Interoperability and Interchangeability validation results

Version 1.0

Deliverable D3.7

17/12/2019

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

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<tr><td colspan="2">ID & Title :</td><td colspan="4">D3.7 - Interoperability and interchangeability validation results</td></tr>
<tr><td colspan="2">Version :</td><td>1.0</td><td colspan="2">Number of pages :</td><td>91</td></tr>
<tr><td colspan="6">Short Description</td></tr>
<tr><td colspan="6">This deliverable presents the results of the interoperability validation lab tests conducted at AIT’s SmartEST and Digital Labs with some hardware in the lab and some remotely accessed.</td></tr>
<tr><td colspan="6">Revision history</td></tr>
<tr><td>Version</td><td>Date</td><td colspan="2">Modification’s nature</td><td colspan="2">Authors</td></tr>
<tr><td>0.1</td><td>26/09/2019</td><td colspan="2">Document structure</td><td colspan="2">Friederich Kupzog, Jawad Kazmi, Mihai Calin</td></tr>
<tr><td>0.2 - 0.7</td><td>26/11/2019</td><td colspan="2">Documented five case studies, methodology, introduction, and Annex</td><td colspan="2">Friederich Kupzog, Jawad Kazmi, Mihai Calin, Marco Cupelli, Amir Ahmadifar, Mirko Ginocchi, Olivier Genest</td></tr>
<tr><td>0.8</td><td>11/12/2019</td><td colspan="2">TC review comments addressed and Case study 6 updated</td><td colspan="2">Friederich Kupzog, Jawad Kazmi, Mihai Calin, Marco Cupelli, Amir Ahmadifar, Mirko Ginocchi, Olivier Genest</td></tr>
<tr><td>0.9</td><td>13/12/2019</td><td colspan="2">Final version</td><td colspan="2">Friederich Kupzog, Jawad Kazmi, Mihai Calin, Marco Cupelli, Amir Ahmadifar, Mirko Ginocchi, Olivier Genest</td></tr>
<tr><td>1.0</td><td>17/12/2019</td><td colspan="2">Revised final version</td><td colspan="2">Jawad Kazmi</td></tr>
<tr><td colspan="6">Accessibility</td></tr>
<tr><td>☒Public</td><td>☐ Consortium + EC</td><td colspan="2">☐ Restricted to a specific group + EC</td><td colspan="2">☐ Confidential + EC</td></tr>
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<tr><td colspan="6">AIT Austrian Institute of Technology, RWTH Aachen University, TRIALOG</td></tr>
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EXECUTIVE SUMMARY

The use of flexibility for the grid and generation-load balance management is a key factor in renewable-based electricity systems. However, the way such flexibility services are activated from an ICT perspective requires harmonization across Europe, as there are multiple different approaches currently under evaluation. Still, the interface between the distribution grid operator and the flexibility provider, be it direct or indirect via an aggregator, is lacking a widely accepted and applied technical reference solution. High shares of intermittent renewables require the wide use of system flexibilities from controllable generation and dedicated storage to load management. In an electricity system with separate roles for grid operation and energy retail, the activation of flexibilities can be realized in many different ways. However, from a European perspective, the provision of flexibility should require the same technical interfaces disregarding the region or utility. Such a technical solution would provide interoperability that is a key feature of digitalized energy systems. In this work, the different services required in flexibility use cases of the European demonstration project InterFlex are validated in AIT's SmartEST and Digital Labs for the evolution of interoperability between the different components, namely the flexibility itself, the flexibility requester and potential intermediates such as aggregators. Some hardware components are accessed remotely from the InterFlex partners.

This deliverable provides six case studies for interoperability validation featuring the upper and lower-bound architectures (Deliverable D3.1), the most common flexibility services (Deliverable D3.2) in the context of InterFlex. The tests are conducted following the JRC Smart Grid Interoperability validation methodology. In the methodology, the interfaces need to be validated along with all possible communication technologies. These Basic Application Profiles (BAP) as they are called are created for each of the identified interfaces. BAPs are combined based on a use case and called Basic Application Interoperability Profile (BAIOP). Each BAIOP is then a complete validation scenario that can be tested.

Each case study is structured in a similar way so that it provides sufficient detail to the reader about the background, the use case, a high-level conceptual view of the test design with all the involved actors in the flexibility chain, etc. Furthermore, the details of the testbed and configured components along with results and short discussions are also provided.

After analyzing the interoperability validation tests, some of the conclusions are that the activation of flexibility directly via a Remote Terminal Unit (RTU) or indirectly via an intermediate actor (such as an energy management system or aggregators) is possible however it is to be noted that the indirect activation mechanism is relatively easy to manage and could be scaled up while the direct mechanism provides a more robust solution but lacks the scalability. Additionally, the telecommunication infrastructure does have an impact on the quality of service delivered by the sources of flexibility in terms of activation and response times. From the demonstration analysis it can be concluded that the system integrations are complex and are subjected to the DSO desired service. The DSOs can build up an interoperable infrastructure based on their targeted quality of service, the available amount of flexibility, market and grid constraints, and economic considerations.

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1 INTRODUCTION

The use of flexibility for the grid and generation-load balance management is a key factor in renewable energy-based electricity systems. However, the way such flexibility services are activated from an ICT perspective requires harmonization across Europe, as there are multiple different approaches currently under evaluation. Still, the interface between the distribution grid operator and the flexibility provider, be it direct or indirect via an aggregator, is lacking a widely accepted and applied technical reference solution. High shares of intermittent renewables require the wide use of system flexibilities from controllable generation and dedicated storage to load management. In an electricity system with separate roles for grid operation and energy retail, the activation of flexibilities can be realized in many different ways. However, from a European perspective, the provision of flexibility should require the same technical interfaces disregarding the region or utility. Such a technical solution would provide interoperability that is a key feature of digitalized energy systems. Interoperability, as stated by CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG),[1] is

> "*the ability of two or more networks, systems, devices, applications, or components to interwork, to exchange and use information in order to perform required functions.*"

In this work, the different services required in flexibility use cases of the European demonstration project InterFlex are validated in AIT's SmartEST and Digital Labs for the evolution of interoperability between the different components, namely the flexibility itself, the flexibility requester and potential intermediates such as aggregators. For this purpose, six case studies featuring the upper and lower-bound architectures[2], the most common flexibility services[3] in the context of InterFlex are conducted for the validation of interoperability. The tests are designed and conducted following the JRC Smart Grid Interoperability validation methodology. In the methodology, the interfaces that need to be validated along with all possible communication technologies. These Basic Application Profiles (BAP) as they are called are created for each of the identified interfaces. BAPs are combined based on a use case and called Basic Application Interoperability Profile (BAIOP). Each BAIOP is then a complete validation scenario that can be tested. Each case study is structured similarly so that it provides sufficient detail to the reader about the background, the use case, a high-level conceptual view of the test design with all the involved actors in the flexibility chain, etc. Furthermore, the details of the testbed and configured components along with results and short discussions are also provided. Please do note that some contents are repeated to make each case study self-contained.

1.1 Scope of the document

The scope of this document is to report the interoperability validation test conducted in AIT's SmartEST and Digital labs for accessing the interoperability for the upper and lower-bound architectures for two selected flexibility activation services. For this, the JRC Smart Grid Interoperability validation methodology is used and six case studies are constructed to cover both the voltage support and congestion management use cases in upper and lower-

[1] https://www.cenelec.eu/aboutcenelec/whatwestandfor/societywelfare/interoperability.html
[2] InterFlex Deliverable D3.1
[3] InterFlex Deliverable D3.2

bound architectures. For the test both hardware in the loop and controller hardware in the loop modalities are utilized.

1.2 Notations, abbreviations, and acronyms

The table below provides an overview of the notations, abbreviations, and acronyms used in the document.

Table 1-1: List of acronyms

BAIOP	Basic Application Interoperability Profile
BAP	Basic Application Profiles
BAT	Battery
BMS	Building Management System
CP	Customer Premises
DER	Distributed Energy Resource
DG	Diesel Generator
DSO	Distribution System Operator
DSR	Demand Side Response
EC	European Commission
EC-GA	European Commission Grant Agreement
EMS	Energy Management System
ESCO	Energy Service Company
EU	European Union
EV	Electric Vehicle
GA	General Assembly
GW	Gateway
GWP	General Work Package
HP	Heat Pump
HV	High Voltage
IMP	Intermediate Management Platform
JRC	Joint Research Center
KPI	Key Performance Indicator
LV	Low Voltage
MDM	Meter Data Management
MGC	Microgrid Controller
MV	Medium Voltage
PC	Project Coordinator
PV	Photo Voltaic
RES	Renewable Energy Source
RTU	Remote Terminal Unit
SC	Steering Committee
SGAM	Smart Grid Architecture Model
SGILab	Smart Grid Interoperability Laboratory
SSU	Smart Storage Unit
TC	Technical Committee
WP	Work Package
WPL	Work Package Leader

1.3 EU Expectations from InterFlex

InterFlex is a response to the Horizon 2020 Call for proposals, LCE-02-2016 ("Demonstration of smart grid, storage, and system integration technologies with an increasing share of renewables: distribution system").

This Call addressed 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 promoted the development of technologies with a high TRL (technology readiness level) into a higher one.

InterFlex explored 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 were 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 ČEZ Distribuce as the technical director, InterFlex relied on a set of innovative use cases. Six industry-scale demonstrators were put in place in the participating European countries:

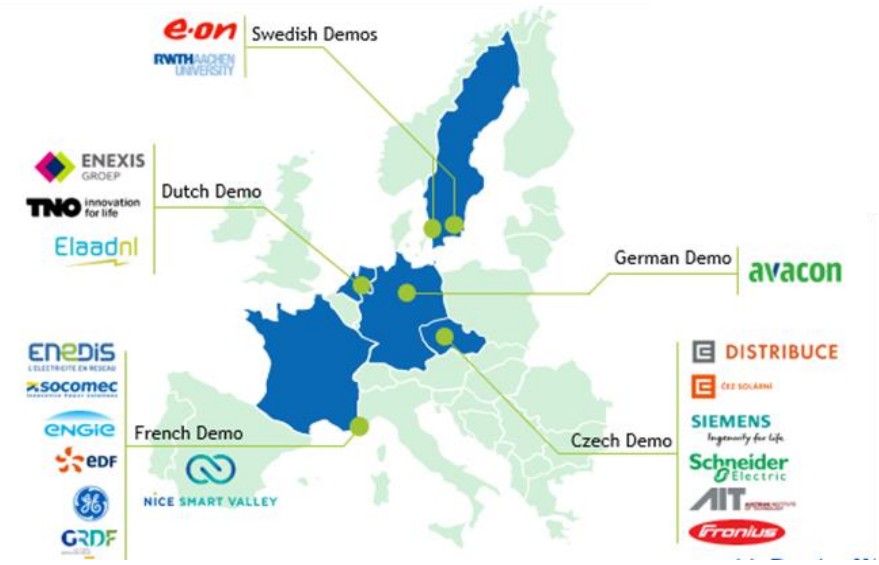

Figure 1-1. InterFlex Demo Map

Through the different demonstration projects, InterFlex assessed how the integration of the new solutions can lead to local energy optimization.

The LCE-02-2016 call, as well as the other smart grid calls from Horizon 2020 program, explicitly required to perform "a detailed analysis of current regulations, standards, and interoperability/interfaces issues applying to their case, in particular in connection to ongoing work in the Smart Grid Task Force and its Experts Groups in the field of Standardization (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 work detailed in this deliverable replies to these expectations by assessing the interoperability of the demonstrated solutions, at several layers, and based on the Smart Grid Architecture Model (SGAM).

1.4 Deliverable organization

The core of the present deliverable is organized in four chapters. The next chapter (Chapter 2) describes the methodology and explains the related concepts. Chapters 3, 4 and 5 feature two case studies each. Chapter 3 provides two case studies for the voltage support flexibility service for upper and lower-bound architectures where interoperability validation is performed. Similarly, Chapter 4 provides two case studies for congestion management flexibility service for upper and lower-bound architectures where interoperability validation is performed. Chapter 4 features two case studies when power hardware is used to extend the interoperability validation testbed. One such case study focuses on storage systems while the other one is with an electric vehicle charging station. The two Annexes (A & B) provide the JRC templates and a short description of some of the testbed components.

2 METHODOLOGY

This chapter provides detailed information about the preparation for conducting the interoperability validation tests in AIT's SmartEST and Digital Labs. The preparation involves both the theoretical and the practical parts. However, this chapter focuses only on the former and documents the methodology and design of experiments with it. The chapter starts with providing background about the chosen interoperability validation test methodology and its different steps in Section 2.1. The design of the experiment for the evaluation of the conducted test is explained in Section 2.2. Later, the validation architectures and the services that are to be used for the test are described in Sections 2.3 and 2.4. The two main use cases derived based on the identified services are documented in Section 2.6. Since the validation tests extensively use the communication technologies, Section 2.7 discusses some communication technologies and the corresponding interfaces for the test.

2.1 The BAPs and the BAIOPs definition

Within the interoperability testing framework, in 2018 the Smart Grid Interoperability Laboratory (SGILab) at the Joint Research Center (JRC) of the European Commission has produced a technical report, which aims at defining a unified approach towards a European framework for developing interoperability testing specifications.

Specifically, the JRC methodology is designed in response to the questions similar to:

> *"How to ensure the interworking of networks, systems, devices, applications, components? Ability to exchange meaningful, actionable information in support of the safe, secure, efficient, and reliable operations?"*[4]

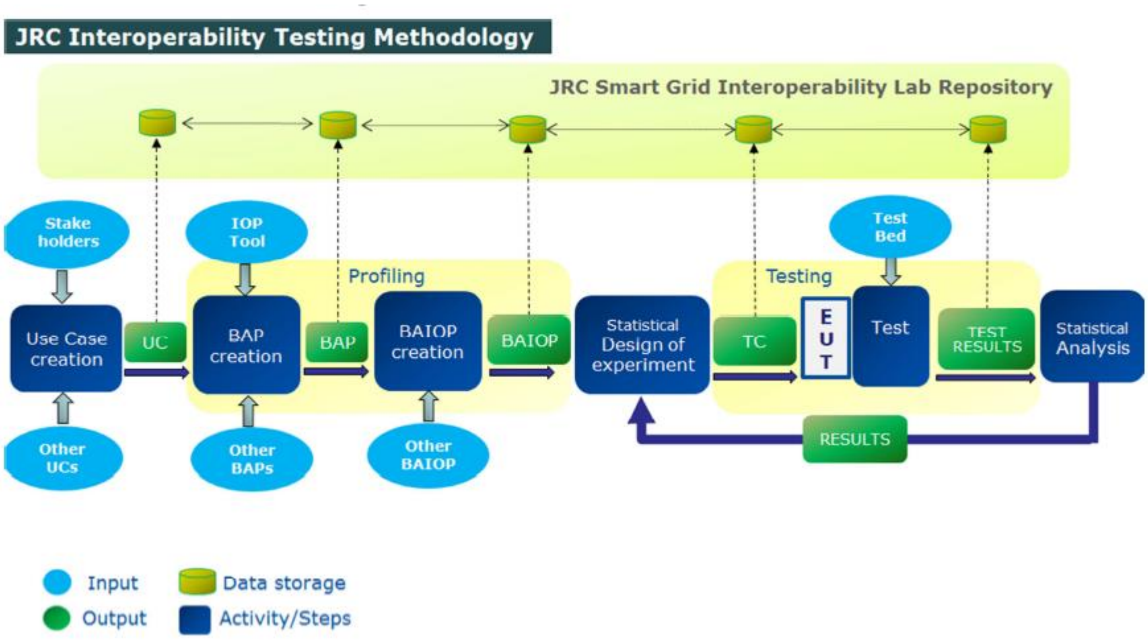

Figure 2-1: A schematic overview of the JRC Interoperability testing methodology.

[4] https://www.etip-snet.eu/wp-content/uploads/2017/06/2.-The-role-of-Interoperability-Marcelo-Masera.pdf

The whole interoperability testing work performed in the InterFlex project (which is detailed in this deliverable) mostly follows some methodological guidelines proposed in the JRC report (see a useful tutorial paper [1]).

The block diagram of the JRC methodology is depicted in Figure 2-1, where the six-steps-workflow is detailed, from the Use Case creation and the profiling phase all the way to the testing specification and analysis.
In order to perform the interoperability and interchangeability testing, two Use Cases (UCs) have been employed:

- Voltage Support (see Section 2.6.1)
- Congestion Management (see Section 2.6.2).

These UCs are the chosen services which have been identified and studied in detail in InterFlex deliverable D3.2 [4]. In Section 2.4 additional information will be provided about the reasoning of choosing these functionalities for the interoperability tests.

In the JRC report[5], the Use Case creation is followed by the profiling procedure, which implies two steps, namely the specification of:

- Basic Application Profile (BAP) and
- Basic Application Interoperability Profile (BAIOP).

Interested readers can consult the Annex A for a detailed description of the defined BAPs and BAIOPs by the help of a complete JRC interoperability test template filled for one of the case studies.

Table 2-1: BAPs defined according to different communication technologies.

Interaction Link between actors		Technology	BAP ID
From	To		
DSO	Aggregator	Fiber (pro)	BAP1.1
Aggregator	RTU	Fiber (home) / Local Ethernet	BAP2.1
Aggregator	RTU	xDSL / cable	BAP2.2
Aggregator	RTU	Mobile network	BAP2.3
DSO	RTU	xDSL / cable	BAP3.1
DSO	RTU	Mobile network	BAP3.2
DSO	RTU	RTC	BAP3.3
DSO	RTU	Narrow-band PLC / RF Mesh	BAP3.4
RTU	Device	Fiber (home) / Local Ethernet	BAP4.1
RTU	Device	Narrow-band PLC / RF Mesh	BAP4.2
RTU	Device	Mobile network	BAP4.3

One BAP is based on the information flows that are exchanged between all the different actors involved in the UC, with the precondition that two actors interact with each other if they exchange information at least once in the UC. Strictly speaking, standards and protocols specifying these information flows should be taken into account for creating BAPs. In this deliverable, the BAPs are defined by considering different communication technologies that are implemented in InterFlex as well as potential candidates for future implementations

[5] ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/SGCG_Interoperability_Report.pdf

having in mind the state of the art solutions. The resulting BAPs characterizing the actors taking part in the UCs are shown in Table 2-1, while the communication parameters defining the specified communication technologies are reported in Table 2-2. The technology options specified in Table 2-2 have been selected in order to represent InterFlex demo-specific implementations.

After defining the BAPs for each interface, the BAIOPs need to be specified. Each BAIOP contains a unique combination of BAPs for all the interfaces involved in the UC. Therefore, the BAIOPs define the test cases that will be run in the testing phase in order to prove that the functions described in the UC are correctly supported.

Table 2-2: Communication parameters characterizing the different technology options.

Technology	Techno	Bandwidth	Background traffic	Delay	Jitter	Packet loss	Duplicate
	-	Mbps	Mbps	µs	µs	%	%
Fiber (pro)	Ethernet	1000	link dependent	3000	1000	0	0
Fiber (home) / Local Ethernet	Ethernet	100	link dependent	3000	1000	0	0
xDSL / cable	Ethernet	20	link dependent	30000	10000	0	0
Mobile network	Radio	10	link dependent	60000	20000	1	0
Narrow-band PLC / RF Mesh	PLC	0.1	link dependent	300000	100000	3	0
RTC	Twisted pair	0.056	link dependent	150000	50000	0	0

The considered BAIOPs are reported in Table 2-3. BAIOP1-3 are grouped under the class of the “Upper Bound” BAIOPs, while BAIOP4-6 belongs to the class of the “Lower Bound” BAIOPs, where “Upper” and “Lower” bound are the validation architectures detailed in Section 2.3. The crosses (X) here represents the selected unique BAPs that will be part of a BAIOP. As can be seen in the table, there are six interoperability tests for selected interfaces and the respective communication technologies considered. The table should always be read with Table 2-1 for BAP definitions and Table 2-2 for communication technologies and parameters.

Table 2-3: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

2.2 Design of Experiments

After the preliminary stages of Use Case creation and BAP-BAIOP specification, the focus of the JRC methodology is oriented to the Design of Experiments (DoE), which is the systematic method of laying out a detailed plan in advance of carrying out experiments [1].

The suggested DoE procedure should include the subsequent steps:

1. Definition of the goals of the experiments
2. Identification of the system response(s), or output(s), which have to be measured
3. Identification of the process variables or input factors (IFs) which potentially may influence the system output(s)
4. Statistical characterization of each input factor
5. A sampling of N values within the input factors' distribution functions

The consequent produced N test cases are then used as experimental points to be tested in the laboratory environment.

However, since the interoperability testing, in the InterFlex project, mainly aims at validating the interfaces between the actors involved in the flexibility activation chain, the input factors' variability is not explored, and no stress tests or reliability analyses are performed. Therefore, the DoE procedure applied specifically in these tests does not include the above-mentioned Step 5. In other words, for each BAIOP the input factors, once identified (Step 3) and statistically characterized (Step 4), are fixed at a specific value within the respective range of variability, and the correspondent tests are carried out for this "one-row" input configuration. The variability ranges of each input factor are defined only in order to choose the specific (i.e., mean) values in which the lab experiments have to be run.

2.3 Validation architectures

The architectures of InterFlex demonstrators have been analyzed from the interoperability viewpoint in deliverable D2.1. One of the results is that the DSO-oriented flexibility services demonstrated in InterFlex involve communication between the DSO and several Devices and that, as described in the so-called "orthogonality theory", this communication goes through an intermediate actor which can be:

- An Aggregator (or EMS) offering the service to the DSO with a connection at Enterprise or Market SGAM zone. This Aggregator (or EMS) is then taking care of the connection to the Device, within the DER or Customer Premises SGAM domain. This option is called "Upper bound" as the horizontal (cross-domain) connection is done in the upper zones.
- A Remote Terminal Unit (RTU), owned and/or operated by the DSO, providing him a local connection to the Device, at Field zone. This option is called "Lower bound" as the horizontal (cross-domain) connection is done in the lower zones.

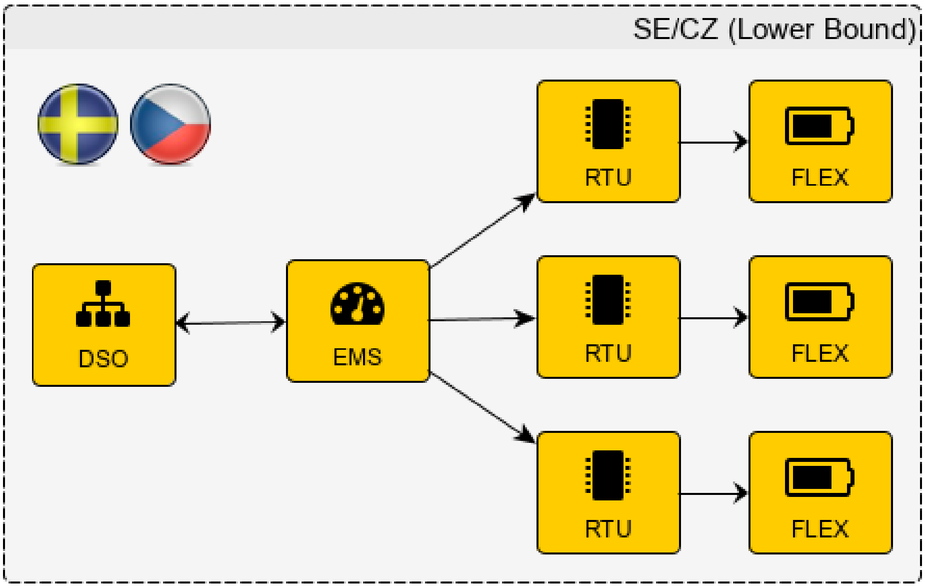

Figure 2-2: High-level view of SE and CZ demos as using the lower-bound architecture.

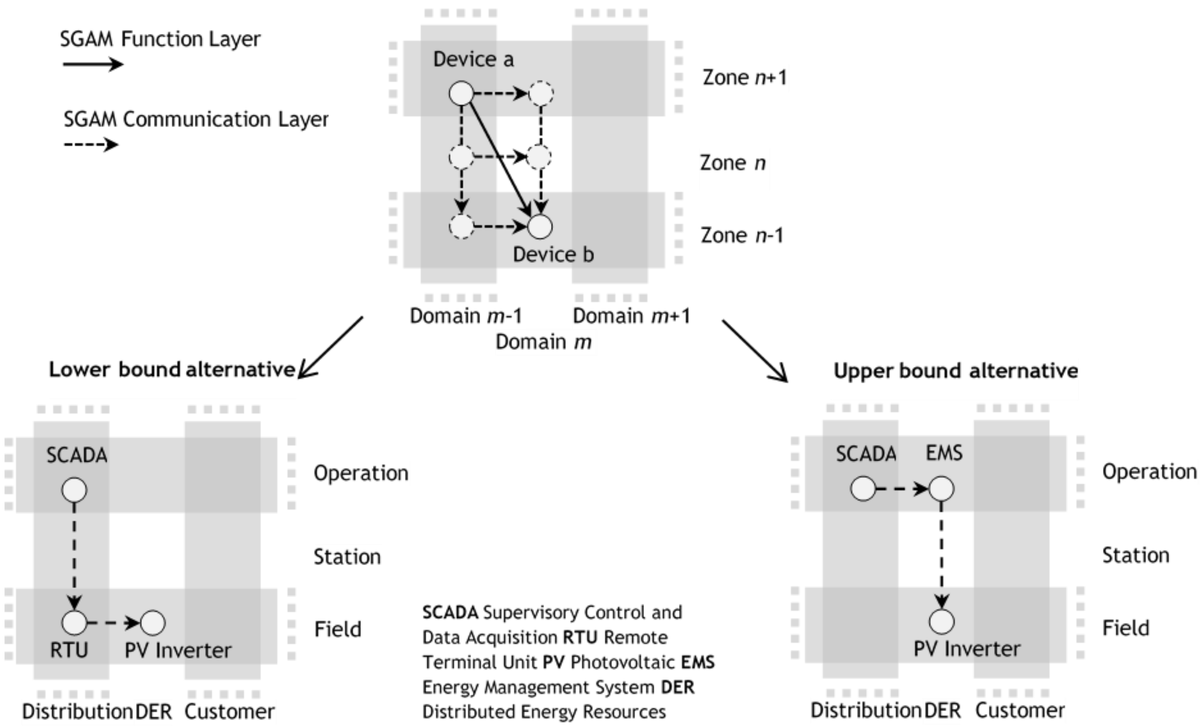

Figure 2-3: Realization of cross-domain and cross-zone links following either the Lower bound or the Upper bound alternative (extracted from Deliverable D3.1 and [2]).

In the scope of these interoperability and interchangeability tests in the laboratory, both architectures are tested. In the InterFlex demo, both of these architectures have been employed by the DSO for activating the flexibilities when they are needed. The three figures (Figure 2-2, Figure 2-4, and Figure 2-5) try to show at a high-level the demos employing these architectures.

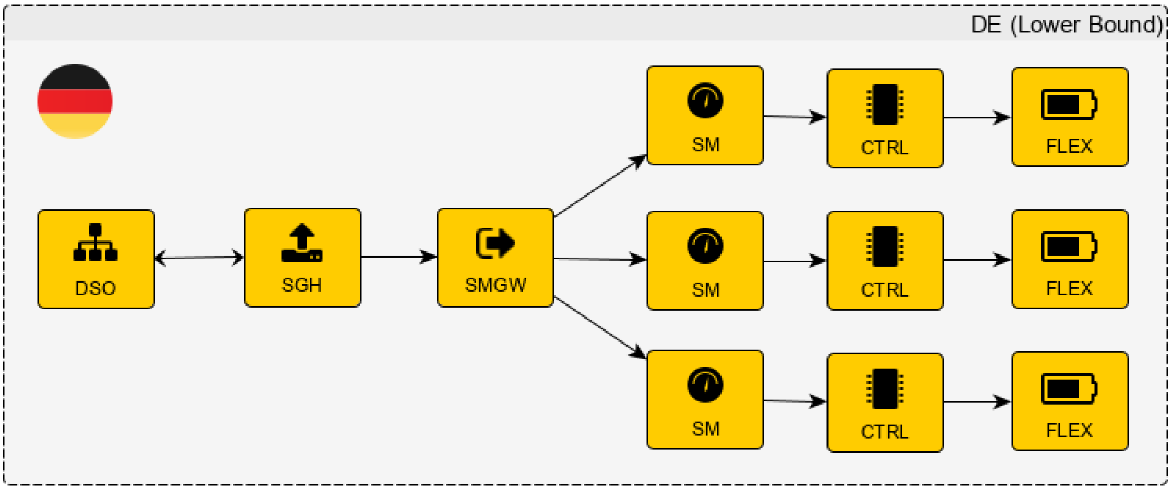

Figure 2-4: High-level view of DE demo as using the lower-bound architecture.

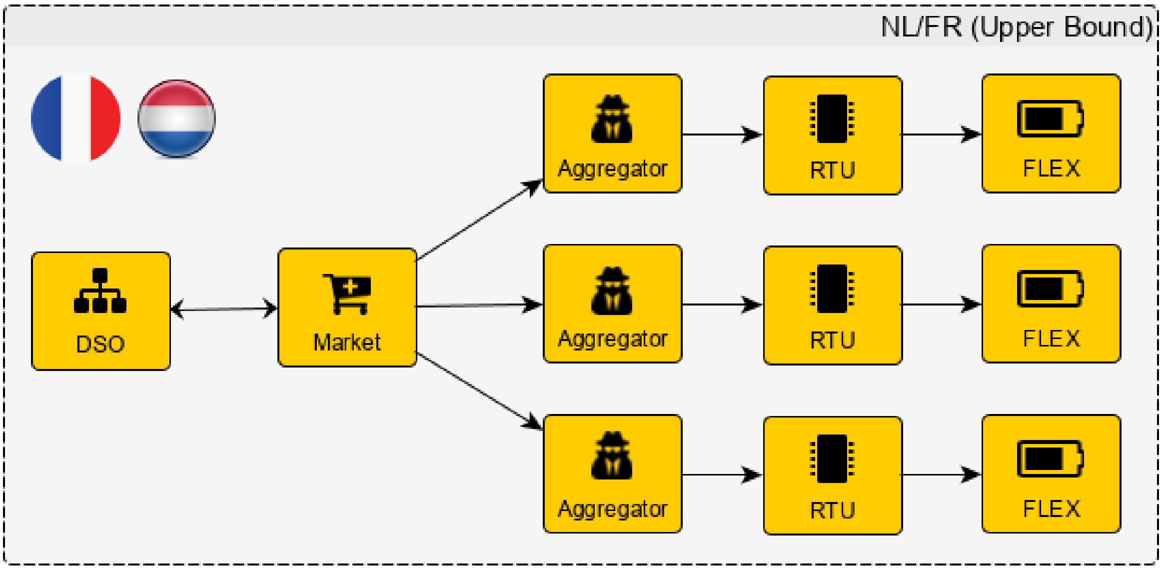

Figure 2-5: High-level view of NL and FR demos as using the lower-bound architecture.

2.4 Chosen services

For performing the validation tests, there need to be some flexibility services for which interoperability is to be shown. Therefore, the first logical steps are to identify these services. This activity is performed before and reported in the Deliverable D3.2. In this deliverable, all the 18 use cases from the 6 demonstrations are analyzed with an innovative methodology. The said methodology extends the process-model proposed by the Sustainable Processing Working Group under EU Mandate M/490. The methodology adds three additional steps that are then used to analyze the use cases hierarchically at three levels – use case, demonstration and then at the project level.

Table 2-4: Identified "Common Patterns" in Deliverable D3.2 [3].

Common patterns	Pilot and respective use cases															
	Czech				French			German			Dutch			Swedish 1		Swedish 2		
	1	2	3	4	1	2	3	1	2	3	1	2	3	1	2	1	2	3
Using voltage support	×	×		×		×			×		×	×						
Using frequency support and related system services	×	×		×		×			×		×				×	×		
Using battery for congestion management			×	×			×				×	×						×
Using EV and Loads for congestion management							×			×			×					×
Using islanding for congestion management																×	×	
By Load monitoring									×								×	
By RES monitoring									×		×					×	×	
By Load forecasting						×				×	×	×				×		×
By RES forecasting						×										×	×	
By Security of supply and RES maximization	×				×	×		×	×		×					×		
Through customer engagement																	×	
By energy management including cross carrier and self consumption							×							×	×			

The results of this analysis are the identification of some "common patterns" (see Table 2-4: Identified "Common Patterns" in Deliverable D3.2) and then "services" (see Table 2-5). From the identified 5 services finally, two are selected for lab validation.

Table 2-5: Identified flexibility services in Deliverable D3.2.

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

The two selected services for lab validation are:

1. Voltage Support
2. Congestion Management

Interested readers can find the details and rationales for selecting only these two services for the lab validation can consult the Deliverable D3.2 available from the project website.

2.5 Validation Modes

For the interoperability tests to be conducted in the AIT SmartEST and Digital Labs, a testbed was constructed. This testbed is case study specific and is adapted to suit the actors and corresponding interfaces that are to be validated. The customization of the testbed for each case study is documented in the following chapters. However, the composition of the testbed can be broadly classified at either:

1. Power Hardware in the Loop

2. Controller Hardware in the Loop

In the first case, the testbed is extended with power-hardware. Two case studies featuring this form of validation are presented as Case study 5 and 6, where a storage system and an electric vehicle charging station are used respectively. In the second case, some models of actors together with controller models are validated in a real-time mode.

2.6 Derived use cases

For conducting the interoperability tests, the involved actors and their interaction need to be defined in the form of an implementable use case. For this purpose, two use cases are developed combing the chosen services (see Section 2.4) together with validation architectures (see Section 2.3). This section briefly describes the defined two use cases.

2.6.1 Voltage support

As discussed in Section 2.4, voltage support is one of the main flexibility services that DSOs can procure taking advantage of the increased penetration of DERs and of the assets that are already connected to their distribution networks.

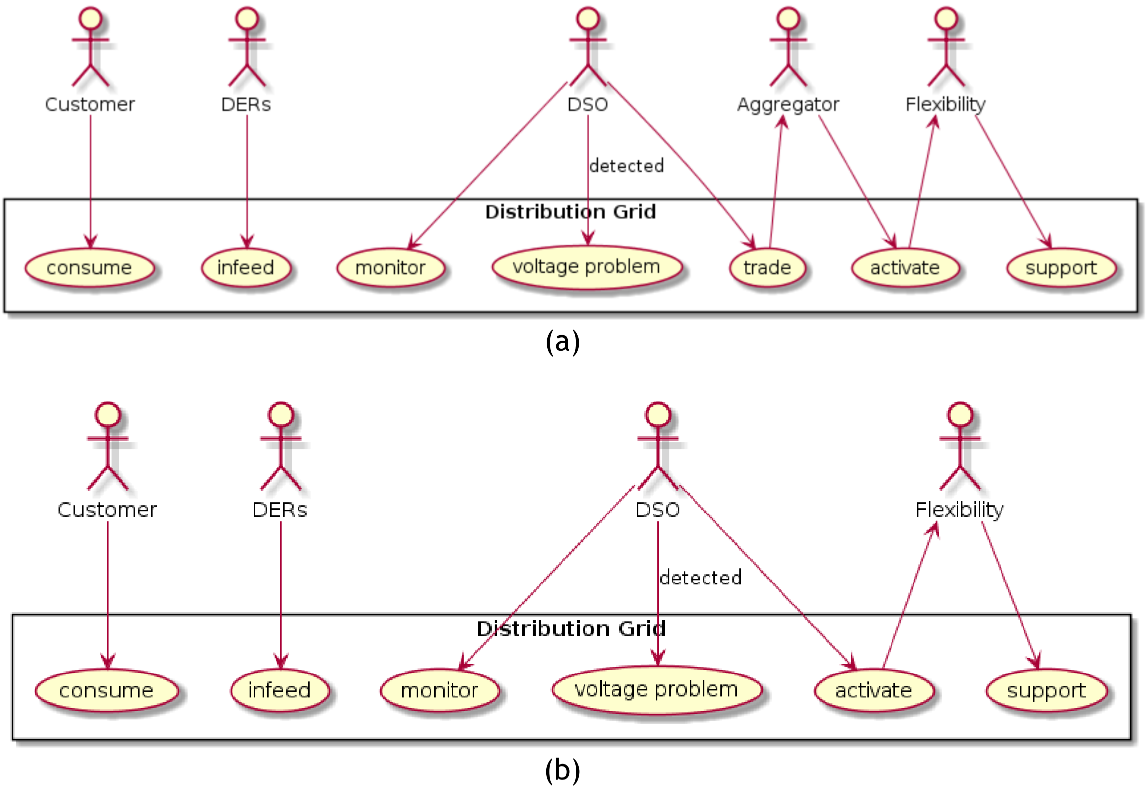

Figure 2-6: A simplified UML use case diagram for the voltage support use case. The top view (a) is for the upper-bound case while the bottom view (b) is for the lower-bound architecture.

Voltage support aims to maintain the voltage profile within acceptable limits, which in return increases the quality of supply and could prevent interruptions. DSOs can provide support for voltage deviations (under and over-voltage) in two different cases; either the voltage deviations beyond the limits set by regulations, or the deviations beyond the limits set by themselves. The focus in this study is on the latter one, i.e., the nodal voltages at the distribution level are considered to be kept within the operational limits. Whenever the voltage deviates beyond the desired set-point (within the regulated operational set-point), the DSO can make use of the sources of flexibility such as storage units to compensate for the voltage deviation. In this voltage support mechanism, the DSO can provide support for the distribution system by delivering a better quality of service. It is noteworthy that the DSOs should take the decision on what is the best solution to help with their specific challenges, either by use of flexibility or through the expansion of the grid. This use case is used in case studies 1, 2, 5 and 6.

2.6.2 Congestion management

Congestion in a power system is a phenomenon that occurs when the power lines and/or transformers are not sufficient to deliver power according to needs. In other words, the power flowing in the lines is more than the capacity that the cables/lines can support and there could be an over-current situation on the lines. Congestion management is a way to effectively overcome the problem without violating the system constraints and bringing the system back to the "safe" state again. Keeping this definition in mind, the Congestion management Use Case is defined. In the use case, the case of this congestion is assumed to be increased penetration of the DERs [4].

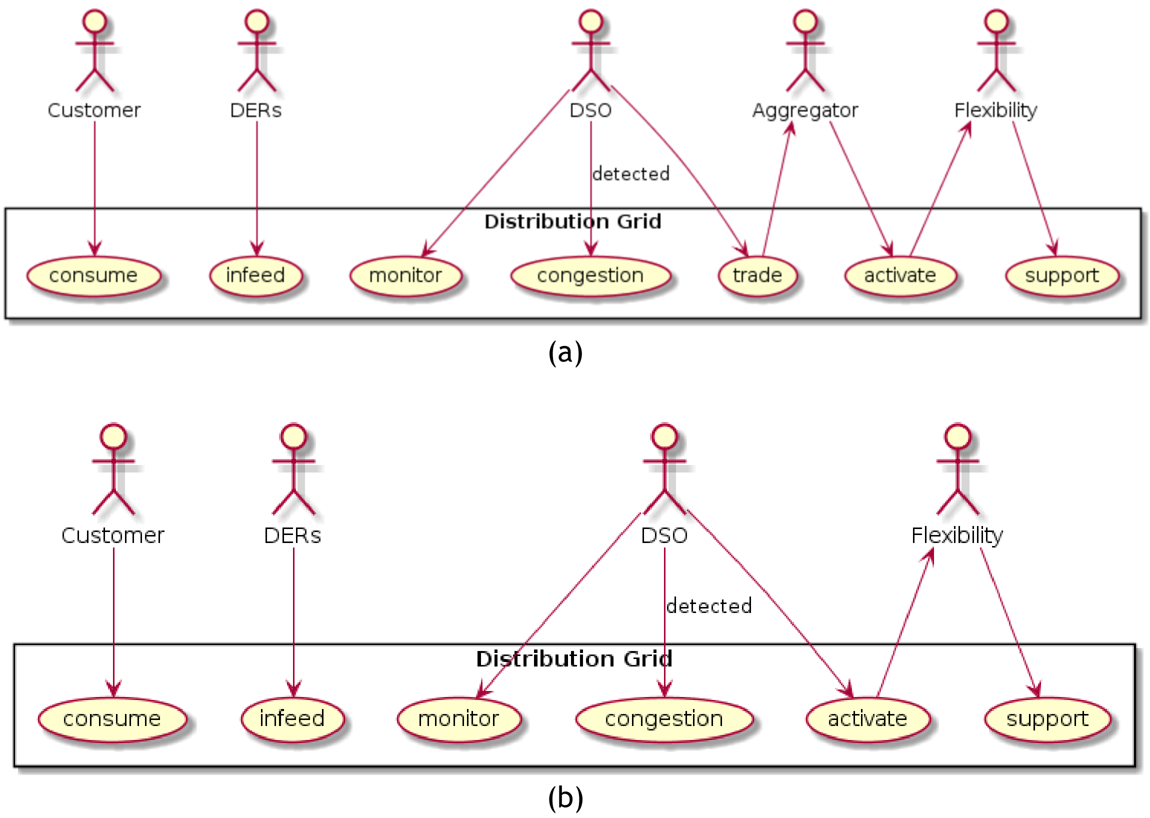

Figure 2-7: A simplified UML use case diagram for the congestion management use case. The top view (a) is for the upper-bound case while the bottom view (b) is for the lower-bound architecture.

The use case is defined as a system consisting of a power grid that is being monitored by the DSO through its SCADA system. There are some DERs that are in-feeding into the system. The SCADA continuously monitors the power system through the measurements at different points of interest to keep the voltage under the limits set and to avoid any constraints violations. At some point a disturbance in the system occurs that may be for example due to the DERs injecting too much power causing congestion. However, this is one of many possibilities. The DSO SCADA that is monitoring the system, immediately detects the situation and takes the measures to bring the system back to normal. The flexibility chain that will be followed depends on the type of architecture that is being tested.

Figure 2-7 depicts two views of the use case. The top view is summarizing the use case in the upper-bound architecture where the flexibility activation interaction is between the four major actors i.e. the DSO, Market, Aggregator, and Flexibility once congestion is ducted. Similarly, the bottom view (b) is for lower-bound cases where DSO interacts directly with Flexibility in the case of congestion. While *DERs* actor is the one responsible for the congestion and the *Customer* consumes and servers as loads for the distribution grid. This use case is used in case studies 3 and 4.

2.7 Telecommunication Architectures

In both Validation architectures (see Section 2.3), i.e. Lower bound and Upper bound, the DSO and the Device are exchanging some information (e.g. measures or commands) by relying on one or several communication links.

As depicted in Figure 2-3 :

- In the Lower bound architecture, the communication path goes from the DSO to the Device through an RTU. With this Validation architecture, two communication links are involved: DSO ↔ RTU and RTU ↔ Device.
- In the Upper bound architecture, the communication path goes from the DSO to the Device through the aggregator. With this Validation architecture, two communication links are involved: DSO ↔ Aggregator and Aggregator ↔ Device.

Table 2-2 in Section 2.1, lists 6 communication technologies. Their relevance for each of the communication links is depicted in Table 2-6:

Table 2-6: Relevancy of the communication technologies for each communication link “++” means “very relevant”, “+” means “quite relevant”

Technology	DSO ↔ RTU	RTU ↔ Device	DSO ↔ Aggregator	Aggregator ↔ Device
Fiber (pro)	+		++	
Fiber (home) / Local Ethernet		+		+
xDSL / cable	++			++
Mobile network	++			
Narrow-band PLC / RF Mesh	+	++		
PSTN	+			

Based on this table (Table 2-6), 4 Telecommunication architectures are defined:

- Upper bound: 1 Telecommunication architecture
- Lower bound: 3 Telecommunication architectures

2.7.1 Upper bound (UB1)

The communication between the DSO and the Aggregator is typically a cloud-to-cloud connection based on professional broadband connections (mostly fiber). The communication between the Aggregator and the Device is typically using the Internet connection of the home, i.e. public broadband such as fiber, xDSL or cable.

Therefore, only one Telecommunication architecture is defined:

Table 2-7: Telecommunication architecture for Upper bound.

Architecture	Interface	
	DSO ↔ Aggregator	**Aggregator ↔ Device**
UB1	Fiber (pro)	xDSL / cable

2.7.2 Lower bound (LB1, LB2, LB3)

The communication between the DSO and the RTU is a field connection for which several options are considered:

- Public broadband such as xDSL, which is quite common as an upgrade of legacy PSTN links.
- A mobile network such as GPRS, which is very common due to its high coverage.

The communication between the RTU and the Device is a local network for which several options are considered:

- Low data-rate technologies such as Narrowband PLC (such as ITU-T G.9903) or Mesh RF (such as IEEE 802.15.4), which are very common as they are quite cheap to install and use.
- Local Ethernet or similar technology, which is currently quite rare for households but is relevant for DER producers or district storage.

Finally, three Telecommunication architecture are defined:

Table 2-8: Telecommunication architecture for Lower bound

Architecture	Interface	
	DSO ↔ Aggregator	**Aggregator ↔ Device**
LB1	xDSL / cable	Fiber (home) / Local Ethernet
LB2	xDSL / cable	NB-PLC / RF Mesh
LB3	Mobile network	NB-PLC / RF Mesh

2.8 Next steps

In the scope of the InterFlex project, this chapter provided an in-depth explanation of the theoretical background for conducting the interoperability tests in AIT's SmartEST and Digital Labs. The explanation not only includes the test methodology and the design of experiments but also includes the description and definition of the use case and the interoperability validation modes. It also explains the inputs like the flexibility activation architectures (D3.1) and common flexibility services and validation architectures (D3.2) from the existing work. The next steps are to define the case studies based on these theoretical bases and conduct the tests. Therefore, the next three chapters are documenting the six case studies covering the power network interfaces, functionality, and communication point of view for DSO, aggregator IT system, grid integrated energy storage systems and EV charging stations.

3 VOLTAGE SUPPORT

As one of the major services provided by DSOs, this chapter focuses on voltage support for both upper and lower-bound architectures. For this purpose, the chapter is organized in two sections. In Section 3.1, the first case study is documented. This case study investigates the flexibility activation chain when the DSO has a direct connection to flexibility. This type of flexibility activation architecture is defined at lower-bound architecture. The section is dedicated to present the details of the formulation, the composition of the tests and some discussion of the results. Additionally, some information of the developed testbed can also be found.

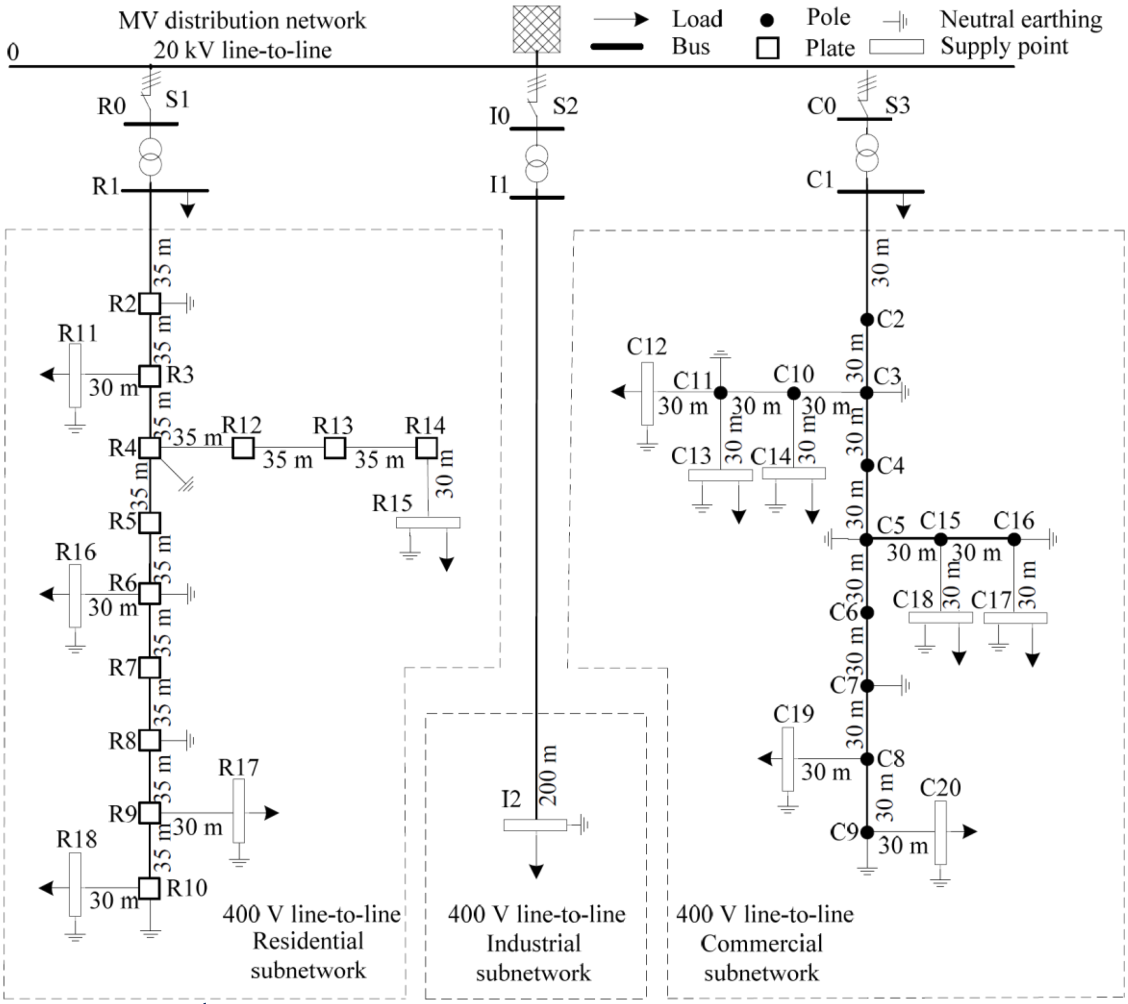

Figure 3-1: CIGRE[6] European Low-voltage benchmark network model used in both the case studies described in this chapter.

In the second section (Section 3.2), the fourth case study of this deliverable is documented, featuring flexibility activation in an upper-bound architecture. In this case study, the interoperability for the selected interfaces between the major flexibility players is validated which is the whole flexibility activation chain. There is no direct interface between flexibility and the DSO, but there are other players involved, like the Market and Aggregators, etc. Both case-studies are documented in a way that they provide some details on interoperability tests and the used testbed along with the composition and configuration of different components. They further provide some results along with the test verdicts and their bases.

[6] https://www.cigre.org/

3.1 Case study 1: Voltage Support in Lower-bound architecture

The focus in this case study lays down on the lower bound setup in which the DSO is directly interfaced with the flexibility device through a Remote Terminal Unit (RTU). Figure 3-2 shows the two major actors involved in this case study.

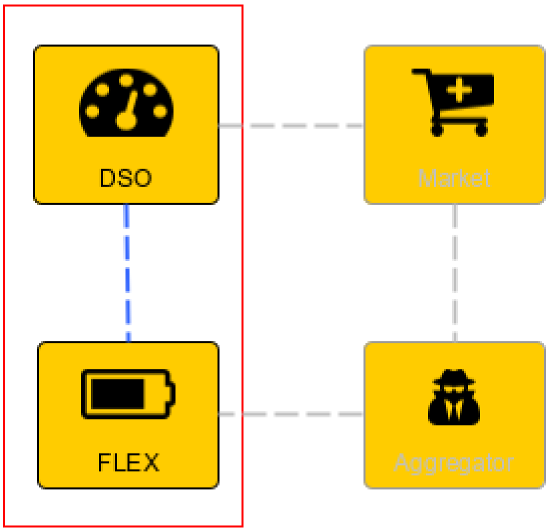

Figure 3-2: Highlighted the two major flexibility activation players having interaction in lower-bound architecture focused on in Case Study 1.

3.1.1 Description

The DSO SCADA is monitoring the power system voltage level constantly. As soon as the voltage is violated from a certain threshold, the SCADA system detects it. At this point, the DSO requires support from the sources of flexibility at the customer end side. This is translated as a flexibility request signal which is sent via an RTU towards a flexibility source. In this work, it is supposed that when flexibility is requested, there is already some amount of flexibility (in terms of KW) which could potentially provide voltage support for the distribution system. It is considered that a disturbance at a specific time occurs at a specific node[7] of the simulated CIGRE EU LV distribution grid benchmark model which leads to a voltage drop. As soon as the voltage drop is detected by the SCADA, the RTU sends the activation signal to the source of flexibility which can deliver a certain amount of flexibility to the above-mentioned node. The activation of flexibility translates into a voltage support mechanism (in this case as a voltage increase). SCADA, by constantly monitoring the system and reading the voltage measurements from the grid reports back the restored voltage. It is noteworthy that the distribution system is operating in the normal condition and the voltage values at the different nodes are compliant with reference values[8].

3.1.2 Test concept

Figure 3-3 shows the high-level schematics of the tests performed for the LB validation architecture, with all the actors involved in the flexibility activation chain. In Figure 3-4 their interaction is explained with the help of a message sequence diagram.

[7] For this purpose, a small utility program is developed to introduce the disturbance
[8] Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources: Task Force C6.04 (ISBN: 978-285-873-270-8)

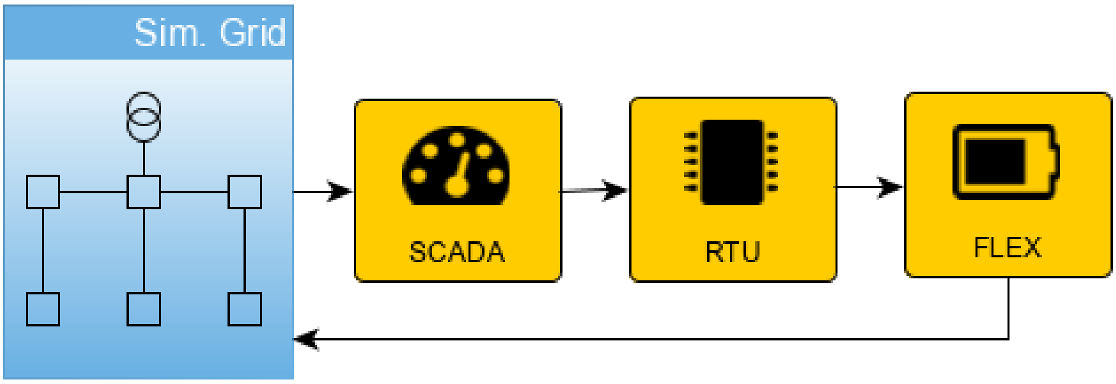

Figure 3-3: A depiction of the high-level test concept.

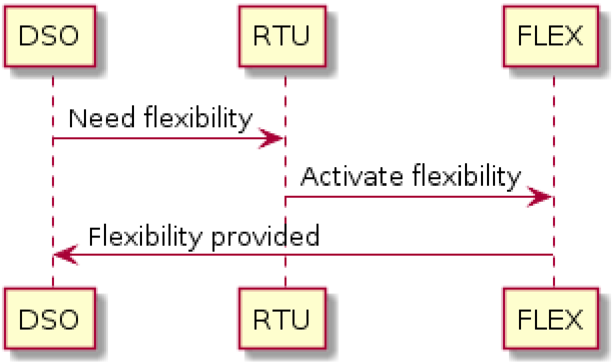

Figure 3-4: Sequence diagram for flexibility activation chain in Case Study 1.

3.1.3 Testbed

For the interoperability testing, AIT Lablink simulation and middle-ware framework have been utilized. For the testbed, the three components of DSO Supervisory Control and Data Acquisition (SCADA), Remote Terminal Unit (RTU), and (FLEX) is running on three Raspberry Pi single-board computers (three control boards). The SCADA monitors the system, detects voltage deviations and instructs the RTU for the activation of the selected flexibility source available in the system. CIGRE European LV distribution network benchmark model is used as the reference grid and is simulated using the OPAL-RT real-time simulator. A network emulator (NRL CORE) running on a laptop with UBS-to-RJ45 connectors is also used for communication network emulation. Any external hardware extension of this setup is also possible via a VPN connection. The schematic representation of the testbed using Lablink and the Network Emulator can be observed in Figure 3-6. For the detailed information about the modelling of different actors as well as the grid and network models, please refer to Annex B.

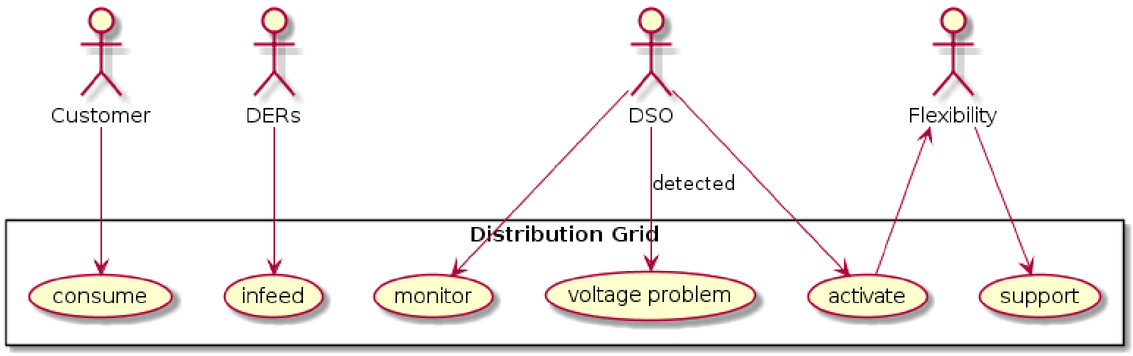

Figure 3-5: A schematic of the voltage use case for upper-bound architecture focused Case Study 1 is based on.

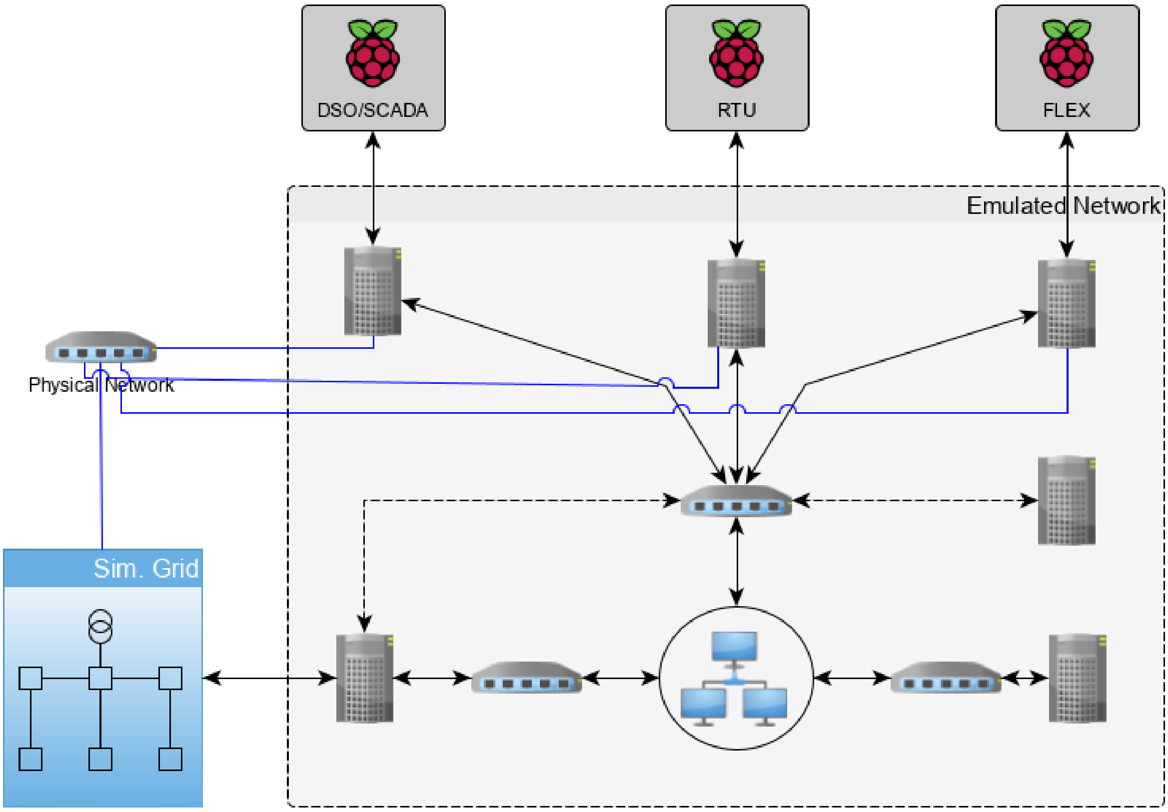

Figure 3-6: Schematic of testbed developed and used for the interoperability validation tests for Case Study 1. The interaction and information interchange between the real-time power grid simulator, ICT emulator, number of controllers and other devices is visible.

3.1.4 Tests

For conducting the tests, the set of inputs and outputs need to be identified, as discussed in Section 2.2. Regarding the identification of the output factors, the DSO measures two system responses:

- V_{res}^{i} i.e. the value of the voltage measured at node i after the flexibility (located at the same node) is activated in the attempt of restoring the voltage within the allowed DSO-specific voltage range

- t_{res}^{i} i.e. the time the system took in order to restore the voltage at node i (in the case the voltage restoration is not successful, t_{res}^{i} is given an infinite value)

Regarding the identification of the input factors, they can be divided into two categories: (i) those related to the telecom architecture and (ii) those related to the power grid including different actors involved in the flexibility activation chain.

Table 3-1: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

The former will be considered as telecom-related parameters, and characterize each BAIOP (Section 2.1) as depicted in Table 3-1. The latter ones are service-related parameters and can be related to the three actors of DSO, FLEX, and RTU as depicted in Table 3-4. Below, you can see the detailed information about these input factors.

$\mathrm{IF}_1 = \mathrm{RTUProcT}$, which refers to the internal RTU time delay

$\mathrm{IF}_2 = AVD$, which is the “Admitted Voltage Deviation”

$\mathrm{IF}_3 = FlexRespT$, which is the time required for Flex to activate

$\mathrm{IF}_4 = FlexCap$, which is the available flexibility capacity

As anticipated in Section 2.2, for each BAIOP these service-related input factors along with the above-mentioned outputs create the experiments for this case study.

In order to understand the impact of the telecom architectures (BAIOPs) on the system response towards a flexibility activation request in the LB validation architecture, test experiments are conducted for each telecom architecture. This set of experiments covers the lower bound architectures mentioned in Section 2.7.2 which are directly mapped to BAIOP 4, 5 and 6 (see Section 2.1, Table 3-1). In particular, for each BAIOP the service-related input factors, i.e., IF_{1-4} , are set at predefined values (mean value of each input factor considered for the possible range of their variation). Those values are reported in Table 3-4. Afterward, the DSO voltage support service is assessed through the analysis of V_{res} and t_{res}. The results are shown in Section 3.1.5.

Table 3-2: Defined communication parameters for the selected upper-bound interfaces for the three basic application interoperability profiles (BAIOP).

Scenario	Links	Technology	Bandwidth	Background traffic	Delay	Jitter	Packet loss	Duplicate
			Mbps	Mbps	µs	µs	%	%
BAIOP4	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Fiber (access provider) / Local Ethernet	80		30000	1000	0	0
BAIOP5	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0
BAIOP6	DSO <-> RTU	Mobile network	10	0,1	60000	20000	1	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0

Table 3-3: Telecom-related input factors.

Fixed input factors					
Bandwidth	**Background traffic**	**Delay**	**Jitter**	**Packet loss**	**Duplicate**
Mbps	**Mbps**	**µs**	**µs**	**%**	**%**
Characterizing the analyzed communication architectures (BAIOPs)					

Table 3-4: Service-related input factors.

Variable input factors			
FlexRespT	**FlexCap**	**RTUProcT**	**AVD**
ms	**KVh**	**ms**	**%**
Flexibility-related		RTU-related	DSO-related

3.1.5 Results and discussions

The results for the tests conducted for each of the three BAIOPs (reflecting the different telecom architectures) are presented here. Please keep in mind that the system response during the tests is analyzed after the system is exposed to a fixed disturbance which leads to a fixed amount of voltage drop from 1 to 0.92 per unit.

By running the experiments for each BAIOP, the system response towards the different possible communication links between the lower bound actors is analyzed (Figure 3-7)

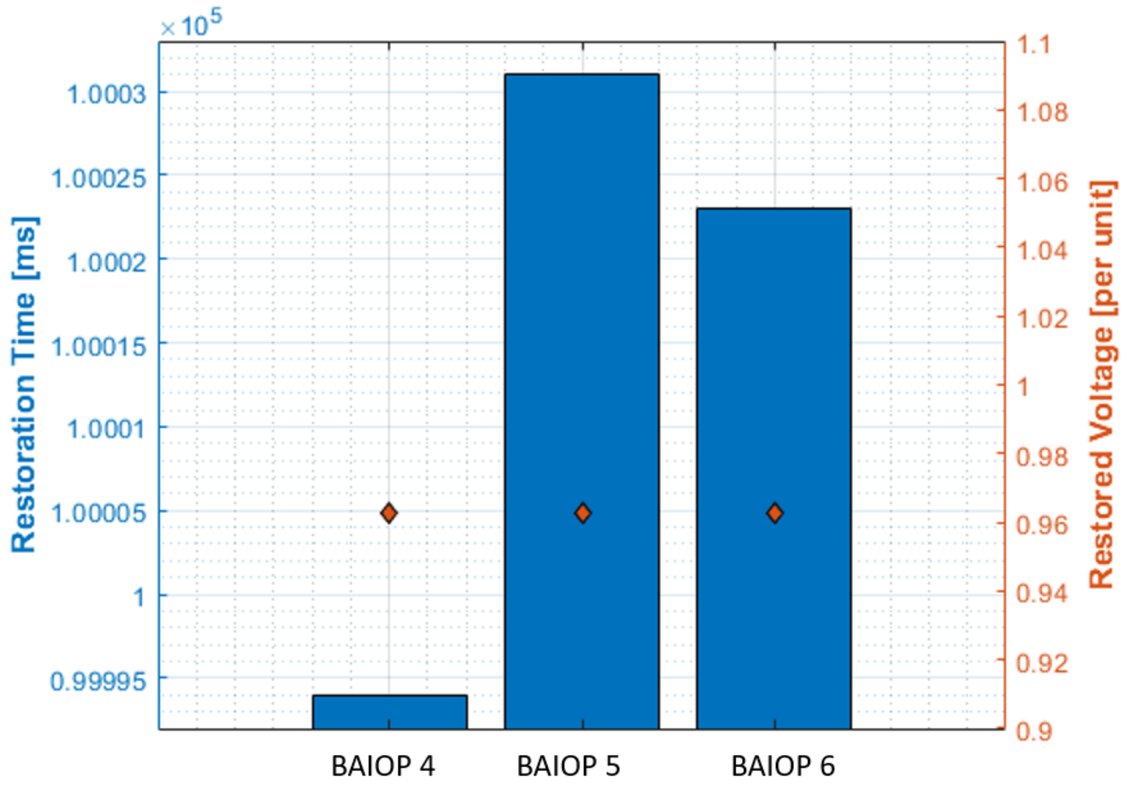

Figure 3-7 Plotted average restoration time for the three basic application interoperability profiles (BAIOP) for Case Study 1.

As observed in Figure 3-7, the different telecommunication architectures can equally support the voltage deviation and restore the voltage to 0.96 per unit. However, the system response in terms of restoration time shows more dependency on the telecom infrastructure. As a result, for the proposed test case study, the DSO can decide to rank the quality of the voltage support service by focusing only on the architecture that delivers the best restoration time, i.e., the least restoration time.

After analyzing the voltage support LB for the different BAIOPs, it can be concluded that the DSO can decide about the telecommunication infrastructure based on the optimal restoration time irrespective of the restored voltage. However, the selection of the telecom architecture cannot be independent of the available technologies and economic considerations.

3.2 Case study 2: Voltage Support in Upper-bound architecture (AIT)

This section describes the voltage support interoperability tests using the upper-bound architecture for flexibility activation. This is the second case study documented in this deliverable. In this case study, as shown in Figure 3-8, all four major players in the flexibility game (i.e. DSO, Market, Aggregator, and Flexibility) are involved. The tests are conducted in Controller Hardware in the Loop (CHIL) manner in AIT's SmartEST[9] and Digital Labs. Like the other case studies in this deliverable, a description of the test, the involved use case and the test concept will be presented first. This will be followed by a brief description of the testbed, the tests and configured parameters (test scenarios) and at the end, the results and some discussions about the test will be presented. Please do note that for the readability, some text is repeated to make this case study self-contained.

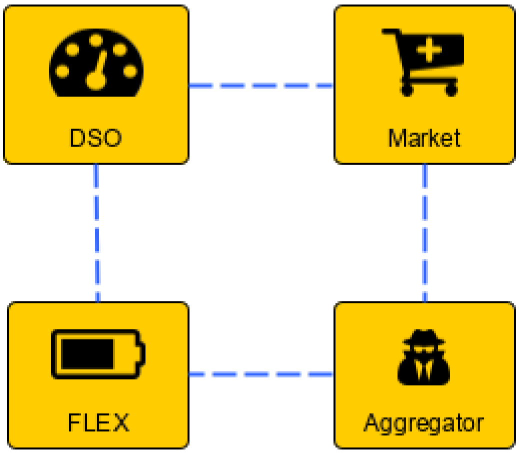

Figure 3-8: Highlighted four major flexibility activation players having interaction in upper-bound architecture focused on in Case Study 2.

3.2.1 Description

This case study is based on the voltage support use case as described in Section 2.6.1. For this, however, the upper-bound architecture is considered. The simplified UML diagram for voltage support use case in upper-bound architecture is again depicted in Figure 3-9. As can be seen in the figure, in the upper-bound case, the DSO does not have a directed access/link to the flexibility but the DSO has to trade for flexibility in the market. This means the flexibility chain involves also this link is through the Market → Aggregator. In this sense, the upper-bound architecture is more versatile as it involves all the four actors as depicted in Figure 3-8. In InterFlex, the Dutch and French demos (see Figure 2-5) have use cases that fall into this category.

In this case study the DSO is using a SCADA system for monitoring and controlling the distribution grid. The SCADA uses measurements collected from the sensors installed in the grid. These measurements are transmitted over an ICT network. The SCADA also uses ICT network for control commands to RTUs and other remote agents. In this case study, it is assumed that the DSO has a contingency measure planned for voltage support using an upper-bound architecture with the help of flexibilities. In this setting, the DSO does not have a direct link to the flexibility sources but the flexibilities are traded on the local energy market once they are needed. This trade happens similarly to the way depicted in the Figure 3-9.

[9] https://www.ait.ac.at/fileadmin/mc/energy/downloads/Smart_Grids/Produktblatt_CI_SmartEST_lowRes.pdf

The DSO-SCADA monitors the grid for any problem. Once it detects one, it starts trading for the required flexibility in the local energy market. The aggregators send their offers to DSO. The DSO chooses the first offer that meets its criteria and notifies the respective aggregator. The aggregator then activates the flexibility through some infrastructure and then enables the DSO to bring the system to a stable state again.

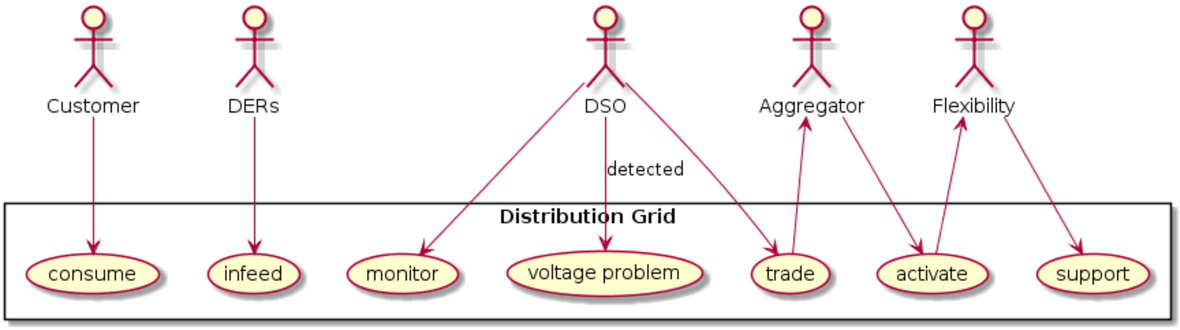

Figure 3-9: A schematic of the voltage use case for upper-bound architecture focused Case Study 1 is based on.

3.2.2 Test concept

Based on the use case, the test concept is depicted in Figure 3-10. As can be seen, a DSO SCADA system is monitoring a power gird. Once it detects any issues (in this case voltage drop), its algorithm activates. A DSO's Market Agent trades for the flexibility on the DSO's behalf in the (local) energy market asking for offers from the local energy market.

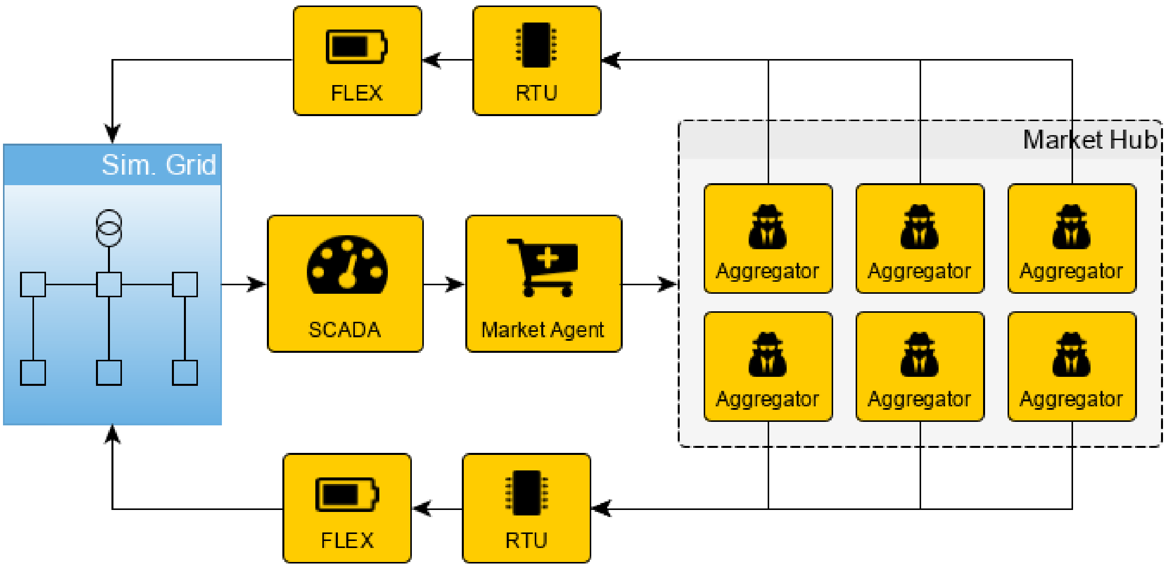

Figure 3-10: High-level conceptual view of the test.

Once the negotiation is complete, one of the presented offers is accepted and the corresponding Aggregator is notified. Please note that in principle it is possible to have more than one aggregator to provide the flexibility partially and the DSO can choose to accept more than one offer if for example the required amount of flexibility is not available from a single aggregator or there are some other business or technical rules. However in this test, it is assumed that the DSO accepts offers from only one of the aggregators based on the first-come-first-serve rule. The selected Aggregator then activates the flexibility through its RTU or any other intermediate device. This ultimately provides the purchased flexibility from the aggregator to the grid and the problem is rectified restoring the system in a "safe" state again. This process repeats as many times as needed. However, for this test, only one such case is simulated. In Figure 3-12 this interaction is explained with the help of a UML sequence diagram.

3.2.3 Testbed

A testbed is constructed in AIT's SmartEST and Digital Labs for performing all these tests. A high-level overview of the constructed testbed is depicted in Figure 3-11. It is constructed in the form of large real-time hardware in the loop co-simulation. For the construction of individual components and for the communication of data and control commands, AIT's Lablink is used. AIT Lablink is an enterprise-class co-simulation framework that works equally well for both real-time and simulated systems. The testbed simulates the CIGRE European LV benchmark power grid model (see Figure 3-1) using the real-time simulator OPAL-RT[10]. A software model encapsulating a SCADA algorithm is monitoring the selected nodes of the system through the measurements for the power grid model. Along with this, the testbed has controllers for RTU and Flexibility. There is a DSO agent model together with a market simulator having many aggregators trying to sell their flexibilities.

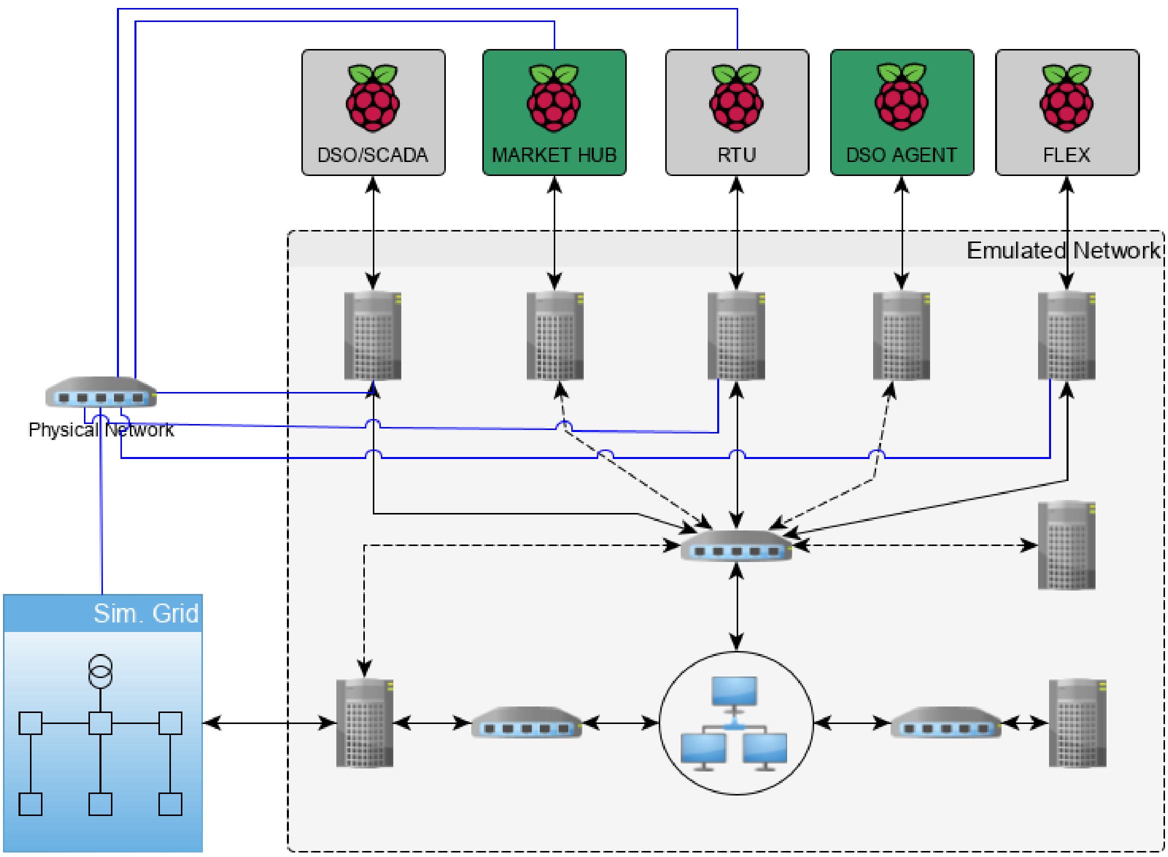

Figure 3-11: Schematic of testbed developed and used for the interoperability validation tests for Case Study 2. The interaction and information interchange between the real-time power grid simulator, ICT emulator, number of controllers and other devices is visible.

[10] https://www.opal-rt.com/

There are two ICT networks in the testbed. In the figure, the blue lines mean the ICT network used for management and simulation control while the black lines are representing the emulated network used for providing realistic network behaviours. The SCADA, RTU, FLEX, Market and DSO Agents are running on individual Raspberry Pi 3 B+[11] single board computers.

To summarize the testbed the major components of the testbed as seen in the figure includes:

1. The real-time power grid simulator (OPAL-RT)
2. Network emulator (NRL CORE)
3. Physical ICT network
4. The energy market simulator
5. The DSO Agent model
6. The DSO SCADA, RTU and Flexibility controllers

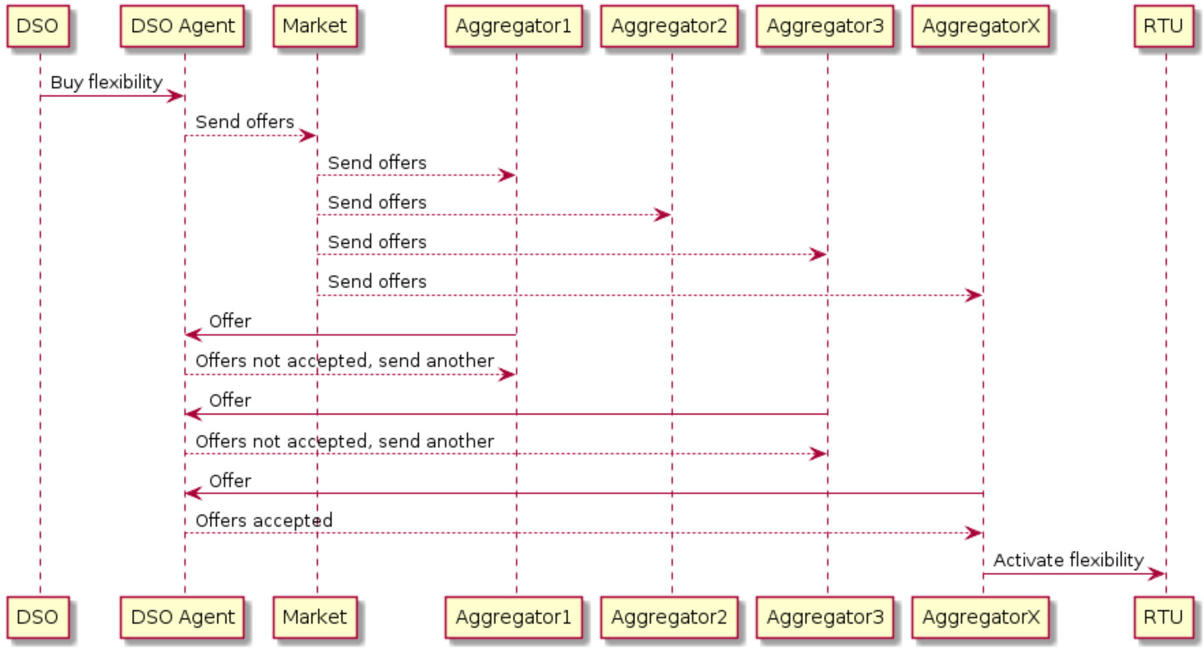

Figure 3-12: The sequence diagram of the market negotiation.

3.2.4 Tests

For conducting the tests, different scenarios are created. Since the major focus of these interoperability tests is to validate the interfaces between the major players in activating the flexibility. In the case of upper bound architecture, the selected interfaces/links are:

1. DSO ←→ Market (BAP1.1)
2. Aggregator ←→ RTU (BAP2.1, BAP2.2, BAP2.3)
3. RTU ←→ Flexibility (BAP4.1, BAP4.2, BAP4.3)

For constructing these scenarios, the whole system is logically divided into two parts:

1. Emulated ICT network between the selected interfaces
2. Rest of the testbed

[11] https://www.raspberrypi.org/

For the second part, the parameters are fixed as per Figure 3-13 for the SCADA algorithm, the RTU and Flexibility controllers. In this case, RTU has an activation time delay of 80ms. This means, once a signal is received from Aggregator for activation of flexibility, it takes the RTU controller 80ms to activate and pass the signal to the connected Flexibility. Also, for this experiment, the flexibility has a capacity of 149.34kW and an activation time of 80 seconds.

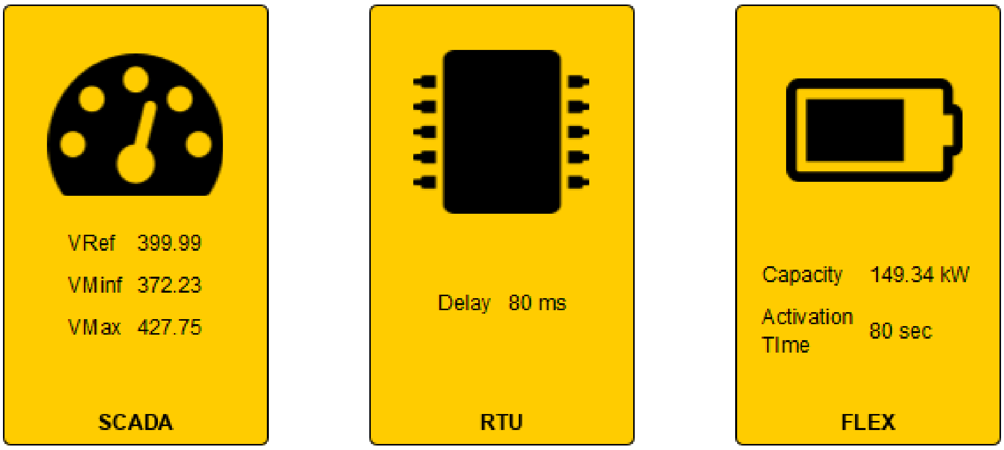

Figure 3-13: Case study 2, SCADA, RTU and FLEX parameters for the test.

The parameters for the SCADA algorithm are explained in Figure 3-14. As can be seen, the algorithm makes 399.99 as the reference voltage and there is ≈ 6.6% on both directions for upper and lower voltage values. Any voltage values during the tests that are beyond these ranges make the SCADA algorithm look for flexibility as explained above.

Table 3-5: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

For the ICT interoperability, the BAIOPs for upper-bound architecture from Table 3-5 are chosen for selected interfaces. This means the selected BAIOPs are BAIOP1, BAIOP2, and BAIOP3. Similarly, for the selected BAIOPs, the corresponding BAPs are BAP1.1, BAP2.1, BAP2.2, BAP2.3, BAP4.1, BAP4.2 and BAP4.3. The corresponding communication architectures are presented in Table 3-5.

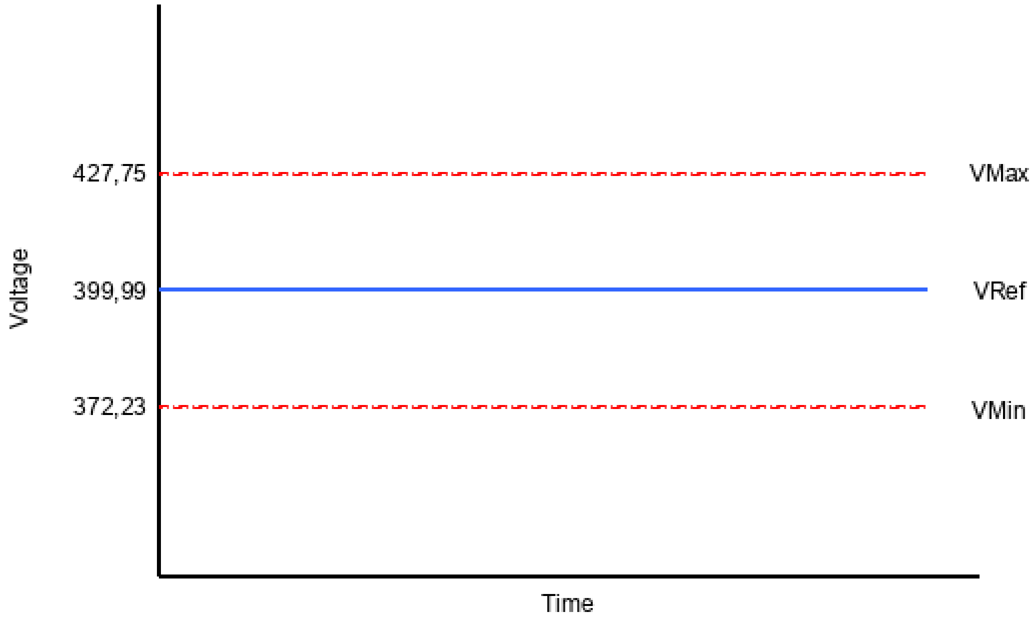

Figure 3-14: Case study 2, SCADA algorithm parameters visualization. These parameters are set in line with power quality standard EN 50160.

Table 3-6: Defined communication parameters for the selected upper-bound interfaces for the three basic application interoperability profiles (BAIOP).

Scenario	**Links**	**Technology**	**Bandwidth**	**Background traffic**	**Delay**	**Jitter**	**Packet loss**	**Duplicate**
			Mbps	Mbps	µs	µs	%	%
BAIOP1	DSO ↔ Market	Fiber (access provider)	80	0,1	30000	1000	0	0
	AGGR ↔ RTU	xDSL / cable	8		30000	10000	0	0
	RTU ↔ Device	Fiber (access provider) / Local Ethernet	80		30000	1000	0	0
BAIOP2	DSO ↔ Market	Fiber (access provider)	80	0,1	30000	1000	0	0
	AGGR ↔ RTU	xDSL / cable	8		30000	10000	0	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0
BAIOP3	DSO ↔ Market	Fiber (access provider)	80	0,1	30000	1000	0	0
	AGGR ↔ RTU	Mobile network	10		60000	20000	1	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0

3.2.5 Results and discussions

Here a summary of the results is presented along with some discussion and intermediate conclusions. These results are calculated based on the system response during the tests when it is exposed to a fixed disturbance which leads to a fixed amount of voltage drop. First, Table 3-7 summarizes the results of nine selected tests for three communication scenarios. The most important column is the average restoration time. This time is the sum of all factors including ICT, market negotiation and device activations time.

Table 3-7: Summary of the results for the selected runs while testing three basic application interoperability profiles (BAIOP) for Case Study 2.

Voltage (V)		Flex provided	Restoration Time (ms)			Restoration (Average)			Power (kW)	
Before	After		Market	Others	Total	Time (sec)	Voltage	Power (kW)	Before	After
399,9877	370,2574	149344,6	4125	95876	100001	**106,6680**	391,99	59,66	0	209
399,9877	370,2574	149344,6	3924	96075	99999					
399,9877	370,2574	149344,6	22310	97694	120004					
399,9877	370,2574	149344,6	5126	94875	100001	**106,6687**				
399,9877	370,2574	149344,6	29279	90724	120003					
399,9877	370,2574	149344,6	8113	91889	100002					
399,9877	370,2574	149344,6	5052	94923	99975	**113,3193**				
399,9877	370,2574	149344,6	24373	119997	100005					
399,9877	370,2574	149344,6	40571	99407	139978					

Figure 3-15, plots the average restoration time from the summary table. As can be seen, the time in the first two communication scenarios is very much the same however for BAIOP3 is 6% more than these two. One explanation for this increase is the lower bandwidth and increase delay along with low network reliability for the communication interfaces between AGGR ←→ RTU and RTU ←→ FLEX. One other important aspect to note from these results is that the time spent in the market for negotiating for flexibility is stochastic and in this case varies between as low as 4 seconds to 40 seconds. It should also be noted that this also depends on the market model and size along with the aggregator and DSO policies.

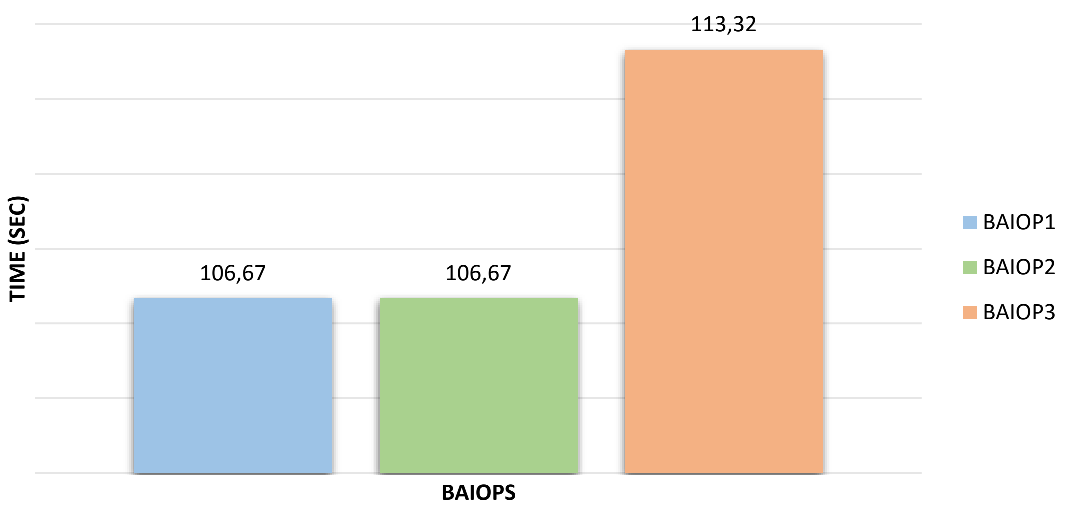

Figure 3-15: Plotted average restoration time for the three basic application interoperability profiles (BAIOP) for Case Study 2.

4 CONGESTION MANAGEMENT

Congestion in a power system is a phenomenon that occurs when the distribution or transmission lines are not sufficient to deliver power according to needs. In other words, the power flowing in the lines is more than the capacity of the cables/lines and there could be in an over-current situation on the respective node. Congestion management is a way to effectively overcome the problem without violating the system constraints and making the system in the “safe” state again [4]. In this chapter, the interoperability validation for two case studies one each for the lower and upper bound architectures are presented. Figure 4-1 shows the power grid model that is used in both case studies. These case studies demonstrate the situations when a DSO detects and proceeds to perform a congestion management action to fix a congestion issue. The rest of the chapter is organized into two further sections. Each section is dedicated to one case study. Section 4.1 describes the congestion management with lower-bound architecture while Section 4.2 is dedicated to congestion management in the upper-bound architecture. These sections provide some details on interoperability tests and the used testbed along with the composition and configuration of different components. They further provide some results along with the test verdicts and their bases.

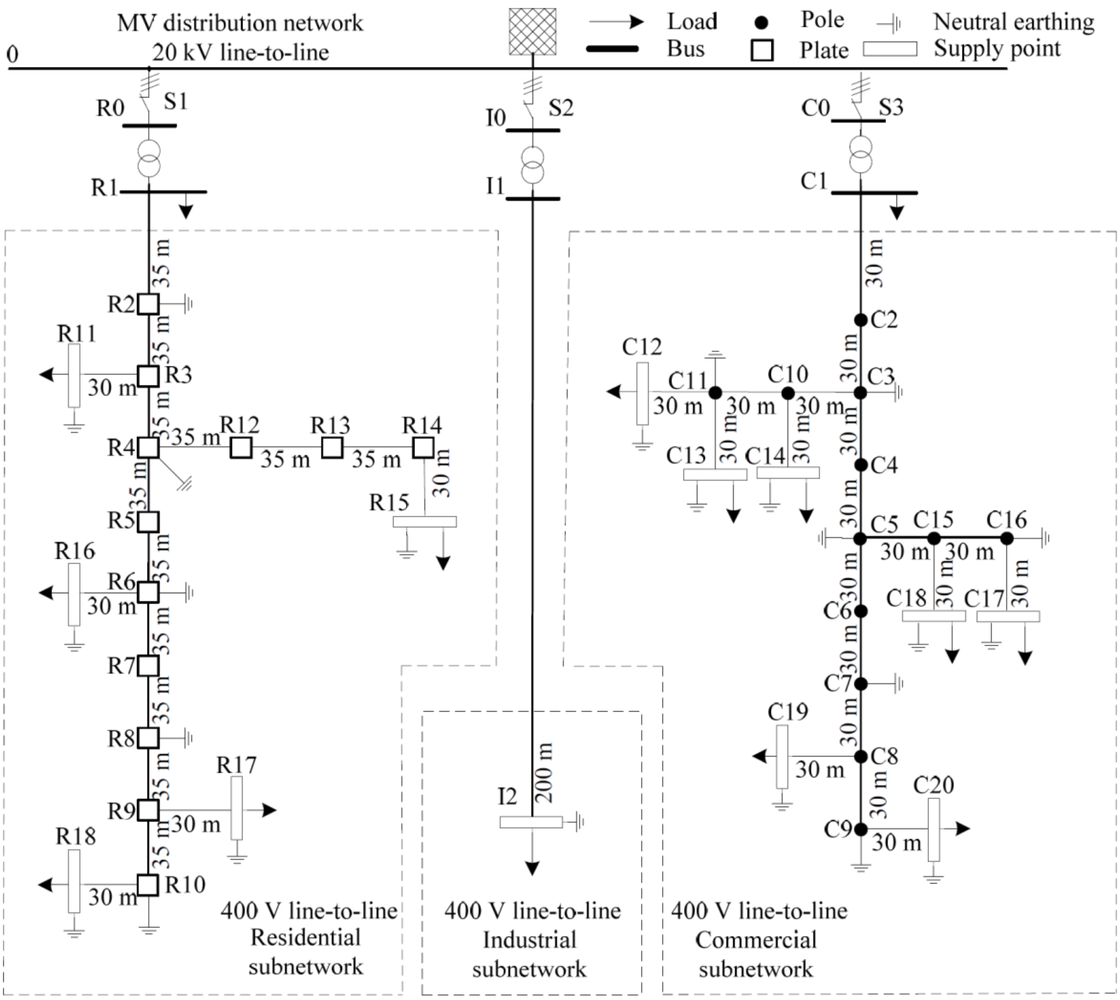

Figure 4-1: CIGRE[12] European LV Distribution grid benchmark network model.

[12] https://www.cigre.org/

4.1 Case study 3: Congestion Management in Lower-bound architecture

This section describes the congestion management tests for the lower-bound case as the third case study documented in this deliverable. In this case study, as Figure 4-2 depicts, only two major players i.e. DSO and Flexibility out of four in the flexibility game are participating. The tests are conducted in Controller Hardware in the Loop (CHIL) fashion in AIT's SmartEST[13] and Digital Labs.

The organization of this section is similar to the other case studies in this deliverable. First, a description of the test, the involved use case and the test concept will be presented. This will be followed by a brief description of the testbed, the tests and configured parameters (test scenarios) and at the end, the results and some discussions about the test will be presented. Please do note that some of the text is repeated to make the description and this case study self-contained.

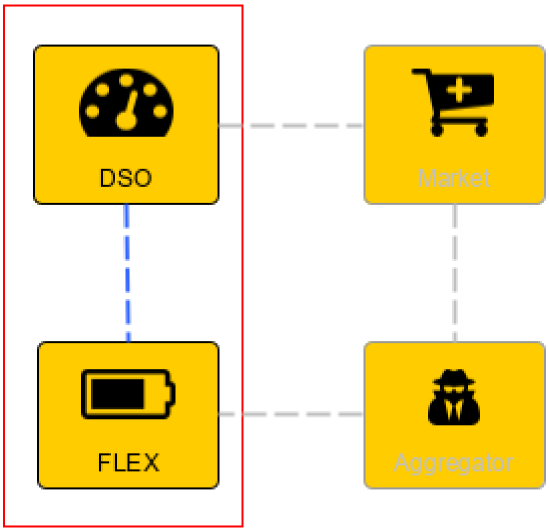

Figure 4-2: Highlighted the two major players having interaction in lower-bound architecture focused on in Case Study 3.

4.1.1 Description

This case study reports and documents the interoperability validation test for the actors involved in the congestion management in the lower-bound architecture. The lower-bound architecture is simple both to construct and use, however, it is limited in certain cases as its capacity is fixed. In the context of InterFlex, the Czech, Swedish and German demos (see Figure 2-2 and Figure 2-4) have use cases that fall into this category.

The use case on which this case study is based is presented in Section 2.6.2. However, for this case study, the lower-bound architecture variant is considered and tested. The lower-bound variant is depicted in Figure 4-3. As shown in this UML diagram, the flexibility activation chain contains a direct link between the DSO and the respective Flexibility (through an intermediate device, the RTU).

[13] https://www.ait.ac.at/fileadmin/mc/energy/downloads/Smart_Grids/Produktblatt_CI_SmartEST_lowRes.pdf

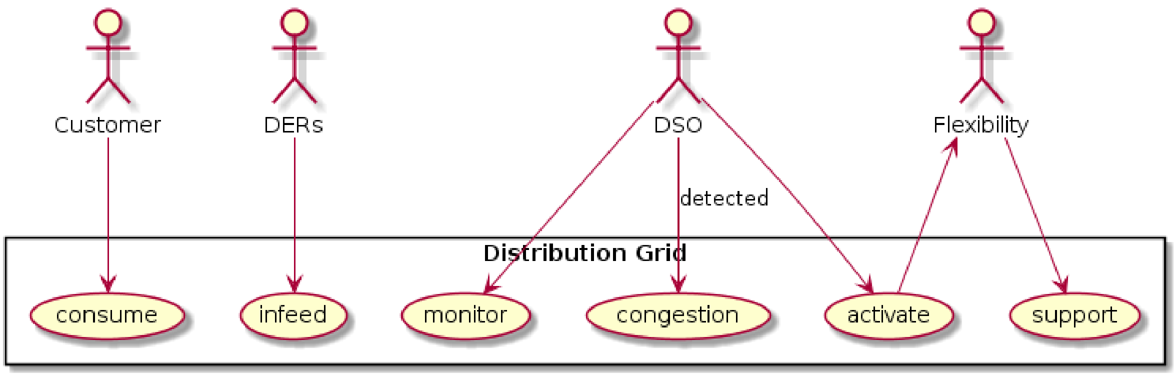

Figure 4-3: Congestion management use case for lower-bound architecture.

In the case study, the DSO is responsible for monitoring and mitigating the congestion by the means of installed flexibilities that many be also owned by it. For the monitoring, the SCADA is used that can activate flexibilities through some remote intermediate devices using some form of ICT. These intermediate devices are connected to the respective flexibilities again using some ICT infrastructure and communicate using some protocols. In this case study, the interoperability between ICT links for the major actors for the flexibility chain in lower-bound architecture is validated.

4.1.2 Test concept

At a higher level, the lower-bound architecture test design concept for this case study is very similar to its counterpart in the voltage support case study documented in Section 3.1. However, there is one important difference. This conceptual test design overview is presented in Figure 4-4.

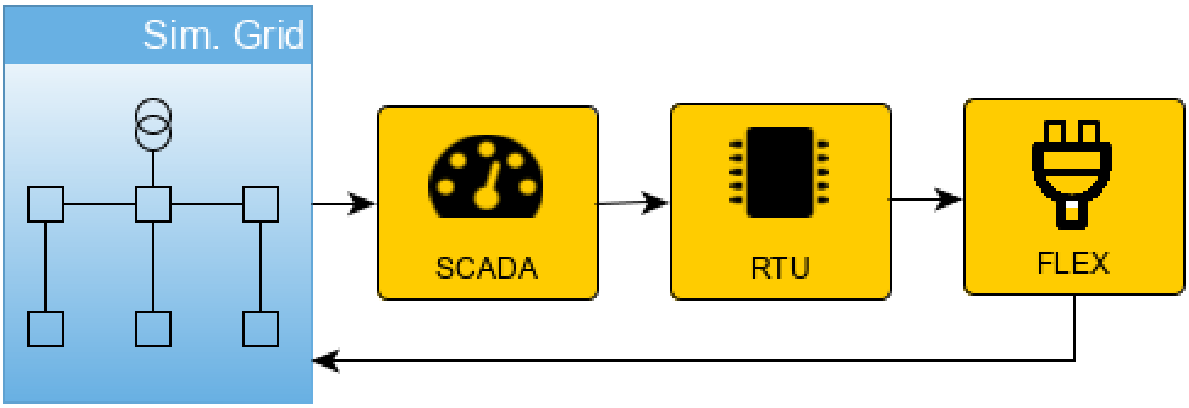

Figure 4-4: A depiction of a high-level conceptual model for the lower-bound congestion management test design.

As evident from the figure, in the congestion case, the flexibility provides support for the system in a completely different way than in the case of voltage support. According to this design, the DSO SCADA system is monitoring the distribution power gird. For the monitoring, it receives measurements that are then used by the algorithm to analyze the system's stability in terms of voltage being under certain bands. Once, the SCADA detects congestion at some node in the system, it activates the congestion management algorithm. The congestion management, in this case study, is through support from a flexibility source present in the system and that can be activated directly by the DSO SCADA through an intermediate device – an RTU. This interaction in the flexibility chain between the actors once a problem is detected is also explained using a UML sequence diagram as depicted in Figure 4-5.

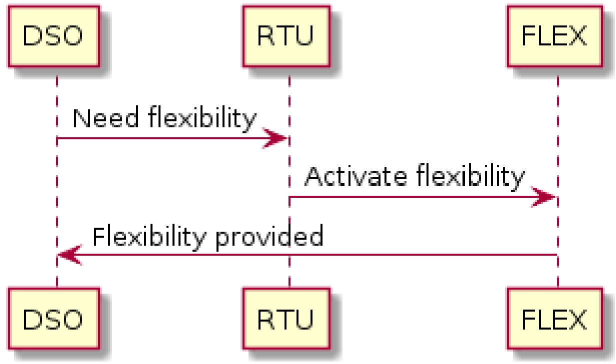

Figure 4-5: Sequence diagram for flexibility activation chain in Case Study 3.

4.1.3 Testbed

A testbed was constructed in AIT's SmartEST and Digital Labs for performing all these tests. A high-level overview of the constructed testbed is depicted in Figure 4-6. It is constructed in the form of large real-time hardware in the loop co-simulation.

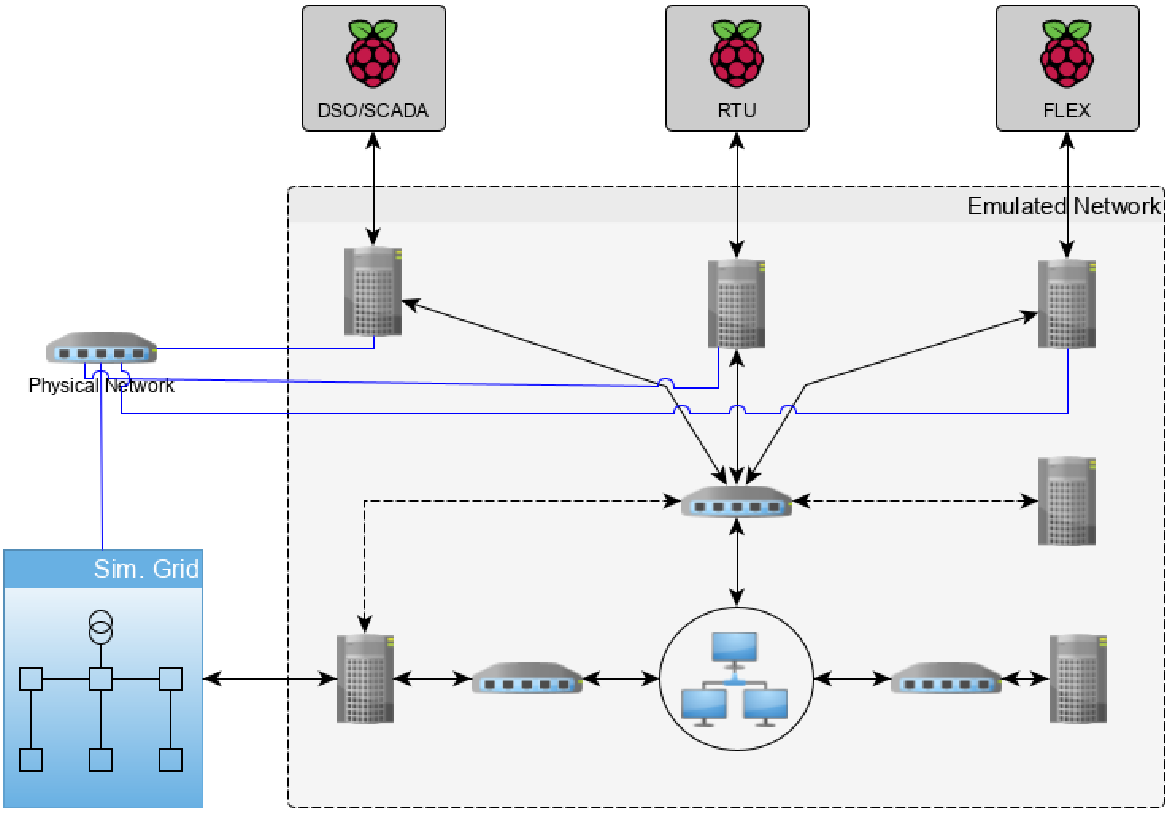

Figure 4-6: Schematic of testbed developed and used for the interoperability validation tests for Case Study 3. The interaction and information interchange between the real-time power grid simulator, ICT emulator, number of controllers and other devices is visible.

For the construction of individual components and for the communication of data and control commands, AIT's Lablink[14] is used. AIT Lablink is an enterprise-class co-simulation framework that works equally well for both real-time and simulated systems. The SCADA, RTU, and FLEX are running on individual Raspberry Pi 3 B+[15] single board computers. The testbed simulates the CIGRE European LV benchmark power grid model (see Figure 3-1) using the real-time simulator OPAL-RT[16]. A software model encapsulating a SCADA algorithm is monitoring the selected nodes of the system through the measurements from the power grid model. Along with this, the testbed has controllers for RTU and the Flexibility that takes care of activating and providing configured support to the grid when needed. There are two ICT networks in the testbed. In the figure, the blue lines mean the ICT network used for management and simulation control while the black lines are representing the emulated network used for providing realistic network behaviors.

For the network emulation, a specialized network emulator NRL CORE is used. The emulator is running on a dedicated computer that has a number of RJ45 USB adaptors. These adaptors are then used to connect the controllers and software model hosted on individual computational devices (mostly Raspberry Pi in this case). This emulator is used during the test to test the interoperability of the flexibility activation chain using different communication settings as defined and explained later. To summarize the testbed, it is designed for tests in a real-time co-simulation fashion and its major components, as seen in Figure 4-6 includes:

1. The real-time power grid simulator (OPAL-RT)
2. Network emulator (NRL CORE)
3. Physical ICT network with Ethernet switch and cables
4. The DSO SCADA, RTU and Flexibility controllers

4.1.4 Tests

For conducting the tests, the JRC[17] methodology is followed and the BAPs and the BAIOPs are defined for the selected interfaces. The defined BAIOPs are documented in Table 4-1. From these only three BAIOPs defined on interfaces for lower-bound (BAIOP4, BAIOP5, and BAIOP6) are selected.

As shown in Figure 4-2, the following interfaces are for interest for the two major players involved in this case study:

1. DSO ←→ RTU (BAP2.1, BAP2.2, BAP2.3)
2. RTU ←→ Flexibility (BAP3.1, BAP3.2, BAP3.3)

[14] https://www.ait.ac.at/en/research-topics/smart-grids/network-operators-and-energy-service-providers/ait-lablink/
[15] https://www.raspberrypi.org/
[16] https://www.opal-rt.com/
[17] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC110455/kjna29416enn_final.pdf

Table 4-1: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

Next, for these interfaces, the communication parameters and technologies are defined corresponding to each of the involved BAP. These parameters along with corresponding BAIOPs are documented in Table 4-2.

Table 4-2: Defined communication parameters for the selected upper-bound interfaces for the three basic application interoperability profiles (BAIOP).

Scenario	Links	Technology	Bandwidth	Background traffic	Delay	Jitter	Packet loss	Duplicate
			Mbps	Mbps	µs	µs	%	%
BAIOP4	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Fiber (access provider) / Local Ethernet	80		30000	1000	0	0
BAIOP5	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0
BAIOP6	DSO <-> RTU	Mobile network	10	0,1	60000	20000	1	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0

The controllers for RTU and FLEX, and SCADA algorithm, the parameters are fixed as per Figure 4-7. In this case, RTU has an activation time delay of 80ms. This means, once a signal is received from SCADA for activation of flexibility, it takes the RTU controller 80ms to pass the signal to connected Flexibility. Also, for this experiment, the flexibility has a capacity of 138.79kW and an activation time of 70.6 seconds. These parameters have been derived after consulting the device manuals, contacting the experts and by the hit-and-trial method.

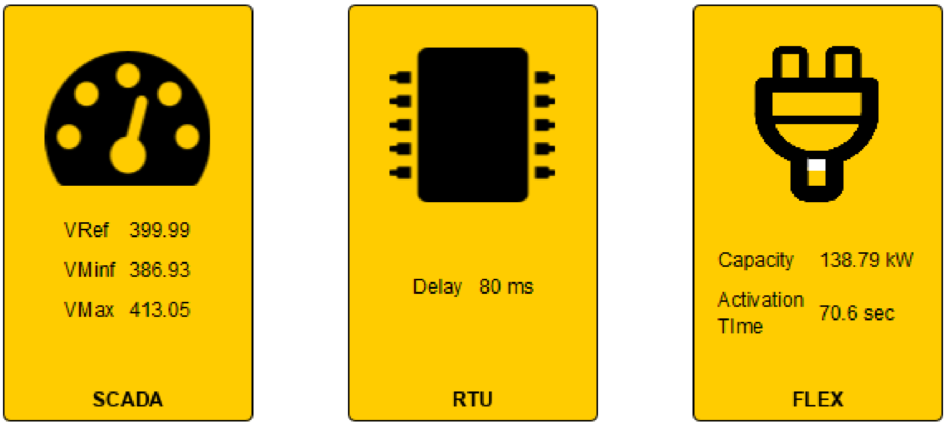

Figure 4-7: Configured parameters for the test.

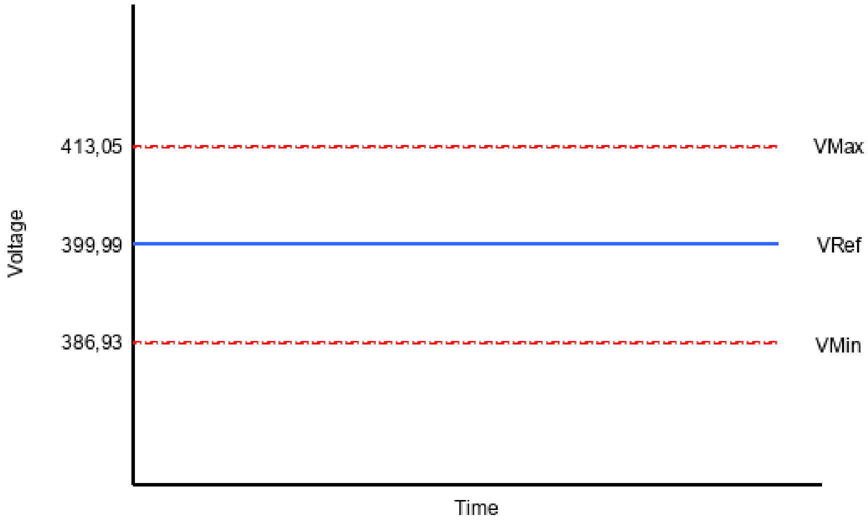

Figure 4-8: The SCADA algorithm parameters with Ref, min and max values configured for the test.

Since the SCADA algorithm in these experiments is responsible for identifying and then activating the flexibility chain its parameters are defined with visualization as shown in Figure 4-8. The configured parameters take 399.99 as the reference voltage, with a 3.26% deviation on the upper and lower side. This means a flexibility activation request will be issued if a violation of this voltage band occurs.

4.1.5 Results and discussions

These results are calculated based on the system response during the tests when it is exposed to a fixed disturbance which leads to a fixed amount of congestion at some nodes in the distribution grid. A number of tests are conducted for each BAIOP with the setup and configurations described previously. From these tests, the results for a total of nine runs, three each for a BIOAP are reported in Table 4-3 below. The table reports different values recorded for each run. One of the important measures is the *average restoration time*. This is the time that is elapsed from the identification of the problem by the DSO until the system becomes stable again.

Table 4-3: Summary of the results for the selected runs while testing three basic application interoperability profiles (BAIOP) for Case Study 3.

Scenario	Injection (kW)	Voltage (V)		Flex provided	Restoration (Actual)			Restoration (Average)			Power (kW)	
		Before	After		Time (ms)	Voltage	Power (kW)	Time (sec)	Voltage	Power (kW)	Before	After
	-209	399,9877	425,667	138789	100003	408,9880	70,21					
BAIOP4	-209	399,9877	425,667	138789	100047	408,9880	70,21	**100,0193**				
	-209	399,9877	425,667	138789	100008	408,9880	70,21					
	-209	399,9877	425,667	138789	99999	408,9880	70,21					
BAIOP5	-209	399,9877	425,667	138789	100000	408,9880	70,21	**100,0113**	408,9880	70,2100	0	-209
	-209	399,9877	425,667	138789	100035	408,9880	70,21					
	-209	399,9877	425,667	138789	99999	408,9880	70,21					
BAIOP6	-209	399,9877	425,667	138789	100000	408,9880	70,21	**100,0007**				
	-209	399,9877	425,667	138789	100003	408,9880	70,21					

Figure 4-9 plots the average restoration time. As can be seen, the time in the BAIOPs is a bit higher than 100 sec. in all three cases. One possible explanation for this can be the fact that the SCADA has a direct connection to the respective flexibility source and even a bandwidth of 0.1 Mbps between RTU ←→ Flexibility is enough to transmit the activation signal in a timely manner.

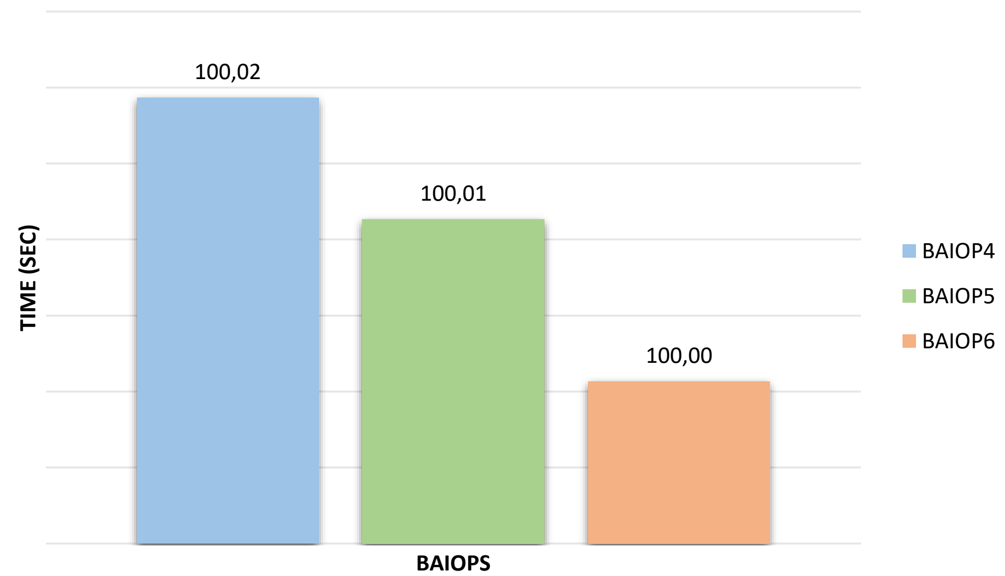

Figure 4-9 Plotted average restoration time for the three basic application interoperability profiles (BAIOP) for Case Study 3.

4.2 Case study 4: Congestion Management in Upper-bound architecture

This section documents and reports the fourth case study for this deliverable. The case study validates the interoperability among the actors involved in congestion management through flexibilities in an upper-bound architecture. In upper-bound, the flexibility activation chai involves all four major players in the flexibility game i.e. DSO, Market, Aggregator, and Flexibility. The tests are conducted in Controller Hardware in the Loop (CHIL) fashion in AIT's SmartEST[18] and Digital Labs. Like the other case studies in this deliverable, a description of the test, the involved use case and the test concept will be presented first. This will be followed by a brief description of the testbed, the tests and configured parameters (test scenarios) and at the end, the results and some discussions about the test will be presented. Please do note that for improving the readability some text is repeated to make this case study self-contained.

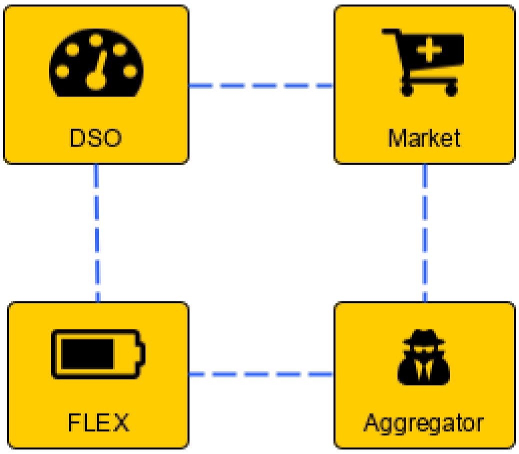

Figure 4-10: Highlighted the four major flexibility activation players having interaction in upper-bound architecture focused on in Case Study 4.

This section describes the congestion management tests for the lower-bound case as the third case study documented in this deliverable. In this case, study, as Figure 4-2 depicts, only two major players i.e. DSO and Flexibility out of four in the flexibility game are participating.

The organization of this section is similar to the other case studies in this deliverable. First, a description of the test, the involved use case and the test concept will be presented. This will be followed by a brief description of the testbed, the tests and configured parameters (test scenarios) and at the end, the results and some discussions about the test will be presented. Please do note that some of the text is repeated to make the description and this case study self-contained.

4.2.1 Description

This case study is based on the voltage support use case as described in section 2.6.1. For this, however, the upper-bound architecture is considered. In the upper-bound case, the DSO does not have a directed access/link to the flexibility but the DSO has to trade for flexibility in the market. This means the flexibility chain involves also this link is through the Market → Aggregator. In this sense, the upper-bound architecture is more versatile as it

[18] https://www.ait.ac.at/fileadmin/mc/energy/downloads/Smart_Grids/Produktblatt_CI_SmartEST_lowRes.pdf

involves all the four actors as depicted in Figure 3-8. In InterFlex, the Dutch and French demos (see Figure 2-5) have use cases that fall into this category.

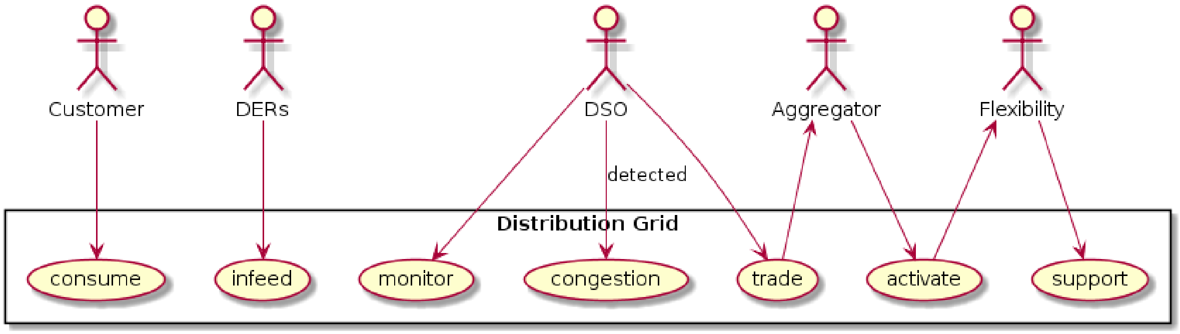

Figure 4-11: Congestion use case for upper-bound architecture.

In this case study a DSO is using SCADA system for monitoring and controlled a distribution grid. The SCADA uses measurements collected from the sensors installed in the grid. These measurements are transmitted over an ICT network. The SCADA also uses ICT network for control commands to RTUs and other remote agents. It is assumed that the DSO has a contingency measure planned for voltage support using an upper-bound architecture with the help of flexibilities. In this setting, the DSO do not have a direct link to the flexibility sources but the flexibilities are traded on the local energy market once they are needed. This trade happens similarly to the way depicted in the Figure 3-9. The DSO-SCADA monitors the grid for any problem. Once it detects one, it starts trading for the required flexibility in the local energy market. The aggregators send their offers to DSO. The DSO chooses the first offer that meets it criteria and notifies the respective aggregator. The aggregator then activates the flexibility through some infrastructure and then enables the DSO to bring the system to a stable state again.

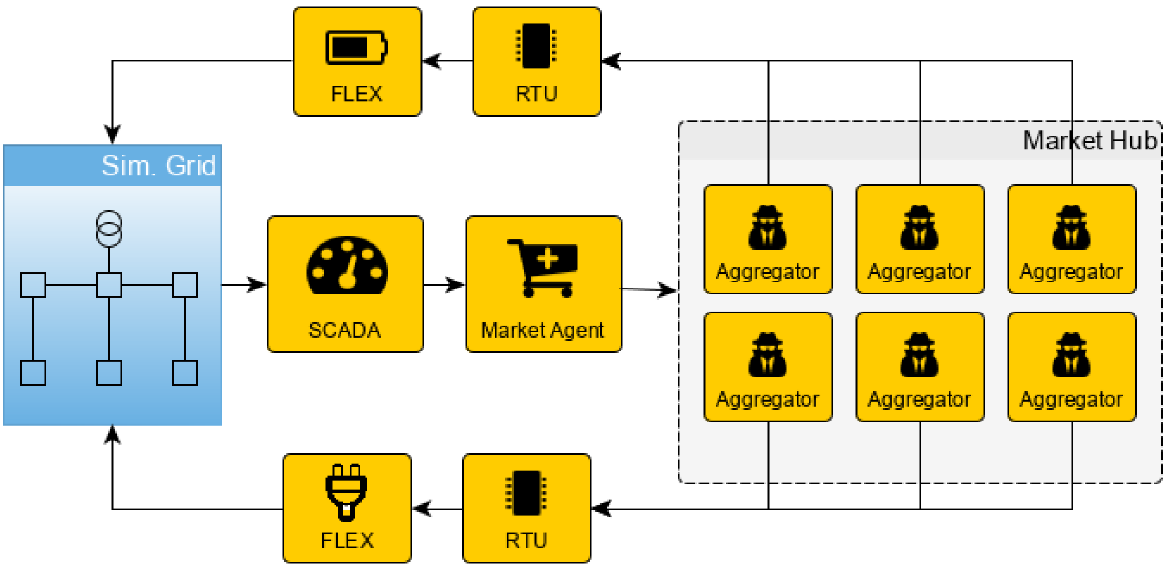

Figure 4-12: A depiction of a high-level conceptual model for the upper-bound test for congestion management test design.

4.2.2 Test concept

Based on the use case, the test concept is depicted in Figure 4-12. As can be clearly seen in the figure, a DSO SCADA system is monitoring a power gird for any disturbances using the measurements from the distribution grid. Once it detects congestion the algorithm activates to trigger the congestion management.

Since this is the upper-bound architecture where the flexibility is not directly accessible/available the process goes through trading in the energy market. A DSO's Market Agent trades for the flexibility on DSO's behalf in the energy market asking for offers from the available Aggregators. Once, the negotiation is complete, one of the presented offers is accepted and the corresponding Aggregator is notified. The selected Aggregator then activates the flexibility through its RTU or any other intermediate device. This ultimately provides the purchased flexibility from the aggregator to the grid and the congestion management process is completed restoring the system in a "safe" state again. In reality, this process (can) repeat(s) as many times as needed. However, for this test, only one such case is simulated. In Figure 4-13 this interaction is explained with the help of a UML sequence diagram.

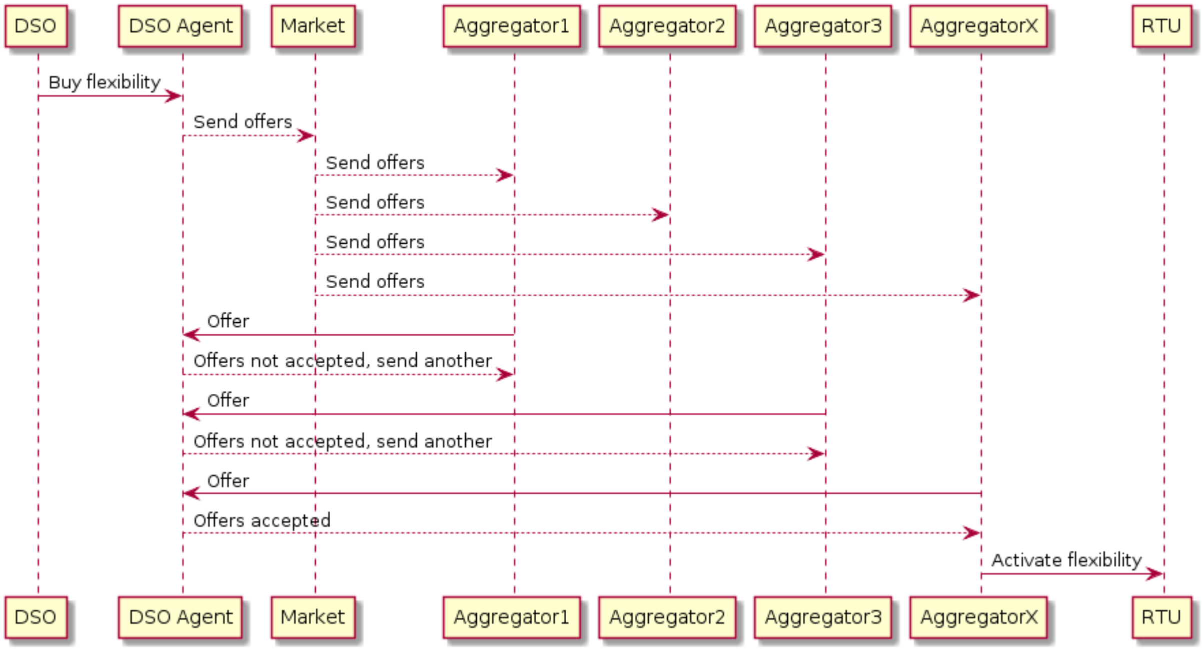

Figure 4-13: The sequence diagram of the market negotiation.

4.2.3 Testbed

A testbed was constructed in AIT's SmartEST and Digital Labs for performing all these tests. A high-level overview of the constructed testbed is depicted in Figure 4-14. It is constructed in the form of large real-time hardware in the loop co-simulation. For the constructing individual components and for the communication of data and control command, AIT Lablink is used. AIT Lablink is an enterprise-class co-simulation framework that works equally well for both real-time and simulated systems. The testbed simulates the CIGRE European LV benchmark power grid model (see Figure 4-1) using the real-time simulator OPAL-RT[19]. A software model encapsulating a SCADA algorithm is monitoring the selected nodes of the system through the measurements for the power grid model. Along with this, the testbed has controllers for RTU and Flexibility. There is a DSO agent model together with a market simulator having many aggregators trying to sell their flexibilities.

[19] https://www.opal-rt.com/

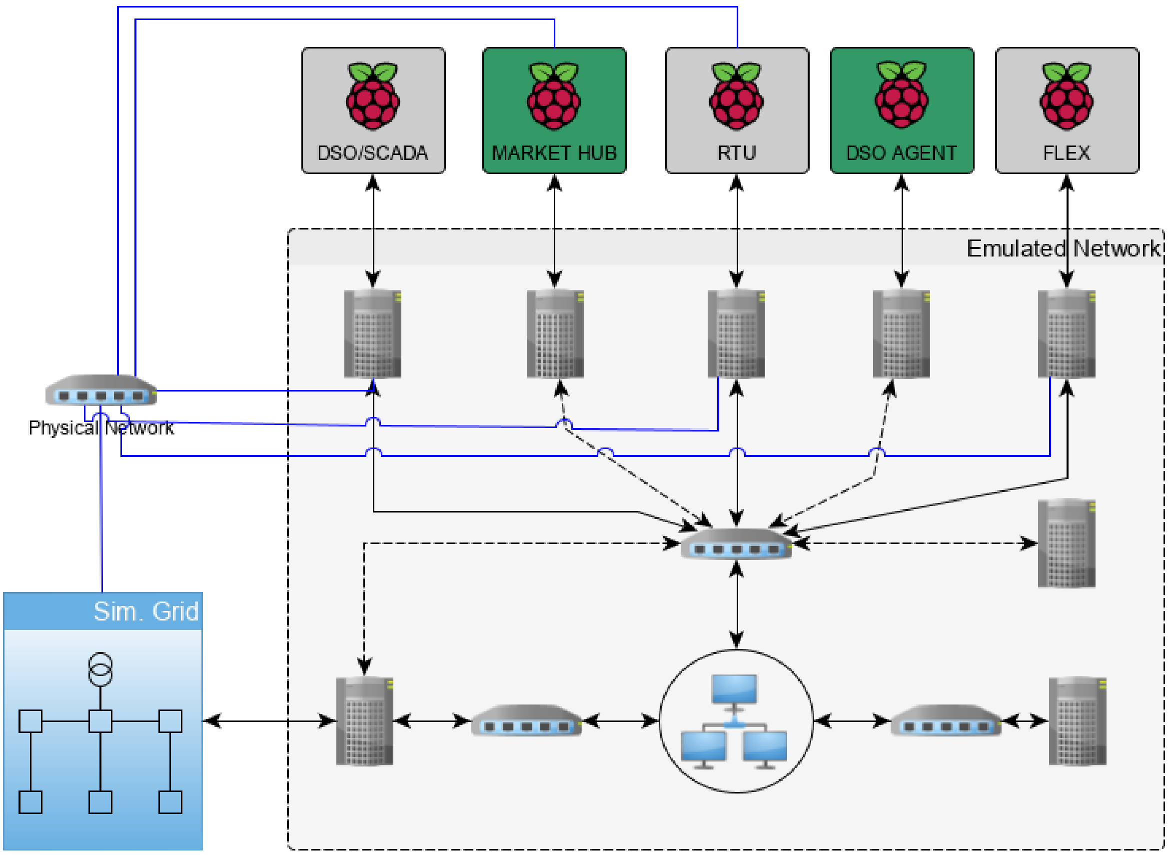

Figure 4-14: Schematic of testbed developed and used for the interoperability validation tests for Case Study 4. The interaction and information interchange between the real-time power grid simulator, ICT emulator, number of controllers and other devices is visible.

There are two ICT networks in the testbed. In the figure, the blue lines mean the ICT network used for management and simulation control while the black lines are representing the emulated network used for providing realistic network behaviors. The SCADA, RTU, FLEX, Market and DSO Agents are running on individual Raspberry Pi 3 B+[20] single board computers.

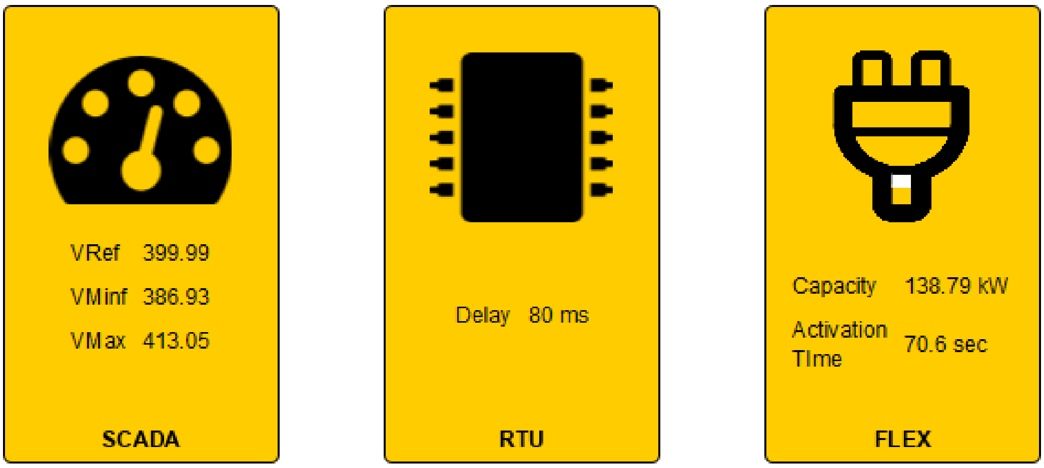

Figure 4-15: Configured parameters.

[20] https://www.raspberrypi.org/

To summarize the testbed, the major components of the testbed as seen in the figure include:

1. The real-time power grid simulator (OPAL-RT)
2. Network emulator (NRL CORE)
3. Physical ICT network
4. The energy market simulator
5. The DSO Agent model
6. The DSO SCADA, RTU and Flexibility controllers

4.2.4 Tests

For conducting the tests, the JRC smart grid interoperability methodology is employed. Following the methodology first, Basic Application Profile (BAP) were identified as well as a set of communication technologies that can be used on these interfaces. These communication technologies have already been identified and reported in Section 2.7. Since for this case study, the major focus of these interoperability tests is to validate the interfaces between the major players in activating the flexibility involved in an upper-bound architecture, the selected interfaces/links are:

1. DSO ←→ Market (BAP1.1)
2. Aggregator ←→ RTU (BAP2.1, BAP2.2, BAP2.3)
3. RTU ←→ Flexibility (BAP4.1, BAP4.2, BAP4.3)

Later, based on the use case, Basic Application Interoperability Profile (BAIOP)s are defined. Once, the interfaces are identified and the BAPs and BAIOPs are selected the next step is to configure the testbed with appropriate parameters ready for simulation. For constructing these simulation scenarios, the whole system is logically divided into two parts:

1. Emulated ICT network between the selected interfaces
2. Rest of the testbed

For the second part, the parameters are fixed as per Figure 4-15 for the SCADA algorithm, the RTU and Flexibility controllers. In this case, RTU has an activation time delay of 80ms. This means, once a signal is received from Aggregator for activation of flexibility, it takes the RTU controller 80ms to activate and pass the signal to connected Flexibility. Also, for this experiment, the flexibility has a capacity of 138.794kW and an activation time of 70.6 seconds.

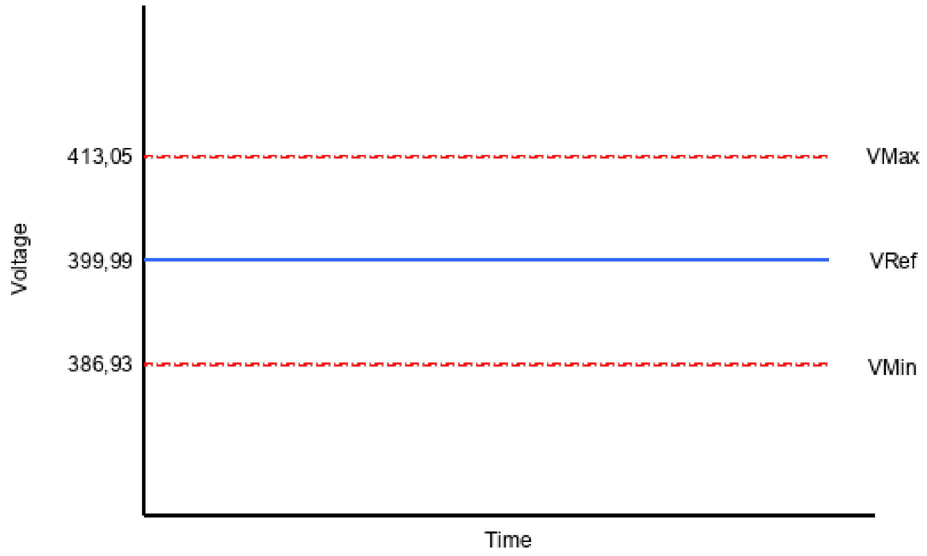

Figure 4-16: SCADA algorithm

The parameters for the SCADA algorithm are explained in Figure 4-16. As can be seen, the algorithm makes 399.99 as the reference voltage and there is ≈ 6.6% on both directions for upper and lower voltage values. Any voltage values during the tests that are beyond these ranges make the SCADA algorithm look for flexibility as explained above.

Table 4-4: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

For the ICT interoperability, the BAIOPs for upper-bound architecture from Table 4-4 are chosen for the selected interfaces. This means the selected BAIOPs are BAIOP1, BAIOP2, and BAIOP3. Similarly, for the selected BAIOPs, the corresponding BAPs are BAP1.1, BAP2.1, BAP2.2, BAP2.3, BAP4.1, BAP4.2 and BAP4.3. The corresponding communication architectures are presented in Table 4-5.

Table 4-5: Defined communication parameters for the selected upper-bound interfaces for the three basic application interoperability profiles (BAIOP).

Scenario	Links	Technology	Bandwidth	Background traffic	Delay	Jitter	Packet loss	Duplicate
			Mbps	Mbps	µs	µs	%	%
BAIOP1	DSO ↔ Market	Fiber (access provider)	80	0,1	30000	1000	0	0
	AGGR ↔ RTU	xDSL / cable	8		30000	10000	0	0
	RTU ↔ Device	Fiber (access provider) / Local Ethernet	80		30000	1000	0	0
BAIOP2	DSO ↔ Market	Fiber (access provider)	80	0,1	30000	1000	0	0
	AGGR ↔ RTU	xDSL / cable	8		30000	10000	0	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0
BAIOP3	DSO ↔ Market	Fiber (access provider)	80	0,1	30000	1000	0	0
	AGGR ↔ RTU	Mobile network	10		60000	20000	1	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0

4.2.5 Results and discussions

These results are calculated based on the system response during the tests when it is exposed to a fixed disturbance which leads to a fixed amount of congestion at some nodes in the distribution grid. Here a summary of the results is presented along with some discussion and intermediate conclusions. First, Table 4-6 summarizes the results of nine selected tests for three communication scenarios. The most important column is the average restoration time. This time is the sum of all factors including ICT, market negotiation and device activations time.

Table 4-6: Summary of the results for the selected runs while testing three basic application interoperability profiles (BAIOP) for Case Study 4.

Scenario	Injection (kW)	Voltage (V)		Flex provided	Restoration Time (ms)			Restoration (Average)			Power (kW)	
		Before	After		Market	Others	Total	Time (sec)	Voltage (W)	Power (kW)	Before	After
BAIOP1	-209	399,9877	425,667	138789	39628	100369	139997	**133,3340**	408,9880	70,21	0	-209
	-209	399,9877	425,667	138789	39242	100759	140001					
	-209	399,9877	425,667	138789	22310	97694	120004					
BAIOP2	-209	399,9877	425,667	138789	14145	105855	120000	**119,9987**				
	-209	399,9877	425,667	138789	18220	101780	120000					
	-209	399,9877	425,667	138789	21226	98770	119996					
BAIOP3	-209	399,9877	425,667	138789	8205	111800	120005	**120,0030**				
	-209	399,9877	425,667	138789	2021	97984	100005					
	-209	399,9877	425,667	138789	37501	102498	139999					

Figure 4-17, plots the average restoration time from the summary table. As can be seen, the time in the first two communication scenarios is very much the same however for BAIOP3 is 6% more than these two. One explanation for this increase in time is the lower bandwidth and increase delay along with low network reliability for the communication interfaces between AGGR ←→ RTU and RTU ←→ FLEX. One other important aspect to note from these results is that the time spent in the market for negotiating for flexibility is stochastic and in this case varies between as low as 4 seconds to 40 seconds. It should also be noted that this also depends on the market model and size along with the aggregator and DSO policies.

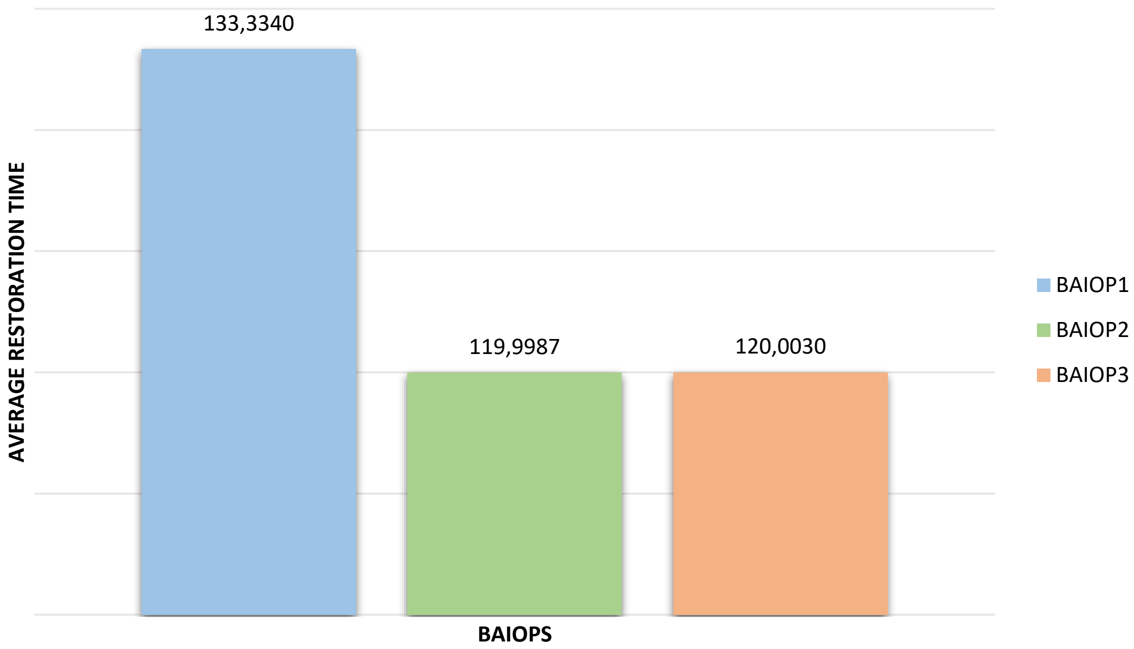

Figure 4-17: Plotted average restoration time for the three basic application interoperability profiles (BAIOP) for Case Study 4.

5 HARDWARE INTEROPERABILITY

The previous four case studies are dedicated to interoperability validation in the lab where the power hardware is not used but only the controllers were used to different use cases and architectures involved in the flexibility activation chain. This chapter, however, documents two case studies where the testbed is extended with power hardware, making it a PHIL testbed. In both case studies, the voltage support use case in the lower-bound architecture is validated, however, the testbed is capable to perform the same for the upper-bound architecture. In the first case study, the voltage support is achieved using a battery storage system while in the second case study, the same is achieved using an electric vehicle charging station.

(a) (b)

Figure 5-1: Overview of the two case studies documented in this chapter. Case study 5 (a) is featuring a battery storage system while case study 6 (b) is with an electric vehicle charging station.

Both case studies are organized the same way as the other four documented in the previous two chapters. However, since the testbeds used for validating these case studies are extended with power hardware, additionally a brief description of the used hardware is provided.

Individual sections are dedicated to each case study. These sections provide some details on interoperability tests and the used testbed along with the composition and configuration of different components. They further provide some results along with the test verdicts and their bases.

To cover both the services and the two use cases with the hardware-in-the-loop simulations for performing the interoperability validation test the first case study demonstrates the voltage support interoperability while the second is dedicated to congestion management interoperability validation. Although, both tests are constructed using lower-bound architecture, the same experiment design can be adopted to extend the testbed for performing the upper-bound interoperability tests.

5.1 Case study 5: Voltage support in Lower-bound Architecture using battery/storage system as flexibility

This section describes the congestion management tests for the lower-bound case as the third case study documented in this deliverable. In this case, study, as Figure 5-2 depicts, only two major players i.e. DSO and Flexibility out of four in the flexibility activation chain in the lower-bound architecture that is the focus of this case study. The tests are conducted in Power Hardware in the Loop (PHIL) fashion in AIT's SmartEST[21] and Digital Labs. For this study, the power hardware is the Fronius[22] inverter and the battery storage system.

The organization of this section is similar to the other case studies in this deliverable. First, a description of the test, the involved use case and the test concept will be presented. This will be followed by a brief description of the testbed, the tests and configured parameters (test scenarios) and at the end, the results and some discussions about the test will be presented. Please do note that some of the text is repeated to make the description and this case study self-contained.

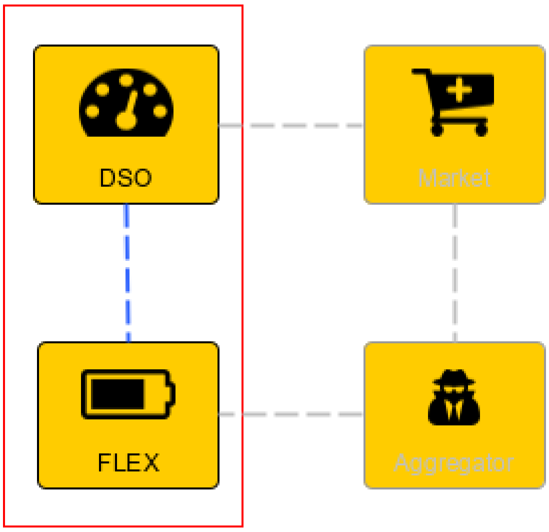

Figure 5-2: Highlighted the two major flexibility activation players having interaction in lower-bound architecture focused on in Case Study 5.

5.1.1 Description

This case study reports and documents the interoperability validation test for the actors involved in the voltage support in the lower-bound architecture. In the context of InterFlex, the Czech, Swedish and German demos (see Figure 2-2 and Figure 2-4) have use cases that fall into this category. However, in this case study, the interoperability test is conducted by extending the testbed with power hardware. This makes it different from case study 1 (see Section 3.1) that also features voltage support in the lower-bound architecture.

[21] https://www.ait.ac.at/fileadmin/mc/energy/downloads/Smart_Grids/Produktblatt_CI_SmartEST_lowRes.pdf
[22] https://www.fronius.com/

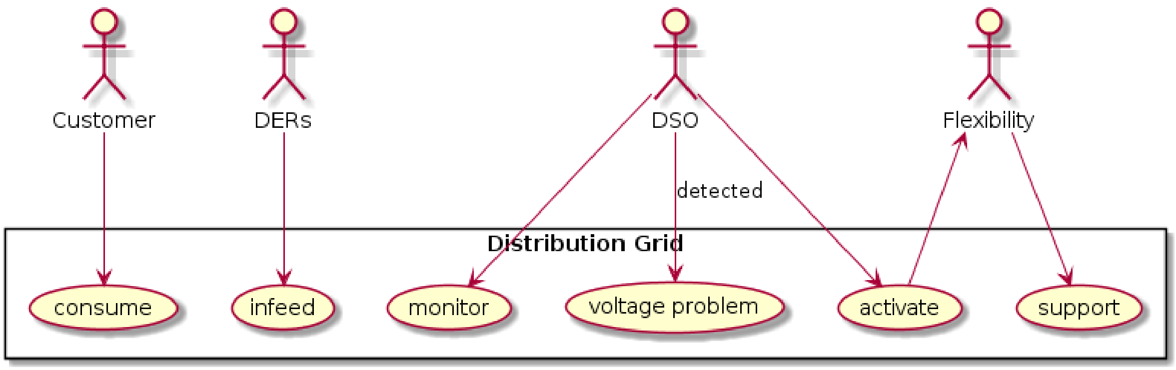

Figure 5-3: Voltage support use case for lower-bound architecture.

The voltage support use case on which this case study is based is presented in Section 2.6.2. However, for this case study, the lower-bound architecture variant is considered and tested. This variant in lower-bound is depicted again in Figure 5-3. As shown in this UML diagram, the flexibility activation chain contains a direct link between the DSO and the respective Flexibility (through an intermediate device, the RTU). In the case study, the DSO is reasonable for monitoring and mitigating the congestion by the means of installed flexibilities that many be also owned by it. For the monitoring, the SCADA is used that also can activate flexibilities through some remote intermediate devices using some form of ICT. These intermediate devices are connected to the respective flexibilities again using some ICT infrastructure and communicate using some protocols. In this case study, the interoperability between ICT links for the major actors for the flexibility chain in lower-bound architecture is validated.

5.1.2 Test concept

At a higher level, the lower-bound architecture test design concept for this case study is very similar to its counterpart in the voltage support case study documented in Section 3.1. However, there is one important difference that in these tests, these tests are conducted by including the real battery storage system in the testbed. This conceptual test design overview is presented in Figure 5-4 that demonstrates how the tests are designed.

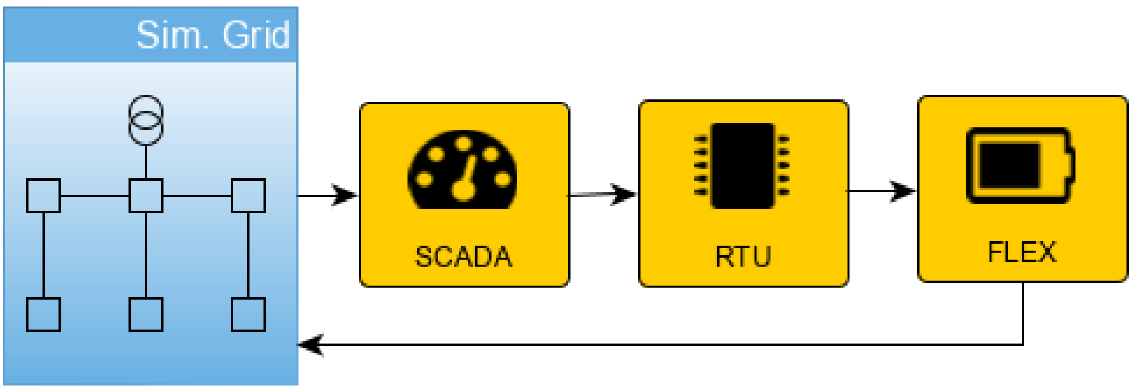

Figure 5-4: A depiction of a high-level conceptual model for the lower-bound test.

According to this design concept, the DSO SCADA system is monitoring the distribution power gird using the measurements. The received measurements are then used by the SCADA algorithm to analyze the system's stability in terms of voltage being under certain bands. Once, the SCADA detects congestion at some node in the system, it activates the congestion management algorithm. The congestion management, in this case study, is through support from a flexibility source present in the system and that can be activated directly by the DSO SCADA through an intermediate device – an RTU. This interaction in the flexibility chain between the actors once a problem is detected is also explained using a UML sequence diagram as depicted in Figure 5-5.

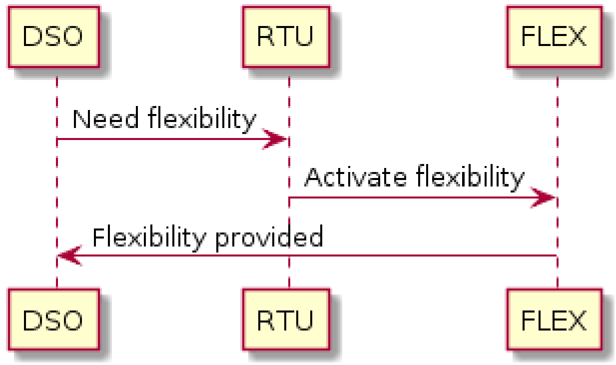

Figure 5-5: Flexibility Activation chain in lower-bound architecture.

5.1.3 Testbed

A testbed was constructed in AIT's SmartEST and Digital Labs for performing all these tests. A high-level overview of the constructed testbed is depicted in Figure 5-6. It was constructed in the form of large real-time hardware in the loop co-simulation. For the constructing individual components and for the communication of data and control command, AIT's Lablink[23] is used. AIT Lablink is an enterprise-class co-simulation framework that works equally well for both real-time and simulated systems.

The SCADA, RTU, and FLEX are running on individual Raspberry Pi 3 B+[24] single board computers. The testbed simulates the CIGRE European LV benchmark power grid model using the real-time simulator OPAL-RT[25]. A software model encapsulating a SCADA algorithm is monitoring the selected nodes of the system through the measurements from the power grid model. Along with this, the testbed has controllers for RTU and the Flexibility that takes care of activating and providing configured support to the grid when needed.

There are two ICT networks in the testbed. In the figure, the blue lines mean the ICT network used for management and simulation control while the black lines are representing the emulated network used for providing realistic network behaviors.

For the network emulation, a specialized network emulator NRL CORE is used. The emulator is running on a dedicated computer that has a number of RJ45 USB adaptors. These adaptors are then used to connect the controllers and software model hosted on individual computational devices (mostly Raspberry Pi in this case). This emulator is used during the test to test the interoperability of the flexibility activation chain using different communication settings as defined and explained later.

To summarize the testbed, it is designed for tests in a real-time co-simulation fashion and its major components, as seen in Figure 5-6 includes:

1. The real-time power grid simulator (OPAL-RT)
2. Network emulator (NRL CORE)

[23] https://www.ait.ac.at/en/research-topics/smart-grids/network-operators-and-energy-service-providers/ait-lablink/
[24] https://www.raspberrypi.org/
[25] https://www.opal-rt.com/

3. Physical ICT network with Ethernet switch and cables
4. The DSO SCADA, RTU and Flexibility controllers
5. Power Hardware

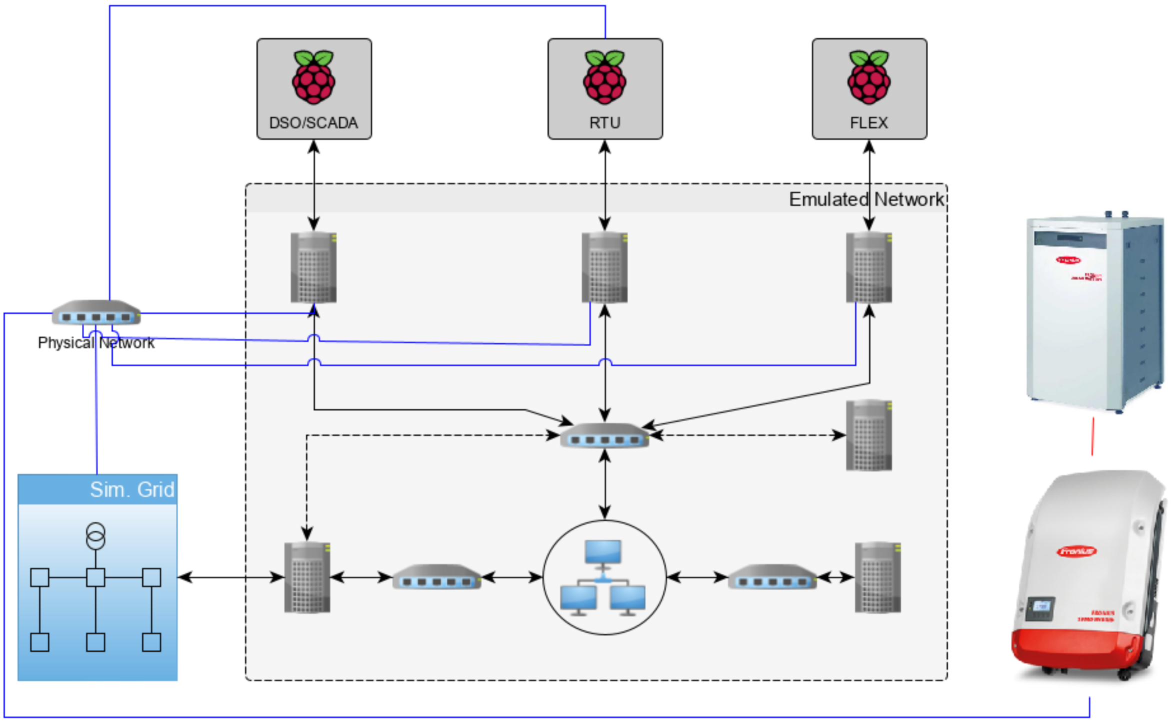

Figure 5-6: Schematic of testbed developed and used for the interoperability validation tests for Case Study 5. The interaction and information interchange between the real-time power grid simulator, ICT emulator, number of controllers and other devices is visible.

Table 5-1: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

The power hardware is the Fronius Hybrid Simo system that is installed in the AIT SmartEST Inverter Lab. The description of this test setup along with some technical specifications are provided in Annex B (8.4 Storage System).

5.1.4 Tests

For conducting the tests, the JRC[26] methodology is followed and the BAPs and the BAIOPs are defined for the selected interfaces. The defined BAIOPs are documented in Table 5-1. From these only three BAIOPs defined on interfaces for lower-bound (BAIOP4, BAIOP5, and BAIOP6) are selected.
As shown in Figure 5-2, the following interfaces are for interest for the two major players involved in this case study:

1. DSO ←→ RTU (BAP2.1, BAP2.2, BAP2.3)
2. RTU ←→ Flexibility (BAP3.1, BAP3.2, BAP3.3)

Next, for these interfaces, the communication parameters and technologies are defined corresponding to each of the involved BAP. These parameters along with corresponding BAIOPs are documented in Table 5-2.

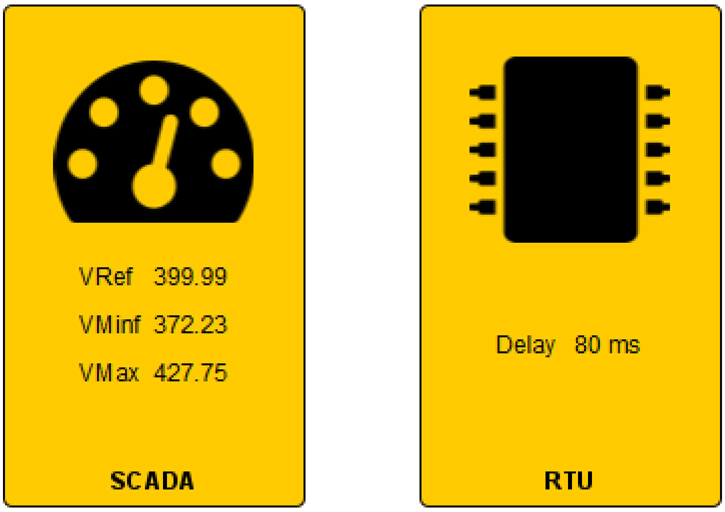

Figure 5-7: Configured test parameters.

The controllers for RTU and FLEX, and SCADA algorithm, the parameters are fixed as per Figure 5-7. In this case, RTU has an activation time delay of 80ms. This means, once a signal is received from SCADA for activation of flexibility, it takes the RTU controller 80ms to pass the signal to connected Flexibility. These parameters have been derived after consulting the device manuals, contacting the experts and by the hit-and-trial method. However, in this case, no delay parameters are configured for the FLEX actor as such is the actual value from the power hardware. Another important thing to note that in these tests the FLEX controller's behaviour has been slightly modified. The modification monitors the battery charge state once the flexibility has been activated and only sends an acknowledgment when the battery charge has been dropped at least 1% to make sure that the flexibility activation is indeed happening. This behaviour, on one hand, ensures that the flexibility has been activated and the required support will be provided, while on the other hand increases the

[26] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC110455/kjna29416enn_final.pdf

overall time the system needs to reach the stability. The results reported for this case study includes the times with this behaviour. In practice, the overall time can be a bit lower than reported here, if such a behaviour is not used. It is however advised to have a service check mechanism that guarantees that the activation indeed happed and the flexibility is providing the required support.

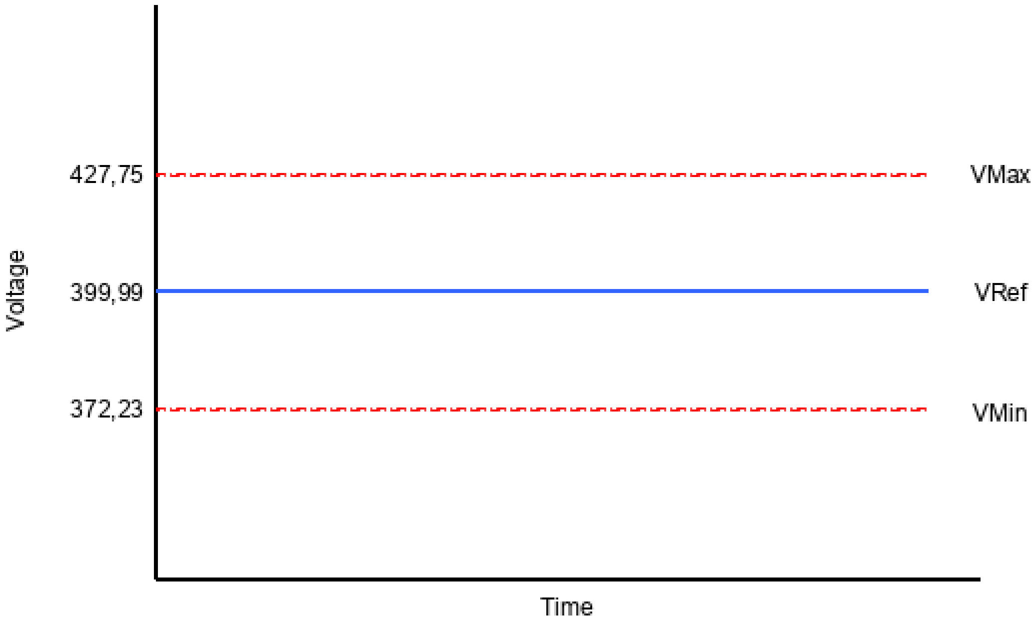

Figure 5-8: SCADA algorithm

Table 5-2: Defined communication parameters for the selected upper-bound interfaces for the three basic application interoperability profiles (BAIOP).

Scenario	Links	Technology	Bandwidth	Background traffic	Delay	Jitter	Packet loss	Duplicate
			Mbps	Mbps	µs	µs	%	%
BAIOP4	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Fiber (access provider) / Local Ethernet	80		30000	1000	0	0
BAIOP5	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0
BAIOP6	DSO <-> RTU	Mobile network	10	0,1	60000	20000	1	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0

5.1.5 Results and discussions

A number of tests are conducted for each BAIOP with the setup and configurations described previously. From these tests, the results for a total of nine-runs, three each for a BIOAP are reported in Table 5-3 below. The table reports different values recorded for each run. One of the important measures is the *average restoration time*. This is the time that is elapsed between the identification of the problem by DSO until the system becomes stable again.

Table 5-3: Summary of the results for the selected runs while testing three basic application interoperability profiles (BAIOP) for Case Study 5.

Scenario	Run #	Injection (kW)	Voltage (V)		Flex provided	Restoration Time (ms)	Restoration (Average)			Power (kW)	
			Before	After			Time (sec)	Voltage	Power (kW)	Before	After
BAIOP4	**1**	209	399,9877	370,2574	149344,6	69999	**66,7003**	391,9900	59,6600	0	209
	2	209	399,9877	370,2574	149344,6	64566					
	3	209	399,9877	370,2574	149344,6	65536					
BAIOP5	**1**	209	399,9877	370,2574	149344,6	79988	**78,8960**				
	2	209	399,9877	370,2574	149344,6	76699					
	3	209	399,9877	370,2574	149344,6	80001					
BAIOP6	**1**	209	399,9877	370,2574	149344,6	79003	**79,6707**				
	2	209	399,9877	370,2574	149344,6	79998					
	3	209	399,9877	370,2574	149344,6	80011					

Figure 5-9, plots the average restoration time from the summary table (Table 5-3). As can be seen, the time in BAIOP5 and BAIOP6 is very much the same however for in the case of BAIOP4, the system on average restored around 16% faster than the other two. One possible explanation for this is the increase bandwidth decreased delay.

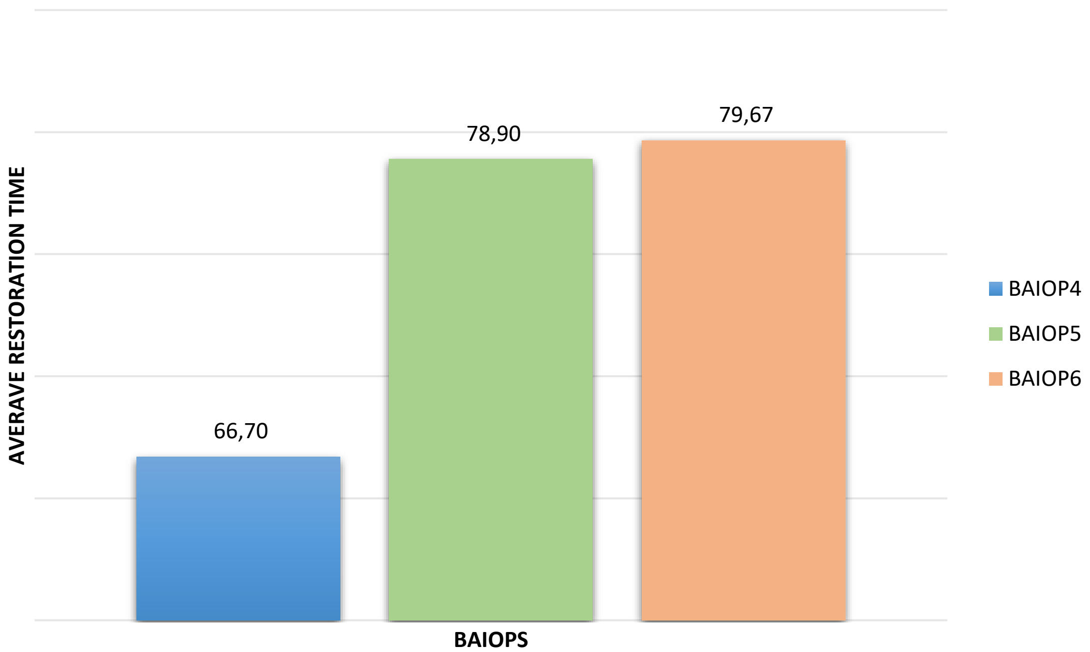

Figure 5-9: Plotted average restoration time for the three basic application interoperability profiles (BAIOP) for Case Study 5.

5.2 Case study 6: Congestion management in lower-bound architecture using a charging station as flexibility

This section describes the congestion management tests for the lower-bound case as the third case study documented in this deliverable. In this case, study, as Figure 5-10 depicts, only two major players i.e. DSO and Flexibility out of four in the flexibility game are participating. The tests are conducted in Hardware in the Loop (HIL) fashion in AIT's Digital Lab. The power hardware is owned by InterFlex partner ElaadNL and is located in The Netherlands.

The organization of this section is similar to the other case studies in this deliverable. First, a description of the test, the involved use case and the test concept will be presented. This will be followed by a brief description of the testbed, the tests and configured parameters (test scenarios) and at the end, the results and some discussions about the test will be presented. Please do note that some of the text is repeated to make the description and this case study self-contained.

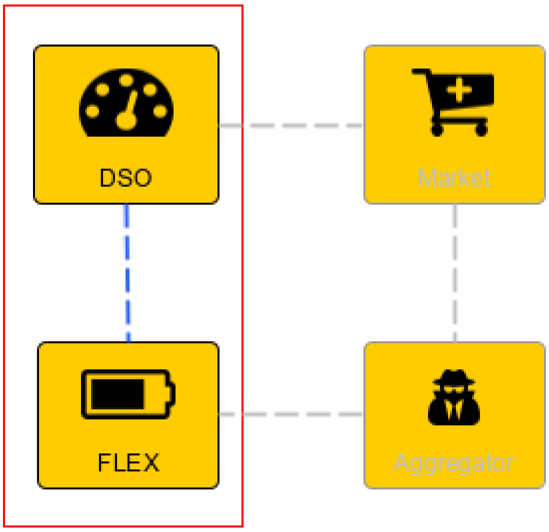

Figure 5-10: Highlighted the two major flexibility activation players having interaction in lower-bound architecture focused on in Case Study 6.

5.2.1 Description

This case study is aimed at validating the interoperability with an electric vehicle and charging station infrastructure. The flexibility activation architecture, in this case, is lower-bound architecture where the flexibility is controlled by the DSO directly without any third-party like Aggregator and/or Market. In this architecture, this can be assumed that the flexibility source is somehow owned by the DSO itself. The use case for this case study is based on is about congestion management. The detail of the use case is presented in Section 2.6.2. The lower-bound architecture variant of this use case is considered and is presented again in Figure 5-11. In the use case, multiple DERs are injecting power into the grid in which power is provided to the customers that then consume it. To keep the voltage and power under limits, the SCADA is continuously monitoring the grid with measurements at different points of interest. Since in this use case, a fixed amount of disturbance is introduced in the system at a random time that causes a congestion situation at selected lines. The SCADA detects this disturbance and initiates the congestion management activities which in this case is through support from the electric vehicle charging station.

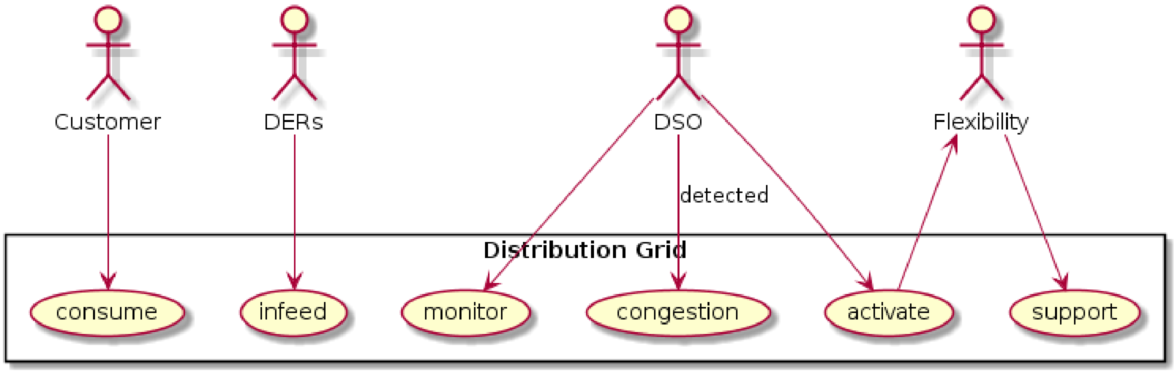

Figure 5-11: Congestion management use case for lower-bound architecture.

5.2.2 Test concept

The test concept is in line with the use case. At a high-level, a distribution grid system is monitored by the DSO SCADA to keep the voltage and power in the allowable rages by performing different measurement and control actions. Once congestion is detected, the SCADA immediately activates the congestion management actions. However, in this specific case, this action is to activate the available flexibilities to bring the system in a stable state again. As this is a low-bound architecture, that means that the SCADA can directly access and request and activate the flexibility through a Remote Terminal Unit (RTU). The concept is depicted in Figure 5-12.

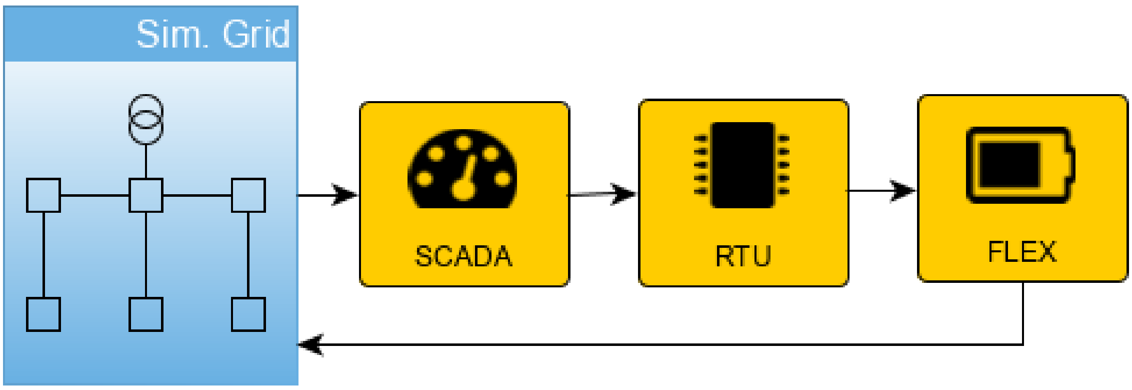

Figure 5-12: High-level Test concept.

To better explain the interaction between the involved actors in this case study, a sequence diagram is presented in Figure 5-13. As can be seen here, the DSO (SCADA), once a disturbance is detected asks the intermediate device like a RTU to activate the respective flexibility. The respective flexibility is in turn activated and the required support is provided to the system.

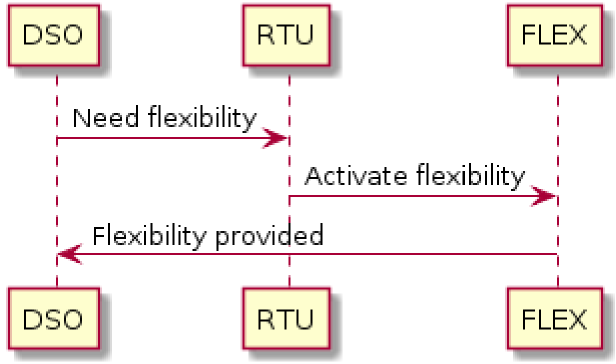

Figure 5-13: Flexibility Activation chain in lower-bound architecture.

5.2.3 Testbed

For conducting the test, the testbed used for Case study 5 is adopted to include the remote electric vehicle charging infrastructure hosted and provided by InterFlex partner ElaadNL in The Netherlands. A high-level view of the testbed is depicted in Figure 5-14, which shows some physical components and devices along with communication networks for simulation control and data exchange. The testbed is constructed in the form of a real-time hardware-in-the-loop co-simulation form where AIT Lablink is used for managing and constructing the co-simulation.

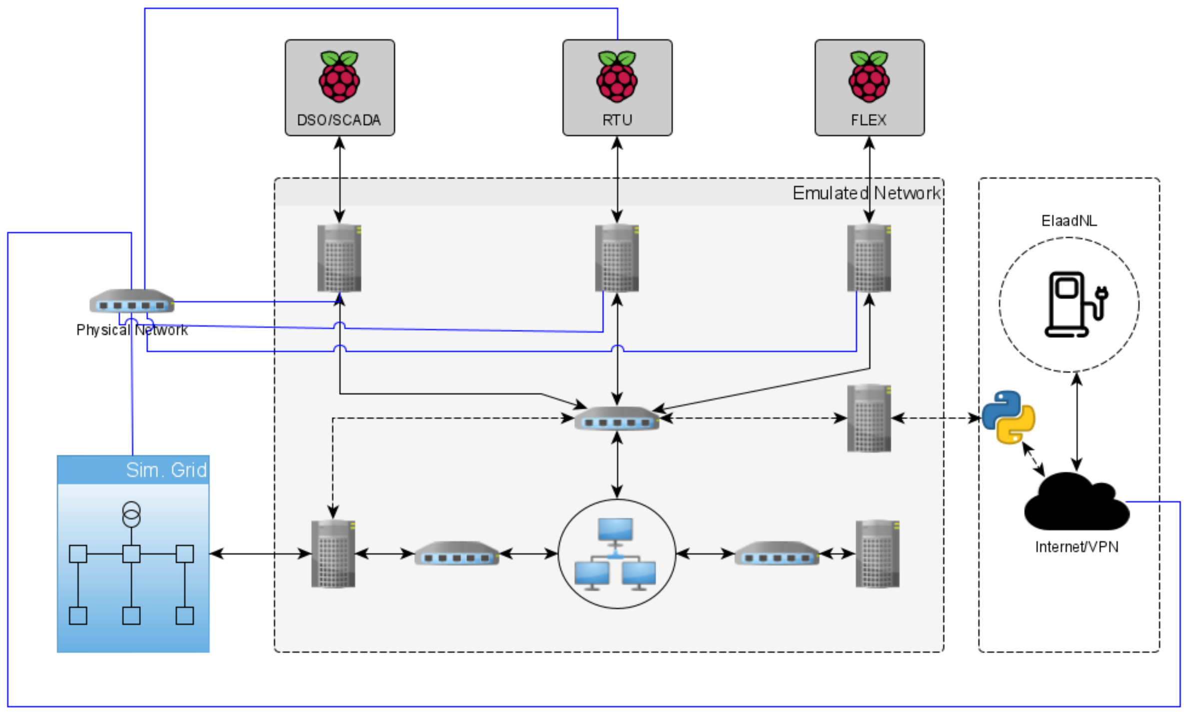

Figure 5-14: Schematic of testbed developed and used for the interoperability validation tests for Case Study 6. The interaction and information interchange between the real-time power grid simulator, ICT emulator, number of controllers and other devices is visible.

AIT Lablink is an enterprise-class co-simulation framework that works equally well for both real-time and simulated systems. The SCADA, RTU, and FLEX are running on individual

Raspberry Pi 3 B+[27] single board computers. The testbed simulates the CIGRE European LV benchmark power grid model (see Figure 3-1) using the real-time simulator OPAL-RT[28]. A software model encapsulating a SCADA algorithm is monitoring the selected nodes of the system through the measurements from the power grid model. Along with this, the testbed has controllers for RTU and the Flexibility that take care of activating and providing configured support to the grid when needed. The configured parameters for SCADA and RTU are described in Figure 5-15. The SCADA algorithm is further explained in Figure 5-16 when the reference voltage along with minimum and maximum are depicted.

There are two ICT networks in the testbed. In the figure, the blue lines mean the ICT network used for management and simulation control while the black lines are representing the emulated network used for providing realistic network behaviours.

For the network emulation, a specialized network emulator NRL CORE is used. The emulator is running on a dedicated computer that has a number of RJ45 USB adaptors. These adaptors are then used to connect the controllers and software model hosted on individual computational devices (mostly Raspberry Pi in this case). This emulator is used during the test to test the interoperability of the flexibility activation chain using different communication settings as defined and explained later. To summarize the testbed, it is designed for tests in a real-time co-simulation fashion and its major components, as seen in Figure 4-6 includes:

1. The real-time power grid simulator (OPAL-RT)
2. Network emulator (NRL CORE)
3. Physical ICT network with Ethernet switch and cables
4. The DSO SCADA, RTU and Flexibility controllers

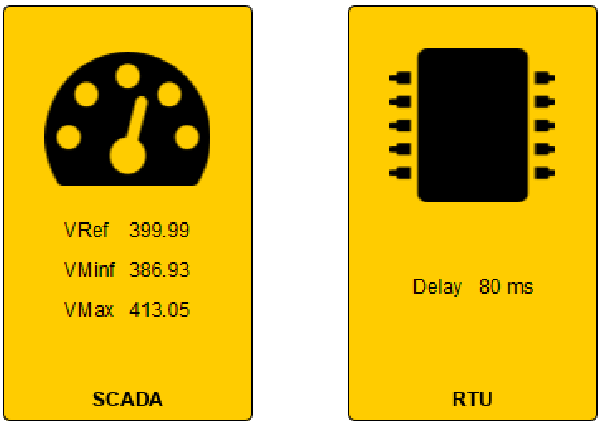

Figure 5-15: Configured parameters for SCAD and RTU components.

The access to the charging station is over HTTP protocol. It is worth mentioning here that due to some technical reasons, this access is available only through a web portal that cannot be directly integrated into the simulation programmatically. In this situation, the only possibility is to adopt a man-in-the-loop approach. However, it can be clearly seen that such an approach is not feasible when there needs to be a lot of simulation runs having response time as an important KPI. To get around this limitation, the process of using the web portal

[27] https://www.raspberrypi.org/
[28] https://www.opal-rt.com/

is "automated" with a Python script. Although, this is not an ideal solution it is more robust and scalable than man-in-the-loop.

The readers should note that this automation requires additional time as part of the activation process. The additional steps are related to the web portal interface that requires login with provided credentials, navigating to the appropriate charging station and initiating the activation process. It is, therefore, to be noted that the times recorded in these experiments could be slightly higher than the time that ElaadNL reported for such operations. In this case, it is mentioned again that the objectives of these case studies are more on the validation of the interoperability between the interfaces when different devices and services are used for flexibility activation.

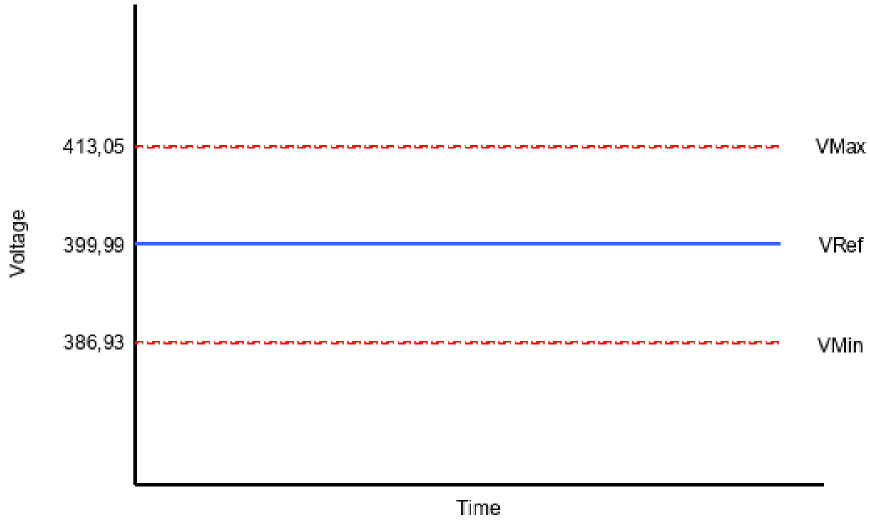

Figure 5-16: SCADA algorithm with ref, maximum and minimum voltage ranges visualization.

5.2.4 Tests

For conducting the tests, the JRC[29] methodology is followed and the BAPs and the BAIOPs are defined for the selected interfaces. The defined BAIOPs are documented again in Table 5-4. Since this case study conducts the interoperability validation tests for the lower-bound architecture, only three BAIOPs defined for the interfaces in this architecture (BAIOP4, BAIOP5, and BAIOP6) are selected.
As can be seen, the following interfaces are for interest for the two major players involved in this case study:

1. DSO ←→ RTU (BAP3.1, BAP3.2, BAP3.3)
2. RTU ←→ Flexibility (BAP4.1, BAP4.2, BAP4.3)

[29] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC110455/kjna29416enn_final.pdf

Table 5-4: Defined JRC BAPs and BAIOPs for upper and lower bound architectures.

BAP	BAIOP					
	Upper Bound			Lower Bound		
	BAIOP1	BAIOP2	BAIOP3	BAIOP4	BAIOP5	BAIOP6
BAP1.1	X	X	X			
BAP2.1	X					
BAP2.2		X				
BAP2.3			X			
BAP3.1				X		
BAP3.2					X	
BAP3.3						X
BAP4.1	X			X		
BAP4.2		X			X	
BAP4.3			X			X

Next, for these interfaces, the communication parameters and technologies are defined corresponding to each of the involved BAP. These parameters along with corresponding BAIOPs are documented in Table 5-5 below.

Table 5-5: Defined communication parameters for the selected upper-bound interfaces for the three basic application interoperability profiles (BAIOP).

Scenario	Links	Technology	Bandwidth	Background traffic	Delay	Jitter	Packet loss	Duplicate
			Mbps	Mbps	µs	µs	%	%
BAIOP4	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Fiber (access provider) / Local Ethernet	80		30000	1000	0	0
BAIOP5	DSO <-> RTU	xDSL / cable	8	0,1	30000	10000	0	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0
BAIOP6	DSO <-> RTU	Mobile network	10	0,1	60000	20000	1	0
	RTU ↔ Device	Narrow-band PLC / RF Mesh	0,1		30000	100000	3	0

5.2.5 Results and discussions

These results are calculated based on the system response during the tests when it is exposed to a fixed disturbance which leads to a fixed amount of congestion at some nodes in the distribution grid.

Table 5-6: Summary of the results for the selected runs while testing three basic application interoperability profiles (BAIOP) for Case Study 6.

Scenario	Injection (kW)	Voltage (V)		Flex provided	Restoration (Actual)			Restoration (Average)			Power (kW)	
		Before	After		Time (ms)	Voltage	Power (kW)	Time (sec)	Voltage	Power (kW)	Before	After
BAIOP4	-209	399,9877	425,667	138789	71575	408,99	70,21	73,1717	408,9880	70,2100	0	-209
	-209	399,9877	425,667	138789	70169	408,99	70,21					
	-209	399,9877	425,667	138789	77771	408,99	70,21					
BAIOP5	-209	399,9877	425,667	138789	81733	408,99	70,21	86,7840				
	-209	399,9877	425,667	138789	86439	408,99	70,21					
	-209	399,9877	425,667	138789	92180	408,99	70,21					
BAIOP6	-209	399,9877	425,667	138789	87834	408,99	70,21	87,5733				
	-209	399,9877	425,667	138789	86901	408,99	70,21					
	-209	399,9877	425,667	138789	87985	408,99	70,21					

A number of tests are conducted for each BAIOP with the setup and configurations described previously. From these tests, the results for a total of nine-runs, three each for a BIOAP are reported in Table 4-3 below. The table reports different values recorded for each run. One of the important measures is the *average restoration time*. This is the time that is elapsed between the identification of the problem by DSO until the system becomes stable again.

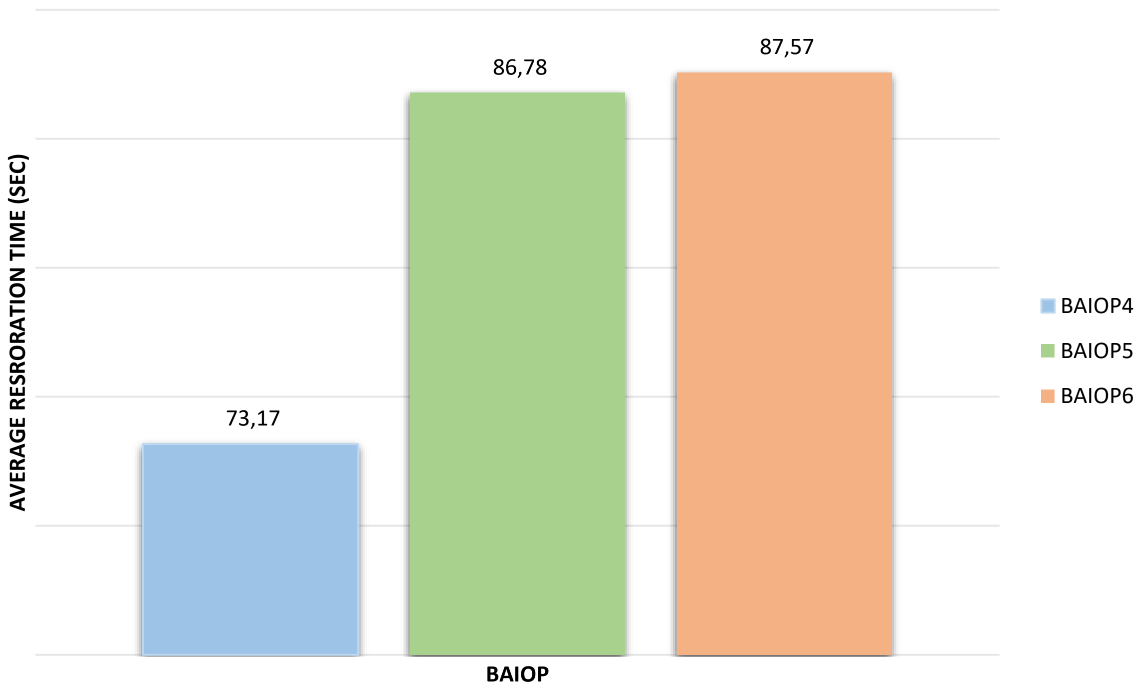

Figure 5-17: Plotted average restoration time for the three basic application interoperability profiles (BAIOP) for Case Study 6.

The average restoration times from the three BAIOPs are plotted in Figure 5-17. As per this plot generated from the result summary table (Table 5-6), the time is 15% lower in BAIOP4 then the other two profiles (BAIOP5 & BAIOP6). One obvious explanation is the availability of more bandwidth and low latency (see Table 5-5). Please, note again that these times could be slightly higher than the actual values in the field as the interface used to access the electric vehicle charging stations is not ideal. The results would be closer to reality in the fields if the same interface had been available and not an automated man-in-the-loop interface.

6 CONCLUSION

Within this work, specific attention was drawn towards the laboratory-based interoperability validation for the InterFlex demonstrations. As the first step, the services identified in the Deliverable D3.2 were further investigated out of which two use cases that have been derived for laboratory testing. The selection of these use cases is in line with the InterFlex demo implementations. As another attempt for the preparation of the testbeds and by referring to the SGAM studies conducted in Deliverable D3.1, the communication platforms of different InterFlex use cases have been identified. Consequently, the telecommunication infrastructure for the testbed has been modelled in accordance with the demo implementations and the identified lower bound and upper bound flexibility activation mechanisms reported in the same deliverable (Deliverable D3.1).

After identifying the communication part, test cases have been designed to test the interoperability and interchangeability of components and systems involved. Each case study is identified as either an upper or a lower-bound architecture along with the involved actors. The test based on these case studies covers the hardware interoperability as well as the controller hardware in the loop validation modes. The former focuses on the flexibility activation mechanism of the grid-integrated storage units as one of the critical components within InterFlex while the latter focuses on the other critical interfaces of the project related to the aggregator market mechanism (market-driven upper bound flexibility activation) and the gateway mechanism (direct DSO lower bound flexibility activation). For all these case studies, specific components have been modelled to simulate the behaviour of the power grid and the flexibility activation mechanisms. It is noteworthy that for the methodological interoperability testing, the well-known JRC methodology has been applied. The table 6-1 summarizes the focus of these tests for the critical project interfaces and their coverage from different points of view considering the derived use cases:

Table 6-1: Interoperability matrix and validation tests

SUT	Point of view			Case studies
	Power network interface	Functionality	Communication	
DSO System (SCADA)	✓	✓	✓	1-6
Aggregator IT System	✓	✓	✓	2&4
Grid integrated energy storage systems	✓	✓	✓	5
EV Charging Station	✓	✓	✓	6

After analyzing the different validation use cases and laboratory tests, it can be concluded that:

- The activation of flexibility directly via a Remote Terminal Unit (RTU) or indirectly via an intermediate actor (such as an energy management system or aggregators) is possible
    - The indirect activation mechanism is relatively easy to manage and could be scaled up
    - The direct mechanism provides a more robust solution but lacks the scalability

- The telecommunication infrastructure does not have a strong impact on the quality of service delivered by the sources of flexibility
    - It mainly impacts the time constraint and additional attention is needed to satisfy the service requirement
    - In this regard, the available technologies and economic considerations could potentially play important roles.

From the demonstration analysis, it can be concluded that the system integrations are complex and are subjected to the DSO desired service. The DSOs can build up an interoperable infrastructure based on their targeted quality of service, the available amount of flexibility, market and grid constraints, and economic considerations.

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[2] F. Kupzog, O. Genest, A. Ahmadifar, F. Berthome, M. Cupelli, J. Kazmi, M. Savic and A. Monti, “SGAM-Based Comparative Study of Interoperability Challenges in European Flexibility Demonstrators: Methodology And Results,” in *IEEE 16th International Conference on Industrial Informatics (INDIN)*, 2018.

[3] J. Kazmi, A. Ahmadifar, M. Ginocchi, F. Kupzog, M. Cupelli, O. Genest, M. Calin, M. Savic and A. Monti, “Identification of common services in European flexibility demonstrators for laboratory-based interoperability validation,” in *8th International Conference on Renewable Energy Research and Applications (ICRERA),* Brasov Romania, 2019.

[4] A. Pillay, S. P. Karthikeyan and D. Kothari, "Congestion management in power systems – A review," *International Journal of Electrical Power & Energy Systems,* vol. 70, pp. 83-90, 2015.

7 ANNEX A – JRC UC AND TEST TEMPLATES

Here, the reader can find the JRC use case template filled out for one of the telecommunication architectures, i.e., BAIOP 1 which consists of BAP 3.1 and BAP 4.1. For the sake of redundancy and to save space, only BAOPI 1 is reported here but a similar approach could easily be followed for any other telecom architecture.

7.1 JRC Use Case Template

UC.1.1 General

UC.1.2 Name of Use Case

ID	Domain see Annex A Selection List	Name of Use Case	Level of Depth Cluster, High Level Use Case, Detailed Use Case
VoltSupp_case study 1	Voltage regulation	Voltage Support	High level use case

UC.1.3 Version Management

Changes / Version	Date	Name Author(s) or Committee	Domain Expert	Area of Expertise / Domain / Role	Title	Approval Status draft, for comments, for voting, final
Amir Ahmadifar and Mirko Ginocchi	10 October 2019	RWTH University	Primary	Power Systems & Statistics	PhD students	Final

UC.1.4 Basic Information to Use Case

Source(s) / Literature	Link	Conditions (limitations) of Use
Cen/Cenelec/Etsi Smart Grid Coordination Group – Smart Grid Reference Architecture Nov 2012 pp.107	http://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf	NA
CEN-CENELEC-ETSI Coordination Group on Smart Energy Grids (CG-SEG) “SEGCG/M490/G_Smart Grid Set of Standards Version 4.1- January 2017”	https://www.cencenelec.eu/standards/Sectorsold/SustainableEnergy/SmartGrids/Pages/default.aspx	NA
Smart Grid Interoperability tool - SGCG WebSite	https://www.cencenelec.eu/standards/Pages/default.aspx	NA
Cen/Cenelec/Etsi SG-CG-Sustainable Processes Doc. Nov 2012	http://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_sustainable_processes.pdf	NA

Maturity of Use Case – in business operation, realized in demonstration project, , realised in R&D, in preparation, visionary
Under development in the InterFLEX project.
Prioritization
Generic, Regional or National Relation

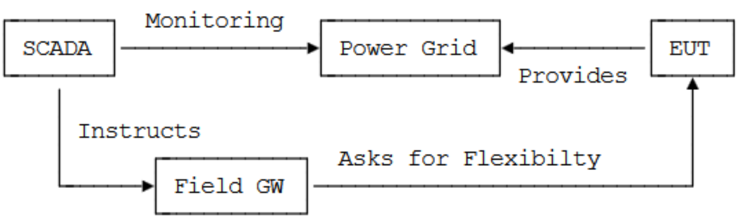
Generally applicable in Europe

View *- Technical / Business*
Technical
Further Keywords for Classification
Flexibility, Voltage Support, Remote Terminal Unit (RTU), Distribution System Operator – Supervisory Control And Data Acquisition (DSO-SCADA)

UC.1.5 Scope and Objectives of Use Case

Scope and Objectives of Function
The scope of this Use Case is to analyse the capability of the Lower Bound flexibility activation chain (Sections 3.1 and 2.3.1) in satisfying the DSO's flexibility request. The triggering event of the flexibility request is a voltage disturbance at a specific grid node, which is detected by the DSO-SCADA and the consequent flexibility request is sent through a field gateway (RTU) all the way to the available flexibility. The performance of this function is assessed under an interoperability point of view, where different system variables (input factors) potentially affecting the system performance are considered and their effect on the system response is analysed.

UC.1.6 Narrative of Use Case

Narrative of Use Case
Short description *– max 3 sentences*
Considering a reference grid model, this Use Case analyses what is the performance of the "voltage restoration" function after a voltage disturbance is occurred in the power grid when different system variables (input factors) are considered and changed.
Complete description
In this Use Case, the DSO-SCADA is directly interfaced with the flexibility device through a field gateway (RTU). The power system voltage level is constantly monitored by the DSO-SCADA. When a voltage drop is detected (according to a predefined tolerance threshold), the need of voltage support is translated into a flexibility request command directly sent to the flexibility source via the RTU. The RTU, in turn, activates the flexibility, which offers its voltage support service in order to make the system stable again. The SCADA keeps on monitoring the system and reports back once the voltage is in the defined limits again. The schematics of the use case validation scenario is provided in the following. 

UC.1.7 Actors: People, Systems, Applications, Databases, the Power System, and Other Stakeholders (from CEN-CENELEC-ETSI Smart Grid Coordination Group – Sustainable Processes list of actors)

Actor Name	Actor Type	Actor Description	Further information specific to this Use Case
SCADA system	Application	Supervisory Control And Data Acquisition system provides the basic functionality for implementing EMS or DMS, especially provides the communication with the substations to monitor and control the grid.	DSO SCADA here refers to the monitoring actor of the distribution grid
Energy Management Gateway	System	An access point (functional entity) sending and receiving smart grid related information and commands between actor A and the CEM, letting the CEM decide how to process the events. The communication is often achieved through an internet connection or through a wireless connection	In this use case, EMG is intended to be the Remote Terminal Unit through which the DSO-SCADA interfaces the flexibility
Flexible Load		Load that can be modulated	

UC.1.8 Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	Impact of Issue on Use Cases	Reference – law, standard, others

UC.1.9 Preconditions, Assumptions, Post condition, Events

Actor/System	Triggering Event	Pre-conditions	Assumption
DSO		DSO has a contract with the flexible load owner	DSO keeps the operational condition of the grid based on regulations
DSO-SCADA, RTU and FLEX			All the actors operate under nominal values
DSO-SCADA, RTU and FLEX			The communication links between the actors are reliable and they do not affect the performance of the analyzed function
FLEX			FLEX always respond to the flexibility request initiated by the DSO-SCADA based on their contractual agreement

UC.1.10 Referenced Standards and / or Standardization Committees (if available) from IOP TOOL and IEC smart grid standards map found in http://smartgridstandardsmap.com/

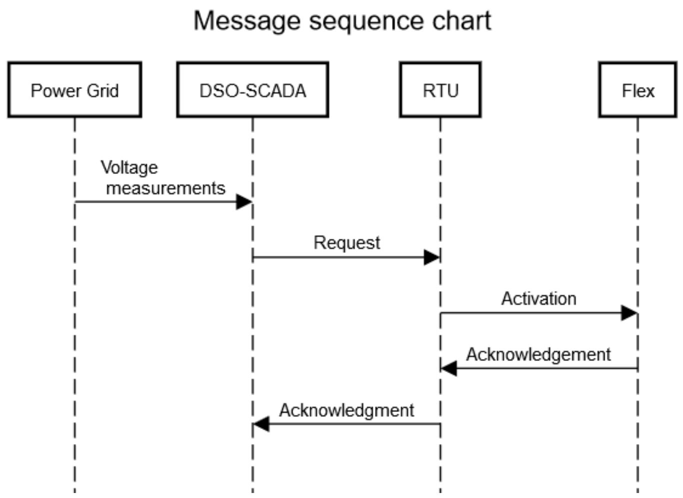
Relevant Standardization Committees	Standards supporting the Use Case	Standard Status

UC.1.11 General Remarks

General Remarks
This Use Case is under development in the InterFLEX project. Expected finalisation of the work is Q4 2019.

UC.2 Drawing or Diagram of Use Case

Drawing or Diagram of Function *– recommended "context diagram" and "sequence diagram" in UML*



UC.3 Step by Step Analysis of Use Case

UC.3.1 Steps – Normal Sequence

Function Name :		*DSR activation*				
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Technical Requirements ID
1	Data acquisition	DSO-SCADA monitors nodal voltages of the power grid.	R11, CIGRE LV	DSO-SCADA	Measured Voltage	
2a	DSO-SCADA logic actuation	If the average of the latest 10 node voltage measurements is higher than a predefined threshold, no flexibility request is sent.	R11, CIGRE LV	DSO-SCADA	Measured Voltage	
2b	DSO-SCADA logic actuation	If the average of the latest 10 node voltage measurements is lower than a predefined threshold, a flexibility request is produced.	R11, CIGRE LV	DSO-SCADA	Measured Voltage	

3	Flexibility request to RTU	If event 2b happens, the DSO-SCADA sends a flexibility request to RTU.	DSO-SCADA	RTU	Flexibility Request Signal	
4	Flexibility activation	RTU sends the flexibility activation request to FLEX	RTU	FLEX	Flexibility activation signal	
5	Flexibility dispatch	The FLEX injects all its amount of flexibility into R11	FLEX	R11, CIGRE LV	Active Power	

UC.3.2 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Use Case Name :		Voltage Support				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
N/A	N/A	N/A	N/A	N/A	N/A	N/A

7.2 BAP template

BAP.1.1 Identifiers

BAPs ID	USE CASE ID	Standards
BAP 3.1 and BAP 4.1	VoltSupp_case study 1	

BAP.1.2 Version Management

Changes / Version	Date	Name Author(s) or Committee	Domain Expert	Area of Expertise / Domain / Role	Title	Approval Status draft, for comments, for voting, final
Version 1	10/10/2019	Amir Ahmadifar and Mirko Ginocchi	RWTH University	Power Systems & Statistics	PhD students	Final

BAP.1.3 Referenced Documents/ Terms/ Definitions

Source(s) / Literature	Link	Conditions (limitations) of Use
xDSL technologies description	https://www.etsi.org/technologies/fixed-line-access/xdsl	
xDSL technologies description	https://whatis.techtarget.com/reference/Fast-Guide-to-DSL-Digital-Subscriber-Line	
Baromètre des connexions Internet fixes en France métropolitaine	https://media.nperf.com/files/publications/FR/2019-01-09_Barometre-connexions-fixes-metropole-nPerf-2018.pdf	
Fiber/Local Ethernet description	https://www.intelligentfiber.com/products/ethernet-private-local-area-network/	
IEEE 802.3-2012 - IEEE Standard for Ethernet	https://standards.ieee.org/standard/802_3-2012.html	

Terms	Definitions
N/A	N/A

BAP.1.4 Functionality

Scope and Objectives of Functionality
The focus lays on the lower bound of activating the flexibility via a direct access from DSO to the sources of flexibility while setting the telecommunication architecture as specified in BAIOP 1. The goal of the present study is to analyse interoperability between the different actors after a disruption in the context of voltage support. This is done by observing the interactions

between different input factors and outputs, which can be related to all the factors involved in the system under study (DSO-SCADA, RTU and FLEX).

BAP.1.5 Analysis of the Standard(s)

Analysis
The specific technology configurations of the two BAPs considered in this document are reported in Table 2. These specific values used to characterize the communication technologies for the interfaces DSO-SCADA ↔ RTU and RTU ↔ FLEX are decided in order to represent InterFLEX demo-specific implementations. For further details, the reader is referred to list of referred documents in sub-section BAP 1.3.

7.3 BAIOP template

BAIOP.1.1 Identifiers

BAIOP ID	***BAPs ID***	***USE CASE ID***
BAIOP1	BAP 3.1 and BAP 4.1	VoltSupp_case study 1

BAIOP.1.2 Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	***Domain Expert***	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 1	10/10/2019	Amir Ahmadifar and Mirko Ginocchi	RWTH University	Power Systems & Statistics	PhD students	Final

BAIOP.1.3 Referenced Documents/ Terms/ Definitions

Source(s) / Literature	***Link***	***Conditions (limitations) of Use***
Voltage Disturbances / Standard EN 50160	http://copperalliance.org.uk/uploads/2018/03/542-standard-en-50160-voltage-characteristics-in.pdf	
RTU technical specification	https://www.honeywellprocess.com/library/marketing/tech-specs/SC03-300-101-RTU-2020.pdf	This document has been used for defining the MIN-MAX range for the input factor “RTUProcT”
Flexibility technical specification	http://www.imperial.ac.uk/grantham/energy-storage/	This document has been used for defining the MIN-MAX range for the input factor “FlexRespT”
Flexibility technical specification	https://forschung-energiespeicher.info/en/projektschau/gesamtliste/projekt-einzelansicht/95/Batteriespeicher_mit_5_Megwatt_Leistung/	This document has been used for defining the MIN-MAX range for the input factor “FlexRespT”

Flexibility technical specification	Eid C., Codani P., Perez Y., Reneses J., Hakvoort R., *Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design*, Renewable and Sustainable Energy Reviews, Volume 64, 2016, Pages 237-247	This document has been used for defining the MIN-MAX range for the input factor "FlexRespT"

Terms	***Definitions***
N/A	N/A

BAIOP.1.4 Scope and Objectives of BAIOP

Scope and Objectives of Functionality
As mentioned in Deliverable 3.2 of the InterFLEX Project, one of the main super categories of EU flexibility services offered by DSOs, i.e. voltage support, is considered in this test environment. The scope of BAIOP1 is to describe how the set of interfaces DSO-SCADA ↔ RTU and RTU ↔ FLEX can contribute to voltage support. The focus is on the voltage deviation due to the injection of some interoperability disturbances (in this case, active power injection at a specific node). For this, a reference grid (Cigre LV residential feeder) is considered, with a predefined number of flexible loads. The input factors for the interoperability disturbances are related to the actors of the system under test.

BAIOP.1.5 Testing process

BAIOP.1.5.1 Pre-Test Definitions

Pre- Test Definitions	
Evaluation Criteria	In the system under test, the interoperability test will be in the simple form "pass/fail", as defined below: If $t_{res} = \infty \rightarrow fail;$ $else \rightarrow pass$ in which t_{res} is the time that takes the system to restore its voltage back to value that satisfies the desired allowable voltage deviation (AVD) set by DSO in terms of percentage, i.e., In other words, t_{res} represents the time that system takes to respond to the voltage support mechanism after a disturbance in the power grid. -
Specification of EUT	
Technical Specification	The DSO SCADA is intended to be characterized by *AVD* which is selected based on the desired quality of service that the DSO wants to deliver. Furthermore, the DSO SCADA is constantly measuring the nodal voltages (V_{meas}), detects deviations and restorations (if any) in terms of t_{res} and V_{res} for restoration time and voltages, respectively.
Operational specifications	It is also supposed that the grid boundaries and regulations are followed by the DSO.
Initial Criteria	The grid loads are at their nominal values and there is no disturbance in the grid. Regarding the communication infrastructure, the communication links between different actors are 100% reliable.
Specification of SUT	

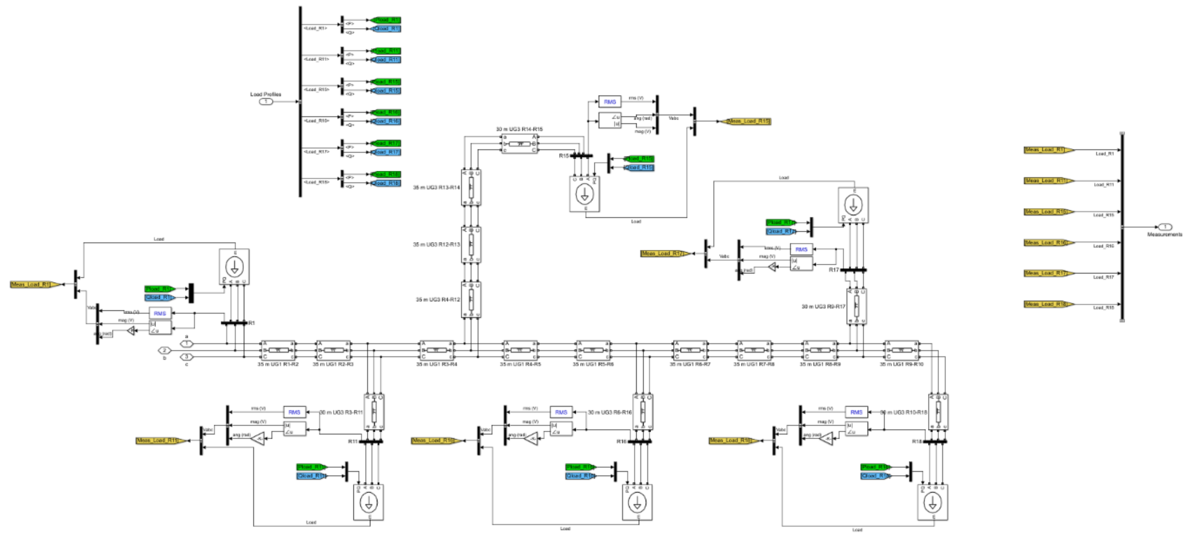
Test Bed	AIT Lablink simulation and middle-ware framework has been utilized. For communication platform between different actors, the network emulation is utilized. CIGRE European LV distribution network benchmark model was used as the reference grid and was simulated using the OPALRT real-time simulator.
Devices/ Equipment	The three components of DSO Supervisory Control and Data Acquisition (SCADA), Real Terminal unit (RTU), and (FLEX) are running on three Raspberry Pi single board computers
Technical Specifications	See BAIOP 1.3
Operational Specifications	See BAOPI 1.3
Configuration	The reference grid model is running in normal condition without any disturbance.
Interfaces/ Communication Infrastructure	A network emulator (NRL CORE) running on a laptop with UBS-to-RJ45 connectors is used to emulate the behavior of the communication infrastructure. The power grid is running on an Opal-RT station. Interfaces are Simulink model and the laptop which contains the network emulator
Service Access Point	SMARTEST laboratory infrastructure at AIT
Special Equipment	N/A
Software	Simulink, Opal-RT, NRL-CORE, MATLAB Simulink
Metering and control infrastructure	Nodal real time voltage measurements
Measuring values	Measured voltage and restoration time at the predefined node
Others	
Ambient Conditions	Ambient temperature in the lab is kept within a range of 20-25°C

Human Intervention	An operator has to initiate the power module and change manually the values of the input factors, then starting the session. Automation of the procedure can be taken into account in future steps.
Staffing and training needs	Simulink and Lablink general knowledge, Laboratory trained personnel
Security Aspects	AIT Lablink and SMARTEST safety procedures

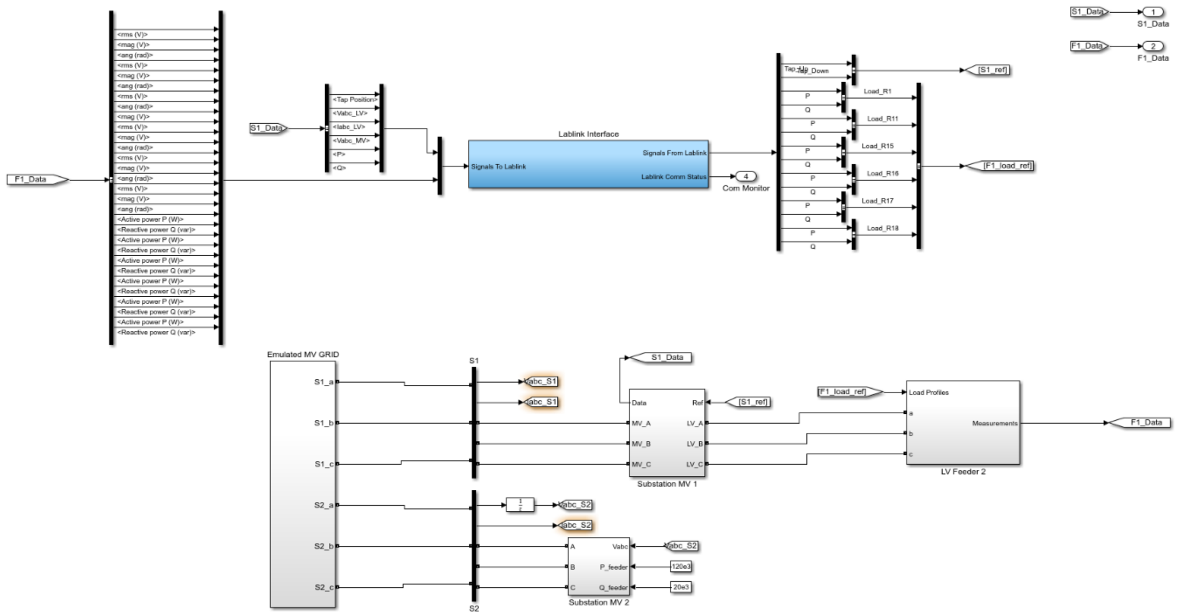
8 ANNEX B – TESTBED COMPONENTS

8.1 Real-time Power Grid Simulator

The real-time simulator used for this project is an Opal-RT 5600. The Opal System is operated via RT-Lab, the software suite provided by the manufacturer. Models for the real-time simulator are prepared using MATLAB/Simulink. Part of the CIGRE LV benchmark model, i.e., the model of the residential feeder, is shown Figure 8-1(a). Once finalized and tested offline, the Simulink model is converted to C code by RT-Lab using Simulink coder, then compiled and executed on the real-time simulator.



(a)



(b)

Figure 8-1: Real-time simulation model and data exchange interface. (a) sample Simulink model of the residential feeder of the CIGRE LV EU benchmark network, (b) Simulink to AIT Lablink interface.

8.2 Power Grid Model

In order to conduct the interoperability laboratory tests, there was a need for a reference grid. As an initial idea, there was a decision to model one of the demonstration power grid. However, in order to avoid any bias towards any specific demo, the LV distribution network benchmark proposed by the European Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources Task Force C6.04 is used [Cigre]. It is noteworthy that using the proposed grid model removes the dependency of results to any specify demo but at the same time could be mapped to the European context of flexibility services and DER integration which is also in line with InterFlex demo implementations. Furthermore, as distribution installation common practices vary greatly between North America and Europe, choosing the proposed benchmark grid removes any negative impact on the interoperability testing results which could originate from grid parameters.

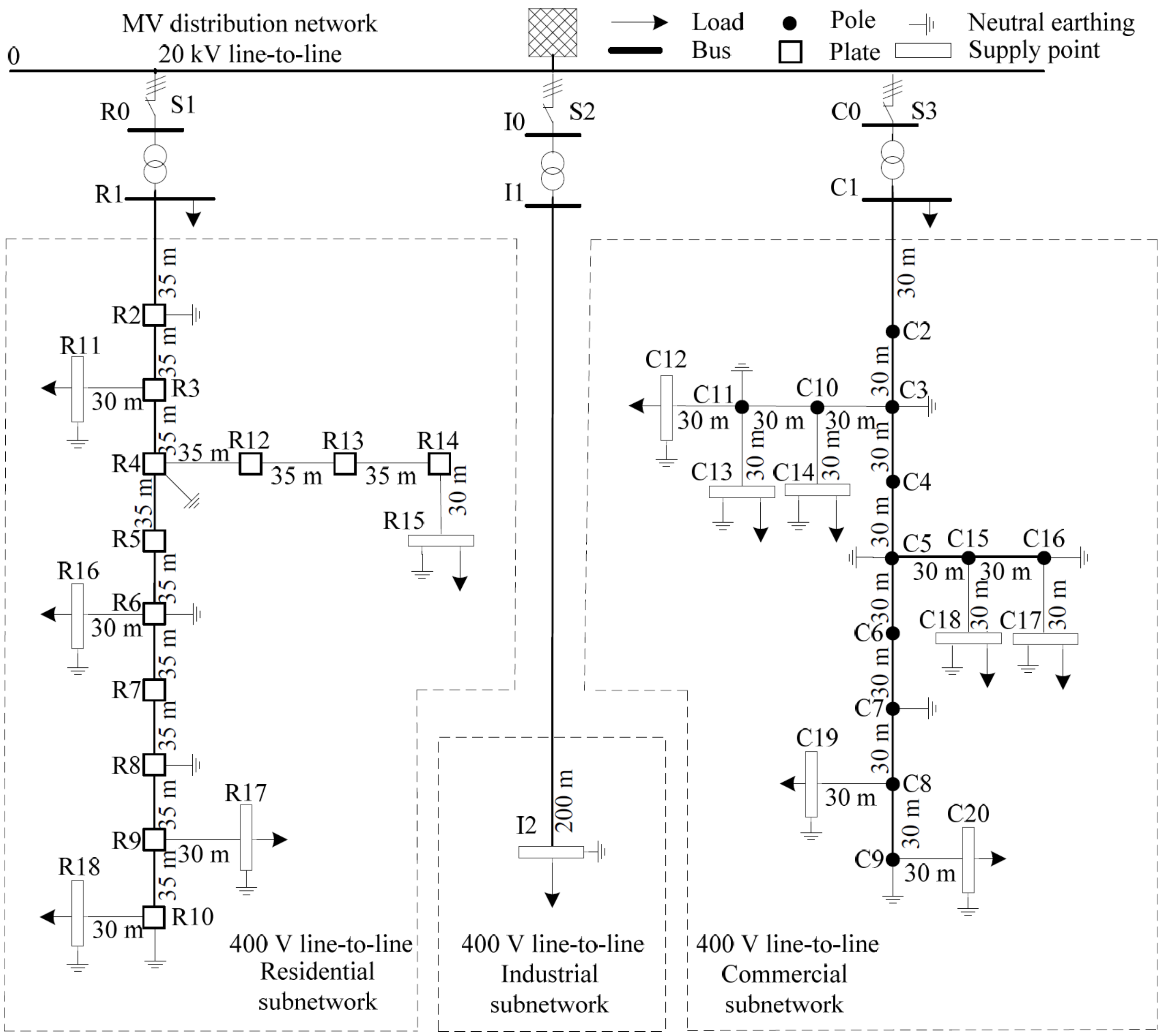


Figure 8-2: topology of the European LV distribution network benchmark

The low-voltage (LV) distribution benchmark network consists of three feeders of a residential, industrial, and commercial character, respectively. In figure [grid topology], the topology of the European LV distribution network benchmark could be observed which was modeled in MATLAB Simulink. For the interoperability testing, the residential feeder was chosen as the power grid under the test.

8.3 Middleware

AIT Lablink is a middleware for developing distributed co-simulation for HIL, PHIL, CHIL or another such variant. It is also possible to do both real-time and/or emulated real-time simulations using it. It not only provides the communication middleware for the co-simulation but also has useful services for running and scenario creations. The AIT Lablink is mainly written in Java. Its API library is available in Java but it is equally possible to use it from other languages like Python. It is possible to get free access to AIT Lablink's core library. Further information about the usage and licensing is available at https://ait.ac.at.

8.4 Storage System

This section briefly introduces the testbed used for conducting the Case Study 5. Brief technical specification of the inverter and battery are provided here. However, the full specification of the system can be viewed

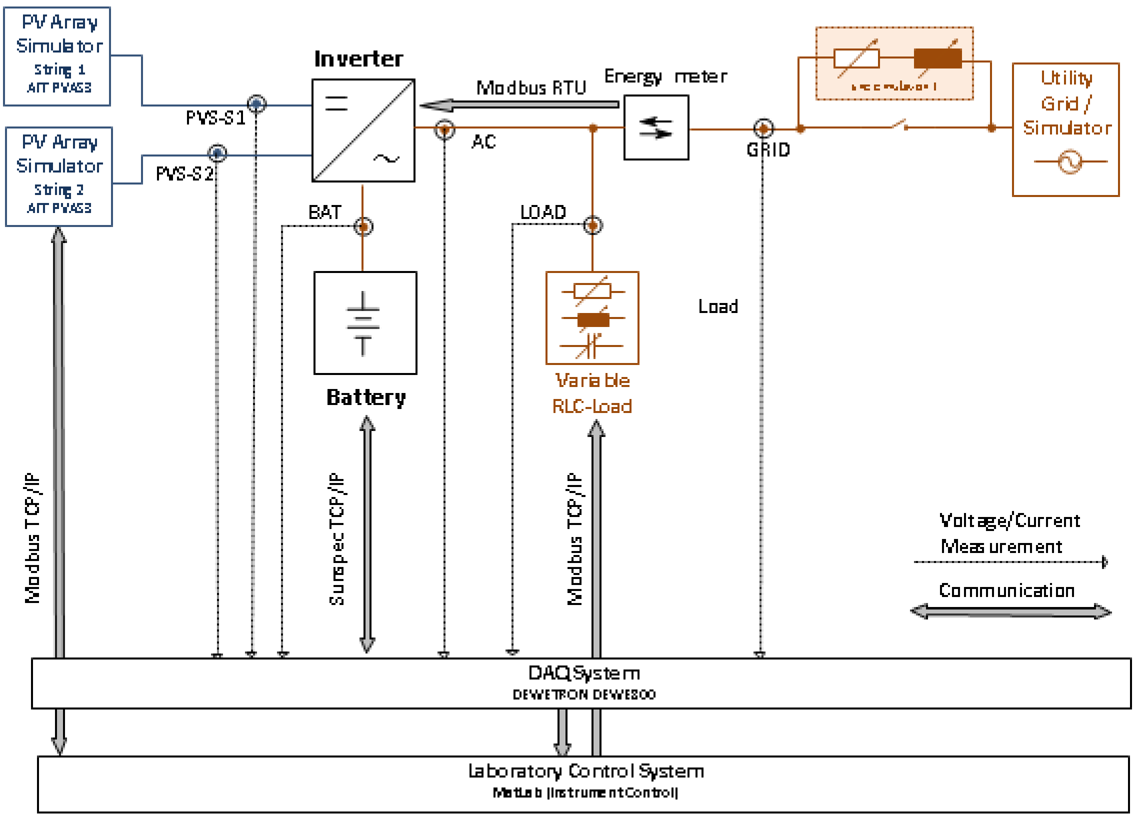


Figure 8-3: AIT SmartEST Inverter Laboratory schematic.

The test environment at the AIT SmartEST Inverter Laboratory developed by AIT consists of a three phase AC test grid. PV simulators are used to vary the generation power and a load emulator can be used to vary the electrical demand. The equipment under test is a bidirectional DC coupled hybrid inverter from Fronius, connected to a 9.6 kWh battery from Sony. The state of charge of the battery is read out over SunSpec[30] TCP/IP and the battery power set points are controlled over this Modbus TCP/IP protocol. The power is measured at

[30] https://sunspec.org/

the measurement points shown in the Figure 8-3. Some technical data for Fronius inverter and battery storage system are provided in Table 8-1 and Table 8-2 while the detailed data sheets can be downloaded from the Fronius web site (https://www.fronius.com).

Table 8-1: Technical data for Fronius Symo Hybrid.

INPUT DATA	SYMO HYBRID 3.0-3-S	SYMO HYBRID 4.0-3-S	SYMO HYBRID 5.0-3-S
Number of MPP trackers	1		
Max. PV input power	5.0 kW	6.5 kW	8.0 kW
Max. input current ($I_{dc\ max}$)	1 x 16 A		
Max. short circuit current, module array	24 A		
DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$)	150 - 1000 V		
Feed-in start voltage ($U_{dc\ start}$)	200 V		
Usable MPP voltage range	150 - 800 V		
Number of DC connections (PV)	2		

BATTERY INPUT	SYMO HYBRID 3.0-3-S	SYMO HYBRID 4.0-3-S	SYMO HYBRID 5.0-3-S
Maximum output power to battery	Depends on connected Fronius Solar Battery		
Maximum input power from battery	Depends on connected Fronius Solar Battery		

OUTPUT DATA	SYMO HYBRID 3.0-3-S	SYMO HYBRID 4.0-3-S	SYMO HYBRID 5.0-3-S
AC nominal output ($P_{ac,r}$)	3,000 W	4,000 W	5,000 W
Max. output power	3,000 VA	4,000 VA	5,000 VA
Max. power from grid to battery	3,000 VA	4,000 VA	5,000 VA
Max. AC output current ($I_{ac\ max}$)	8.3 A		
Grid connection (voltage range)	3-NPE 400 V / 230 V or 3-NPE 380 V / 220 V (+20 % / -30 %)		
Frequency (frequency range)	50 Hz / 60 Hz (45 - 65 Hz)		
Total harmonic distortion	< 3 %		
Power factor ($\cos \phi_{ac,r}$)	0.85 - 1 ind. / cap.		

GENERAL DATA	SYMO HYBRID 3.0-3-S	SYMO HYBRID 4.0-3-S	SYMO HYBRID 5.0-3-S
Dimensions (height x width x depth)	645 x 431 x 204 mm		
Weight	19.9 kg		
Degree of protection	IP 65		
Protection class	1		
Overvoltage category (DC / AC) [1]	2 / 3		
Inverter design	Transformerless		
Cooling	Regulated air cooling		
Installation	Indoor and outdoor installation		
Ambient temperature range	-25 - +60°C		
Permitted humidity	0 - 100 %		
Max. altitude	2,000 m (unrestricted voltage range)		
DC PV connection technology	2x DC+ and 2x DC- screw terminals 2.5 - 16 mm²		
DC battery connection technology	1x DC+ and 1x DC- screw terminals 2.5 - 16 mm²		
AC connection technology	5-pin AC screw terminals 2.5 - 16 mm²		
Certificates and compliance with standards	VDE AR N 4105, ÖVE / ÖNORM E 8001-4-712, DIN V VDE 0126-1-1		
Emergency power function	Yes		

EFFICIENCY	SYMO HYBRID 3.0-3-S	SYMO HYBRID 4.0-3-S	SYMO HYBRID 5.0-3-S
Max. efficiency (PV - grid)	97.7 %	97.9 %	
Max. efficiency (PV - battery - grid)	> 90.0 %	> 90.0 %	> 90.0 %
Europ. efficiency (PV - grid)	95.2 %	95.7 %	96.0 %
MPP adaptation efficiency	> 99.9 %		

Table 8-2: Technical data for Fronius Solar Battery.

ELECTRICAL PARAMETERS	BATTERY 4.5	BATTERY 6.0	BATTERY 7.5	BATTERY 9.0	BATTERY 10.5	BATTERY 12.0
Usable capacity [1]	3.6 kWh	4.8 kWh	6.0 kWh	7.2 kWh	8.4 kWh	9.6 kWh
Cycle stability	8,000 [1]					
Voltage range	120 - 170 V	160 - 230 V	200 - 290 V	240 - 345 V	280 - 400 V	320 - 460 V
Nominal charging power	2,400 W	3,200 W	4,000 W	4,800 W	5,600 W	6,400 W
Nominal discharge power	2,400 W	3,200 W	4,000 W	4,800 W	5,600 W	6,400 W
Max. charging current	16 A					
Max. discharge current	16 A					

GENERAL DATA	BATTERY 4.5	BATTERY 6.0	BATTERY 7.5	BATTERY 9.0	BATTERY 10.5	BATTERY 12.0
Battery technology	LiFePO4					
Dimensions (height x width x depth)	955 x 570 x 611 mm					
Weight	91 kg	108 kg	125 kg	142 kg	159 kg	176 kg
Degree of protection	IP 20					
Protection class	1					
Installation type	Indoor installation					
Ambient temperature range	5 - 35°C					
Permitted humidity	0 - 95 %					
DC connection technology	Screw terminals 2.5 - 16 mm²					
Calendar service life	> 20 Years [2]					
Certificates and compliance with standards	IEC/EN 62133; EN 61000-6-2:2005, EN 61000-6-3:2007 + A1:2011, EN 62311:2008, FCC Part 15 Subpart B:2012 ClassB, UN 38.3					

INTERFACES	BATTERY 4.5	BATTERY 6.0	BATTERY 7.5	BATTERY 9.0	BATTERY 10.5	BATTERY 12.0
Connection to inverter	Modbus RTU (RS485)					

8.5 Controller Models

The models of DSO-SCADA, RTU, and Flexibility have been implemented as shortly detailed in the next three sub-sections.

8.5.1 SCADA

The implementation of the logic behind the DSO-SCADA model is schematically shown in Figure 8-4.

```
% set initial conditions
      Vmeas_IN = [];
      Vref = 399.99;
      Threshold = 0.05;

% start collecting the voltage measurements
      for n = 1:10
            Vmeas_IN(n) = [Vmeas_IN; Vmeas_IN(n)];
      end

% Compute the mean of the latest 10 voltage measurements
      Vmeas_mean10 = mean(Vmeas_IN(1:10));
```

Figure 8-4 Logic implemented in the DSO-SCADA model

In the system under test, the interoperability test will be in the simple form "pass/fail", as defined below:

If $V_{error}^{i} < AVD \rightarrow pass;$

$$else \rightarrow fail$$

where $V_{error}^{i} = \left|\frac{V_{ref}^{i} - V_{meas}^{i}}{V_{ref}^{i}}\right|$, (for the moment with $i = 1$, i.e., the system behavior is analyzed only at one specific node of the power grid)

In particular,

- V_{meas}^{i} and V_{ref}^{i} are respectively measured and reference voltages at node i.
- *AVD* is the "admitted voltage deviation", which is the maximum allowed value from which the node voltage, in percentage, can deviate with respect to the reference voltage. This parameter is meant to be a DSO-oriented factor, and the influence of its variability on the system outputs (together with that of the other considered input factors) is studied.

8.5.2 RTU

The logic behind the RTU model is schematically shown in Figure 8-5.

```
% set initial conditions

      RTU_Proc_T = 0;


% check whether there is a request from SCADA. If yes, send the activation
signal to FLEX

      if send_request_to_RTU == 1

            send_request_to_FLEX = 1;

            elseif send_request_to_FLEX = 0;

      end
```

Figure 8-5 Logic implemented in the RTU model

8.5.3 FLEX

The implementation of the logic behind the FLEX model is schematically shown in Figure 8-6.

```
% set initial conditions
      Power_at_node_11 = 0;
      FLEX_Proc_T = 0;
      FLEX_Cap = 156750;

% check whether there is a request from RTU. If yes, inject the amount
of Flexibility specified by Flex_Cap, after waiting for "Flex_Resp_T"
time;
      if send_request_to_FLEX == 1

            FLEX_Proc_T = FLEX_Proc_T + 70 s;

            Power_at_node_11 = Power_at_node_11 + FLEX_Cap;

      end
```

Figure 8-6 Logic implemented in the FLEX model

It is noteworthy that for the simulations, the CIGRE LV grid is chosen as a reference grid and the focus is towards the flexibility activation mechanism in this context. As for this grid, a dominant resistive behaviour for the lines is observed, the selection of the flexibility source in terms of injection of active power is justified. In fact, reactive power-based flexibility for the test bench could be quite easily integrated but the obtained results in terms of the voltage-support (the amount of restored voltage) were not convincing based on the grid simulations. Instead, keeping in mind the assumptions for the location of the disturbance and the source of flexibility (reported in Annex A above), the flexibility is considered in terms of the injection of active power for the grid under study.

8.5.4 EV and Charging Stations

One of the charging stations from the InterFlex partner ElaadNL is used in the validation tests in Case Study 6. Due to the remote location, the access was provided through a web portal. The charging station is an OCCP 1.6 compliant device. The further technical details and specification please consult the ElaadNL website at https://www.elaad.nl/.