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Table of contents

Acronyms and abbreviations

AMI	Advanced Metering Infrastructure
BAU	Business As Usual
BMS	Battery Management System
CI	Control Indicator
COX	Control Centre Room (Centre d'Operacions de la Xarxa)
CP	Communication and Processing
CT	Current Transformer
DAB	Dual Active Bridge
DCU	Data Concentrator Unit
DMS	Distribution Management System
DSO	Distribution System Operator
EMU	Electrical Measurement Unit
EPU	Electrical Protection Unit
ESB	Enterprise Service Bus
ESG	Electrical Switchgear
HESS	Hybrid Energy Storage System
ILEM	Intelligent Local Energy Manager
LV	Low Voltage
MC	Measurement and Control module
MV	Medium Voltage
PCC	Point of Common Coupling
PED	Power Electronics Device
PMU	Phase Measurement Unit
PQM	Power Quality Monitor
PS	Primary Substations
PSA	Power Sharing Algorithm
PSU	Power Supply Unit
PT	Voltage Transformer
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SS	Secondary Substation
WAMS	Wide Area Moitoring Sistem

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Executive Summary

This report is the second document redacted within the work package dedicated to the validation of RESOLVD in the real environment. It presents the key hardware technologies deployed in the network. The pilot is mainly composed of two Low Voltage (LV) lines, deriving from two different secondary substations, that withn the project, have been linked through the construction of a third line , giving birth to a ring-shaped structure. The key technologies are: (1) Three switchgears will be installed in three strategic points, and permit the grid reconfiguration scenarios, through remote control. (2) The Power Electronics Device (PED) will be installed in one of the two secondary substations, connected to one of the two feeders under consideration. (3) The Wide Area Monitoring System (WAMS) field infrastructure, composed of (3.a) Phase Measurement Units (PMUs) and (3.b) Power Quality Monitors (PQMs) encompass not only the LV network of the pilot, but also the Medium Voltage (MV) lines and secondary substations upstream, to properly check the contribution of the PMU devices in fault detection and localization. To monitor the status of the network and control the grid actuators (PED and switchgears) from the Supervisory Control and Data Acquisition (SCADA), the communication infrastructure needs to be upgraded.

The document also provides a description of the initial pilot set-up, both in terms of physical configuration and complete guidelines for the key technolgoies deployment. Finally, it contains other relevant information of key technologies. It was prepared following a collaborative approach, to have a more holistic and shared vision of what the consortium wants to achieve during the validation phase of the project.

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1. Introduction

1.1. Objectives

The purpose of this document is to present a guideline for the hardware solution deployment on the field. To achieve that, firstly, the electrical specifications and characteristics of the key technologies deployed are introduced. Then, a pilot description and the independent interventions are presented. Finally, the technology deployment is depicted.

1.2. Report structure

This document reports the feedback related to the hardware devices deployment and the actions carried out to transform the pilot into the RESOLVD solution. The document also details the process of integration and includes the telecommunication between the deployed devices and the legacy system (i.e. SCADA system).

The document is structured in the following way: firstly, the objectives and report structure are presented in this chapter (Chapter 1). Then, in Chapter 2, the key technologies are described in detail, including the technical specifications and characteristics. In Chapter 3, the pilot description and interventions are indicated, including the PED and batteries location, the deployment of electrical switchgear, the telecommunication infrastructure, and all the questions related to the WAMS technology. Chapter 4 summarizes how the needed intervetions mentioned in Chapter 3 are scheduled and implemented in the pilot, taking into account all possible previous works before the disconnection and also the works during the scheduled disconnections. Chapter 5 enumerates the conclusions of the hardware deployment.

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2. Hardware devices

2.1. Introduction

This chapter presents the key hardware solutions that are going to be installed in the RESOLVD pilot to improve the efficiency and the hosting capacity of distribution networks, in the context of highly distributed renewable generation by introducing flexibility and control in the low voltage grid.

Chapter 2 presents these technologies, divided in the following subsections:

- Subsection 2.2 details the three switchgear will be installed in three strategic points, and permit the grid reconfiguration scenarios, through remote control.
- Subsections 2.3 and 2.4 specify the PED and Hybrid Energy Storage System (HESS)
- Subsections 2.5 and 2.1 introduce the key technolgoies of the WAMS i.e. the Phase Measurement Unit and Power Quality Monitor.
- Finally, subsection 2.1 presents the Remote Terminal Unit (RTU) in charge of communicating to SCADA the grid measurament and facilitating the remote control of the grid assets.

2.2. Electric switchgear

The RESOLVD pilot will utilize three switchgear devices to change the grid configuration. The switchgear is constituted by the base and the motor; the base contains the protection device, and the motor permits to open and close the switch remotely.

The base depicted in Figure 1 includes some relays that protect against:

- A temporal overcurrent relay with a rated current value configurable.
- Two short-circuit overcurrents relays: a relay instantaneous, and another relay with a regulable delay—both realys with a rated current value configurable.
- A neutral overcharge and short-circuit relays.
- A ground fault relay configurable.

Figure 1 Base of the switchgear

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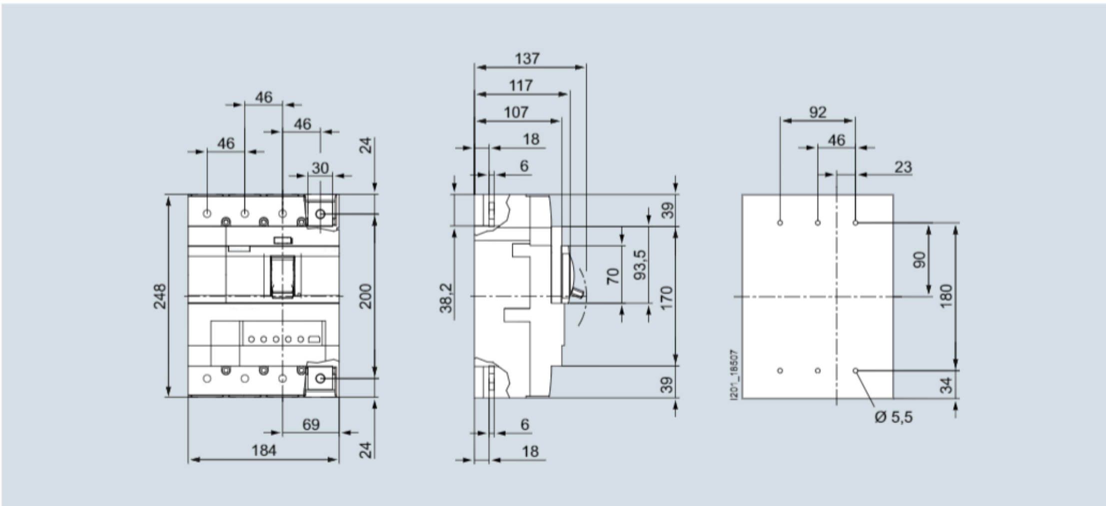
Table 1 indicates the switchgear base technical specifications, and Figure 2 depicts the switchgear base dimensions.

Table 1 Switchgear base specifications

Specification	
Manufacturer	Siemens
Rated current	400 A
Temporal overcurrent	140 …160 A
Short-circuit with delay	240 … 4000 A
Instanteneous short-circuit	600 … 6000 A



3VA23 y 3VA24, 4 polos

Figure 2 Switchgear base dimensions

The switchgear motor depicted in Figure 3 is characterized by the following attributes:

- It can be remotely activated via control signal received through a cable
- It has a visible indicator of the switch position (ON/OFF)
- It has a LED light indicates the automatic switching.
- It fulfills the standard related to islanding processes established in IEC/EN 60947-1.
- It has the possibility to lock the control of the switchgear to avoid non-authorized maneuvers

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Figure 3 Motor of switchgear

Table 2 presents the switchgear motor specifications.

Table 2 Switchgear motor specifications

Specification	
Type of protection	IP 20; IP 30
Possibility to lock it	With three locks (diameter: 4,5 mm – 8 mm)
Nominal voltage	48 V DC
Closing time	< 500 ms
Opening time	< 500 ms
Nominal power	250 W/250 VA (max 500 W/500 VA, 60 ms)

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2.3. Power Electronic Device (PED)

The Power Electronic Device is a high modular and reliable power converter specifically designed and built for the project purposes (WP2). Its compact design, as Figure 4 presents, permits to be easily integrated in a non-intrusive way with the low voltage grid.

Figure 4 PED cabinet without front door

The PED provides advanced services like:

- A four-quadrant controllable storage system, i.e. it can exchange active and reactive power with the grid.
- Power quality functionalities, i.e. it manages to balance downstream three-phase currents, compensate downstream reactive power, and mitigate downstream harmonic currents.
- A stable and controlled island, i.e. after an external grid blackout it can reenergize an isolated grid to supply loads and generators. In addition, when the external network is restored, it can resynchronize this isolated system to this external grid to finish the island operation without a blackout.

The PED integrates a HESS at different voltage levels with galvanic isolation in between thanks to its Dual Active Bridges (DABs) converters.

An Intelligent Local Energy Manager (ILEM) is in the PED. The ILEM is responsible for the whole PED solution according to the operator's setpoints.

The whole solution can be operated locally (via a web application) and remotely (via Modbus TCP/IP). Also, according to the requisites, the PED can be scheduled along 24-hour to exchange energy from its HESS. The Power Sharing Algorithm (PSA) based on this 24-hour schedule is in charge of distributing it among the battery types embedded, looking for the maximum performance and the minimum degradation of batteries.

The design of the PED was carried out in [1], and the requested technical features were:

- AC output power up to 75 kVA for low voltage distribution networks (400 V and 50 Hz)
- 1 DC input power up to 20 kW for a storage system from 315 V to 385 V (detailed below)
- 1 DC input power up to 20 kW for a storage system from 200 V to 270 V (described below)

The technical specifications of the PED are sumarized in the following tables:

- Table 3 presents the electrical specifications,
- Table 4 details the communication specifications, and
- Table 5 presents the mechanical specifications.

Table 3 PED electrical specification

Specification		
Inverter stage topology	4-wires 3-phase bridge split capacitor	
AC rated power	75 kVA	
Rated AC voltage (phase to neutral)	400 V (230 V compatible)	
AC Voltage range	85% - 110% (according to EN 50438)	
AC Frequency	50 Hz (60 Hz compatible)	
AC Rated current	108.6 A	
DC/DC stage topology	DAB (galvanic isolation)	DAB (galvanic isolation)
DC rated power	20 kW	20 kW
Rated DC voltage	345 V	240 V
DC voltage range (at rated power)	315 V – 385 V	200 V- 270 V
DC rated current	63.5 A	100 A

Table 4 PED communications specifications

Specification	
Supported protocols	CAN bus, Modbus RTU and Modbus TCP/IP
BMS interaction	CAN bus and Modbus RTU
PED interaction	Locally through web application Remotely through Modbus TCP/IP

Table 5 PED mechanical specifications

Specification	
Working temperature	-10 ºC – 40 ºC
Cooling	Forced-Air
IP and IK protection	IP54 and IK10
Weight AC part	~ 180 kg
Weight DC part	~ 200 kg
Dimensions	1900 mm height x 800 mm width x 400 mm depth

Finally, to complement previous tables, Figure 6 presents a schematic where electrical interconnections and telecommunications interfaces are detailed, and Figure 5 plots the PED dimensions and non-occupancy area.

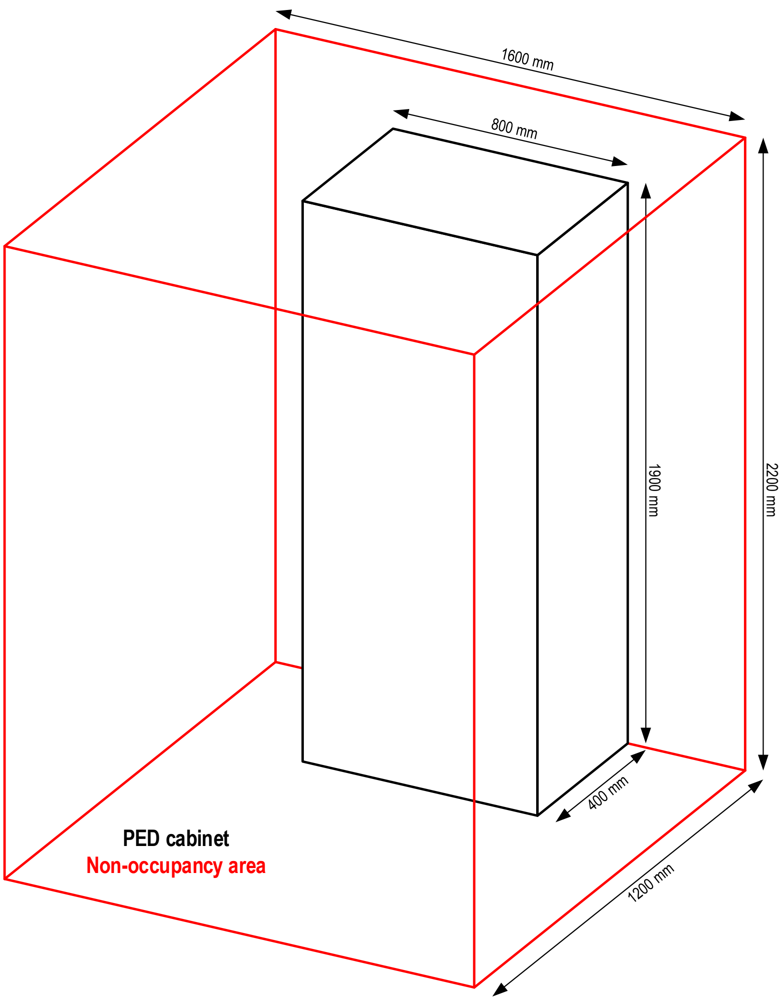

Figure 5 PED dimensions and non-occupancy area

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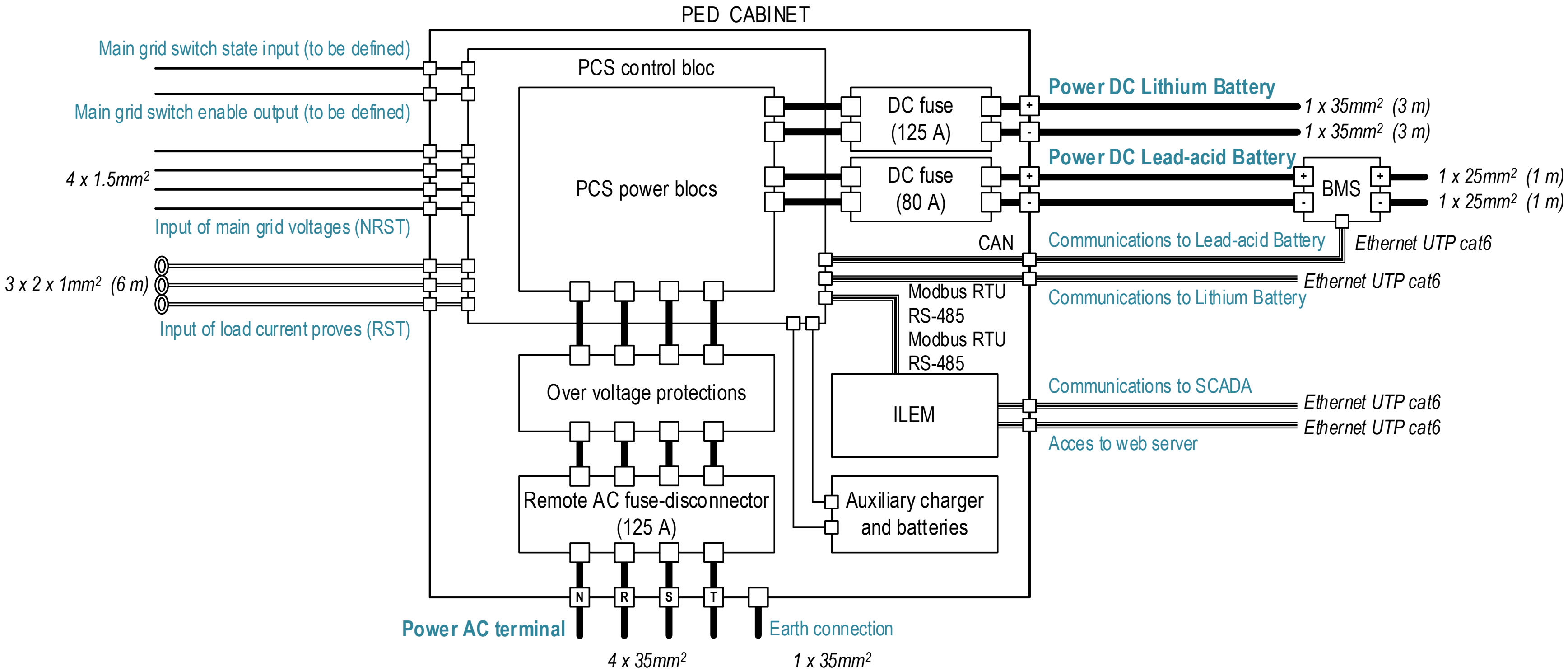

Figure 6 PED external connections

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2.4. Hybrid Energy Storage System (HESS)

A lithium battery pack and lead-acid battery pack constitute the HESS, and the PED interconnects them to the network. Figure 7 shows the lithium battery pack and Table 6 presents the specifications of this pack. Figure 8 shows lead-acid battery pack, and Table 7 details the battery pack specifications. Moreover, to complement this information, Figure 9 plots the PED dimensions and non-occupancy area of the HESS.

Figure 7 Lithium battery pack

Table 6 Lithium battery pack specifications

Specification	
Manufacturer	FENECON
Model	C PLUS 25
Nominal capacity and voltage	87 Ah (C/3)
Rated voltage	348 V nominal voltage for the whole pack, 3.2 V per cell.
Maximum discharge current	90 A (1C)
Discharge temperature	-15 ºC to 50 ºC (25 ºC recommended)
Charge temperature	0 ºC to 40 ºC (25 ºC recommended)
Efficiency (round trip)	94.7%

Figure 8 Lead-acid battery pack

Table 7 Lead acid battery pack specifications

Specification	
Manufacturer	Ultracell
Model	UCG75-12
Nominal capacity	75 Ah (C/10)
Rated voltage	240 V for the whole pack, 12 V per battery.
Maximum discharge current	900 A
Discharge temperature	-15 ºC to 50 ºC (25 ºC recommended)
Charge temperature	0 ºC to 40 ºC (25 ºC recommended)
Efficiency (round trip)	91.6% [1]

[1] This efficiency has been derived from the information in the datasheet. The number was not directly included in there.

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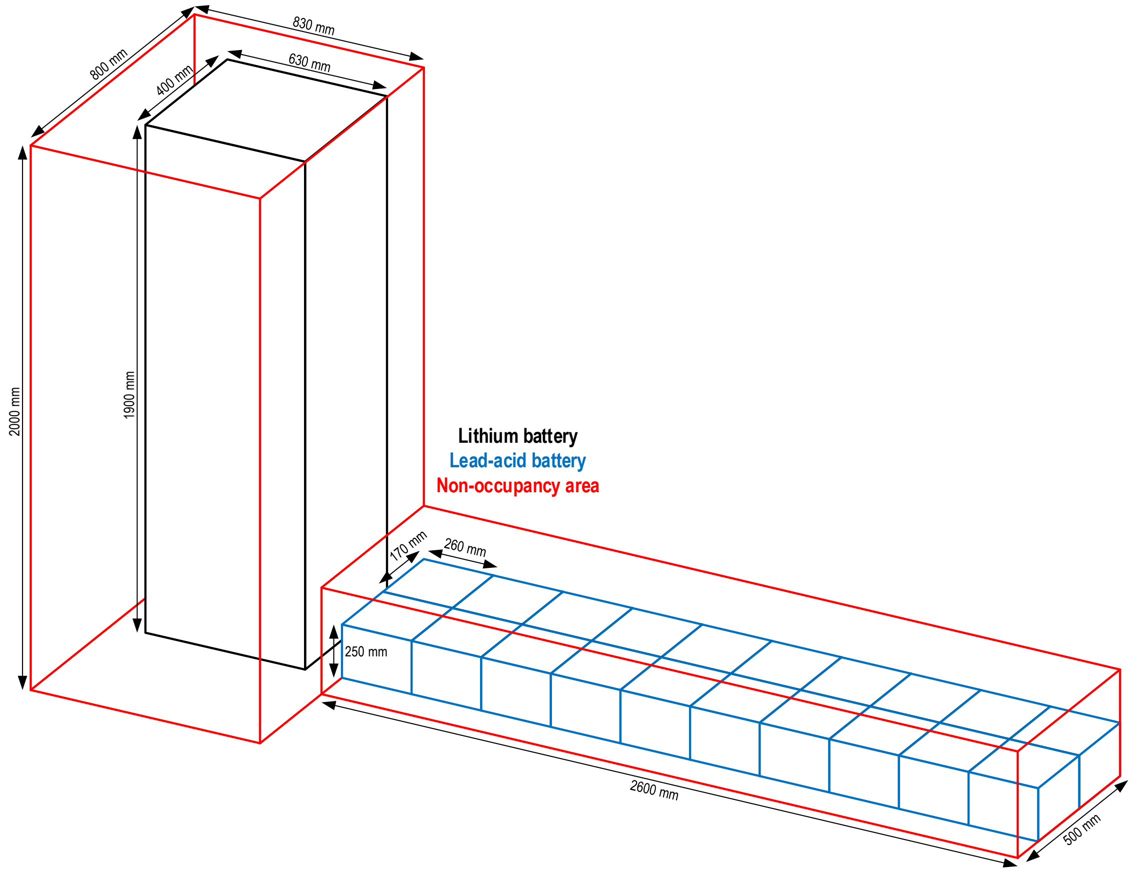

Figure 9 Non-occupancy area of HESS

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2.5. Phase Measurement Units (PMU)

The Phase Measurement Unit is a multifunctional metering and control electronic device which design has been adapted to the RESOLVD requirements for low voltage grid monitoring. It measures phasor data (for instance, currents, voltages, symmetrical components, and frequency information), voltage and current waveforms, and digital signals, with a high sampling data rate that enables to follow highly dynamical phenomena on all voltage levels of the grid.

The PMU offers versatility for different types of implementation on all stages of the power system from generation, transmission to the distribution, also in combination with modern trends as renewable sources, battery storages, charging stations, and among other applications. Figure 10 shows a PMU.

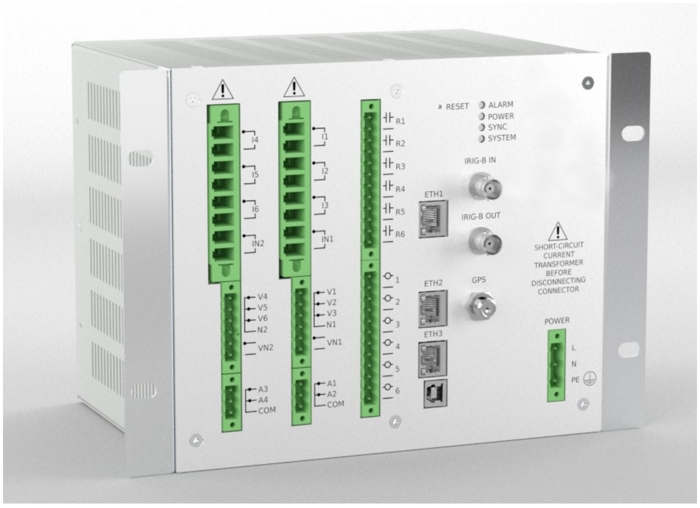

Figure 10. PMU device

Table 8 and Table 9 present the basic supported settings and its physical dimensions [2].

Table 8. Basic supported PMU settings profiles

Specification	
Reporting interface	Ethernet
IP transport	UDP, TCP
Format	C37.118.2-2011
Nominal frequency	50 or 60 Hz
Reporting rate (for 50 Hz)	10, 25, 50, 100, 200 ms
Reporting rate (for 60Hz)	10, 12, 15, 20,30, 60, 120, 240 ms
Reporting number format	Integer or float (IEEE 754)
Phasor format	Rectangular or polar

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Table 9. PMU device physical dimension

Dimension	
Width	209 mm
Height	178 mm
Depth	155 mm

The PMU needs to be connected to voltage and current transformers to get data from the network:

- Current transformers (CTs) to measures AC currents.
- Voltage transformers (PTs) to measure AC voltages.

Figure 11 shows the selected CT, and it is a split-core current transformer. Table 10 details its main characteristics.

Figure 11 The selected CT for PMU

Table 10. CT specifications

Specification	
Manufacturer	WAGO
Rated input current	600 A
Rated output current	5 A
Rated power	0.5 VA
Accuracy class	0.5
Cable length	3 m

Figure 12 shows the selected PT, and Table 11 presents its main features.

Figure 12 The selected PT for PMU

Table 11. PT specifications

Specification	
Manufacturer	Laboratorio Electrotecnico s.c.c.l
Rated input voltage	5250 V
Rated output votlage	110 V
Rated power	50 VA
Accuracy class	0.5

Additionally, the PMU has:

- Two DC 4-20 mA input to integrate analog sensors.
- Six digital inputs to integrate digital sensors or wired sources.
- Six digital outputs to control wired sources

According to the RESOLVD WAMS requirements, there are PMUs (deployed in MV network) that requires an embedded PC to process the measured data and posteriorly to transfer it to WAMS. And there are PMUs (installed in LV grid) that do not require this data processing. So that the data can be transferred directly to the WAMS through an LTE router.

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Figure 13 Embedded PC for processing the information from MV PMU

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The PMU also needs a GPS antenna, Figure 14 presents the selected solution and Table 12 details its main features.

Figure 14 GPS antenna

Table 12. GPS characteristics

Specification	
Product name	Trimble Bullet GG Antenna
Connector type	F-type
Cable possibilities	RG-6 (up to 30 m) or RG-11 (up to 80)
Mounted Pipe thread	¾ ''

Finally, Figure 15 summarizes the interconnections and interfaces of a PMU.

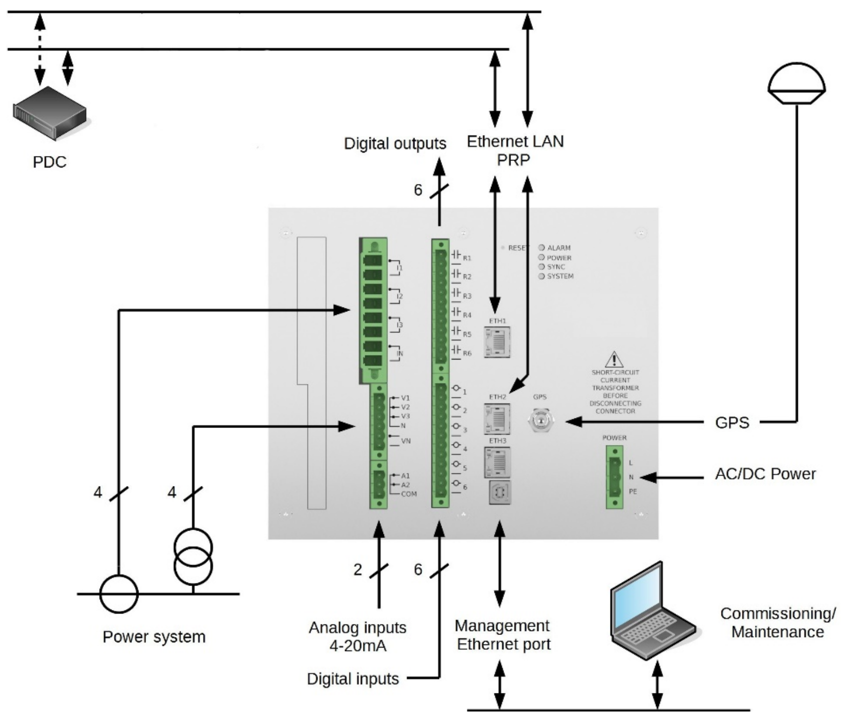

Figure 15 PMU device physical interfaces and wiring

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2.1. Remote Terminal Unit (RTU)

The Remote Terminal Unit is a microprocessor-controlled electronic device. It is used to interface objects in the physical world to the SCADA system. It is responsible for transmitting data to the system and controlling the connected objects. These objects can be switchgear, measurement equipment, etc. Figure 16 depicts the RTU used in RESOLVD pilot, which is a CAP-PRX and Table 13 details its specifications.

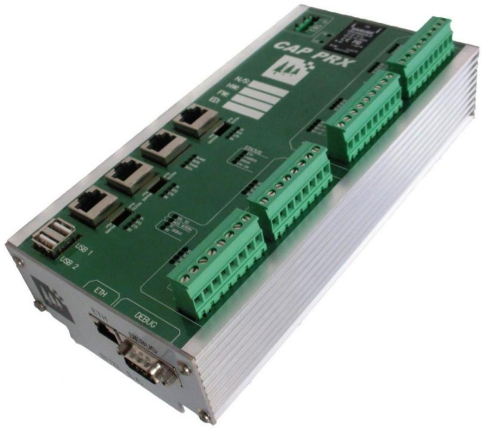

Figure 16 RTU device

Table 13 RTU specifications

Specification	
Provider	SITEL
Operative system	Embedded Linux
CPU	ARM 9 / 18 MHz architecture
Communication protocols	PROCOME and Modbus
Communications ports	2 x USB, 1 Ethernet
Other communications ports	Radio/GPRS
Digital inputs/outputs	16 inputs 8 outputs

2.2. Power Quality Monitor (PQM)

The Power Quality Monitor devices, together with PMUs, are the primary WAMS monitoring devices to supervise the MV and LV networks of the pilot.The PQM is a complete solution to measure and control LV grid and disposes of a multifunctional communication system.

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Figure 17 shows a PQM which has a form factor for DIN-rain mounting. It is composed by two hardware modules: the Communication and Processing (CP) and Measurement and Control (MC) modules.

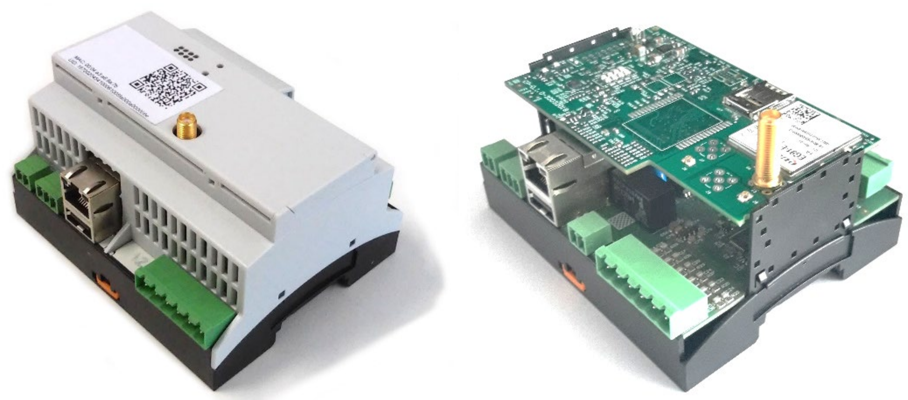

Figure 17. Design of integrated PQM device

The MC module is based on Microchip ATM90E36 integrated circuit, which is an integrated power quality measurement solution compliant with IEC62052-11, IEC62053-21, and IEC62053-23. standards. It embeds the calculation of all power quality parameters according to EN 50160. The data exchange between MC and CP modules is asynchronous. Table 14 presents the communication interfaces which the CP module supports.

Table 14 Communications specifications

Specification	
Supported protocols	LTE cellular connectivity, WiFi, Ethernet, USB and Modbus RTU

The PQM readily supports the 3-phase voltage measurements at 400 V, 3-phase current measurements using current transformers or Rogowski coils. Figure 18 shows and Table 15 details the selected current sensors.

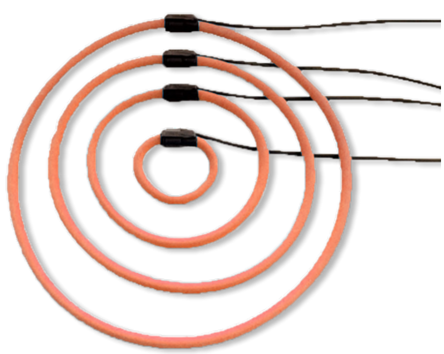

Figure 18 Rogowski Coil current sensor

Table 15. Rogowski current sensor specifications

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Specification

Type	Rogowski coils
Output	100 mV/kA
Maximum diameter	68 mm
Cable length	2 m

Finally, Figure 19 presents the physical layout of connectors and pins. L1, L2 and L3 are the lines voltage inputs, N the neutral line input N and PE the ground input. I1P and I1N, I1P and I1N, I1P and I1N are the current inputs. IN1, IN2 and IN3 are logical inputs with common line (ICOM), and OUT1, OUT2, OUT3 are logical outputs with common line (OOUT). 24V and PGND are DC supply lines.

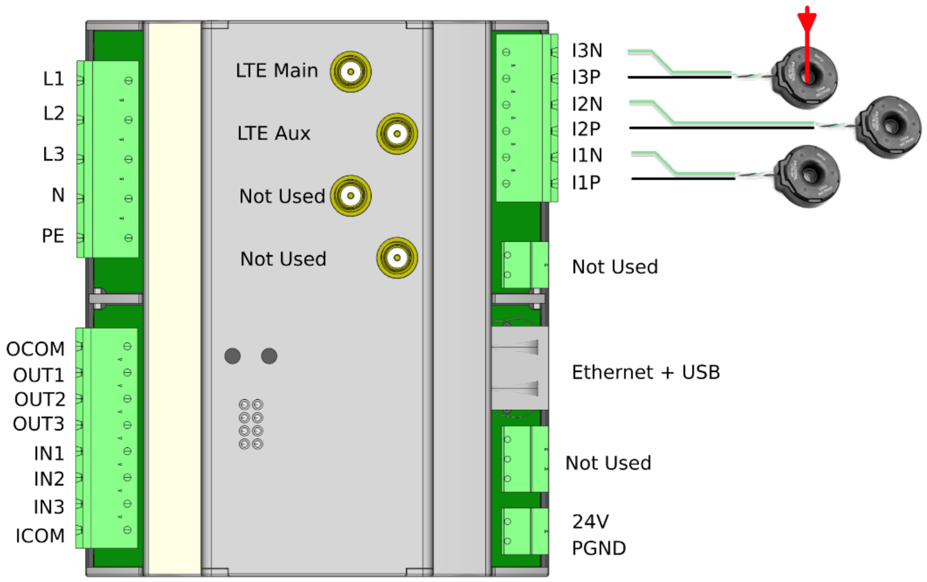

Figure 19. PQM device physical interfaces layout

3. Description of the interventions

3.1. Introduction

The objective of this section is to introduce the pilot and summarize the interventions that are needed to transform the real network into a a proper pilot validation environment. The pilot is presented in section 3.2, the interventions are reporeted into five sections. The first is the accommodation of the line to join the two low votlage lines (see section 3.3); the second intervention is related to the electrical switchgears and RTU deployment (presented in sections 2.2 and 2.1 respectively, see section 3.4); the third is to install the PED and HESS (presented in sections 2.3 and 2.4, see section 3.5); the forth intervention is to arrange the smart metering infraestruture (see section 3.6), and finaly, the fitfh intervention is to deploy the WAMS infrastructure (presented in sections 2.5 and 2.1, see section 3.7).

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3.2. Pilot case description

The pilot is composed by the grid in Figure 21. Part of it is marked in grey since not considered in the project. Hence, just the two radial networks from two secondary substations named SS-A and SS-B are under discussion. The pilot site in EyPESA's grid concerns aa area in which the majority of consumers are residential ones. Thus, every consumer presents a power demand lower than 10 kW peak. Some of these consumers are equipped with distributed generation (PV). Apart from them, there are two industrial consumers in the area, holding important percentage of the total power demand. These are not included in the pilot for the purposes of the project though.

The wwo low voltage lines mainly compose the pilot study case of RESOLVD. Initially, they are fed by two independent Secondary Substations (SS), as Figure 20 presents. In addition, the blue arrows represent the costumers supply points, while the yellow circles stand for the prosumers PV installations. Finally, Table 16 indicates the contracted and installed power of consumers and prosumers.

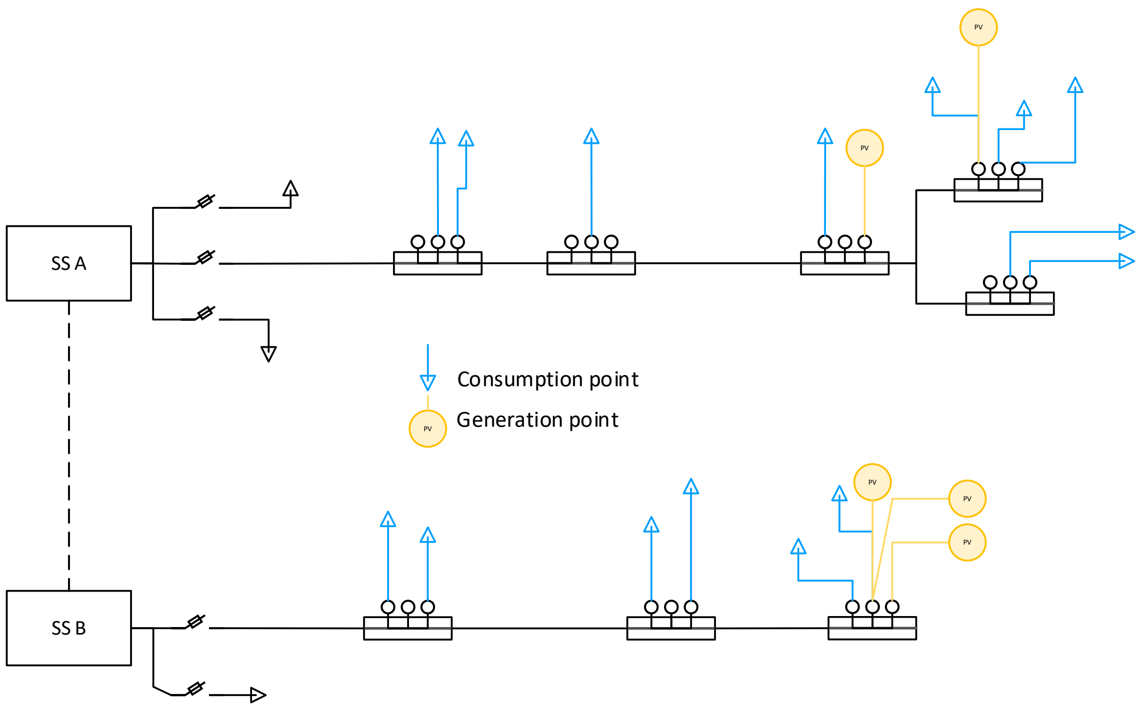

Figure 20: Schematic of the pilot area of RESOLVD

Table 16: Rated power and contracted power values of SS-A and SS-B

Secondary Substation	SS A	SS B
Contracted power	58.3 kW	56.9 kW
PV power installed	12.5 kW	9.9 kW

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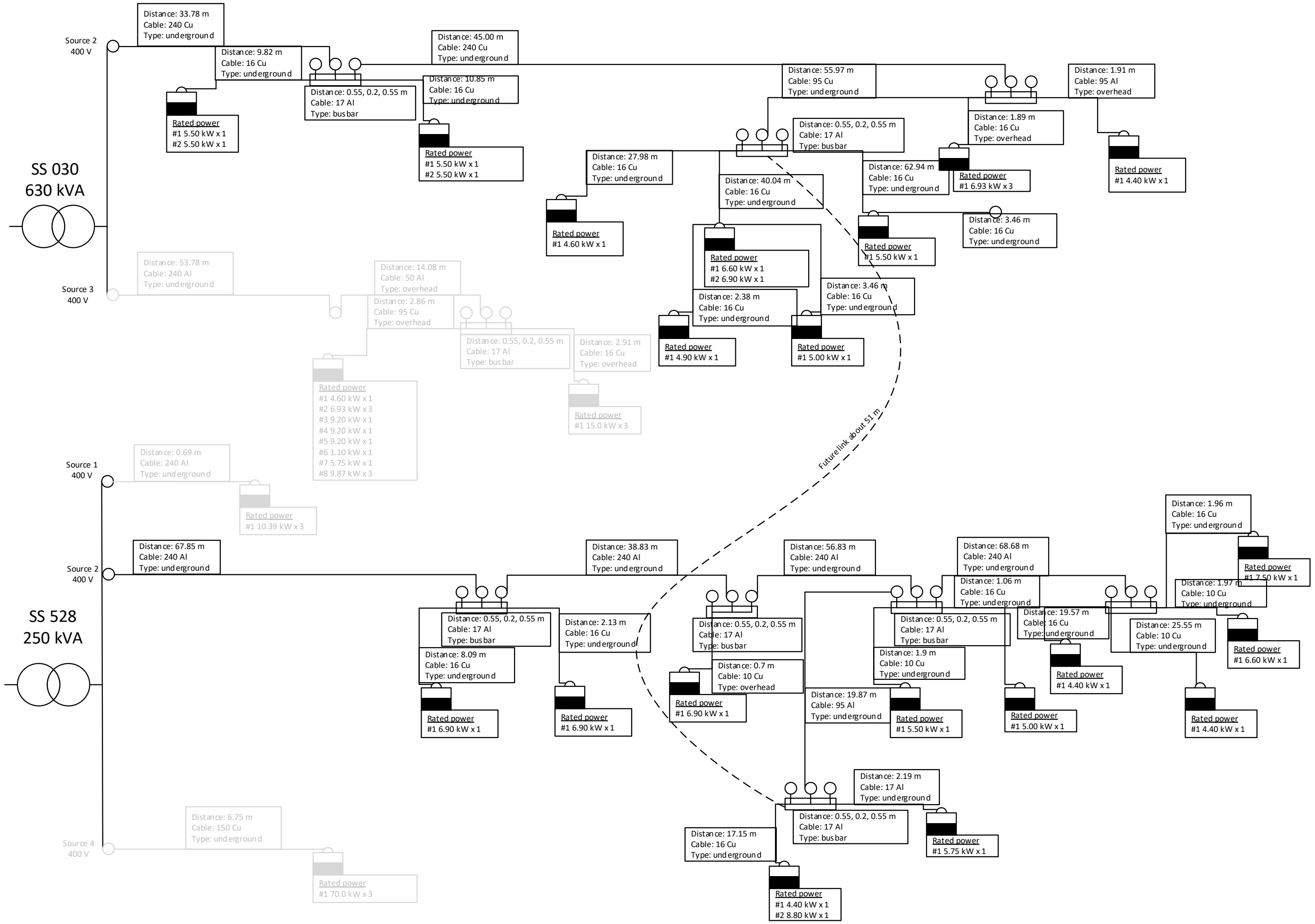

Figure 21 PIlot network characteristics

3.3. The first intervention: a new LV line

The first intervention is to link both radial low voltage lines and create a ring shape through a line. This line connects the two lines where the distance is the minimum, connecting the end of SS-B L2 line and the middle of SS-A L2, as Figure 23 depicts.

The new line must be installed between two distribution boxes; at the end of the SS-B line, there is a distribution box; however, in the middle of SS-A line, there is no distribution box, so the installation of a new one is required. Also, inside of this box must be reserved space to accommodate orther grid assets (further introduced). Figure 22 depicts this first intervention.

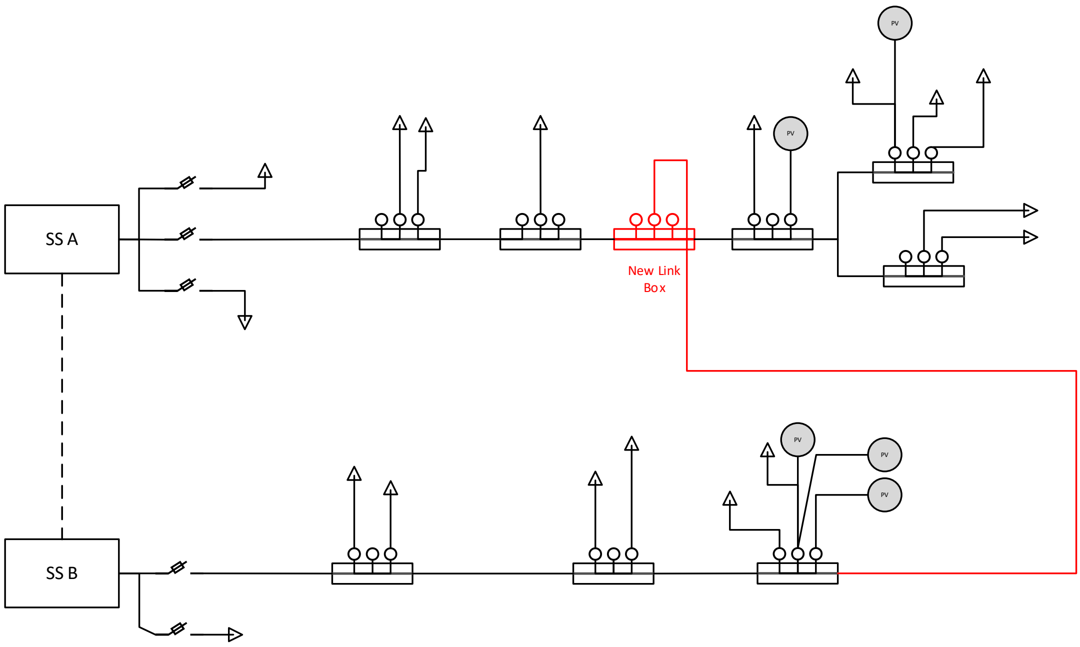

Figure 22: Pilot infrastructure after the first intervention

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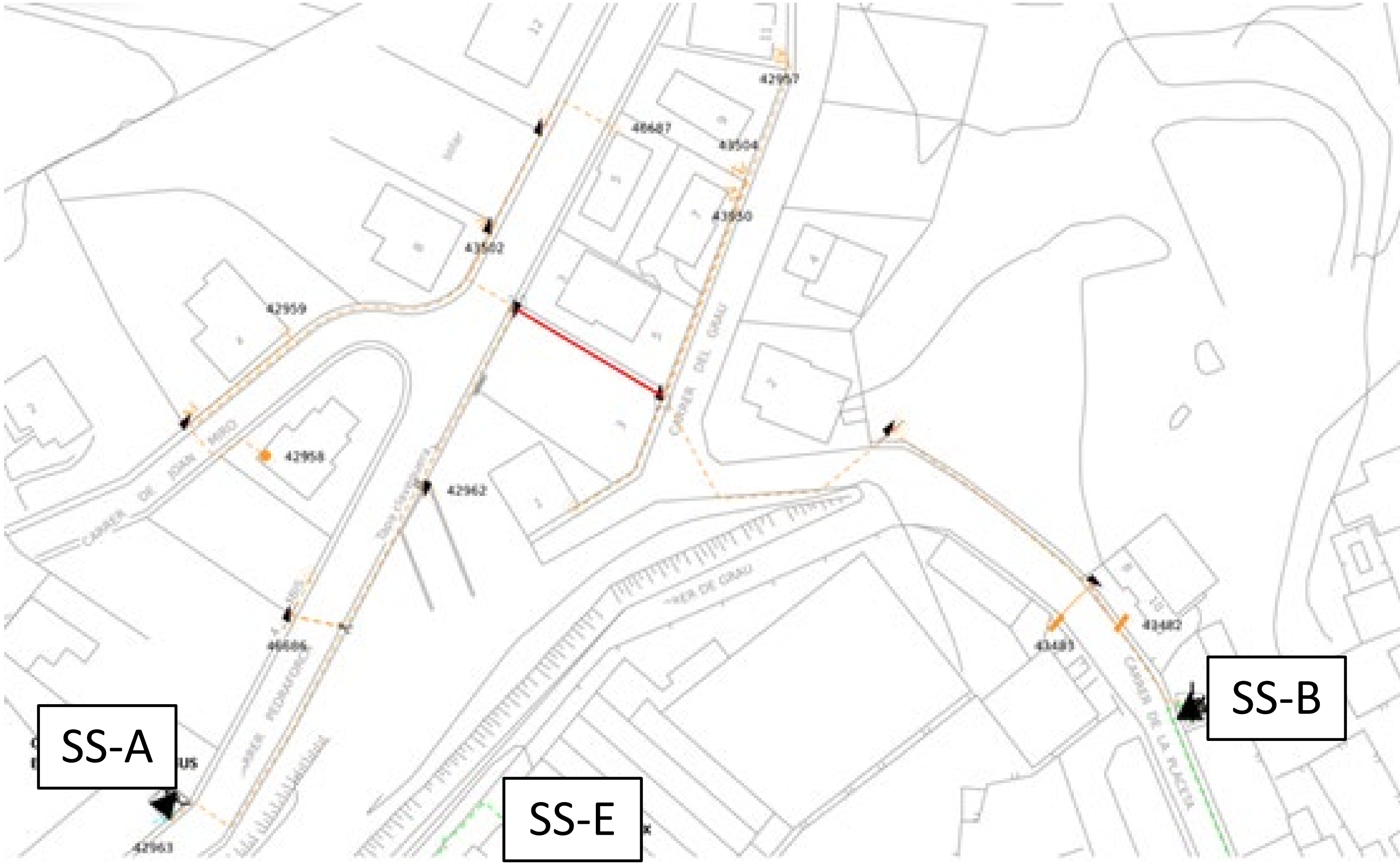

Figure 23: Low voltage diagram with the new LV line marked in red

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3.4. The second intervention: new automated and controlled switchgears.

Three switchgears have been installed. The switchegears must be controllable remotely to allow the grid reconfiguration, for example to avoid a congestion or to permit self-healing manoeuvres. In addition, they are also capable to protect the network against the short-circuits and overcurrent situations. Figure 24 indicates the switchgear location selected, marked in red. It should be noted that the switchgears require a RTU and a Power Supply Unit (PSU) in order to be controlled and monitored. These units should be placed next to the switchgear and must correctly communicate with the SCADA system.

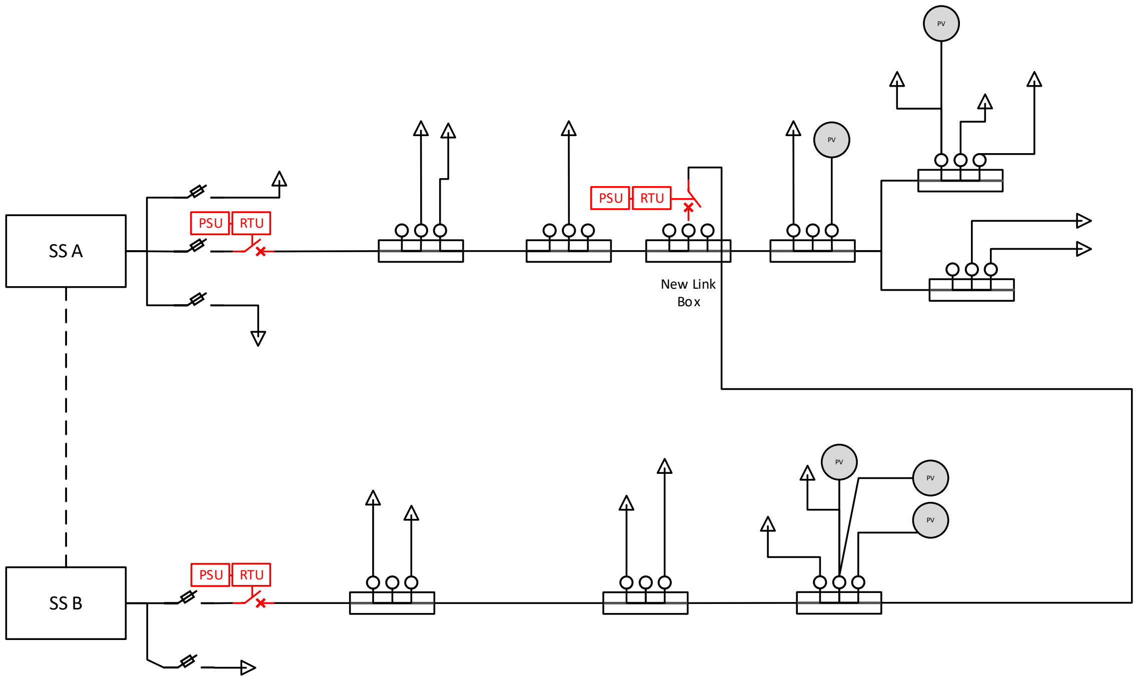

Figure 24: Pilot infrastructure after the second intervention

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3.5. The third intervention: installation of PED and batteries

According to the analysis performed in previous tacks the PED and batteries are installed in SS-B. Initially, there were three main feasible and interesting locations for connecting the PED in the pilot site. In Figure 25, these are noted as LOC1, LOC2 and LOC3. LOC1 and LOC2 correspond to the secondary substations SS A and SS B respectively. LOC3 is placed across the above mentioned new line interconnecting the two radial branches.

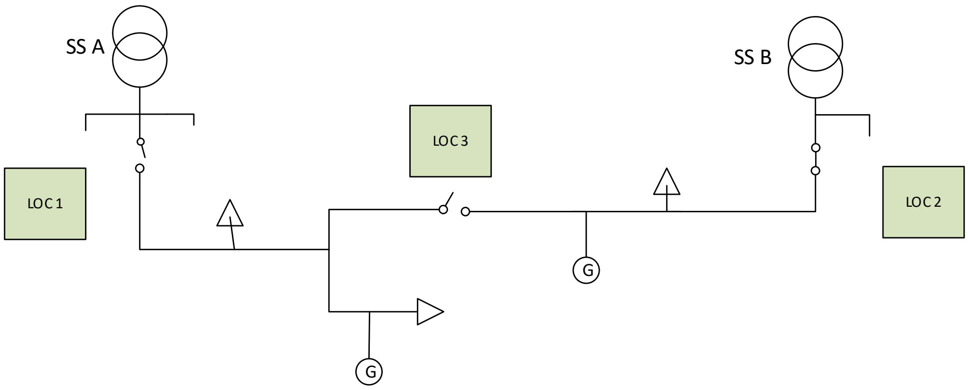

Figure 25 Simple schematics of the pilot network with the three studied locations

The location and sizing of the PED and the hybrid energy storage system performed in the context of the WP2, took into account several aspects such as: i) the requirements of the use cases in RESOLVD; ii) available budget; iii) performance of the eligible energy storage technologies; iv) business exploitation potential of the solution.

In general terms, to install the PED in a secondary substation is preferable than doing it throughout the LV network. It helps to maximize the effectiveness while exchanging reactive power, compensating harmonics and power unbalances among the three phase distribution system. Technically both SS A and SS B are eligible and valid locations, even, the eventual interconnection of the two systems may even ease the decision on the location of the PED, since it could be able to provide services to all consumers, regardless its association to one or another SSs.

Thus, for the final decision on the location of the PED, the available space at each SS comes into play at this point. Available space in SS B is bigger than in SS A. SS B has two floors and all equipment is installed on the ground floor as depicts Figure 26 . The first floor is empty and could be used to install the PED. So, batteries and PED are installed on the first floor, as it can offer a higher space availability.

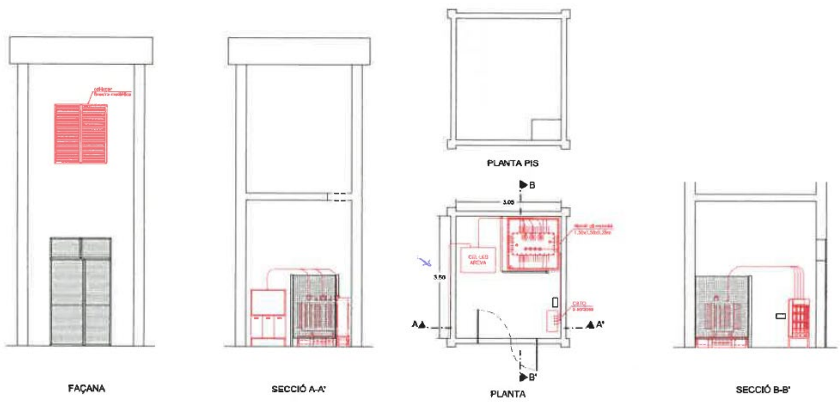

Figure 26 SS B schematics

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Figure 27 presents the electrical scheme of this third intervention. Note that the batteries and the Battery Management System (BMS) will be electrically connected to the PED by a cable. Also, all the communication connections converge into the communication box, which is located on the ground floor. Finally, the PED is connected downstream the LV switchgear which is installed in the second intervention in a new junction point.

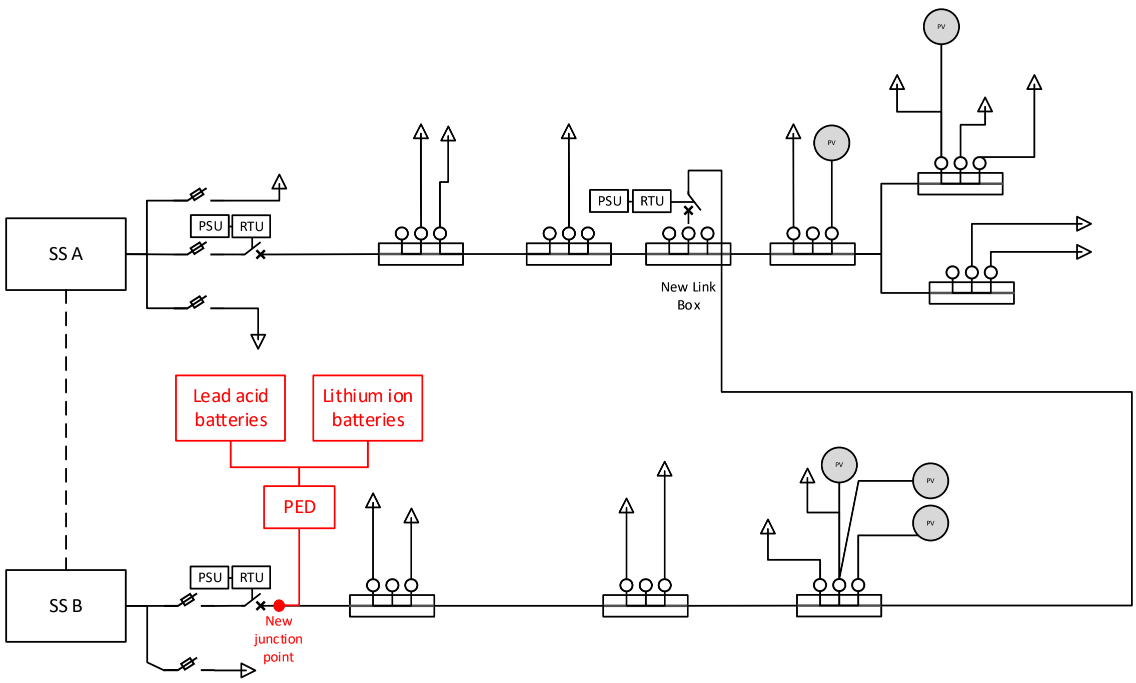

Figure 27: Pilot infrastructure after the third intervention

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3.6. The fourth intervention: installation of smart metering infrastructure

In order to better analyze the energy exchanged between the pilot area, the batteries and the rest of the grid, and to evaluate the performance and efficiency of the technology, it was also decided to install smart meters at the beginning of the two feeders and in the point of common coupling (PCC) of the PED. In Figure 28, they are marked in red.

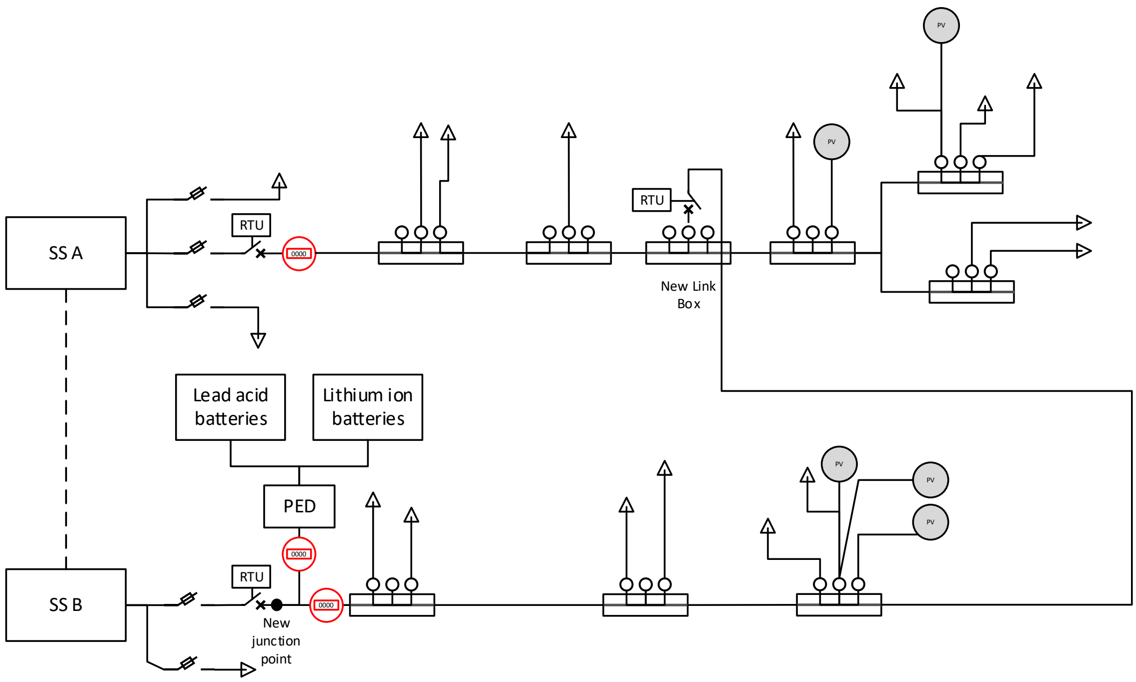

Figure 28: Pilot infrastructure after the forth intervention

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3.7. The fifth intervention: installation of WAMS (PMUs and PQMs) in the low voltage grid and medium voltage grid.

The in-field components of the Wide Area Monitoring System are PMUs and the PQMs. Even though the RESOLVD pilot is focusing on the LV segment of the network, the WAMS will take into account the borders of the pilot, encompassing MV level to demonstrate with more quality the contribution of the PMU devices in fault detection and localization. PMUs are deployed both on the low voltage (inside the RESOLVD pilot area) and on the medium voltage sides (outside the RESOLVD pilot area). PQMs are installed in the low votlage grid. In addition, each PMUs requires a GPS antena, an Embedded PC with a SIM card and a PSU, while the PQMs are compact solutions which integrate a SIM card to communicate with WAMS.

The red labels indicate the locations of PMUs and PQMs in the low voltage grid or pilot case (see Figure 29), and medium voltage grid (see Figure 30). Note that Figure 30 depicts the MV network upstream of the LV pilot area (connected through SS-A and SS-B).The different boxes labelled as SS-A, SS-B, SS-C, SS-D, SS-E and SS-F are the secondary substations composing the MV network and connected to the Primary Substations (PS).

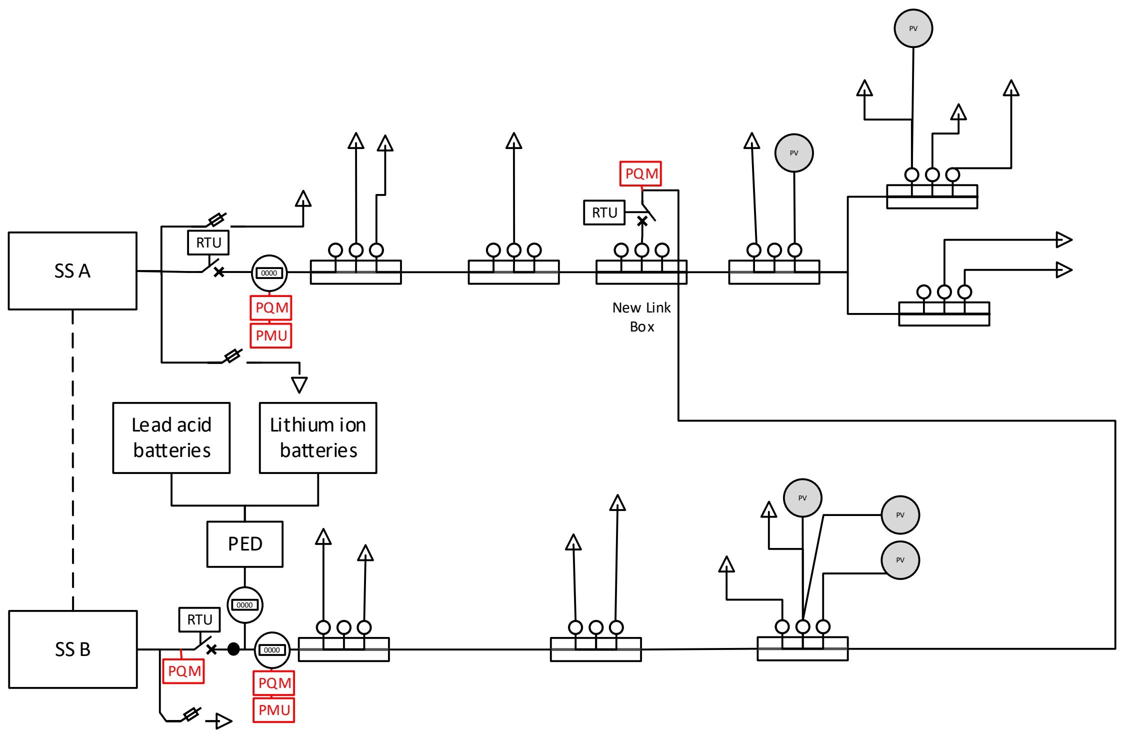

Figure 29: Pilot infrastructure after the fiffh intervention

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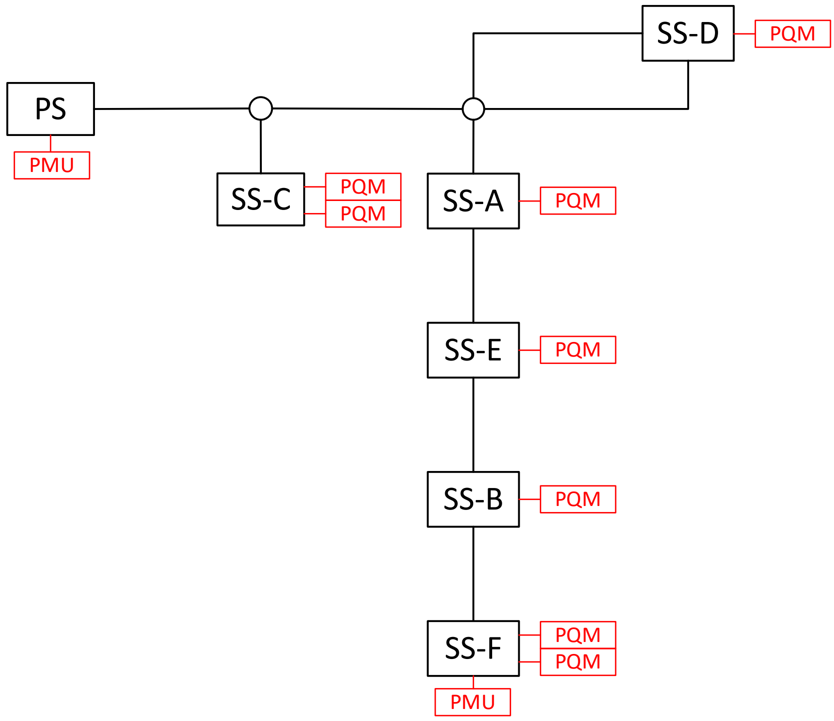

Figure 30 Wider area of pilot infrastructure after the firth intervention

There are two PMUs connected to the two end points of the network (PS and SS-F) at MV level, and 1 or 2 PQMs in each of the 6 secondary substations, connected at the output of the transformer (LV level), to measure the load flow of each node of the network.

PMUs and PQMs analyze the power waveform and thus need connected voltage and current measurements inputs. The voltage and current ranges permitted by these devices necessitate the installation of voltage and current transformers.

The reason why in SS-C and in SS-F, two PQMs are needed, is because in these substations there are two parallel LV boards at different voltage levels, one at 400 V line to line and the other at 230 V line to line.

The LV PMUs voltage measurement inputs are rated 430 Vac rms line to line and 110 Vac rms through voltage transformers with a 5250V/110V ratio, thus, in the case of the two PMUs installed at MV level, it is necessary to use voltage measurement transformers. In the case of the primary substation an equivalent equipment is already present, while for SS-F, it will be necessary to install a new one.

Measurement transformers are needed also for the current inputs, both for PMUs and PQMs at MV and LV level.

The communication will be ensured by the presence of an embedded gateway in each PQM. In the case of the PS, where there is no PQM, an UNO-2372G embedded PC will be installed. The WAMS technology will operate on an independent network with respect to the DSO's LAN, to ensure a faster and more effective communication.

The installation of an extra PQM device on L2 of SS-B was necessary, to permit an effective calculation of the KPIs related to the performance of the PED.

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4. Deployment of hardware solutions on the field

4.1. Introduction

The objective of this section is to summarize how the needed intervetions mentioned in Chapter 3 are scheduled and implemented in the pilot, taking into account all possible works without requiring network disconnection and also the works during the scheduled disconnections. That is why each major intervention is divided in two subsections, "Previous Works" and "During the Network Disconnection".

The implementation in the pilot of all the equipment needed to develop the project has been divided in four major interventions, all of them requiring network disconnection during a certain amount of time.

The first intervention consists of connecting the end of SS-B to the DSPD box, with the previous work of preparing the new line. This intervention is related to the Section 3.1 where the ideal case scenario is described.

The second intervention consists of changing the transformer of the substation SS-A, it is a major intervention but not much previous work is needed. It has been necessary to assure the same voltage reference system for both lines being interconnected. This intervention has not been described in Section 3 because it does not represent a new installation, but just an adequacy action, necessary to connect the lines of the two secondary substations in ring configuration. In Section 4.3 the specific reason of this unplanned intervention is developed.

The third intervention consists of the installation of the PED and the switchgear, together with the polishing of the second intervention via some changes in the DSPD box layout. This intervention encounters its ideal counterparts in Sections 3.2 and 3.3, except for the DSPD box layout modifications that as already said were unexpected.

The forth intervention consists of the installation of a voltage transformer in the MV level, and the further connection of the WAMS (PQMs, and PMU) at medium and low voltage level. These interventions are related to the Section 3.5 and consist of the installation of a current transformer in the MV level of the primary substation, upstream the whole network, , and the further connection of the WAMS (PMUs).

Finally there are two non-major intervention (non-intrusive):

- smart meters installation: this intervention is related to Section 3.4.
- installation of a current transformer in the MV level of the primary substation, upstream the whole network, , and the further connection of the WAMS (PMU). This intervention is related to Section 3.5.

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4.2. First Network disconnection (Month 24)

Previous Works

Previous to the first major intervention, during the first week of **Month 24**, some "non-intrusive" operations were done in order to reduce the duration of it and thus minimize the negative effects on the supply interruption for final users. The installation of a new DSPD box in the SS-B line was done, mainly in order to be able to connect the linking cable which will create the new line structure. Within the DSPD box the LV switchgear was installed to be able to actively manage the network configurations.

The installation of the cable connecting both lines allows to create a ring-shaped line. This intervention is the first major step towards the realization of the project and consisted of the installation of a RZ 50 aluminium cable as an aerial power line.

During the Network Disconnection

With most of the "non-intrusive" interventions already done the weeks before, the network disconnection was carried out the morning of the day 16 (**Month 24)**, and it had a duration of an hour and a half. It consisted on connecting the end of SS-B to the DSPD box installed on SS-A via the aerial line.

Figure 31. New aerial power line connected to the DSPD box and a closer look at the DSPD box at the moment of the first intervention.

4.3. Second Network disconnection (Month 33)

This second intervention was not ideally planned but it became crucial when scheduling the interconnection between the two lines due to the fact that, the phasors of both lines do not coincide, because the transformers of both lines had diferent configurations.

In the pilot site and issue with the electrical configuration of the transformers was identified that made it impossible to interconnect both lines without previous works.

In order to connect two lines without affecting the grid performance three conditions are required:

- Both lines have to have the same frequency.
- Both lines have to have the voltage amplitude.
- Both lines have to have the same phasors of voltage.

While frequency is a concern depending of the overall grid, and in terms of voltage both transformers have the same transformer ratio, in the pilot site there is not a phasor coincidence because the transformer configurations are different (see Table 17). During the scheduling phase of the interventions, it was identified that within the pilot site the power transformer of one of the lines had a Dy configuration whereas the other one had a Yy configuration (see Table 17), so it was impossible to connect the lines without creating a shortcut. In order to solve this issue, the only way to proceed was to change one of the power transformers to match configurations between them, and thus make the interconnection viable.

Table 17. Power transformers main characteristics.

	Power transformer SS-B	**Power transformer SS-A**
Transformer rated power	630 kVA	250kVA
Configuration	Dyn11	Yyn0
Tensions (MV/LV)	5250/400 V	5250/400 V

Previous Works

During the Network Disconnection

During the network disconnection the power transformar of the SS-A was changed for a new one with the technical requirements needed, so with a configuration Dyn01/Dyn11, but this depends on the MV transformer phase layout. Figure 32 shows the old and new transformers respectively.

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Figure 32 The old Yyn0 power transformer (left side) and the new Dyn01/11 power transformer (right side) in the SS-A

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4.4. Third Network disconnection (Month 34)

This third major intervention was initially planned to be focused on the PED installation and connection to the pilot site. However, after the second intervention an issue related to the transformers configuration arised.

Even in the scenario of having two DynXX transformers to interconnect the two LV lines of these transformers depend on the MV phases order connection. This connection order is not relevant in the traditional power system since low voltage distribution lines usually were not meant to interconnect. However, in the pilot scenario it is relevant to verify this condition.

During the verification, carried out on the limit between the two lines (DSPD box), it was noted that the voltage difference betwen pahses of the C.Ts did not have the same polarity. In fact, the SS-B had a Dyn11 configuration while the new SS-A had a Dyn01 configuration, so it was necessary to change configurations in order to make them match.

Finally during the third major intervention the SS-B configuration was changed to Dyn01, by changing the MV phases connection to the transformer. The intervention was carried out in the SS-B for simplicity reasons.

In order to solve this last inconvinence another unexpected major intervention was needed, in this case it was done together with the switchgear connection, and the PED installation.

Previous Works

Before the third intervention three are the main works that are being developed: firstly the adequation of the SS-B transformer building, particularly the second floor will be done. The interventions are mostly already done, with some remaining. The order of the following images tries to be chronological, however, in some cases the actuations were developed simultaneously:

- Replacement of the second-floor window to have an external entry for deploying and installing the PED and batteries.

Figure 33. SS-B window intervention, before and after.

- Construction of a bench for the batteries together with an opening on the floor to pass all the cables connecting the ESS and PED to the grid.

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Figure 34. SS-B interventions to install the PED and the batteries.

- The cat-type ladder that gave access to the second floor was lengthened and updated to fulfil with safety requirements such as the installation of safety hoops.

Figure 35. SS-B interventions to adapt the building to the new functionalities.

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- Installation of another bench for the PED due to its repositioning from the first to the second floor, and platform for switchgear, PMUs, PQMs, etc.

Figure 36. SS-B installation of the bench for the PED and the platform for the other devices.

- During the same day the installation of the PED and ESS was carried out. It was done through new window, and with the ESS disassembled due to space constraints. Once inside the building it was mounted.

Figure 37. Installation of the PED and ESS

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On the other substation SS-A, the one where the transformer was substituted, some preparatory work was also done. To be more specific. it was the installation of the platform where the switchgear PMU, PQM and RTUs, will be placed.

Figure 38. SS-A intervention to install the platform for the WAMS equipment.

After that, the reorganization of the layout of the DSPD box in order to fit inside the switchgear together with the PQM, RTU and PSU was done. Once the DSPD is adapted to fit all the metering and control devices, the final "non-intrusive" step is the installation of all the switchgear and other devices: at substation SS-A, inside the new DSPD box, and at the SS-B substation.

During the Network Disconnection

Once all the provious works were already carried out, the final step of this intervention is the netwok disconnection.

During the disconnection two major events took place simultaneousy. The connection of the PED, already installed, to the grid. In figure 36 the process of final configuration of the PED, once it was fully integrated into the pilot, can be seen.

Figure 39 PED connection to the grid and configuration.

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And the chage of the MV phases order connection into the SS-B transformer, in order to change its layout from Dyn11 to Dyn01 and thus match with the SS-A and allow the interconnection of the lines. In figure 37 the connections of the SS-B transformer can be seen.

Figure 40. SS-B intervention to change configuration to Dyn01

Figure 41 SS-B intervention to change configuration to Dyn01

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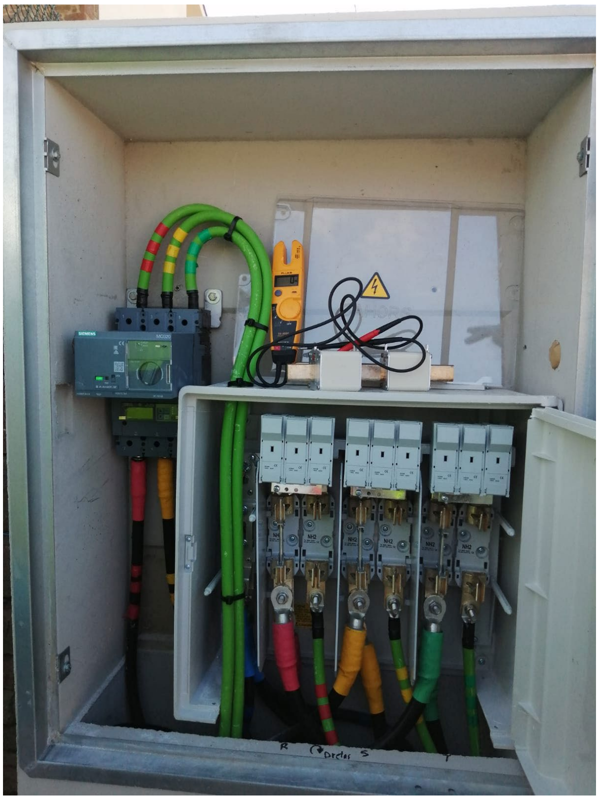

Figure 42. Test to verifty the intervention of changing configuration to Dyn01

4.5. Forth Network disconnection (Month 34)

Previous Works

The previous works necessary for this intervention, such as the PQMs and PMUs (WAMS) installation, were developed during the Third Network disconnection previous works.

During the Network Disconnection

During this network diconnection, a voltage transformer was installed in the SS-F (SS), with the objective to allow the WAMS infrastructure to collect data at the MV level.

5. Conclusions

The document provides a description of the initial pilot set-up, both in terms of physical configuration and complete guidelines for the key technologies deployment. It contains other relevant information of key technologies. It was prepared following a collaborative approach, to have a more holistic and shared vision of what the consortium wants to achieve during the validation phase of the project.

One unexpected hindrance for the deployment of RESOLVD technologies on the distribution grid might be the already existing grid infrastructure, for example the power transformer configurations. In the pilot the interconnection of two low voltage lines turned out to be harder than expected, first of all because the transformers of both lines had different configurations which did not allow an interconnection without the removal of one to make them match. But even after this first investment, the configurations were not matching because up until now the order of the MV phases connected to the LV transformer was not relevant. If the interconnection of LV lines starts to spread to create a more reliable, distributed energy system, unexpected costs like transformers upgrades could hinder the DG widespread.

One crucial point to take into account the deployment of the presented technologies is the physical space required. This constraint is so determinant, and it conditionates the whole solution. So, for this reason, the solutions developed must be capable of being adaptated and accomodated a variety of situations.

Another essential point is that these technolgoies must be well communicated with the SCADA and/or platforms, to make the best use possible of their potencial, so this aspect must be tackled during the deployment process.

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