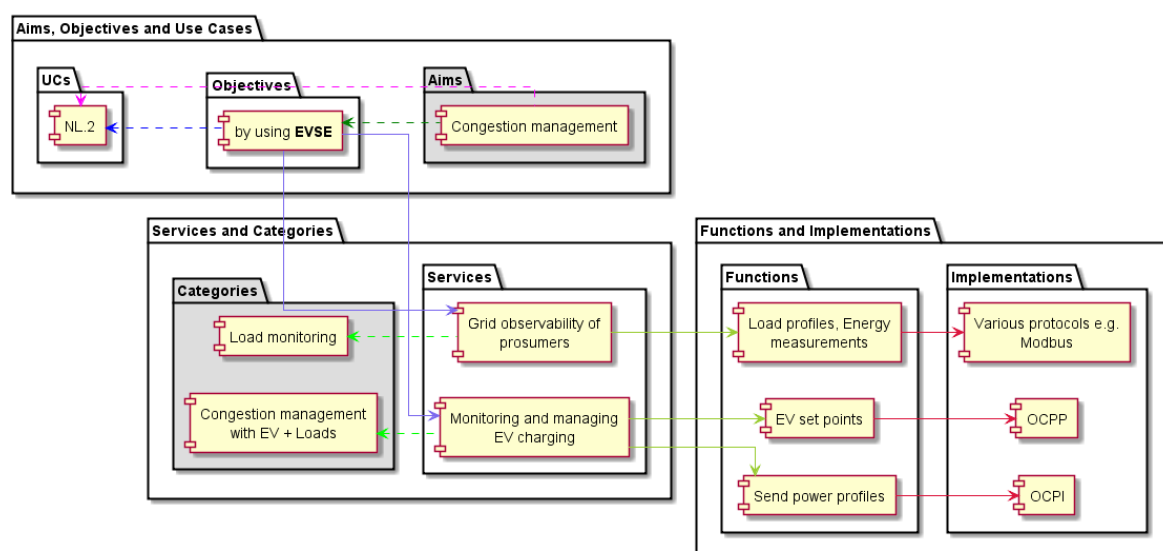


Figure 3.15: Analysis for the Dutch Demo UC NL.2.

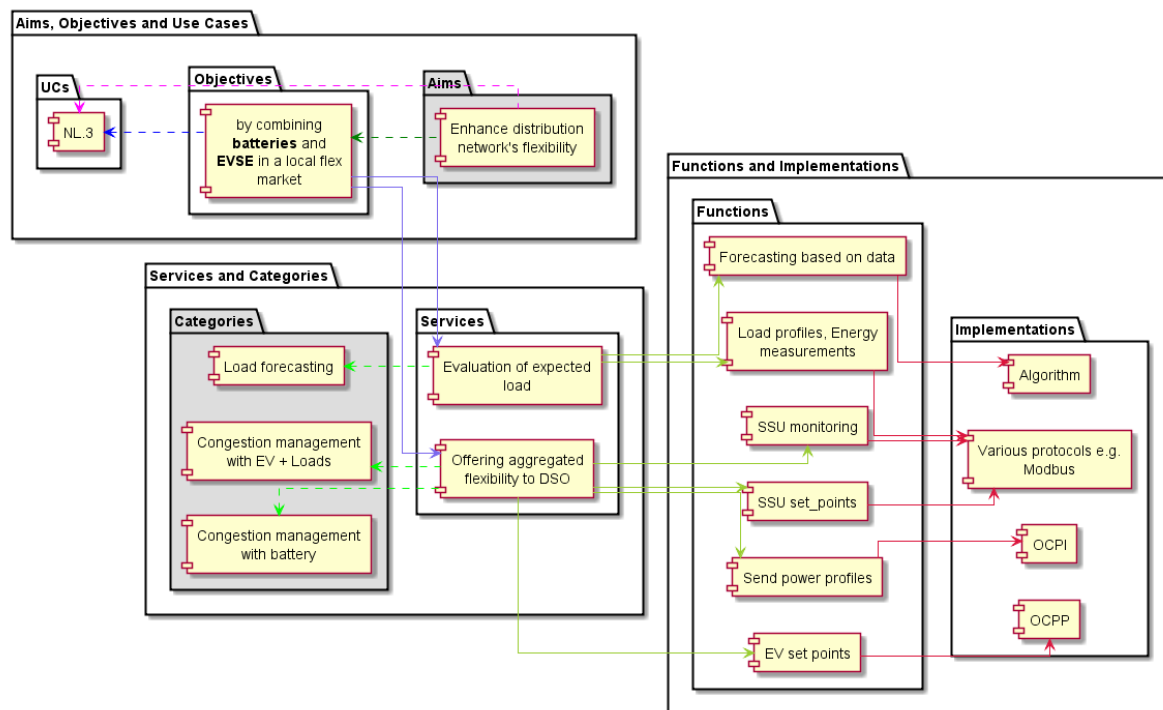


Figure 3.16: Analysis for the Dutch Demo UC NL.3.

3.1.4.2 Analysis at the demonstrator level

While Figure 3.17 shows the result of the analysis when all three (NL.1, NL.2, NL.3) UCs are analyzed together for the NL demonstrator. Looking at the aggregated analysis diagram, it can be seen the analysis has found five CPs from this demonstrator.

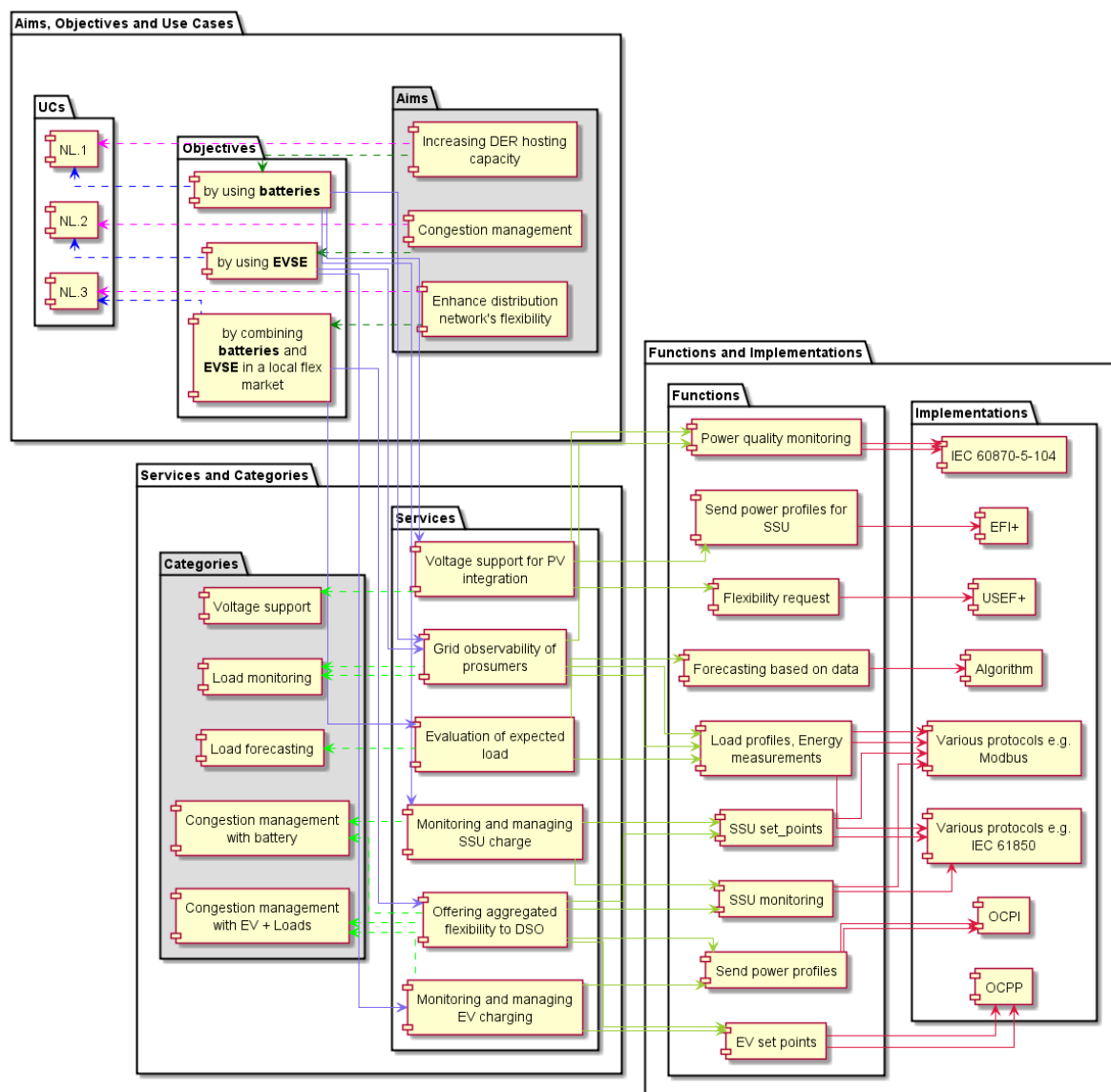


Figure 3.17: Analysis for the Dutch demonstrator.

3.1.5 Swedish Demonstrators

The Swedish demonstration (WP8) is managed by E.ON⁷ as a DSO and heat network operator and addresses the enhancement of the distribution system flexibility in two different urban and rural demonstrations.

The first demonstrator, implemented in Malmö, includes use cases SE.1 and SE.2. Use case 1 uses the thermal inertia of building envelopes to provide flexibility to district heating and cooling grids via DSR. Through utilising thermal inertia of buildings, shifting of energy demand in time is enabled via a cloud platform (EctoCloud). By connecting Building Management Systems (BMS) to the platform via a gateway (Energy Manager), the houses can support the district heating grid by lowering heat demand in each building connected to the platform or in a specific area of the heating grid. Use case 2 focuses on the deployment of

⁷ <https://www.eon.com/>

heat pumps to increase energy flexibility in thermal networks. With a large number of commercial heat pumps, connected between both heating and cooling networks, use case 2 exploits the flexibility potential of thermal networks and flexibility provided to the electricity grid.

The second demonstrator, implemented in Simris in Southern Sweden, operating a local microgrid with the capability of going islanded and be powered by 100% of renewable sources is implemented. It encompasses use cases SE.3, SE.4 and SE.5. Use case 3 focuses on technical microgrid management in terms of DSR and islanding capabilities of the system. Power to Heat and Power to Power assets are distributed at customer residents and connected to a DSR-platform to provide flexibility to the grid. The Energy Management System, is the main grid controller enabling islanding. Use case 4 enables increased direct consumer participation by delivering a ‘peer to peer’ platform to enable customers to visualize and commercialize their available power and flexibility. The platform contains a user interface where each individual customer can view their consumption, autarky level, flexibility and support provided to the LES and the earnings for participation. Use case 5 improves the management of micro-grids with the aid of machine learning algorithms. It aims to make the Simris local energy system a smart one by developing smart algorithms that will target to improve the efficiency and operability of the microgrid as well as the use of the inherent flexibility by the DSO.

Both demonstrators apply a quite similar IT-infrastructure. They use same or similar process interfaces like Modbus on the local side and MQTT for the WAN. Both have resembling IT-Security requirements and utilise comparable encryption and authorization methods. Both platforms are setup in the cloud using the same hosting provider.

A summary of these five UCs is shown in the Table 3.1 while a short description (summarized/adopted from [5], [12] and [7]) of the individual UC is presented below:

- The UC SE.1 - *“Use of DSR operation by exploiting the interaction with different energy carriers, such as district heating and district cooling”* is focused on investigating how the integration of different energy carriers can support the penetration of renewable by testing and demonstrating the available flexibility given in the thermal inertia of a building’s envelope and in the thermal inertia of thermal grids (heating and cooling).
- The focus of the SE.2 - *“Optimal use of distributed heat pump assets providing the district heating grid with heat and electricity flexibility for grid management purposes”* to investigate how different energy carriers can support the integration of renewables by simulating the available flexibility given in the operation of power2heat assets (like e.g. commercial heat pumps) and the respective thermal inertia of district heat/cooling grids.
- The focus of the UC SE.3 - *“Technical management of a grid-connected local energy system that can run in an islanded mode with 100% of renewable generation”* is to evaluate and validate how to operate a micro grid based only on renewable energy sources (RES). When the micro grid operates in islanded mode it must cope with significant power fluctuations as a result of the intermittent qualities of wind and solar generation and for that purpose a central energy storage unit is used to control the system power frequency [Hz]. To decrease the dependency on a single central unit and to increase system resilience, flexible loads are introduced into the system.
- The UC SE.4, *“Microgrid customer flexibility facilitated by a peer-to-peer market platform and enabled by Demand Side Response programs”*, demonstrates and validates

the ability of a local energy market platform to facilitate increased consumer participation within a micro grid by offering direct incentives to elicit an “active” demand side response and thereby increasing grid-friendly consumption/production behaviour.

- The UC SE.5 - “Increased ability to observe and steer the operations of a microgrid in response to distribution network constraints”, is focused on demonstrating and validating the ability of a DSO to observe and steer the operations of a micro grid in response to distribution level network constraints, therein calling on a flexible response from the micro grid. The use case will rely on simulation and advanced power analytics to develop automation modules and focusing on the relationship between DSO and the micro grid.

3.1.5.1 Analysis at UC level

Analyzing the input SGAM for the individual UC in the Swedish demonstrations using the Step 3.1. of the extend methodology resulted into Figure 3.18 for UC SE.1, Figure 3.19 for UC SE.2, Figure 3.20 for UC SE.3, Figure 3.21 for UC SE.4 and Figure 3.22 for UC SE.5. In each of these figure, the analysis has identified at most six different CPs

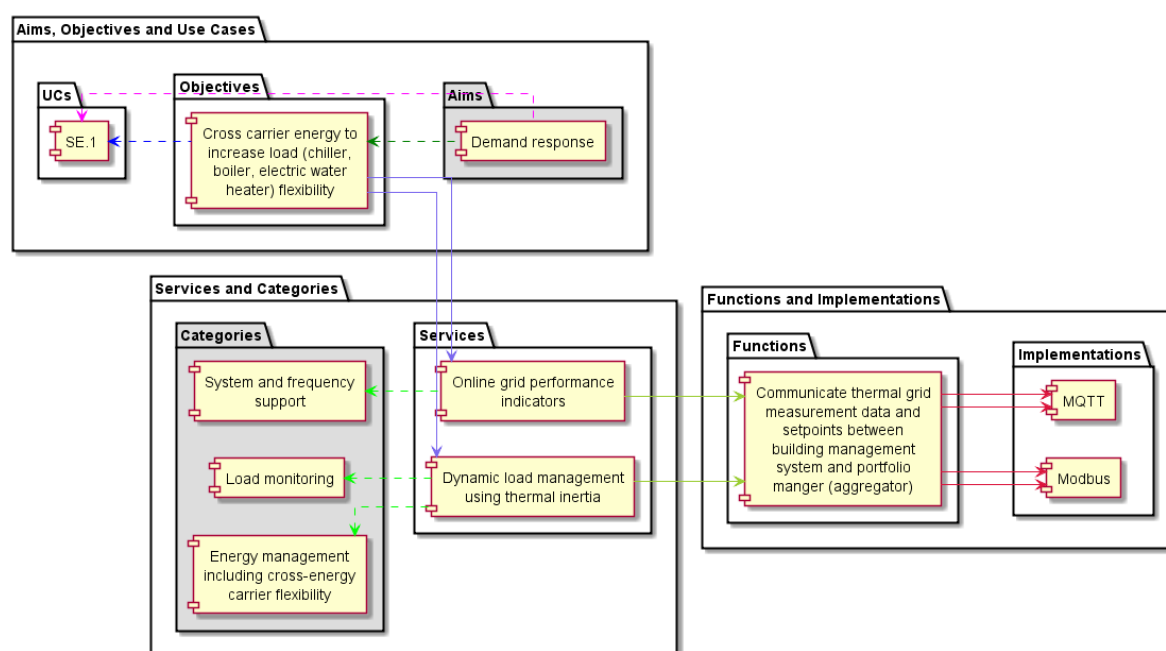


Figure 3.18: Analysis for the Swedish Demo UC SE.1.

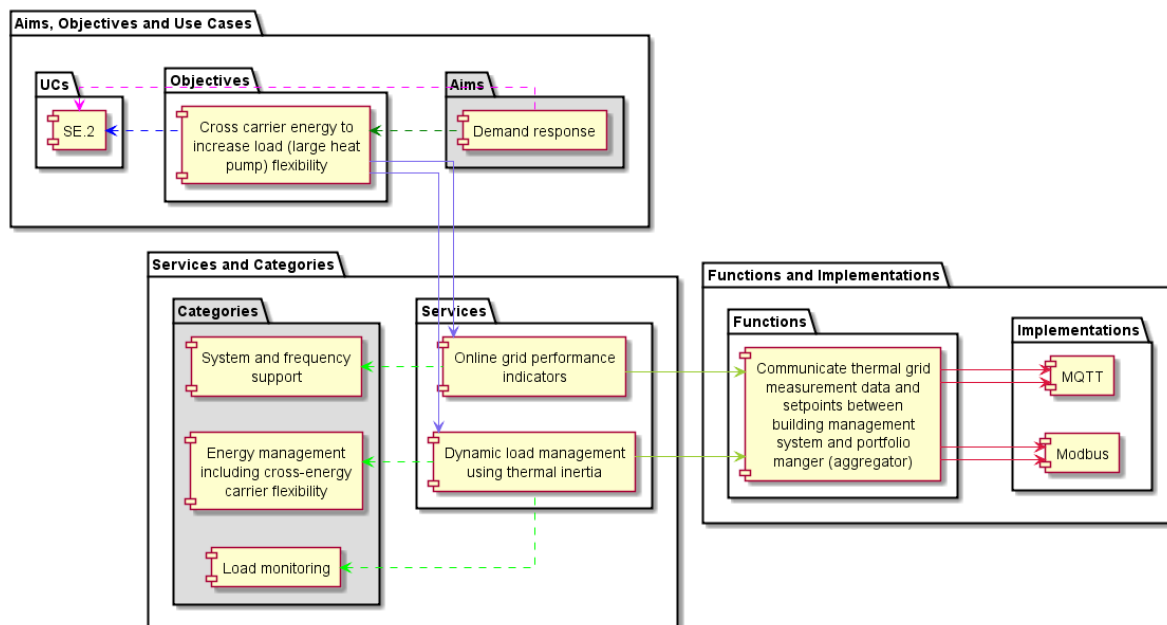


Figure 3.19: Analysis for the Swedish Demo UC SE.2

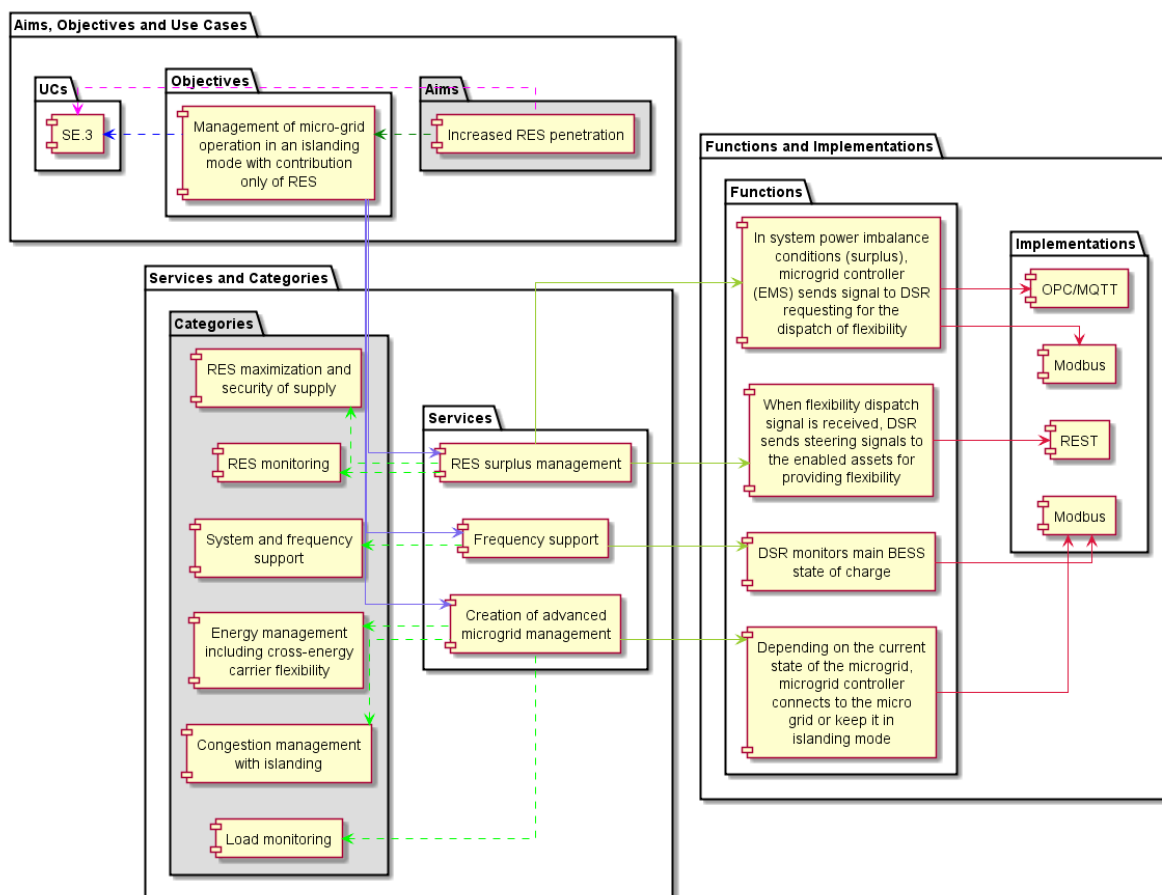


Figure 3.20: Analysis for the Swedish Demo UC SE.3

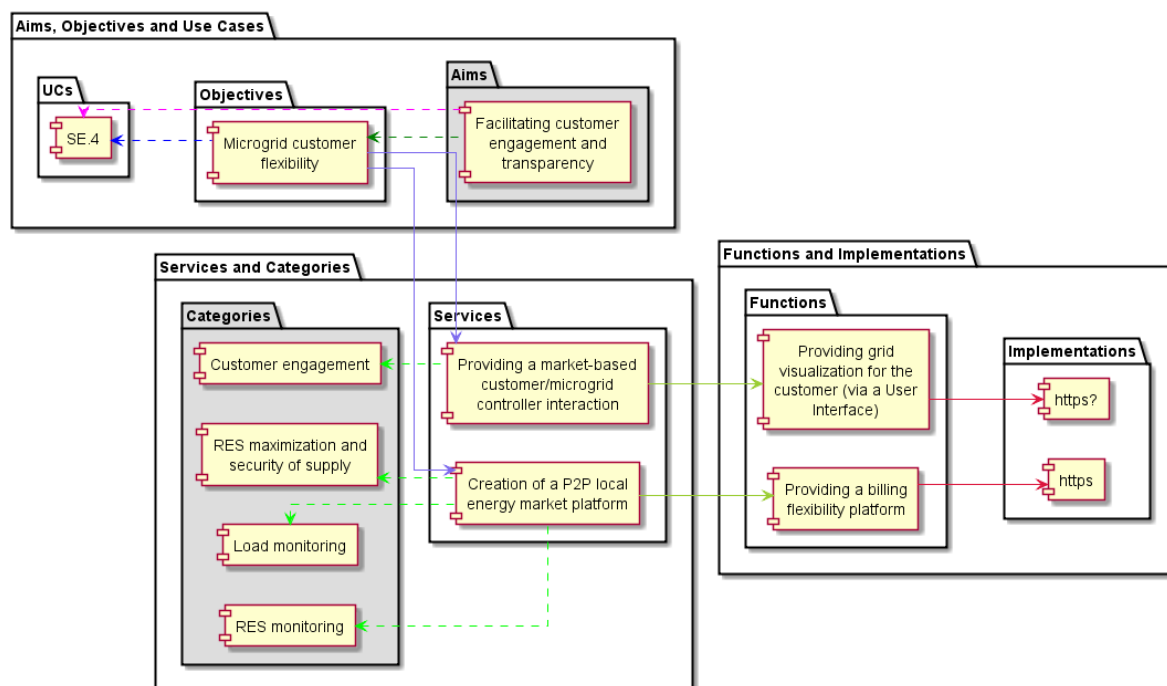


Figure 3.21: Analysis for the Swedish Demo UC SE.4.

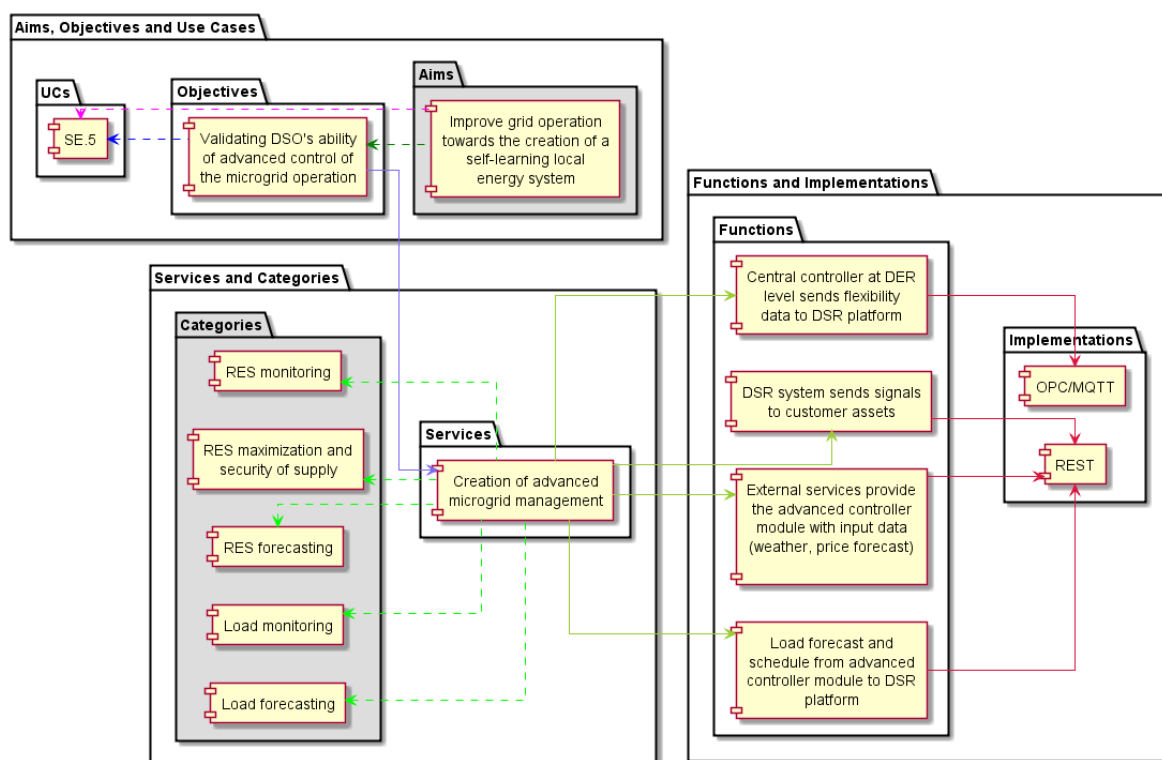


Figure 3.22: Analysis for the Swedish Demo UC SE.5.

3.1.5.2 Analysis at the demonstrator level

The Figure 3.23 presents analysis results graphically, when the analysis for all five UCs from both Swedish demonstrators are analysed together. Looking at the diagram, it can be seen the analysis has found nine CPs that are being used in all the UCs for these demonstrators.

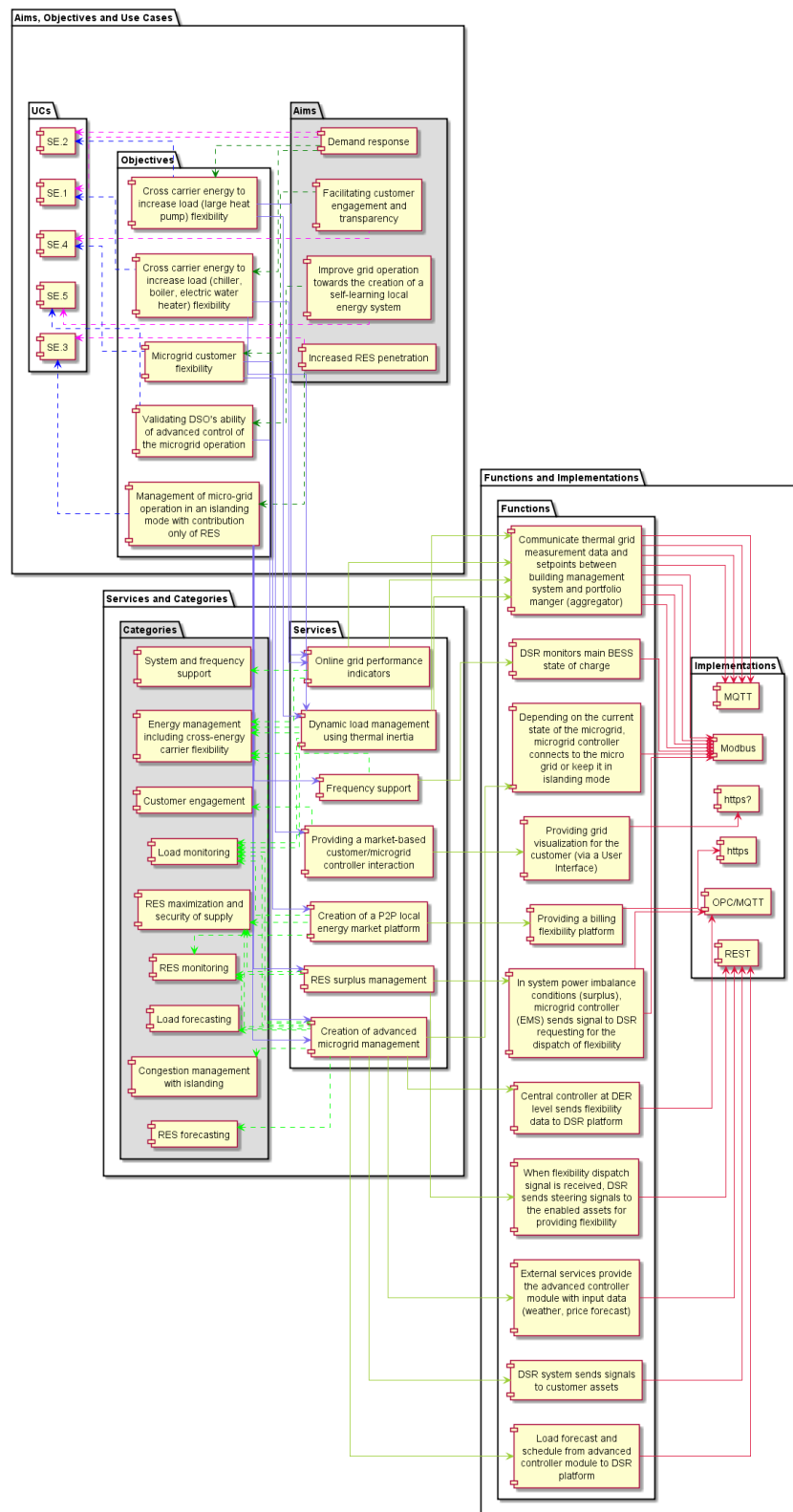


Figure 3.23: Analysis for both Swedish demonstrators.

3.2 Aggregated Demos Analysis

Similar to previous section where performing the individual UC and then demonstrator level analysis for the Czech, German, French, Dutch and Swedish UCs is described, this section presents the analysis done at the project level combining all the 18 UCs together for all the six demonstrators. The analysis found 13 CPs at the project level. For readability sake, the results of this analysis is shown here with the help of a table (Table 3.3). Each of the identified common category is represented as a column in the table. Furthermore, the column are then represented in different colors to show the *Super Category (SC)* they belong to. The derived SCs along with a short description is presented in the Table 3.2. Each SC is represented with a different color for easy identification.

Table 3.2: Name and short description of SCs for laboratory validation suitability analysis.

Name	Description
Voltage	Voltage support pattern
Frequency	Dynamic frequency support pattern
Congestion	Congestion management pattern
Support	Support services pattern; do not have a direct impact
Customer/Prosumer services	These pattern are had to test in a laboratory validation

Table 3.3. Analysis results

Use Case	Voltage support	System services incl. frequency support	Congestion management with battery	Congestion management with EV+Loads	Congestion management with islanding	Load monitoring	RES monitoring	Load forecasting	RES forecasting	RES Maximization and Security of supply	Customer engagement	Energy management incl. cross carrier & self consumption
Czech Demo												
Use Case CZ1: Increase the DER hosting capacity of LV distribution networks by combining smart PV inverter functions (demonstration of Q(U) and P(U))	X	X								X		
Use case CZ.2: Increase the DER hosting capacity in MV distribution network by volt-var control (V/Q regulation)	X	X										
Use case CZ.3: Smart EV charging			X									
Use case CZ.4: Smart energy storage	X	X	X									
French Demo												
Use case FR.1: DSOs can provide a continuous supply of electrical energy to customers, thanks to electricity storage assets operated by the DSO and/or aggregators										X		
Use case FR.2: DSOs could integrate large scale storage volume and enable multiservice electricity storage operated by storage aggregators or DSO, with a focus on PV integration	X	X						X	X	X		
Use case FR.3: innovative flexibilities can be aggregated and bid either on a local DSO mechanism to reduce local grid constraints or on national market to ensure global stability			X	X								X

Table 3.3. Analysis results (continued)

Use Case	Voltage support	System services incl. frequency support	Congestion management with battery	Congestion management with EV+Loads	Congestion management with islanding	Load monitoring	RES monitoring	Load forecasting	RES forecasting	RES Maximization and Security of supply	Customer engagement	Energy management incl. cross carrier & self consumption
German Demo												
Use case DE1: Controlling small RES-units										X		
Use case DE.2: Ancillary services provided by generation, consumption and storage devices	X	X				X	X			X		
Use case DE3: Distributed sources of flexibility within the distribution grid				X				X				
Dutch Demo												
Use case NL.1: enabling ancillary services, congestion management, and voltage support for PV integration using centralized, grid connected storage systems which improve grid observability of prosumers, while promoting batteries in a multi-service approach	X	X	X				X	X		X		
Use case NL.2: enabling the optimal activation of all available local flexibilities, using interactions between the DSO and the Charge Point Operator (CSO) in the role of aggregator using the local installed EVSE's for congestion management and voltage control	X		X					X				
Use case NL.3: validating technically, economically and contractually the usability of an integrated flex market based on a combination of static battery storage and EV				X								

Table 3.3. Analysis results (continued)

Use Case	Voltage support	System services incl. frequency support	Congestion management with battery	Congestion management with EV+Loads	Congestion management with islanding	Load monitoring	RES monitoring	Load forecasting	RES forecasting	RES Maximization and Security of supply	Customer engagement	Energy management incl. cross carrier & self consumption
Swedish Demo n° 1												
Use case SE.1 - Use of DSR to optimize DSO operation by exploiting the interaction with different energy carriers, such as district heating and district cooling												X
Use case SE.2 - Optimal use of commercial heat pumps providing the district heating grid with heat and electricity flexibility for grid management purposes		X										X
Swedish Demo n° 2												
Use case SE.3 - Technical management of a grid-connected Local Energy System that can run in an islanded mode with 100% renewable generation		X			X		X	X	X	X		
Use case SE.4: Micro Grid Customer Flexibility facilitated by a peer to peer market platform and enabled by Demand Side Response Programs					X	X	X		X		X	
Use case SE.5 - Increased ability to observe and steer the operations of a microgrid in response to distribution network constraints			X	X				X				

3.3 Outcome

Section 3.1 describes the analysis at the individual UC level while Section 3.2 describes it at the project level. This section 3.3 provides a short commentary on the outcome from the before mentioned analyses.

In this chapter, the analysis of the 18 InterFlex UCs is conducted using the proposed extended methodology to find the common pattern/practices to overcome the diversity of having different implementations for the same concept applied in the six demonstrators. The analysis is conducted at three different levels namely UC, demonstrator and project. The analysis for the first two levels is presented in the Section 3.1 while the analysis at the third level is discussed in Section 3.2. The aggregated analysis revealed that there are 13 common patterns/practices that are employed by the six demonstrators. These common patterns/practices are further analyzed for their suitability and effectiveness for a laboratory validation. For this analysis, five SCs are derived that are shown in Table 3.4.

Table 3.4: Identified CP with corresponding SCs

Common Pattern (CP)	Super Category (SC)
Voltage support	Voltage
System services including frequency support	Frequency
Congestion management with battery	Congestion
Congestion management with EV + Loads	
Congestion management with islanding	
Load monitoring	Support Services
RES monitoring	
Load forecasting	
RES forecasting	
RES Maximization and security of supply	Customer/prosumer services
Customer engagement	
Energy management including cross carrier and self consumption	

The CPs are the results of aggregated analysis from Table 3.3 that is further analyzed for suitability and effectiveness in a laboratory validation. As the final outcome of the whole analysis, Table 3.4 reports the CP that belongs to them. Since, only the first three SCs are suitable for laboratory validation for the obvious reasons, all the UCs belonging to these three categories are further considered for the OTS validation design and laboratory setup. Next chapter (Chapter 4) will explain the process and steps in more details.

4 THE OPEN TEST SUITE

This chapter presents the Open Test Suite (OTS) for interoperability validation based on the analysis performed in the previous chapter. By definition, a test suite is a collection of test cases that are intended to be used to test a technology solution to show it has a specified set of behaviors. The developed test suite contains detailed instructions or goals for each collection of test cases and information on the system configuration to be used during testing.

4.1 Functions Under Test

The previous chapter presented the detailed analysis at three different levels (UC, demonstrator and project). The results for the first two levels are presented in the Section 3.1, while the results for the analysis at the third level is presented in the Section 3.2. The outcome of the analysis at these levels along with the laboratory suitability analysis is summarized in Section 3.3. Based on these outcomes this chapter considering the three SCs proposes recommendations for the validation design for interoperability validation in the OTS.

- Voltage Support ,
- System Services including Frequency Support and
- Congestion Management.

The SCs that are not considered here are Support services and Customer/prosumer services.

The resulting three SCs are forming the core requirement for any electrical flexibility usage in a European power system context: a device or resource offering electrical flexibility should be technically able to provide the flexibility at least for one, ideally for all three of these SCs.

4.1.1 Test Goals

In each of the three SCs, primarily three different perspectives for testing exist:

1. The behaviour on the power network interface. For instance, in case of dynamic frequency support, the measured power on the power network interface of the flexibility should change according to the system frequency in adequate time and amplitude. This behaviour can be triggered by local (electrical) measurements, such as voltage and frequency, but in many cases an IT signal is used either for configuration (what should happen when the trigger is measured) or for the trigger itself. For testing, test vectors have to be produced on the grid side of the power network interface, and the answer of the flexibility has to be recorded and assessed against expected results.
2. The functionality refers to the way the service implied in the SC is realized and can be technically activated from an IT interface. As an example, voltage support from a DER unit can be realized by active reduction or by adequate reactive power management. For both cases, there might be different activation sequences required over an IT connection. In order to test the functionality, test patterns on the communication interface have to be generated and at least the communication interface itself and the answers of the flexibility have to be monitored. In order to make reasoning if the

functionality is correctly implemented, a combination with the tests on the power network interface is required.

3. On communication level, the correct implementation of the communication protocol and the impact of communication parameters such as bandwidth and latency can be tested by protocol testers and/or application of test vectors in the communication connection itself. While for protocol testing, typically the behaviour on the power network interface does not play a role and therefore only parts of the flexible device have to be present in such a test, the impact on communication parameters might be tested in full loop with monitoring the behaviour on the power network interface.

In addition, it needs to be decided whether component (just one device against a test system) or system tests (interaction of multiple devices implementing a use case) are performed, and if these tests are performed in a real-world environment (with an often restricted set of test vectors) or in a simulation/laboratory environment.

For interoperability and exchange-ability, system testing should be preferred, since direct interaction between at least two devices under test can be validated by this approach.

4.1.2 Upper and lower bound Test Cases

In line with the results from InterFlex Deliverable 3.1[13], solutions in each of the three categories can generally be implemented using a "lower bound" or "upper bound" solution. A DSO who seeks to activate heat pump flexibility can choose between installing DSO-owned RTUs at the heat pumps in question (lower bound: the connection to the customer flexibility is on SGAM process or field zone) or make use of the services of an aggregator, to whom the DSO connects upper bound on SGAM operation or even enterprise zone.

4.1.2.1 Upper bound test case

Figures 4.1 and Figure 4.2 shows two upper bound⁸ validation designs that can be deduced from the InterFlex demonstration use cases. They differ in the type of flexibility is used in the SGAM field zone. According the decomposition presented in Chapter 3, implementation variants for all three categories Voltage Support, Dynamic Frequency Support and Congestion Management can be found. Although not all three categories are present in each demo, an integrated upper bound experimental setup with multiple kinds of flexibilities included can show interoperability and interchangeability of extended solutions based on those developed in the InterFlex demos. In both cases, an aggregator is part of the testing. Here, either the real aggregator software can be used, or a simplified version with a minimal business logic.

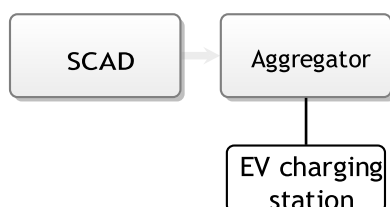


Figure 3.24: Example setup for the NL Demo using USEF

⁸ see D3.1

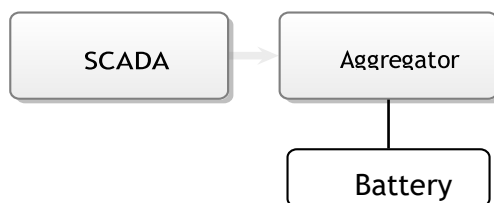


Figure 3.25: Example setup for the FR demo with battery operated by an aggregator

4.1.2.2 Lower Bound Test Case

Figures 4.3, Figure 4.4 and Figure 4.5 show three lower bound⁹ validation designs. Instead of an aggregator, different kind of field gateways with less complex functionality play a role in these test setups. However, the connected flexibilities can be of more complex nature, such as a microgrid or local energy community.

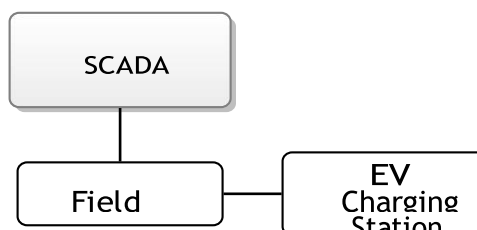


Figure 3.26: Example test setup for the CZ demo power line modem solution

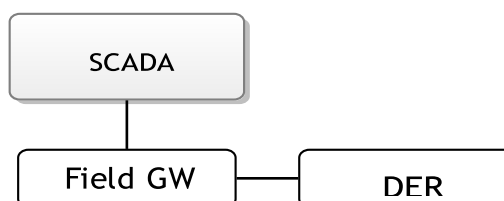


Figure 3.27: Example setup for integrating a microgrid such as in the SE demo into the lower bound test

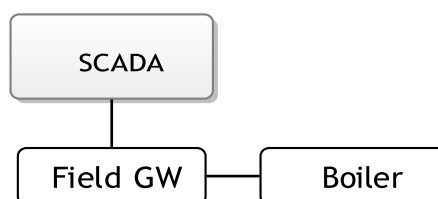


Figure 3.28: Example setup for the DE demo architecture using the smart metering infrastructure as means of communication for a lower-bound solution

4.2 System Configuration

In order to perform the above described system tests, a series of three devices under test (DUTs) has to be connected and realised on the test. This is shown in Fig. 4.6.

⁹ see D3.1

The service requester, which is typically a SCADA or Distribution Management System, acts as the trigger for a flexibility activation. Here, typically a command-line based communication stack implementation with a minimal user interface is sufficient to generate the required commands and log the communication to the next device in the chain.

The second device is an aggregator or field gateway. Although both options have very different functional complexity, the test topology is the same for both options. Only the communication to the service requester changes accordingly.

The last device in the chain is the flexibility. This is the only device, where the behaviour on the physical interface (power grid interface) can matter depending on the type of the test. Therefore, the flexibility device has not only IT connections but is also connected to a laboratory-scale programmable power source with adequate power rating for the test.

This physical interface is driven either by the test generator itself, or for more complex system tests, a full grid simulation can be used to generate realistic measurements at multiple grid nodes. The grid simulation variant is helpful to e.g. stimulate the aggregator to perform congestion management with certain pool members when seeing high line loadings in the simulated grid.

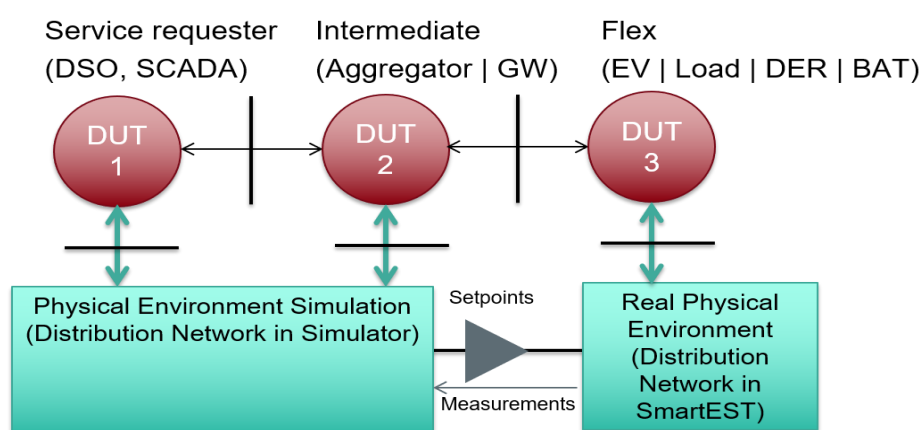


Figure 3.29: Infrastructure for system tests

4.3 The open Test Suite

In order to facilitate the conduction of tests, the proposed Open Test Suite contains 3 main parts: A detailed Holistic Test Case for interoperability which will give the testing frameworks and test specifications and experiment specifications templates that have to be tailored for each individual test that will be performed. Also an example of how this templates should be used is presented in Appendix B.

4.3.1.1 The holistic test case for interoperability validation in a laboratory setup is presented in Table 4.1

Table 4.1. Holistic Test Case: Interoperability validation in a laboratory set-up

Name of the test case:		Interoperability for flexibility provision validation in a laboratory set-up
Narrative: “a storyline summarizing motivation, scope and purpose of the test case”		<p>Cross-cutting issues are of high relevance when trying to overcome the barriers for sustainable commercial models of flexibility service provision. Therefore, the Horizon 2020 program explicitly requires performance of a detailed analysis of current regulations, standards and interoperability/interfaces issues applying to their case, more specifically in connection to ongoing work in the Smart Grid Task Force and its Experts Groups in the field of Standardisation (e.g., CEN-CLC-ETSI M/490). In particular, interoperability and standards are key enablers to allow the replicability of the project results, by ensuring a harmonized solution between EU countries. The holistic use case replies to these expectations by assessing the interoperability of the demonstrated solutions, at several layers, and based on the Smart Grid Architecture Model. Individual ICT architectures of the five InterFlex European partners allow for a systematic deduction of general and specific interoperability challenges in ICT solutions for flexibility provision, as the scope of the topics under study from different InterFlex demonstrators is substantially wide.</p> <p>The design rationale is that demonstration UCs are implementing innovative solutions for achieving the same objective but there is a huge diversity in the implementation strategies and technologies. An Open Test Suite (OTS) can only be developed once all the UCs from the six demonstrators are analyzed and the analysis is able to find CPs. These identified CPs are further needed to be suitable for the laboratory validation that requires performing another round of analysis activity.</p>
System under Test (SuT): “configuration that includes all relevant properties, interactions and behaviours closed loop I/O and electrical coupling), that are required for evaluating an Oul as specified by the test criteria” A list of systems, subsystems, components included in the test case or test setup.		<ul style="list-style-type: none"> • On the power network part, hardware interoperability will be covered mostly based on existing standard in this area (e.g. grid codes and connection standards) to demonstrate the full interchangeability of hardware and software. Tests could be repeated for a set of reference grids. • On the communication part, simulation and testing will demonstrate interoperability and evaluate the constraints /performance requirements on the telecom infrastructure in relation with functions implemented and telecom resilience. • On system level, the full chain from a command (e.g. flexibility activation) though all relevant systems such as gateways, communication systems, data processing down to the field device exhibiting a resulting response on the physical power network interface will be investigated.
	Object under Investigation (Oul): “the component(s) that are characterized or validated”	<ul style="list-style-type: none"> • Hardware • Communication Interfaces • System level flexibility activation
	Domain under Investigation (Dul):	ICT, Electrical Power

	“identifies the relevant domains or sub-domains of test parameters and connectivity”	
	Functions under test (FuT): “the functions relevant to the operation of the system under test, as referenced by the use case”	<ul style="list-style-type: none"> • Voltage support • Dynamic Frequency Support • Congestion management with battery • Congestion management with EV + Loads Congestion • Congestion management with islanding
	Purpose of Investigation (Pol): “a formulation of the relevant interpretations of the test purpose (e.g. in terms of characterization, verification and validation)”	To demonstrate and showcase the interoperability and interchangeability of devices, sub-systems or systems for the selected interfaces (see the Interoperability matrix), in laboratory. A common methodology will be defined (common to all the demonstration and use-cases). This demonstration will be done by simulation and laboratory testing.
	Test criteria: “the measures of satisfaction that a need to be evaluated for a given test to be considered successful”	<p>The purpose of these tests is to verify the proper functioning of the FuT and to characterise the control in terms of:</p> <ul style="list-style-type: none"> • Accuracy • Time behaviour
	Target metrics:	<ul style="list-style-type: none"> • Accuracy • Time behaviour
	Variability attributes:	<p>For Voltage support: the reactive power control mode Q(U) For Dynamic Frequency Support: active power control - P(U)</p>
	Quality attributes: “with reference to purpose of investigation and/or target metrics, the threshold level required to pass a test or the certainty/precision level (e.g. probabilistic measure) required for the quality of a characterization”	<p>For the reactive power control mode Q(U): The accuracy will be evaluated as the deviation between the expected and the actual reactive power, normalized to the maximal apparent power:</p> $\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$ <p>The response time will be determined using a tolerance band of $\pm 5\%$ of the maximal reactive power around the expected value. This value will be compared to the target response time adjusted prior the tests.</p> <p>For the active power control mode P(U): The accuracy will be evaluated as the deviation between the expected and the actual active power, normalized to the maximal active power:</p> $\Delta P = \frac{P_{act} - P_{exp}}{P_{max}}$ <p>The response time will be determined using a tolerance band of $\pm 5\%$ of the nominal apparent power around the expected value. This value will be compared to the target response time adjusted prior the tests.</p>

4.3.1.2 Test Specification Template

The test specification template is set up in such a way that will give a common understanding of the envisioned tests. An example of how the template should be used is given in the Appendix B.

Table 4.2. Test Specification Template

Title	“Test Specification Name”
Ref. Holistic test case	Interoperability validation in a laboratory set-up
Test System (also graphical)	Graphical and textual description of the system under investigation and its components including interfaces between test setup and Object under investigation and type of those interfaces (e.g. electrical)
Target measures	Specification of the target metrics that will be derived from measured parameters in order to evaluate the test objectives. Which variables will be quantified by the test? (formula and explanation)
Input and output parameters	List of inputs for the system under test relevant to the object under investigation, inputs relevant to the object under investigation itself and outputs / measured parameters divided into: <ul style="list-style-type: none"> • Controllable input parameters • Uncontrollable input parameters • Measured parameters
Test Design	The choice of mapping between required testing target and available test parameters, in terms of test sequence, decision criteria and controlled parameters. Textual or graphical description of the sequence of steps carried out during the test including parameter ranges and variation of input parameter.
Initial system state	Description of conditions that are prerequisites to actually run the test and initial choices of parameters.
Evolution of system state and test signals	Quantitative characterization of the temporal evolution of test events and evolution of the relevant test parameters, as adjustable by the input parameters (e.g. opening breakers after a certain amount of seconds); incl. variability attributes
Other parameters	Information of data that should be tracked apart from the input and output parameters and system state, test signals
Storage of data	In which format are the parameters stored?
Temporal resolution	Discrete or continuous simulation and (if applicable) resolution of the discrete time steps
Source of uncertainty	In order to evaluate the quality of the test, the possible sources of uncertainties are given in how they can be quantified.
Suspension criteria / Stopping criteria	Under which conditions are the test results not valid or the test is interrupted

4.3.1.3 Experiment Specification Template

The experiment specification template is set up in such a way that will give a common understanding of the envisioned experiment. For an example of how the template should be used please see in the Appendix B.

Table 4.3. Experiment Specification Template

Ref. Test Spec.	“Test Specification Name”
Research Infrastructure	Specify the RI where the experiment is carried out.
Experiment Realisation	The setup can be realised in different ways (e.g. simulation, hardware): give a brief description of the realization.
Experiment Setup (concrete lab equipment)	Graphical and textual description of the concrete lab equipment and interconnections
Experimental Design and Justification	For all parameters give a reason why it has been chosen that way
Precision of equipment	For the components of the lab equipment the precision is given such that the experiment’s uncertainty can be derived
Uncertainty measurement	Based on the precision of equipment of the lab instrument and of measurement algorithms, the parameters to model the measured quantities errors are provided it is specified how experiment’s uncertainty can actually be measured

4.4 Next steps

Based on the results of the analysis and the detailed recommendation for the type of tests, validation designs multiple test setup will be moralized for both the upper and lower-bound designs. For this purpose, different laboratory validation methods including Hardware-In-the-Loop (HIL), Controller-Hardware-In-Loop (CHIL), Power-Hardware-In-Loop (PHIL) etc., along with Internet of Things (IoT) and co-simulation and the Open Test Suite will be extensively utilized.

5 CONCLUSIONS

This deliverable documented a methodology proposed for the analysis of 18 InterFlex UCs from the six demonstrators to identify the CPs in implementing flexibility activation techniques. The analysis applying the methodology at three different levels (individual UC, demonstrator and project) was carried out on the 18 UCs. As the main outcome of this three-level analysis, 13 CPs were identified. It was further noted that not all of these CPs are feasible for tests. Also, some of the identified CPs fall in the same type of operation. So, a further classification (called Super Category) of these CPs was performed. This resulted in dividing CPs into five SCs (voltage, frequency, congestion, support service, hard to test). Only three (voltage, frequency, and congestion) of these SCs and five CPs were found suitable for the test in the laboratory. The resulting three SCs are forming the core requirement for any electrical flexibility usage in a European power system context: a device or resource offering electrical flexibility should be technically able to provide the flexibility at least for one, ideally for all three of these SCs.

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A. APPENDIX - ANALYSIS TOOL

Appendix 1. Tool

As part of the analysis, a tool has been developed that when used with the worksheets of analysis produces the analysis diagrams. All the analysis diagrams are generated using this tool. It is developed by AIT and is available from them for download.

The tool is packaged as an executable Jar file and can be used from shell as:

```
java -jar uc2services.jar [-f <excel file path> -s <worksheet name>
    | -h | -v | -src | -poly | -hw]
```

Where:

-f,--file <arg>	full path to the xlsx file
-h,--help	print usage information
-hw,--handwritten	render diagram as “handwritten”
-poly,--polyline	use poly lines instead of orthogonal lines
-s,--sheet <arg>	the name of the sheet containing the mapping
-src,--source	if present, a separate file containing PlantUML source will be created.
-v,--verb	verbose mode on

You MUST create a directory names `output` in the directory where the jar file is saved. This directory will be used to store the generated diagrams and the PlatUML¹⁰ source files. Not having this directory will generate a `FileNotFoundException`. The following command will generate a diagram from the sheet `CZAll` in the file `servicemappings.xlsx` available in the current directory:

```
java -jar us2services.jar -f service_mappings.xlsx -s CZAll
```

The generated diagram will be placed in the output directory with the name pattern:

```
InterFlex_UC2S_ + SHEETNAME + Current DateTime.png
```

Please, note that the generated diagram will use:

- as the diagram TITLE = the Center header specified in the worksheet,
- as the diagram HEADER = the Right header specified in the worksheet,
- As the diagram FOOTER = the Center footer specified in the worksheet.

If none is specified, a default will be used.

¹⁰ <http://plantuml.com/>

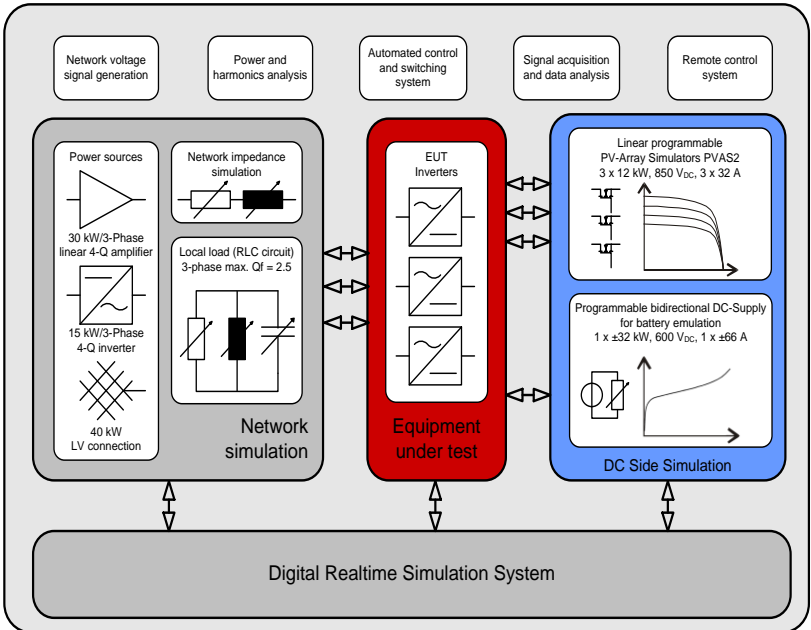
B. APPENDIX - OPEN TEST SUIT EXAMPLE APPLICATION

Holistic Test Case: Interoperability validation in a laboratory set-up

Name of the test case:	Interoperability for flexibility provision validation in a laboratory set-up
<p>Narrative: “a storyline summarizing motivation, scope and purpose of the test case”</p>	<p>Cross-cutting issues are of high relevance when trying to overcome the barriers for sustainable commercial models of flexibility service provision. Therefore, the Horizon 2020 program explicitly requires performance of a detailed analysis of current regulations, standards and interoperability/interfaces issues applying to their case, more specifically in connection to ongoing work in the Smart Grid Task Force and its Experts Groups in the field of Standardisation (e.g., CEN-CLC-ETSI M/490). In particular, interoperability and standards are key enablers to allow the replicability of the project results, by ensuring a harmonized solution between EU countries. The holistic use case replies to these expectations by assessing the interoperability of the demonstrated solutions, at several layers, and based on the Smart Grid Architecture Model. Individual ICT architectures of the five InterFlex European partners allow for a systematic deduction of general and specific interoperability challenges in ICT solutions for flexibility provision, as the scope of the topics under study from different InterFlex demonstrators is substantially wide.</p> <p>The design rationale is that demonstrations UCs are implementing innovative solutions for achieving the same objective but there is a huge diversity in the implementation strategies and technologies. An Open Test Suite (OTS) can only be developed once all the UCs from the five demonstrators are analyzed and the analysis is able to find CPs. These identified CPs are further needed to be suitable for the laboratory validation that requires performing another round of analysis activity.</p>
<p>System under Test (SuT): “configuration that includes all relevant properties, interactions and behaviours closed loop I/O and electrical coupling), that are required for evaluating an Oul as specified by the test criteria” A list of systems, subsystems, components included in the test case or test setup.</p>	<ul style="list-style-type: none"> • On the power network part, hardware interoperability will be covered mostly based on existing standards in this area (e.g. grid codes and connection standards) to demonstrate the full interchangeability of hardware and software. Tests could be repeated for a set of reference grids. • On the communication part, simulation and testing will demonstrate interoperability and evaluate the constraints /performance requirements on the telecom infrastructure in relation with functions implemented and telecom resilience. • On system level, the full chain from a command (e.g. flexibility activation) though all relevant systems such as gateways, communication systems, data processing down to the field device exhibiting a resulting response on the physical power network interface will be investigated.

	Object under Investigation (Oul): "the component(s) that are characterized or validated"	<ul style="list-style-type: none"> • Hardware • Communication Interfaces • System level flexibility activation
	Domain under Investigation (Dul): "identifies the relevant domains or sub-domains of test parameters and connectivity"	ICT, Electrical Power
Functions under test (FuT): "the functions relevant to the operation of the system under test, as referenced by the use case"		<ul style="list-style-type: none"> • Voltage support • Dynamic Frequency Support • Congestion management with battery • Congestion management with EV + Loads • Congestion • Congestion management with islanding
Purpose of Investigation (Pol): "a formulation of the relevant interpretations of the test purpose (e.g. in terms of characterization, verification and validation)"		To demonstrate and showcase the interoperability and interchangeability of devices, sub-systems or systems for the selected interfaces (see the Interoperability matrix), in laboratory. A common methodology will be defined (common to all the demonstration and use-cases). This demonstration will be done by simulation and laboratory testing.
Test criteria: "the measures of satisfaction that a need to be evaluated for a given test to be considered successful"		<p>The purpose of these tests is to verify the proper functioning of the FuT and to characterise the control in terms of:</p> <ul style="list-style-type: none"> • Accuracy • Time behaviour
	Target metrics:	<ul style="list-style-type: none"> • Accuracy • Time behaviour
	Variability attributes:	<p>For Voltage support: the reactive power control mode Q(U)</p> <p>For Dynamic Frequency Support: active power control - P(U)</p>
	Quality attributes: "with reference to purpose of investigation and/or target metrics, the threshold level required to pass a test or the certainty/precision level (e.g. probabilistic measure) required for the quality of a characterization"	<p>For the reactive power control mode Q(U): The accuracy will be evaluated as the deviation between the expected and the actual reactive power, normalized to the maximal apparent power:</p> $\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$ <p>The response time will be determined using a tolerance band of $\pm 5\%$ of the maximal reactive power around the expected value. This value will be compared to the target response time adjusted prior the tests.</p> <p>For the active power control mode P(U): The accuracy will be evaluated as the deviation between the expected and the actual active power, normalized to the maximal active power:</p> $\Delta P = \frac{P_{act} - P_{exp}}{P_{max}}$ <p>The response time will be determined using a tolerance band of $\pm 5\%$ of the nominal apparent power around the expected value. This value will be compared to the target response time adjusted prior the tests.</p>

Test Specification Template (e.g. Test specifications for hardware component testing)

Title	“Voltage support evaluation”
Ref. Holistic test case	Interoperability validation in a laboratory set-up
Test System (also graphical)	<p>The test environment of the AIT SmartEST research test stand developed by AIT consists of the following components:</p> <ul style="list-style-type: none"> • AC supply: The connection to the public grid and a grid simulator are available for the testing procedure (for technical specifications see Chapter 3.2). • AC load: The AC load is connected to all three phases and can either be set symmetrical or individually (for technical specifications see Chapter 3.2). • DC supply: Generally, the DC power for the equipment under test (EUT) is provided by a PV simulator. If needed, there are also two bidirectional DC sources available (for technical specifications see Chapter 3.3). • Real time system: The OPAL-RT system is able to run MATLAB simulink models. It has 32 analogue in- and outputs. It can perform up to 10 µs increment and has two Intel Quad-Core i7 processors. <p>The measurement of voltage and current are done with DEWETRON. The data recording and analysis is done with Dewesoft 7.1.3. The general measurement surface is shown in ScadaBR</p> 
Target measures	<p>The accuracy will be evaluated as the deviation between the expected and the actual reactive power, normalized to the maximal apparent power:</p> $\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$ <p>The response time will be determined using a tolerance band of $\pm 5\%$ of the maximal reactive power around the expected value. This value will be compared to the target response time adjusted prior the tests.</p>

Input and output parameters	Item	Parameter name	Default value	Comment
	React. P. Mode	Q/U	Q/U	
	Time constant (s)	Ch Q (U) TimeC.	will be varied ¹¹ (0.01s for worst case)	Range: 0.01- 60 s
	Active power above which Q(U) is activated	Ch Q (U) P-LockI	0	
	Active power below which Q(U) is deactivated	Ch Q (U) P-LockOut	0	
	Minimal power factor	Ch Q (U) Cos. φ Min.	0	For a rectangular PQ-diagram
	X-coordinate Point 0 (%)	0-0 (x)	94 (96.5 for worst case)	
	Y-coordinate Point 0 (%)	0-1 (y)	43	
	X-coordinate Point 1 (%)	1-0 (x)	97	
	Y-coordinate Point 1 (%)	1-1 (y)	0	
	X-coordinate Point 2 (%)	2-0 (x)	105	
	Y-coordinate Point 2 (%)	2-1 (y)	0	
	X-coordinate Point 3 (%)	3-0 (x)	108 (105.5 for worst case)	
	Y-coordinate Point 3 (%)	3-1 (y)	-43	
	Parameter adjustment ¹²	m/s ¹³		

Test Design	<p>The three tests foreseen for this type of control will be performed for two levels of output power.</p> <ul style="list-style-type: none">• 80 % of the nominal apparent power• 100 % of the nominal apparent power <p>In the first case, the inverter should be able to fully inject or consume the maximal amount of reactive power (43 % of the apparent power) while in the second case, the inverter is not able to fully inject or consume the maximal amount of reactive power and the injected active power must be reduced not to exceed the maximal apparent power.</p>
Initial system state	<p>The tests are started by first verifications related to the correct functionality and the proper configuration of the $Q(U)$ controller. In order to verify or disprove this concern, the following procedure will be employed:</p>

¹¹ a preferred time constant of 5 s has been discussed previously.

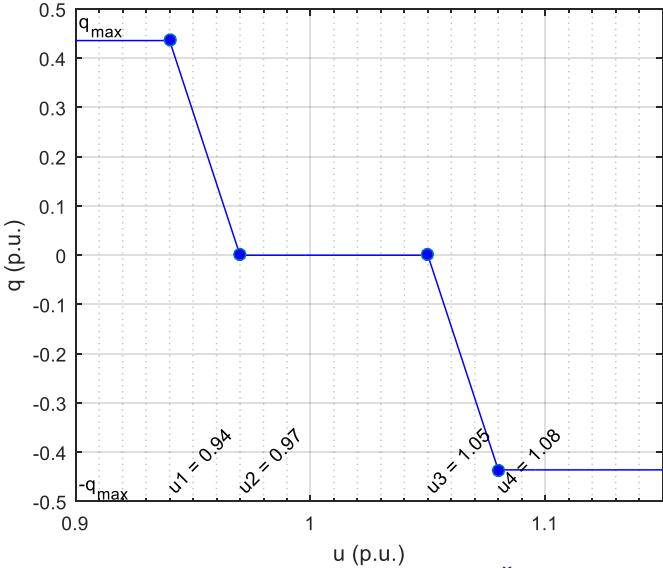
¹² m: manually / r: remotely / s: with service software

¹³ if necessary only

	<ol style="list-style-type: none"> 1. An additional grid impedance of $X_L = 0.156 + i0.158$ and $X_N = 0.096 + i0.102$ will be connected between the inverter and the grid simulator 2. With the Q(U) control disabled the active power of the converter will be set to 80% and the difference between the voltage at the field wiring terminals of the inverter and the voltage at the terminal of the grid simulator will be noted 3. The Q(U) control will be enabled with the settings from the last tests via the control panel of the inverter: <ol style="list-style-type: none"> a. Upper: 44% Capacitive b. Lower: 44% Inductive 4. The voltage of the grid simulator will be set below the nominal operating band so that the Q(U) control activates. 5. The active power will be set to 80% and the two voltages, i.e., the inverter voltage and the grid voltage, will be monitored.
Evolution of system state and test signals	<p>The voltage will be varied via the network simulator between -10 % and + 10 % of the nominal voltage via a stair function. The duration of each stair and the response time are chosen to ensure that the steady-state is reached before the next step. To limit the duration of the tests, the inverter will be parametrized as fast as possible. In total, 20 points are spread along the voltage band (step of 0.5 % of the nominal voltage¹⁴). The voltage will be varied step-wise in both directions (over-voltage and under-voltage) at the output of the network simulator between</p> <ul style="list-style-type: none"> - the nominal voltage and a voltage in the droop area close to the droop start - a voltage in the droop area close to the droop start and a voltage in the droop area close to the droop end - a voltage in the droop area close to the droop end and the nominal voltage
Other parameters	Temperature
Storage of data	The measurement of voltage and current are done with DEWETRON. The data recording and analysis is done with Dewesoft 7.1.3. The general measurement surface is shown in ScadaBR.
Temporal resolution	<p>The following time resolution:</p> <ul style="list-style-type: none"> - Raw data - instantaneous values (sampling rate: 300 kHz) - RMS-values of one or more cycles - RMS-values of optional duration (overlapping or non-overlapping)
Source of uncertainty	Measurement devices
Suspension criteria / Stopping criteria	Measurement failure, OuT failure

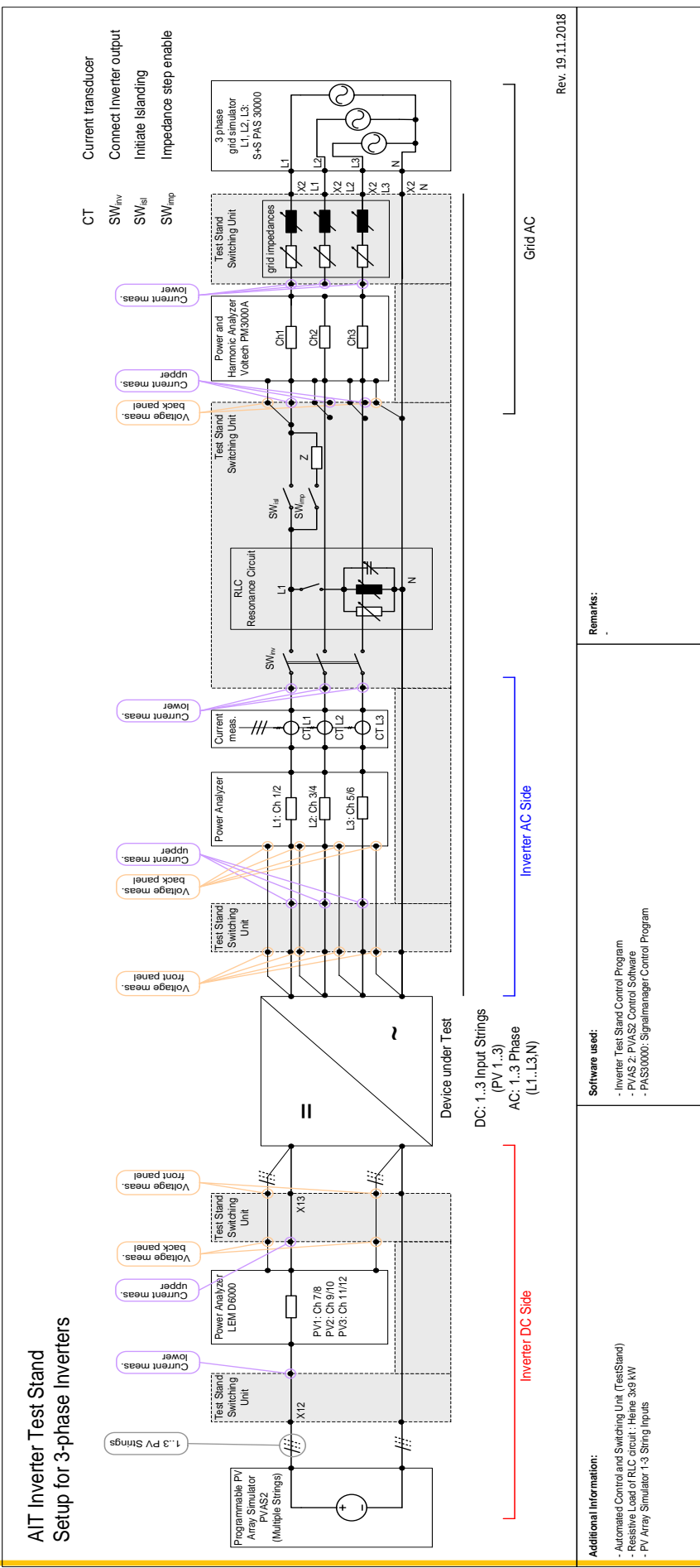
¹⁴ This step is close to the steps of 1 V.

Experiment Specification Template (e.g. Experiment specifications for hardware component testing)

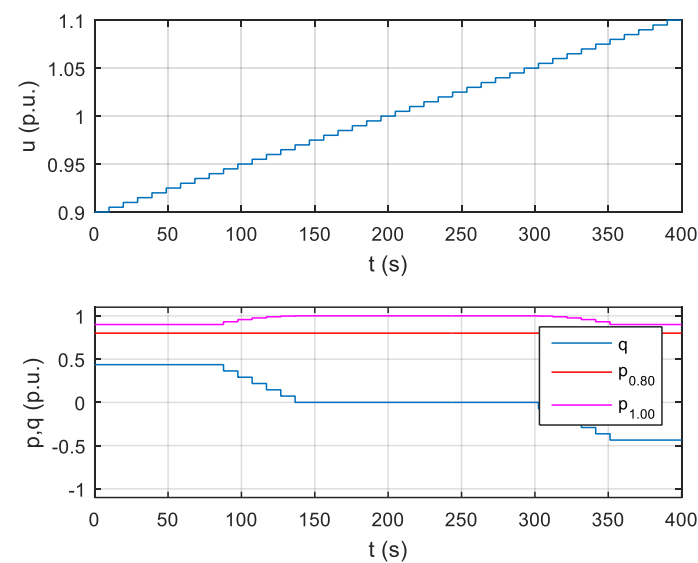
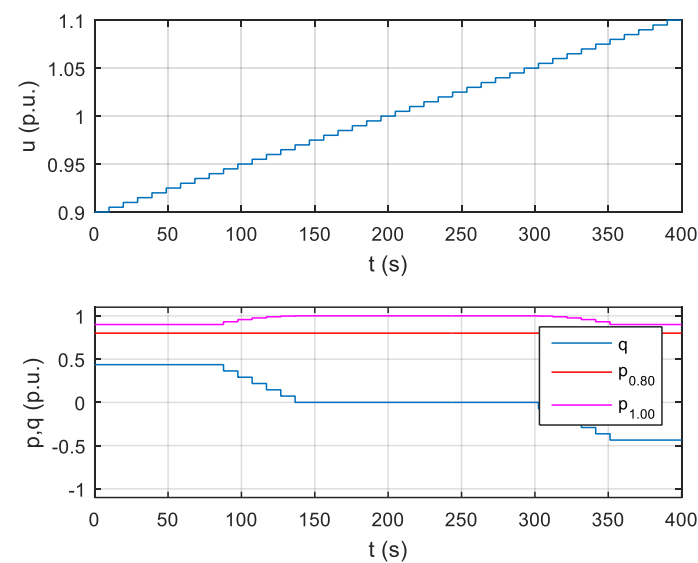
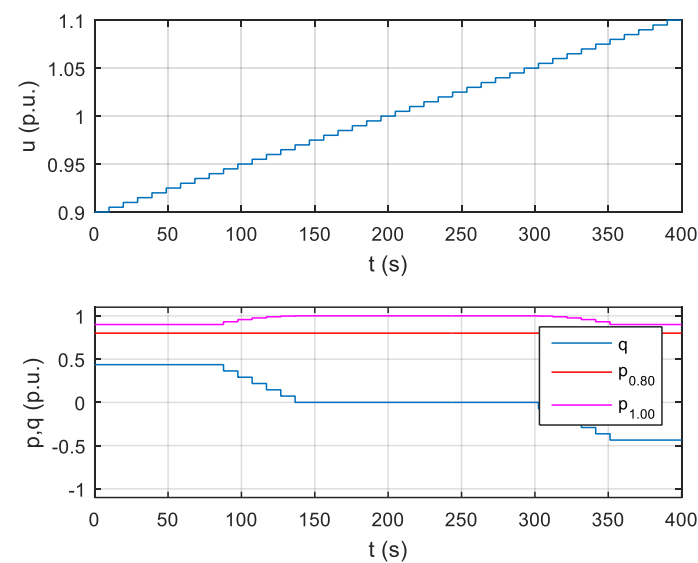
Ref. Test Spec.	“Voltage support evaluation”
Research Infrastructure	AIT SmartEST research test stand
Experiment Realisation	<p>The reactive power control to be tested under UC1 is a local control of the voltage through a voltage-dependant reactive power injection or consumption ($Q(U)$). The default $Q(U)$-characteristic is shown on Figure A.</p>  <p><i>Figure A- Default $Q(U)$-curve for ČEZ Distribuce¹⁵</i></p>

¹⁵ Parameter naming according to [1]

Experiment Setup
(concrete lab equipment)



Test equipment: (Type / SN / Used for)			
Signal measurement s	DEWETRON - Messsystem	SN	Eingang:
	DEWETRON DEWE-808	13090092	-;
	DEWETRON Orion 1	15380102	-;
	DEWETRON Orion 2	15380267	-;
	DEWE Shunt 1	79090017	V _{AC} L1;
	DEWE Shunt 2	79090018	V _{AC} L2;
	DEWE Shunt 3	79090019	V _{AC} L3;
	DEWE Shunt 4	79090020	V _{DC} PV1;
	DEWE Shunt 5	79090021	V _{DC} PV2;
	DEWE Shunt 6	79090022	V _{DC} PV3;
	DEWE Shunt 7	79100135	V _{AC} RLC_L1;
	DEWE Shunt 8	79100136	V _{AC} RLC_L2;
	DEWE Shunt 9	79100137	V _{AC} RLC_L3;
	LEM Danfysik Stromwandler 1 IT200-S	10081347	I _{AC} L1;
	LEM Danfysik Stromwandler 1 IT200-S	10081352	I _{AC} L2;
	LEM Danfysik Stromwandler 1 IT200-S	10081353	I _{AC} L3;
	LEM Danfysik Stromwandler 1 IT200-S	10081355	I _{DC} PV1;
	LEM Danfysik Stromwandler 1 IT200-S	10081356	I _{DC} PV2;
	LEM Danfysik Stromwandler 1 IT200-S	10081357	I _{DC} PV3;
	LEM Danfysik Stromwandler 1 IT200-S	9102860074	I _{AC} RLC_L1;
	LEM Danfysik Stromwandler 1 IT200-S	9102860075	I _{AC} RLC_L2;
	LEM Danfysik Stromwandler 1 IT200-S	9102860080	I _{AC} RLC_L3;
	DEWE MCTS System 1	37-006-0034	-;
	DEWE MCTS System 2	37-003-0097	-;
	DAQP_HV 1	335742	V _{AC} L1;
	DAQP_LV 2	332737	I _{AC} L1;
	DAQP_HV 3	335743	V _{AC} L2;
	DAQP_LV 4	332738	I _{AC} L2;
	DAQP_HV 5	335745	V _{AC} L3;
	DAQP_LV 6	332739	I _{AC} L3;
	DAQP_HV 7	335746	V _{DC} PV1;
	DAQP_LV 8	331207	I _{DC} PV1;
	DAQP_HV 9	335747	V _{DC} PV2;
	DAQP_LV 10	331989	I _{DC} PV2;
	DAQP_HV 11	335749	V _{DC} PV3;
	DAQP_LV 12	331993	I _{DC} PV3;
	DAQP_HV 13	357086	V _{AC} RLC_L1;
	DAQP_LV 14	362408	I _{AC} RLC_L1;
	DAQP_HV 15	357088	V _{AC} RLC_L2;
	DAQP_LV 16	362409	I _{AC} RLC_L2;
	DAQP_HV 17	357090	V _{AC} RLC_L3;
	DAQP_LV 18	362399	I _{AC} RLC_L3;
	DAQP_HV 19	357089	Ext. Trigger;
	DAQP_HV 20	357087	SPS Trigger;
	Digital Storage Scope YOKOGAWA DL716	7018HC148C	
	Differential Probe Testec Si 9001	034442	U _{AC} L1
	Differential Probe Testec Si 9001	040543	U _{AC} L2
	Differential Probe Testec Si 9001	040479	U _{AC} L3
	Differential Probe Testec Si 9001	116254	U _{DC} String 1
	Differential Probe Testec Si 9001	052003	U _{DC} String 2
	Differential Probe Testec Si 9001	052004	U _{DC} String 3
	Current-Transducer (6-channel)	09/04	I _{AC} L1/2/3,
	I _{DC} 1/2/3		

	<table><tr><td>Power measurement</td><td>Power Analyzer LEM NORMA D6200 LEM Triaxial Shunt 30A Int. Nr. R7 LEM Triaxial Shunt 30A Int. Nr. R8 LEM Triaxial Shunt 30A Int. Nr. R9 LEM Triaxial Shunt 30A Int. Nr. R10 LEM Triaxial Shunt 30A Int. Nr. R11 LEM Triaxial Shunt 30A Int. Nr. R12</td><td>K7 60462 OP W1 61594 D W1 61591 D K6 03083 F K6 03078 F K6 03082 F K6 03081 F</td><td>I_{AC} L1 I_{AC} L2 I_{AC} L3 I_{DC} String 1 I_{DC} String 2 I_{DC} String 3</td></tr><tr><td>DC-simulation / supply</td><td>AIT PV Array Simulator PVAS3 Power supply FIV 1000V/32A AIT PV Array Simulator PVAS3 Power supply FIV 1000V/32A AIT PV Array Simulator PVAS3 Power supply FIV 1000V/32A</td><td>PVAS3.2P/C-2174-001 FIV1000-1 PVAS3.2P/C-2174-003 FIV1000-2 PVAS3.2P/C-2174-002 FIV1000-3</td><td>String 1 String 1 String 2 String 2 String 3 String 3</td></tr><tr><td>AC-simulation</td><td colspan="3">Spitzenberger + Spies PAS 30000 3 phase 4 Quadrant Amplifier / Network Simulator A3587 00/0 0705</td></tr><tr><td>Other test equipment</td><td colspan="3">PV inverter test stand, AIT Austrian Institute of Technology GmbH;</td></tr></table>	Power measurement	Power Analyzer LEM NORMA D6200 LEM Triaxial Shunt 30A Int. Nr. R7 LEM Triaxial Shunt 30A Int. Nr. R8 LEM Triaxial Shunt 30A Int. Nr. R9 LEM Triaxial Shunt 30A Int. Nr. R10 LEM Triaxial Shunt 30A Int. Nr. R11 LEM Triaxial Shunt 30A Int. Nr. R12	K7 60462 OP W1 61594 D W1 61591 D K6 03083 F K6 03078 F K6 03082 F K6 03081 F	I _{AC} L1 I _{AC} L2 I _{AC} L3 I _{DC} String 1 I _{DC} String 2 I _{DC} String 3	DC-simulation / supply	AIT PV Array Simulator PVAS3 Power supply FIV 1000V/32A AIT PV Array Simulator PVAS3 Power supply FIV 1000V/32A AIT PV Array Simulator PVAS3 Power supply FIV 1000V/32A	PVAS3.2P/C-2174-001 FIV1000-1 PVAS3.2P/C-2174-003 FIV1000-2 PVAS3.2P/C-2174-002 FIV1000-3	String 1 String 1 String 2 String 2 String 3 String 3	AC-simulation	Spitzenberger + Spies PAS 30000 3 phase 4 Quadrant Amplifier / Network Simulator A3587 00/0 0705			Other test equipment	PV inverter test stand, AIT Austrian Institute of Technology GmbH;			<table><tr><td>Experimental Design and Justification</td><td><p>The purpose of this test is to evaluate the accuracy of the control. This test will be conducted without any additional impedance between network simulator and EUT. The voltage will be varied via the network simulator between -10 % and + 10 % of the nominal voltage via a stair function. The duration of each stair and the response time are chosen to ensure that the steady-state is reached before the next step. To limit the duration of the tests, the inverter will be parametrized as fast as possible. In total, 20 points are spread along the voltage band (step of 0.5 % of the nominal voltage¹⁶). The voltage will follow the test signal shown on Figure B. On the lower part of this figure, the expected response is shown (without considering the time behaviour).</p><div></div><p><i>Figure B - Test signal for the evaluation of the accuracy of the Q(U)-control¹⁷</i> <i>p_{0.80}: active power curve for an available PV power from 80 % of the maximal apparent power</i></p></td></tr></table>	Experimental Design and Justification	<p>The purpose of this test is to evaluate the accuracy of the control. This test will be conducted without any additional impedance between network simulator and EUT. The voltage will be varied via the network simulator between -10 % and + 10 % of the nominal voltage via a stair function. The duration of each stair and the response time are chosen to ensure that the steady-state is reached before the next step. To limit the duration of the tests, the inverter will be parametrized as fast as possible. In total, 20 points are spread along the voltage band (step of 0.5 % of the nominal voltage¹⁶). The voltage will follow the test signal shown on Figure B. On the lower part of this figure, the expected response is shown (without considering the time behaviour).</p> <div></div> <p><i>Figure B - Test signal for the evaluation of the accuracy of the Q(U)-control¹⁷</i> <i>p_{0.80}: active power curve for an available PV power from 80 % of the maximal apparent power</i></p>
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¹⁶ This step is close to the steps of 1 V mentioned in [4].

¹⁷ The duration of each step is set to 20 s which allows to reach the steady-state between each step.

	<i>p_{1.00}: active power curve for an available PV power from 100 % of the maximal apparent power</i>	
Precision of equipment	Test Equipment	
	Current transformer	<ul style="list-style-type: none"> LEM LF 205-S/SP3 (standard) <ul style="list-style-type: none"> Accuracy: 0.5% LEM IT 200-S ULTRASTAB (if higher accuracy is needed) <ul style="list-style-type: none"> Accuracy: 0.0084 %
	Measuring equipment	DEWETRON - measuring system <ul style="list-style-type: none"> Measuring cards for voltage measurement: DAQP-HV (DC Accuracy: ± 0.05 % of reading ± 0.05 % of range) Measuring cards for current measurement: DAQP-LA (Accuracy: ± 0.05 % of reading ± 0.05 % of range)
	DC source	<ul style="list-style-type: none"> AIT PV Array Simulator PVAS3 (standard) TC.GSS.20.130.4WR.S TC.GSS.32.600.4WR.S
	AC source	<ul style="list-style-type: none"> Public grid Grid simulator: 3x Spitzenberger PAS 10000
	Other test equipment	Temperature measurement (ADAM-6018; 8-channel isolated thermocouple input Modbus TCP module with 8-channel DO)
Uncertainty measurement	Based on the precision of equipment of the lab instrument and of measurement algorithms, the parameters to model the measured quantities errors are provided.	