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i-STENTORE

innovative Energy Storage
TEchnologies TOwards increased
Renewables integration and
Efficient Operation

D4.2 I-STENTORE LIVING LAB'S OPERATION AND DEMOS' EXECUTION DOCUMENTATION (PRE-DEMO)

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Abstract	This deliverable covers the Pre-Demo Phase (M5-M16) of the i-STENTORE project demonstration activities. It reports hence on the outcomes and progress achieved during this stage in each of the i-STENTORE demos and the Living Lab. In particular, it provides an update to the status of each demo and the Living Lab following their Baseline Assessment Reports and documents deployment, integration and operation details, the what-if scenarios investigated, as well as early results.
Keywords	Living Lab, Demonstrators, Pre-demo Phase, Demos' Status Update, Demo Deployment and Integration, What-if Scenarios, Demo Operation, Preliminary Results, Lessons Learnt and Next Steps

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REVISION HISTORY

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Version 0.3	13/05/2024	Demo 1 documentation (Section 3) incorporated

Version 0.4	16/05/2024	Demo 5 documentation (Section 7) incorporated
Version 0.5	28/05/2024	Demo 3 documentation (Section 5) incorporated
Version 0.6	03/06/2024	Demo 2 documentation (Section 4) incorporated
Version 0.7	06/06/2024	LL documentation (Section 2) incorporated
Version 0.8	14/06/2024	Demo 4 documentation (Section 6) incorporated
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TABLE OF ABBREVIATIONS AND ACRONYMS

aFRR	Automatic Frequency Restoration Reserve
AND	Active Distribution Network
AI	Artificial Intelligence
ANN	Artificial Neural Networks
API	Application Programming Interface
APV	AgroPhotoVoltaics
BESS	Battery Energy Storage System
BMS	Battery Management System
BUC	Business Use Case
CNMC	National Commission of Markets and Competition
D	Deliverable
DAB	Dual Active Bridge
DAM	Day Ahead Market
DER	Distributed Energy Resources
DSO	Distribution System Operator
DT	Digital Twin
EMS	Energy Management Strategy
ESCO	Electricity Supply Company
ESP	Ensemble Streamflow Prediction
ESS	Energy Storage System
EV	Electric Vehicle
EVCS	EV Charging Station

FFR	Fast Frequency Response
FMS	Furnace Monitoring System
FRT	Fault ride-through
GFL	Grid-following
GFM	Grid-forming
GOT	Gate Opening Time
GCT	Gate Closing Time
HESS	Hybrid Energy Storage System
HHESS	Hydrogen HESS
HOCS	Hierarchical Operation and Control System
HA	Hybrid Automata
IQR	Interquartile Range
IT	Information Technology
KPI	Key Performance Indicator
LCOS	Levelised Cost Of Storage
LIB	Lithium-Ion Battery
LIC	Lithium-Ion Capacitor
LL	Living Lab
LSTM	Long Short-Term Memory
LTO	Lithium Titanate Oxide
M	Month
MHC	Multi-Charging Hub
mFRR	Manual Frequency Restoration Reserve
MP	Market Participator

MPC	Model Predictive Control
MR	Market Representative
NACL	Network Access Control List
OCPP	Open Charge Point Protocol
OCV	Open Circuit Voltage
PDBF	Programa Diario Base de Funcionamiento (Basic Daily Program of Functioning)
PDC	Phase Data Concentrator
PLC	Programmable Logic Controllers
PMU	Phasor measurement units
PV	PhotoVoltaic
RA	Reference Architecture
REC	Renewable Energy Community
RES	Renewable Energy Sources
RT	Real Time
SCADA	Supervisory Control And Data Acquisition
SO	System Operator
SOC	State of Charge
STPMC	Switching, Transformation, Protection, and Measurement Centre
TDD	Total Demand Distortion
TRL	Technology Readiness Level
TSO	Transmission System Operator
UFC	Ultra Fast Charger
VESS	Virtual Energy Storage System

VPP	Virtual Power Plant
VRFB	Vanadium Redox Flow Battery
VSM	Virtual Synchronous Machine
WP	Work Package
Y	Year
ZPM	Zero Power Mode

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EXECUTIVE SUMMARY

Deliverable 4.2 is a report covering the first cycle of the i-STENTORE project demonstration activities, namely the Pre-Demo Phase. The latter has run from M5 to M16, involving demo preparatory activities along with early technology assessment and experimentation, and targeting the identification of limitations and drawbacks, as well as opportunities, pertinent to the energy storage technologies under consideration.

The present deliverable reports on the outcomes and progress achieved during this stage in each of the i-STENTORE demos and the Living Lab. In specific, building on the Baseline Assessment Reports, the document provides an update around the axes that compose the identity of each demo and the LL. Then, depending on the characteristics of each demo case, the deliverable further documents general and technical details about each demo deployment, the what-if scenarios investigated, the demo operation and the early results obtained. Emphasis is put, where possible, on the opportunities and challenges identified, whereas preliminary lessons learnt and next steps are also outlined.

It is worth mentioning that, in general, pre-demo phase activities evolved for the project pilots as planned. Highlights of the pre-demo phase for each of the five demos and the LL are as follows:

For the **LL**, the pre-demo phase involved the development of a generic case study around the deployment and evaluation of a Hybrid Hydrogen Energy Storage System (HHESS), and its specification for the LL infrastructural components under the prism of meeting the energy needs of the Agkistron touristic area, bringing forward important replication opportunities.

In the case of **Demo 1**, progress was achieved in the directions of data collection, model creation and preliminary testing, yielding initial positive assumptions around the models' accuracy and the system's performance.

For **Demo 2**, VRFB design and implementation activities, including the development and testing of new electrolytes, as well as the specification and validation of the field-scale architecture along with significant algorithmic advancements (i.e. water inflow forecasting model, optimisation algorithm) laid the groundwork for the tasks to be carried out during the full demo operation phase.

Demo 3 progressed with the refinement of its business scenarios and corresponding services, the development of the respective optimisation algorithms, the design of its Hierarchical Operation and Control System, the development of its digital platform, and the definition of the on-site specifications, as well as with pre-demo simulation and testing activities that enabled preliminary profitability estimations.

For **Demo 4**, the pre-demo phase has been characterised by efforts to determine the appropriate technical specifications for the power (DC/DC) converter and the energy storage system that will be incorporated in the demo's Ultra Fast Charging Station. An extensive study was also performed, in order to define the best control strategy for optimal dispatching of the micro-grid, whereas four key scenarios were developed for optimising the use of renewable energy sources, effectively managing storage systems and maintaining grid stability.

Finally, **Demo 5** proceeded with technical development and implementation tasks, as well as the extensive modelling of its assets and the simulation of contingency scenarios, also yielding promising results.

1 INTRODUCTION

i-STENTORE is a Research and Innovation Action that aims at showcasing the role of energy storage not only as an energy buffer, but also as an active grid component, capable of providing services and contributing to grid resilience, stability and efficient operation. In this context, the project pursues to examine the integration and applicability of diverse storage solutions and their combinations in one real-condition physical sandbox (Living Lab) and five demos, representing different application sectors, system and consumer needs, economic conditions, climates and timeframes.

WP4, namely "i-STENTORE demonstration across technologies and scenarios" has a central role in this process, being responsible for the overall planning and management of the i-STENTORE Living Lab and demos. In line with the project development cycles, the activities involved are essentially organised in three stages, namely:

- the Pre-demo Phase (M5-M16),
- the Full Demo Operation Phase (M21-M25), and
- the Large-Scale Demo Operation Phase (M30-M33).

The deliverable at hand is part of WP4 activities and relates specifically to the Pre-demo Phase. This phase involves demo preparatory activities along with early technology assessment and experimentation through proof-of-concepts, and early technology probes. Overall, pre-demo prototyping, testing and evaluation target to identify potential limitations and drawbacks, as well as opportunities, pertinent to the energy storage technologies under consideration, in order to fine-tune the i-STENTORE concept, consolidate the i-STENTORE reference architecture and blueprints, and eventually assure satisfying results at the Full Demo Operation Phase.

1.1 PURPOSE OF THIS DOCUMENT

Being part of the WP4 series of deliverables, D4.2 documents all information around the operation of the Living Lab and the demos during the pre-demo phase. In this context, it reports on the outcomes and progress achieved during this stage in each of the following tasks:

- Task 4.2 – Pre-Demo establishment of a Living Lab as a technology sandbox
- Task 4.3 - Demo 1 - Molten glass thermal storage for an increased uptake of renewable energy
- Task 4.4 - Demo 2 - Pump hydro Storage system combined with BESSs
- Task 4.5 - Demo 3 - Virtual Energy Storage System for Renewable Energy Integration
- Task 4.6 - Demo 4 - Cooperative Modular Multi Hybrid ESS for E-mobility Services
- Task 4.7 – Demo 5 - Agri-PV Farm with Energy Storage Capabilities

More specifically, the deliverable provides for each demo and the Living Lab, an update to the contents of the Baseline Assessment Report, originally included in D4.1, and further documents general and technical details about the demo deployment, the what-if scenarios investigated, the demo operation and the early results obtained. Preliminary lessons learnt and next steps in each case are also outlined.

1.2 RELATION TO OTHER PROJECT WORK

The present deliverable reports, as previously mentioned, on the progress achieved during the pre-demo phase in the frame of Tasks 4.2 to 4.7. As such, it follows up on, presenting updates and enriching the information provided within D4.1 - Demos' preparation, baseline analysis and planning, whereas it takes into account developments reported within D3.1 - i-STENTORE energy storage technologies and evolution, and D3.4 – i-STENTORE Digital Ecosystem (Digital Tools and Platforms, Virtual Power Control, Data Governance, Flexibility Services), which represent the 1st technology release, that has been put into testing and evaluation during the pre-demo phase.

With an outlook on future activities, the present document constitutes a precursor to deliverables D4.3 to D4.9, which are intended to document developments in the upcoming demo cycles, as well as reference material to WP5 activities, and thereby deliverables D5.1 to D5.3 (i-STENTORE evaluation results and lessons learnt, replication / scalability roadmap, multi-dimensional impact assessment, regulation briefing (1st, 2nd and final versions).

1.3 STRUCTURE OF THE DOCUMENT

The remainder of this document is structured as follows:

- Section 2 lays out a summary of the i-STENTORE Planning, Measurement and Verification Framework, which has been thoroughly presented in D4.1, for the sake of clarity and inclusiveness.
- Sections 3 to 7 focus on each of the five i-STENTORE demos and the LL. For each of the former, at first a relevant status update is provided. This documents refinements and/or alterations around the key axes of information that have composed the demos' Baseline Assessment Reports, namely those of the context and objectives, the stakeholders, the services, data and infrastructures, the KPIs, the risk analysis and the engagement and implementation plan of each demo. Then, the analysis focuses on the actual progress achieved in each demo and the LL, specifically during the months that have followed the finalisation of deliverable D4.1 until the closure of the pre-demo phase and the submission of the current document (M14 to M17). Key details are presented regarding the on-site deployment and integration, the scenarios considered at this phase, operation and testing, as well as the related outcomes and lessons learnt towards setting the path for the activities of the Full Demo Operation Phase. An indicative although not restrictive structure is used for this purpose,

covering the aforementioned aspects, indicating that the demos may apply adjustments to report on their progress in the best possible way.

- Section 8 concludes the document, summarising the work performed under this deliverable and exposing next steps regarding the demonstration activities' implementation.

2 I-STENTORE PMV

Identification, scheduling, documentation, review and assessment of the demo activities and results are guided in i-STENTORE by the project's Planning, Measurement and Verification (PMV) Framework [1]. A brief summary of the latter is provided in this section to ensure consistency of the work across the WP4 series of deliverables. The i-STENTORE PMV consists, as shown in Figure 1, of 4 pillars, two horizontal, i.e. the "Planning" and "Measurement and Verification", and two vertical ones, namely the "Context, Actors and Infrastructures" and "Risk Analysis and Assessment".

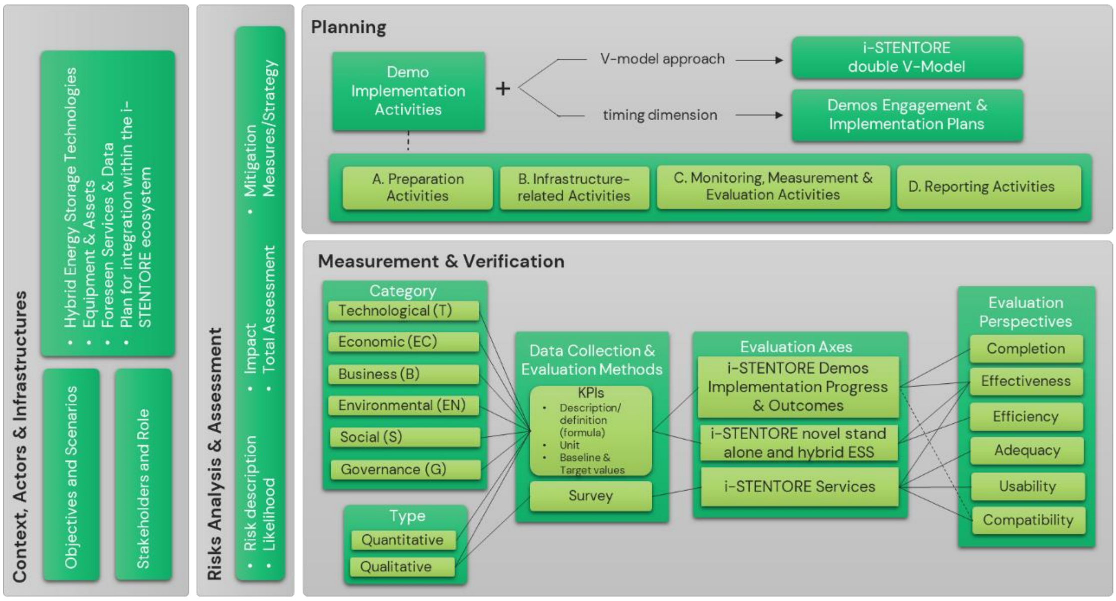


FIGURE 1: THE I-STENTORE PMV FRAMEWORK

The Planning pillar involves the identification of the demo implementation activities, their structuring on the basis of common verification and validation methodologies into the i-STENTORE double V-model, as well as integration of the timing dimension that results in the demos' engagement and implementation plans, i.e. the means for tracking and monitoring the demos' status and progress.

The Measurement and Verification pillar, on the other hand, outlines the demo evaluation axes, the respective evaluation perspectives, as well as the data collection and evaluation methods. The demo evaluation axes include:

i. the demos' actual implementation progress and outcomes
ii. the novel stand alone or Hybrid Energy Storage Systems (HESS) to be implemented and
iii. the digital services to be developed

Evaluation perspectives involve those of Completion, Effectiveness, Efficiency, Adequacy, Usability and Compatibility and are to be captured via Key Performance Indicators (KPIs) and surveys. KPIs are metrics that derive from the demos' characteristics and describe how well the latter are progressing according to predefined standards and goals. They are accompanied by a baseline assessment as well as an estimated target value, which are intended to facilitate the quantification of impact of the energy storage technologies and innovative solutions introduced by the i-STENTORE project, enabling the comparison of the 'as-is' and 'to-be' circumstances for each demo. KPIs further follow a classification scheme depending on their scope and nature.

The two vertical pillars, "Context, Actors and Infrastructures" and "Risks Analysis and Assessment" are complementary pillars, allowing determining the context and circumstances under which the demos will operate, and thereby providing input regarding their planning and execution as well as the targets and goals for their evaluation.

For a more detailed presentation of the i-STENTORE Planning, Measurement and Verification Framework the reader is directed to deliverable 4.1.

3 LIVING LAB

This section aggregates the updates regarding the Baseline Assessment Report provided by the Living Lab in D4.1. This report outlined the LL context, objectives and stakeholders, the services, data and infrastructures involved, a list of relevant Key Performance Indicators along with their baseline and target values, a short risk analysis, as well as the respective engagement and implementation plan. This update focuses on the pre-demo phase activities (deployment, operation, testing, etc.) that have been performed during M14 – M17 which involve scenario formulation, simulation, and some indicative results and insights.

3.1 LL STATUS UPDATE

An update to the contents of the Baseline Assessment Report for the LL is presented in the following paragraphs.

3.1.1 Context and Objectives

For the elapsed period of the project since the Baseline Analysis report no changes are to be reported in the context and objectives of the Living Lab. A more detailed presentation of the objectives was presented in D4.1.

3.1.2 Stakeholders

The stakeholders involved in the i-STENTORE Living Lab are: ORIZON, CERTH, and CLUBE. No changes are to be reported in the stakeholder mix since the baseline analysis. For more information regarding the role of the stakeholders, see D4.1.

3.1.3 Services, Data and Infrastructures

Deliverable 4.1 has already set the goals to be achieved through the available services, data and infrastructure of the Living Lab. In summary, the goal is to: i) Minimise renewables curtailment; ii) Maximise the lifetime of the hybrid ESS components; and iii) Achieve the optimal energy management. In line with the goals that the LL aims to achieve, the infrastructure to be installed targets to improve RES utilisation for the satisfaction of local needs for energy and energy related services.

The Living Lab will provide a data set and information in the form of a case study, so that they are integrated into the i-STENTORE digital ecosystem. The Living Lab will provide case study scenarios that will be formulated by communicating with the demos to set the range of case studies to be studied for the next phase. The scenarios will comprise real operating data of the individual subsystems behaviour which are the following:

- The hybrid hydrogen energy storage system - HHESS (fuel cell, electrolyser, and accumulators) to cover power demand.
- The gasifier gen-set operation.

- The generated electricity management system, which consists of DC/DC and AC/DC power converters and power electronics.
- The interconnection system with the hydroelectric plant.
- The charging/discharging supervision and control system for the batteries (Battery Management System-BMS).
- The EV charger operation.
- The supervision and control system of the integrated system.
- The control system of the loads.

The implementation of the scenarios will be presented in the upcoming deliverable D4.3 that will include the full demo operation.

3.1.4 Key Performance Indicators

The KPIs selected for the i-STENTORE Living Lab are presented in D4.1. Preliminary results and achieved values for the KPIs are presented in Table 5 in the results section of this Chapter.

3.1.5 Risk Analysis

Table 1 below illustrates potential risks associated with the Living Lab and the relevant mitigation measures. Their current status as "Open" or "Mitigated/Closed" is also depicted as an update.

TABLE 1 : RISKS IN LIVING LAB

Risk ID	Description of Risk	Likelihood	Impact	Total Risk	Mitigation Measures / Strategy	Status
RO.1	Delays in procurement and delivery of equipment	Medium	Medium	Low	The timeline is planned to absorb any potential delays. In case unexpected delays occur, backup plans are established without compromising the project objectives.	Open
RO.2	Regulatory barriers	Medium	High	Medium	CERTH and ORIZON possess extensive experience in dealing with the regulatory authorities regarding RES and energy storage technologies. The Living Lab partners will establish from early on communication channels with the regulatory authorities to identify	Mitigated

					potential regulatory barriers.	
RO.3	Increase in the cost of the battery racks and solar PV	Medium	Low	Low	Communication with other suppliers will be established. Alternative equipment will be identified, without compromising the project's objectives.	Open
RO.4	Integration issues between new and existing equipment	Low	Medium	Low	Before the purchase and procurement of the equipment, a relevant list of prerequisites was delivered to the manufacturers. In case of unexpected failures and integration issues, a communication channel will be established with the manufacturers as well as with the technical personnel of CERTH and ORIZON.	Open

3.1.6 Engagement and Implementation Plan

The activities of the Living Lab's establishment have been progressing as planned and according to the Grant Agreement. The relevant Gantt chart for the LL's engagement and implementation plan has been presented in D4.1 and no deviations have been recorded in the meantime. During M14 to M17 the actions carried out, included **the procurement finalization** of the battery and the EV charger to be installed in the Living Lab, as well as the additional panels to increase the PV total capacity. Furthermore, after consulting with the relative regulatory authorities that are involved in the permitting procedures of the subsystems to be installed, no apparent obstacles have been identified and the installation is progressing as foreseen.

3.2 LL DEPLOYMENT

Hybrid Hydrogen Energy Storage Systems (HHESS) can be implemented across various sectors, including buildings, transportation, and power generation, in different configurations. A prevalent application of such systems, as seen in Agkistro village, is in remote locations where the electrical grid is either non-existent or weak. This hybrid approach effectively tackles the challenges of energy accessibility and stability.

These systems typically integrate renewable energy sources, such as solar or wind power, with hydrogen storage technologies to create a resilient and self-sufficient energy infrastructure. The hydrogen storage system utilises surplus electricity generated by renewables to produce hydrogen through electrolysis. This hydrogen is then stored and can be converted back into electricity using fuel cells when renewable sources are not generating enough power, ensuring a continuous energy supply.

In local touristic areas like Agkistro, implementing such systems offers significant benefits. Tourism requires a reliable energy source to power accommodations, restaurants, attractions, and other facilities. A hybrid hydrogen energy storage system can meet these needs while enhancing the sustainability profile of the destination. By reducing dependency on diesel generators, fossil fuels, or the electricity grid, these systems lower greenhouse gas emissions and other pollutants, contributing to a cleaner environment. Furthermore, showcasing advanced renewable energy solutions can attract environmentally conscious tourists and provide educational opportunities, demonstrating the region's commitment to sustainability. The living lab approach, where the system is continuously monitored, evaluated, and improved, ensures that the technology remains efficient and adaptable to changing energy demands and conditions, making it an ideal fit for dynamic environments.

3.2.1 Methodology of Deployment

In general, the deployment method is based on the simulation of the detailed dynamic behaviour of the HHESS through a model of the system components, the layout of the system and the control strategy, which set the base for the energy and economic performance evaluation. The economic analysis is performed developing a model that converts the energy flows on a yearly basis to costs and savings. The model is also coupled with the costs of investment in the system and this allows one to assess the overall economic performance of the proposed system.
To test and evaluate the case studies performed, a suitable Energy Management Strategy (EMS) has been developed and implemented that dictates the operation of HHESS. This strategy is responsible for the decision-making on energy distribution, considering the status of each subsystem and the overall goal of the operation. It is based on a hybrid-automata algorithm [2], [3] incorporating propositional logic. One of the characteristics of the EMS is that it can incorporate different subsystems by using different developed models. This means that the EMS can be applied upon various configurations, each possibly representing the project demos' infrastructure and/or the different goals and services that are evaluated within these demos.

3.3 PRE-DEMO PHASE SCENARIOS

To demonstrate the Living Lab's use case and to illustrate the capabilities of the developed EMS, an indicative case study has been defined and simulated. This case study has been developed according to the realistic energy needs of entities present in the local ecosystem of Agkistro (and Thessaloniki). The relative daily energy needs for the respective case study are shown in Figure 2Figure 2. The load profiles are produced considering data from local hotel facilities and have been adjusted to exhibit 30 kW peak loads analogous to the RES capacity of the Living Lab. The idea of designing the case studies based on real operation data of both the systems installed in the LL as well as the local loads, ensures the replicability aspect of the hybrid storage system and the accuracy of the calculated KPIs.

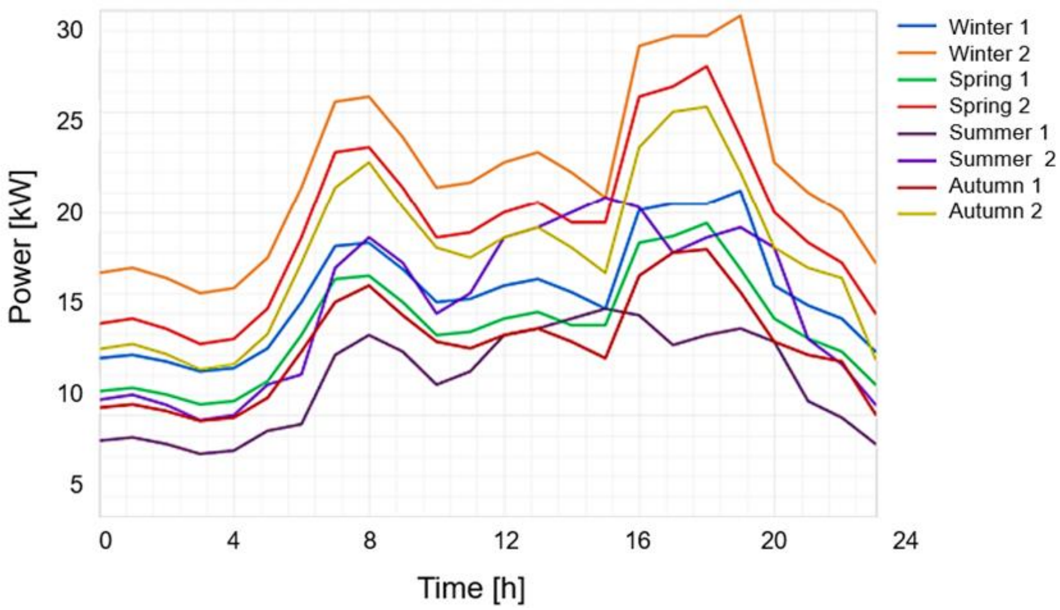


FIGURE 2: DAILY LOAD CURVES FOR THE TOURISTIC ATTRACTION IN THE AREA OF AGKISTRO

The configuration of the performed case study in terms of equipment is shown in Table 2 below.

TABLE 2: INFRASTRUCTURE CONFIGURATION AND SIZES

Equipment	Description
PEM Water Electrolyser	25 kW
2x PEM fuel cells	2x25 kW
Hydrogen Tank	1,000 kWh / 30 kgH_2
Lithium-Ion Battery Energy Storage Systems	200 kWh
PV panels	30 kW
Electricity production from biomass gasifier/syngas	30 kW

3.4 OPERATION, TESTING AND PRELIMINARY RESULTS

When the systems are operating, excess energy can either be stored as hydrogen or electricity, or it can be curtailed. In this case study, a supervisory control framework based on a generic Energy Management Strategy was developed and implemented. This EMS was realised using a Hybrid Automata (HA) architecture that incorporates propositional-based logic. This showcased the performance and operation of the hybrid hydrogen energy storage system for the satisfaction of local real loads. The example case achieved optimal RES utilisation, fulfilled load demand, while minimising the external use of back-up power and curtailed energy, and demonstrated uninterrupted load satisfaction. Additionally, this flexible and systematic approach preserved battery life and ensured the safe operation of all electrochemical subsystems, including fuel cells and the electrolyser.

The results of the case study simulation are presented in the next figures. Figure 3 shows the distribution of power among subsystems. Power from biomass gasification and the respective CHP engine is the major contributor to the load after the RES input from PVs. The curves for back-up power and curtailment are typical of the operation of autonomous off-grid systems. Such systems curtail the energy that they cannot spend or store and require external source back-up in the case of RES and storage depletion. The trend of the state of charge (SOC) for hydrogen and battery electricity is shown in Figure 4.

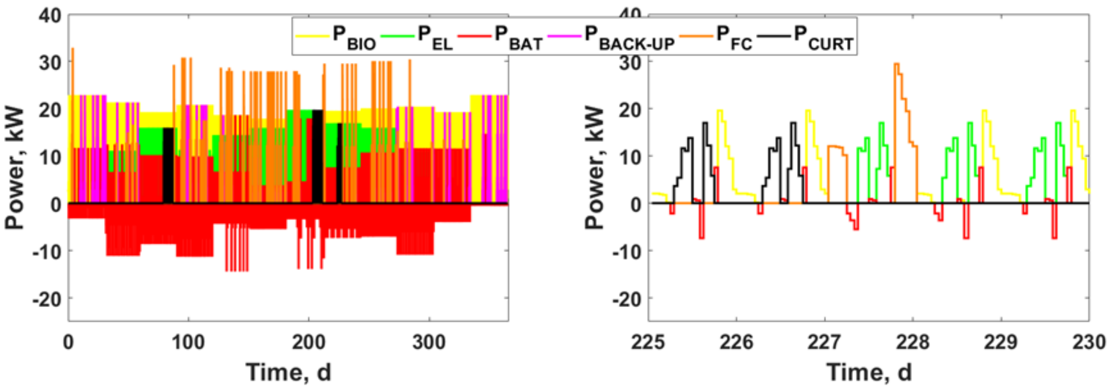


FIGURE 3: (LEFT) YEARLY DISTRIBUTION OF POWER AMONG SUBSYSTEMS, (RIGHT) DISTRIBUTION OF POWER AMONG SUBSYSTEMS FOR 5 CONSECUTIVE DAYS WITHIN AUGUST.

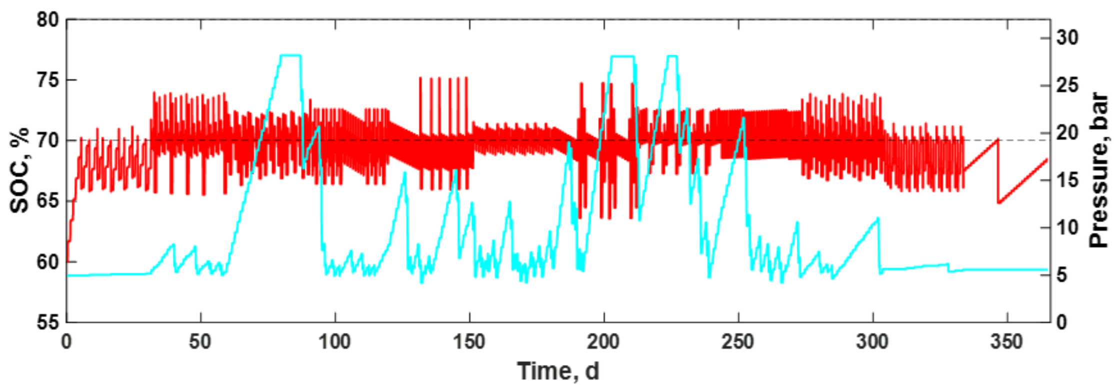


FIGURE 4: YEARLY DISTRIBUTION OF ENERGY AMONG THE TWO ENERGY STORAGE MEDIUMS (BATTERY, HYDROGEN).

To evaluate the HHESS performance, a set of key performance indicators allows the assessment of the effects that each technology has to the example case (Figure 5). The control strategy and its application to the case is examined using these indicators, which are defined as ratios of the cumulative energy (kWh) of each subsystem divided by the total RES surplus (kWh) or total load demand (kWh) over the course of a year. Subsequently, ratios are converted to percentages (%) to present a clearer definition of the case's performance.

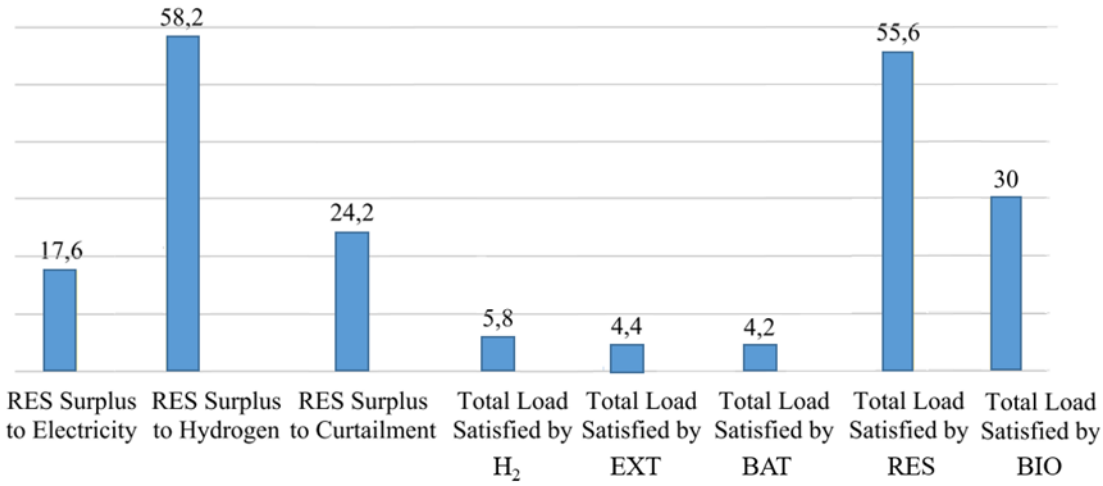


FIGURE 5: KEY PERFORMANCE INDICATOR PERCENTAGES FOR THE INDICATIVE CASE STUDY PERFORMED.

Table 3 shows the KPIs with updated values as baseline and their achieved values up until the time of reporting (M17).

TABLE 3 : LIVING LAB KPIS

ID	Name	Description / Definition (formula)	Unit	Baseline Value	Target Value (estimated)	Pre-Demo Phase Value
Axis I. Demo's Implementation Progress & Outcomes						
21	Share usage of novel energy storage mechanisms	a. Potential Energy Storage satisfied by H_2 b. Potential Energy Storage satisfied by battery c. Potential Demand satisfied by biomass gasification	[%]	a. 5% b. 25% c. 10%	a. >10% b. >40% c. >20%	a. 5.8% b. 4.2% c. 30%
22	Energy storage capacity	Combined energy storage capacity in the Living Lab	[kWh]	1200	1300	1300
24	New collaborations between SMEs, industry and academia in the	Number of collaborations with SMEs, industries	-	1	2	-

ID	Name	Description / Definition (formula)	Unit	Baseline Value	Target Value (estimated)	Pre-Demo Phase Value
	energy storage sector					
32	N° of data-driven learning algorithms validated over the demos	Tested algorithms within the Living Lab	-	1	2	-
35	N° of storage-centric grid supporting services proposed and validated through the demos	Foreseen Services for the Living Lab	-	0	1	-
Axis II. Novel stand alone or Hybrid Energy Storage Systems (HESS)						
5	Potential increase of renewable-based power generation without jeopardising system security	Increase in installed capacity of RES-based power generation	[kW]	-	30	N/A
20	Energy saving in terms of volume of reduced fossil fuel consumption	Potential avoided diesel fuel consumption for electricity generation	[lt_{Diesel}/ year]	25,000	35,000	N/A

3.5 LESSONS LEARNT AND NEXT STEPS

The preliminary results of the simulation present an example case study of the implementation of the Living Lab infrastructure for the satisfaction of real local loads of the Agkistro area. This case study sets the base upon which what-if scenarios will be designed and run in the next phases of the Living Lab. As a next step, communication with the demos is necessary to set the range of case studies to be studied for the next phase.

4 DEMO 1 - MOLTEN GLASS THERMAL STORAGE FOR AN INCREASED UPTAKE OF RENEWABLE ENERGY

This update focuses on the pre-demo phase activities of Demo 1, which involves a hybrid regenerative glass furnace coupled with a PV plant. The demo's objectives include aligning glass melting with RES availability, optimising energy costs, and providing ancillary services to the DSO. Key activities during this phase included data collection, model creation, and preliminary testing of the flexibility platform. The results show promising capabilities in managing fluctuations in energy demand and supply. The next steps involve a full electric boosting ramp-up, further model refinement, component integration, and KPI monitoring.

4.1 DEMO STATUS UPDATE

An update to the contents of the Baseline Assessment Report for Demo 1 is presented in the following paragraphs.

4.1.1 Context and Objectives

In section 4.2.1 of the D4.1 report, we have established the context and objectives of the Demo 1. The context involves a newly commissioned hybrid regenerative glass furnace that has been coupled with a PV plant to form a thermal storage system. The objectives of the demo have been slightly extended to describe all the capabilities of the hybrid storage system. The extended objectives of the demo are as follows:

- Aligning glass melting with RES availability
- Achieving higher utilisation of PV power plant and lower energy costs
- Optimising energy costs by utilising data from wholesale market
- Opening up glass manufacturing to provide ancillary services to the Distribution System Operator (DSO), such as peak shaving and increased intake from other local RES in the vicinity of the factory.

4.1.2 Stakeholders

The project involves two primary stakeholders: HRAS, which will use the platform, and COMS, which is responsible for developing the flexibility platform. In addition, we have also identified and considered external potential stakeholders. These stakeholders (Table 4) will have the opportunity to participate in Demo 1 once the project is finalised.

TABLE 4 : DEMO 1 STAKEHOLDERS

Actor	Role(s) in Demo 1	Stakeholder Group
HRAS	Demo leader, owner, and end-user of the site infrastructure, that requests a service from the system under discussion, aiming to achieve the use case's main objective.	Manufacturers
COMS	IP owner & service provider involved in the development of deployed flexibility platform.	IT solutions providers
DSO	Participates with ancillary services	Energy sector
Wholesale Market	Provides data to optimise energy costs	Energy market

4.1.3 Services, Data and Infrastructures

Demo 1 focuses on the development of three key services: PV Forecast, Flexibility Service, and Furnace Model. For more comprehensive details, please refer to Section 4.2.3 in deliverable D4.1. Moreover, an exhaustive description of the ancillary services associated with Demo 1 can be found in deliverable D3.4.

Regarding data availability, we have provided more information in Table 5Table 5. Notably, with the acquisition of new data from the new furnace, there is no longer a necessity to rely on data from the older furnace, as initially anticipated. Moreover, we have included external metering data (from external partner DSO, if available), which can be utilised for evaluating ancillary services.

TABLE 5: DEMO 1 DATA STATUS

Asset/service	Input Data (and Status / Availability)	Output Data
PV Forecast	Data available through SolarEdge API from 30.5.2021	Day-ahead PV production forecast
Flexibility service	Meter data (historical data available for older and new furnace)	Possible and realised flexibility of electric melting ΔP_{boost}

Asset/service	Input Data (and Status / Availability)	Output Data
Furnace	Input from new Furnace available from 1.7.2023. Over 40 parameters available with 2 min timestamp	Different profiles of gas and electric energy usage
Meter data	Metering data from substation	-

4.1.4 Key Performance Indicators

Although the Demo 1 KPIs have not been changed or refined, we have focused our efforts on achieving these metrics. Further details on the Demo 1 KPIs can be found in D4.1 Table 9.

4.1.5 Risk Analysis

In the D4.1 we have reported different risks as shown in Table 6 below. We have also updated the table with the Status, since some of the risks have been resolved or mitigated. Additionally, we have opened a new risk related to the Data availability for the new furnace.

TABLE 6 : DEMO 1 RISKS

Risk ID	Description of Risk	Likelihood	Impact	Total Risk	Mitigation Measures / Strategy	Status
R1.1	Prolonged delays in the delivery of equipment and materials	Medium	Critical	Medium	Procurement process initiated as early as possible	Closed
R1.2	Impaired glass quality due to unpredictable characteristics of HESS operation	Very High	Critical	Critical	New operational management strategies will be determined based on the results of continuous performance monitoring during	Open

Risk ID	Description of Risk	Likelihood	Impact	Total Risk	Mitigation Measures / Strategy	Status
					initial furnace trials	
R1.3	High costs of goods and services for project implementation	High	Low	Low	Demo partners have sufficient reserves to cover the project costs	Mitigated
R1.4	Compatibility issues between flexibility platform and HRAS's IT systems and infrastructure	Low	Critical	Low	Application of established standards and specifications, compatibility testing, version control	Open
R1.5	Data availability from the new furnace may be limited due to controlled conditions (operating only in the setpoint), potentially impacting the diversity of available data	Medium	Medium	Low	Create Diverse Test Scenarios. Refine Model with New Data. Calculated initial parameters.	Open

The new R1.5 was already partly mitigated and will be furtherly mitigated by:

1. **Creating a variety of test scenarios:** Implement different test scenarios with higher variations of input parameters to increase the variety of available data.
2. **Refining the model with new data:** Continuously refine the furnace model after receiving new data to ensure that it accurately reflects the furnace's operating characteristics.
3. **Calculating initial parameters:** Mitigate this risk by deriving the initial parameters through calculated values related to the structure of the furnace, such as resistance and heat capacity.

4.1.6 Engagement and Implementation Plan

The Gantt chart of Figure 6 presents the planned activities of Demo 1 in connection with the construction of the hybrid furnace. The furnace reached basic operation in January 2024 and is expected to reach full hybrid operation in January 2025.

Other activities related to the implementation phase are proceeding according to plan. The main focus is now on building services and models to support the flexibility platform, which are described in more detail in the following section.

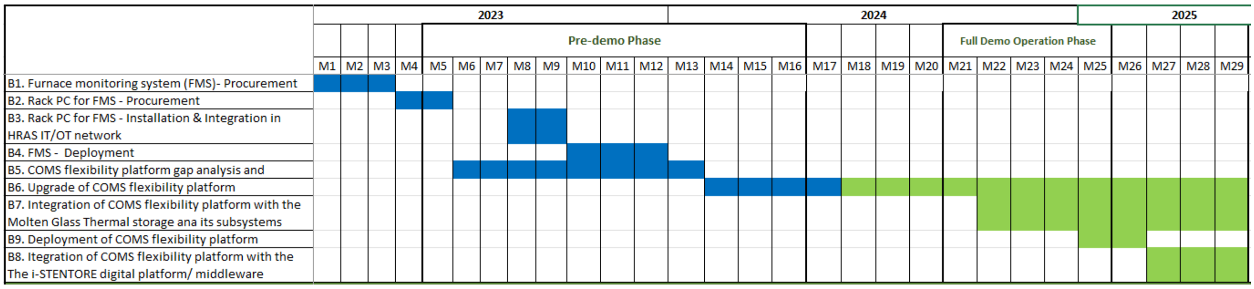


FIGURE 6: DEMO 1 GANTT CHART

4.2 DEMO DEPLOYMENT

Since the deployment of services is in its initial phase, we have focused on integrating together the FMS and flexibility platform provided by COMS. The horizontal components of the 1st technology release will follow, once the internal system is established. The current conceptual architecture of the flexibility platform is shown in Figure 7 and may change in the future to better incorporate the common components of the i-STENTORE architecture. The main focus was on the collection of demo-specific data and the creation of the models.

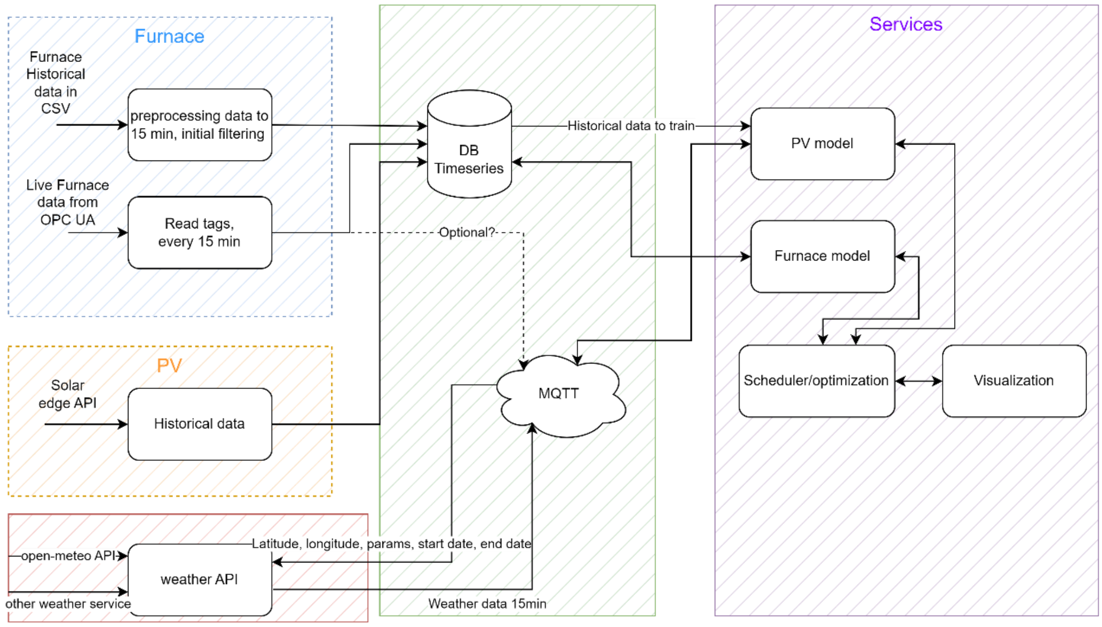


FIGURE 7: FLEXIBILITY PLATFORM OF DEMO 1

4.3 PRE-DEMO PHASE SCENARIOS

During the pre-demo phase of Demo 1, several scenarios and hypotheses were investigated to prepare for the full demo operation phase and improve the performance of the models. These scenarios aim to test various aspects of the hybrid regenerative glass furnace coupled with the PV plant and flexibility platform:

1. Flexibility Service Performance:

   Scenario: Test the performance of the flexibility service components provided by COMS under various load conditions and external factors.

   Hypothesis: The flexibility platform can effectively manage fluctuations in energy demand and supply, optimising the operation of the hybrid storage system and maximising its benefits.

2. Impact of Furnace Model Accuracy:

   Scenario: Evaluate the impact of the accuracy of the furnace model on overall system performance and energy efficiency.

   Hypothesis: Continuous refinement of the furnace model based on new data will lead to improved accuracy in predicting energy usage and optimising furnace operation.

4.4 OPERATION, TESTING AND PRELIMINARY RESULTS

During the pre-demo phase of Demo 1, extensive operation and testing activities were conducted to evaluate the performance of the hybrid regenerative glass furnace, PV plant, and associated flexibility platform components. These activities aimed to collect data, assess achievements, address challenges, and provide preliminary results. The progress made during this phase is summarised below:

Data collection activities

Extensive data collection activities were conducted that included inputs from the SolarEdge API, meter data from historical furnace operation, input data from the new furnace, and weather data collection. Protocols were established to ensure the accuracy and reliability of the data. The selected data collected from the new hybrid furnace is shown in Figure 8 after pre-processing. In addition, the collected data was used to create models and compare the agreement between the trained model and the measured values, as depicted in Figure 9 for the PV model.

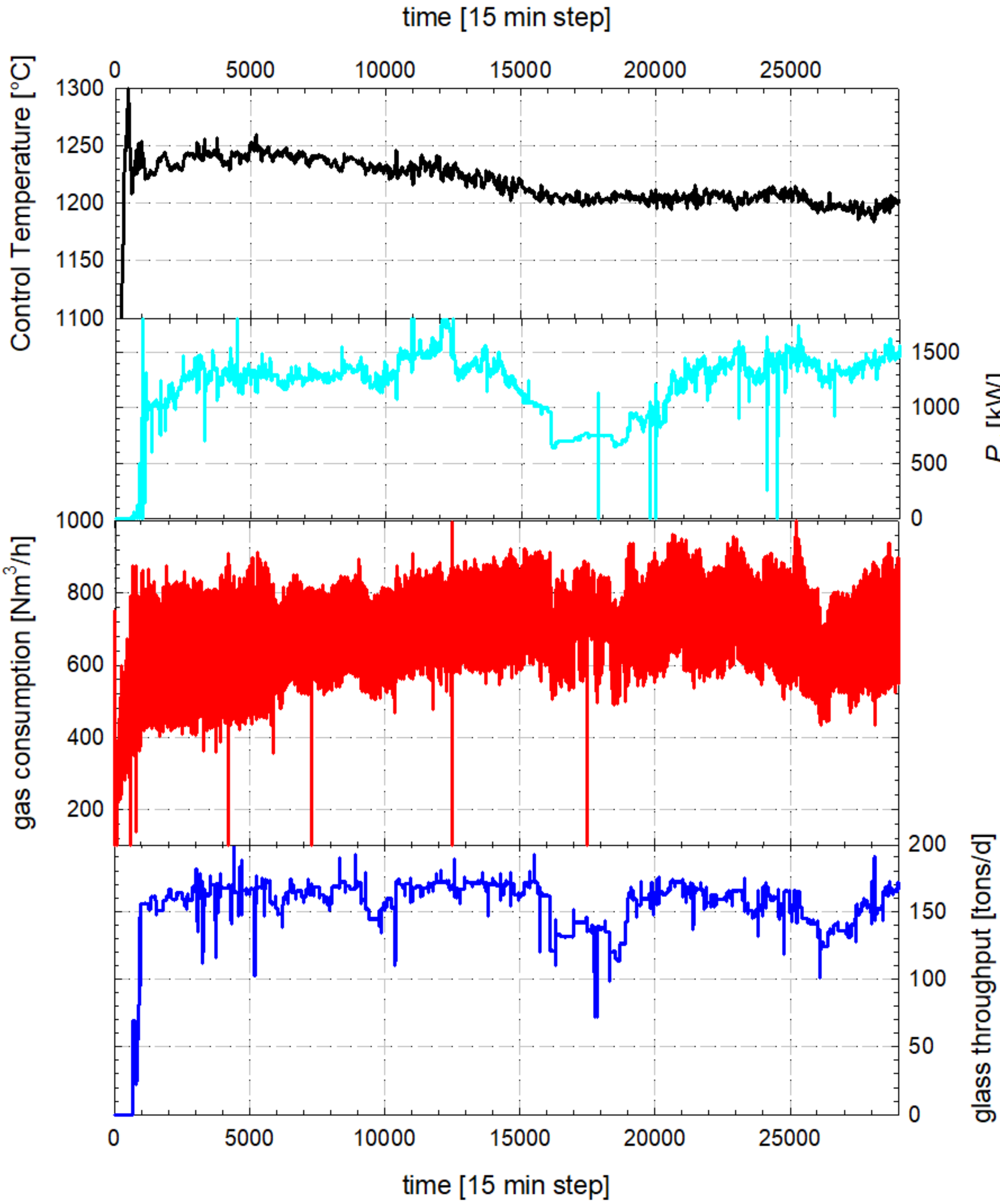


FIGURE 8: SELECTED MONITORED PARAMETERS OF THE FURNACE

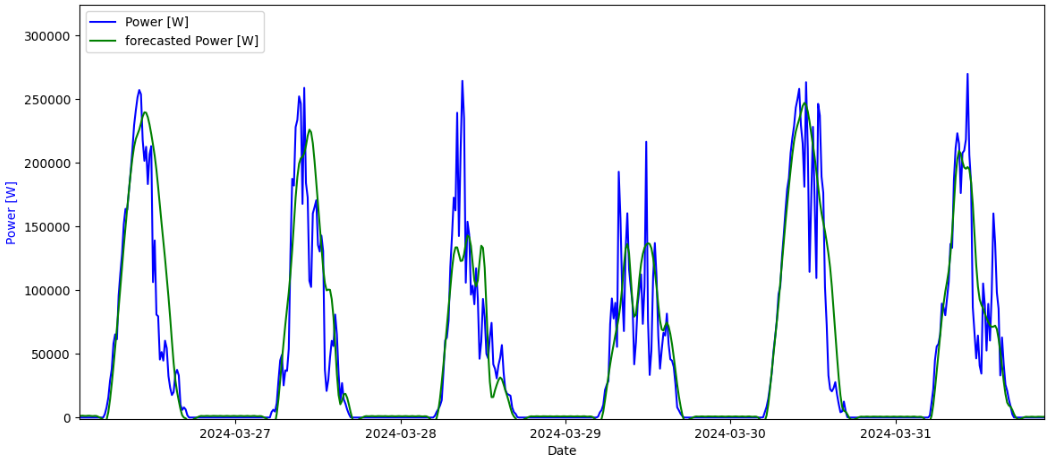


FIGURE 9: MEASURED AND PREDICTED POWER OF THE SH PV SYSTEM

Preliminary results

The data provided, was used to create various models. These were used for the initial pre-demo phase of furnace DT and the evaluation of flexibility under different load conditions. The preliminary results indicate that the flexibility platform has shown promising capabilities in managing fluctuations in energy demand and supply. Initial assessments indicate that the flexibility service has the potential to maximise the benefits of the hybrid storage system by improving the energy efficiency of the system and grid stability. In addition, the accuracy of the furnace model was evaluated in relation to the overall performance of the system, and the parameters of the DT appeared to be close to the expected values. The parameters of the DT of furnace model, defined below, are listed in Table 7:

- C_m: Heat capacitance related to molten glass and furnace envelope. This parameter indicates the system's energy storage capacity.
- R_m: Heat resistance or inverse of thermal conductivity. This parameter is related to energy losses through the furnace envelope.
- α_1: Factor related to the efficiency of gas combustion compared to reference electrical efficiency (expressed in kW with a factor of 1000).
- α_2: Weight of throughput of molten glass.
- α_3: Weight of effect of cullet intake on thermal needs.
- β_1 and β_2: Parameters related to air-gas ratio combustion temperature ($\frac{(\beta_1 - \frac{air}{gas})^2}{\beta_2}$), β_1 is associated with maximal efficiency, while β_2 corresponds to the width of the curve. For more details on the reference curve related to air-gas ratio combustion temperature, please refer to [4].

We have simulated two cases based on these parameters. In the first case (simulation 1), the system is in equilibrium. This means that all the energy supplied to the system is equal to the energy output. Simulation 2 is the case, in which all the energy from the PV system is stored in the furnace. In this case, the control temperature (temperature of the molten glass) rises, as illustrated in Figure 10. The temperature rises until additional energy is fed into the system. After the additional energy supply has ended, the temperature begins to fall towards the equilibrium temperature. This decrease is slow compared to the temperature increase and the energy available for the optimisation scenarios is available within one day. As the temperature only drops slowly, the stored energy can also be used later in the week. However, there is also the so-called effect of self-discharge, which needs to be further investigated and better determined. The effect of temperature on glass quality has yet to be investigated. Based on the investigation, we expect to obtain the capacity and performance of such a hybrid storage system.

TABLE 7: PARAMETERS OF DT OF FURNACE

Parameter	C_m [Wh/K]	R_m [W/K]	α_1 [/]	α_2 [W day/ton]	α_3 [W day/ton]	β_1 [/]	β_2 [/]
Value	420	1293	423	-27526	47	13.2	286

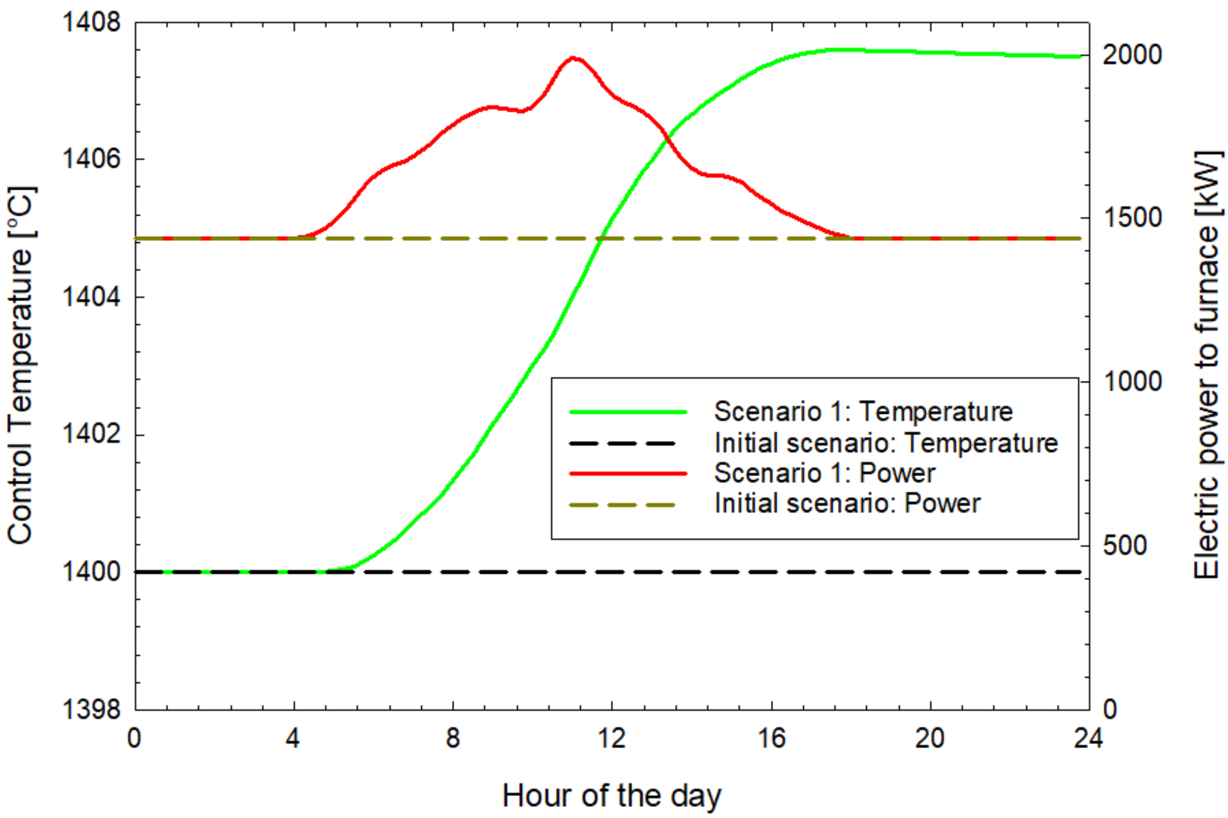


FIGURE 10: SIMULATED TWO SCENARIOS FOR DRIVING THE FURNACE

Co-funded by the European Union

All activities are in line with the defined Key Performance Indicators (KPIs) outlined in the Baseline Assessment Report. The progress made in this phase is summarised in Table 8 below:

TABLE 8: DEMO 1 KPIS

ID	Name	Baseline Value	Pre-Demo Phase Value
Axis I. Demo's Implementation Progress & Outcomes			
8	Implementing a singular high-temperature (1500° C) thermal storage system based on an industrial molten-glass process	0	1
14	Efficient integration of storage technologies in demo sites	0	N/A
18	Deployment of digital platforms	0	N/A
29	Efficient integration of storage technologies in demo sites	0	1
Axis II. Novel stand alone or Hybrid Energy Storage Systems (HESS)			
5	Potential increase of renewable-based power generation without jeopardising system security	0	N/A
7	Energy generation cost decrease, through avoidance of renewables spillage	0	N/A
19	Extension of energy storage capacity	0	N/A
20	Energy saving in terms of volume of reduced fossil fuel consumption	0	N/A
40	Energy density	0	N/A
41	Power density	0	N/A
42	Energy efficiency (energy losses)	-	N/A
44	Discharge rate	-	N/A
47	Life-time	-	N/A

48	Technological Maturity (TRL)	6	N/A
50	Capital/Investment Cost	0	N/A
53	Scalability potential	0	N/A

4.5 LESSONS LEARNT AND NEXT STEPS

Developing accurate models for the hybrid regenerative glass furnace and associated components is essential for predicting system behaviour and optimising performance. Continuous refinement and validation of these models based on new data inputs contribute to improved accuracy and reliability. The evaluation of the flexibility platform under various load conditions has shown its potential to manage energy demand and supply fluctuations effectively. However, small fluctuations in the input parameters resulted in the furnace needing to be more thoroughly tested as we expected in the beginning. This will be also the foundation for maximising hybrid storage performance.

The next steps towards the full operation demo include:

1. Conducting the first full electric boosting ramp-up to evaluate the system's response to increased power input.
2. Refining the furnace and flexibility service models using data collected during the boosting ramp-up to improve their accuracy and reliability.
3. Continuing with data integration and incorporate various components into the flexibility platform to ensure seamless communication and operation.
4. Defining the operational limits of hybrid storage and strategies to optimise system performance while ensuring safe and efficient operation.
5. Monitoring KPIs and evaluation.

5 DEMO 2 - PUMP HYDRO STORAGE SYSTEM COMBINED WITH BESS

Demo 2 is located in Madeira Island and it is focused on developing and integrating new HESS technologies in order to decrease dependency on fossil fuels, reduce renewables curtailment and increase grid stability.

The HESS in demo 2 includes a Li-ion and VRF BESS and hydro with reservoirs, featuring pumping capabilities (allowing for both generation and storage). Demo 2 also includes wind power, PV, synchronous condensers, and gas-fired generators.

Madeira Island's regional government wants to reduce renewables curtailment, which is challenging considering the location and size of the island. Despite being an isolated system, Madeira has been increasing the total installed power of renewable sources but, due to intermittent characteristics of RES, the island is still very reliant on fossil fuels.

Currently, during some periods of the year, the renewable energy produced exceeds the load and thus, part of it must be curtailed. With the installation of further storage devices, the excess energy can be stored and used when renewable generation is lower than load hence reducing curtailment and allowing for further integration of renewable assets.

However, the increase in RES may create problems related to grid security, since total inertia and stability decrease. With the use of HESSs, this problem can be mitigated.

An optimisation algorithm will also be implemented in demo 2 to manage the whole system, including the HESS, providing several ancillary services to the grid, thus increasing system stability and inertia.

The optimisation algorithm will define the grid operation based on weather, load, production forecasts and will consider the cost of operation. By considering all this data, the algorithm will define optimal operating points for the system and contribute to the overall system decarbonisation by reducing thermal units in operation in some periods.

An overview of the Madeira demo is illustrated in Figure 11.

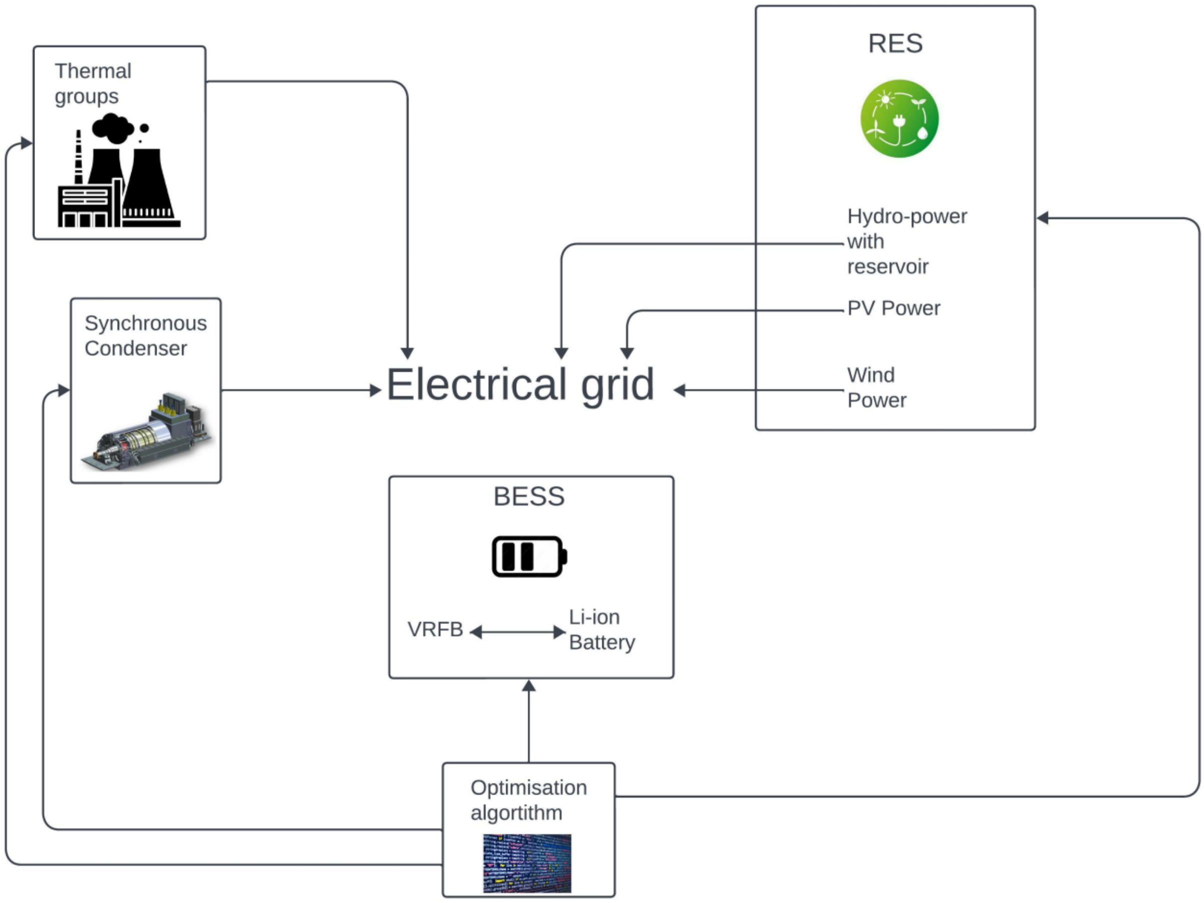


FIGURE 11: MADEIRA ISLAND DEMO OVERVIEW

5.1 DEMO STATUS UPDATE

An update to the contents of the Baseline Assessment Report for Demo 2 is presented in the following paragraphs.

5.1.1 Context and Objectives

This demo main goals are:

- Reduction of the electricity production costs and overall CO_2 emissions in the Madeira electric power system, mainly by reducing the utilisation of thermal units: The incorporation of Li-ion and VRF BESS will attenuate the renewable curtailment, contributing to the reduction of the overall production costs. The use of the BESS combined with synchronous condenser will also increase grid stability allowing a reduction in thermal groups usage.
- Improved utilisation of the water and reduction of renewable energy wasted: A tailor-made AI-based algorithm will use weather forecasts to predict water inflows in addition to the wind/PV forecasts that are determined by EEM. The multitemporal optimisation algorithm will use these forecasts to dynamically adjust the grid point of

operation by strategically storing energy in the BESS during periods of predicted water overflow and/or excess in wind power.

- Decrease LCOS of the VRFB using more cost-effective electrolyte composites: New additives are being tested to optimise the operation of the VRFB, increasing its lifetime and inherently reducing the associated LCOS.
- Increase the lifetime of the Li-ion and VRF batteries: The optimisation algorithm will take into account the degradation of the storage systems and will optimise their operation to avoid fast degradation and increase their lifetime.
- Increase the share of renewable energy: The optimal operation of the Li-ion and VRF batteries, together with the hydro systems and synchronous condensers, has a crucial role in attenuating the curtailment of renewable energy sources, thereby increasing their share in the island's energy mix.

5.1.2 Stakeholders

There are no changes to be reported, please refer to D4.1.

5.1.3 Services, Data and Infrastructures

Demo 2 services, data and infrastructures remain unaltered. For more details, please consult D4.1.

5.1.4 Key Performance Indicators

There are no changes to be reported, please refer to D4.1.

5.1.5 Risk Analysis

Moving ahead with Demo 2 of the i-STENTORE project, it is imperative to proactively address potential risks that could affect the successful execution of the defined tasks. Risk analysis plays a crucial role in the project management strategy, enabling to identify, assess, and mitigate possible challenges that might impede progress. In this regard, several key risks have been identified, requiring attention and deliberate consideration. These risks are presented in Table 9 below.

TABLE 9: DEMO 2 RISKS

Risk ID	Description of Risk	Likelihood	Impact	Total Risk	Mitigation Measures / Strategy
R2.1	Lack of lab material to test the full-scale VRFB	Medium	Critical	Medium	Consider several labs to fully test the battery
R2.2	Limited space for VRFB	High	Medium	Medium	Contact EEM and VGLAB, in order to achieve the

Risk ID	Description of Risk	Likelihood	Impact	Total Risk	Mitigation Measures / Strategy
					optimal solution within restrictions
R2.3	Convergence problems in the optimisation algorithm	Low	Medium	Low	Different techniques and solvers will be tested
R2.4	Problems acquiring data from SCADA	Low	Critical	Low	EEM and INESC TEC are cooperating to implement local server with direct SCADA access
R2.5	Inconsistences in water inflow data	High	Medium	Medium	Ignore data with inconsistences when training the neural network

- R2.1 is being mitigated by using INESC TEC lab, but space (R2.2) continues to be an obstacle to fully test the battery.
- R2.2 is being mitigated with a transportation and installation plan developed by INESC TEC, EEM and VGColab.
- R2.4 is fully mitigated as demo 2 already has a fully operational server from EEM that stores all the data coming from the SCADA. A virtual machine developed by INESC TEC gathers and handles the data from EEM to further use it to input the optimisation algorithms.
- R2.5 is a new risk encountered while developing the AI tool for water inflows predictions. EEM manually closes and opens some water cascades creating unreliable data and making difficult to create a predictive tool.

5.2 DEMO DEPLOYMENT, OPERATION, TESTING AND PRELIMINARY RESULTS

The majority of the technological assets that will be used in demo 2 are already available on-site, such as the wind/PV, Li-ion battery, hydro power plants, thermal units and synchronous condensers. The VRFB is under development by VGLAB and it is expected to be installed before the end of 2024.

As mentioned previously, Madeira Island has several hydro power plants with pumping capacities. Each hydro power plant has several hydro inflows that leads the water to the reservoirs. An AI-based algorithm was developed to forecast water inflows based on weather forecasts. The algorithm is being tested and will be integrated in the INESC virtual machine before August 2024.

An algorithm to perform the day-ahead optimal dispatch of the Madeira power system is also under development. It is currently being tested with hindcast data provided by EEM. The algorithm will be tested on-site after installing the VRFB.

The results from the optimisation algorithm will be checked by a dynamic security assessment procedure, based on Artificial Neural Networks (ANN), which will be trained with the outputs of dynamic simulations performed with POWER FACTORY software, from DIGSilent, over the Madeira Island power system model. This procedure will check the frequency stability of the grid considering the operational points provided by the optimisation algorithm. If the system is unsafe, the optimisation algorithm will redispatch generators enforcing the utilisation of synchronous condensers.

The results will then be stored in EEM database. The whole process is described in Figure 12.

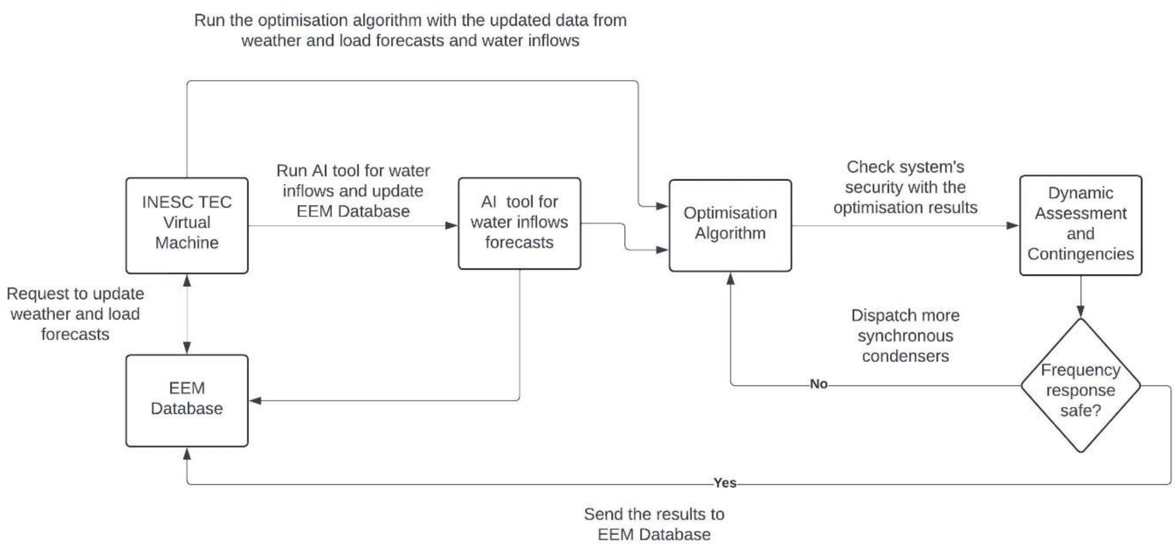


FIGURE 12: OPTIMISATION PROCESS

A front-end to the database in the INESC virtual machine is also under development to facilitate access to data and interactions for external users.

5.2.1 Implementation Plan

As mentioned above, the Demo 2 implementation plan covers several simultaneous tasks. The tasks under development are described in the following subsections.

5.2.1.1 VRFB Design and Deployment

The Demo 2 VRFB design and implementation follows two different and parallel action lines: lab-scale, and field-scale demo. The lab-scale demo is an in-house development of a 4 kW/8 kWh VRFB to validate the development of new electrolyte additives to improve the battery performance. The field scale is the 50 kW/100 kWh containerised battery system that will be connected to the grid in the Madeira Island. In the following subsections, the development phase of each subtask is described.

5.2.1.1.1 Specifications and preliminary design

The specification and preliminary design of the field-scale demo intend to validate the design and performance assessment of the battery system sub-components and their integration. The following companies were contacted to provide an initial quotation for the battery components, namely battery stacks, pumps, piping, BMS, and containers: Invinity, VisBlue, Hydraredox, and Volterion. A public tender for the acquisition of the components has been published and closed. Hydraredox was the only company answering the tender and fulfilling all the requirements. All subcomponents should be in the VGLAB facilities within 7 months (end of October 2024). The power electronics architecture consists of multiple isolated DC/DC converters interconnected in series/parallel with a shared DC bus. A DC/AC inverter is then responsible for controlling the active and reactive power flow with the grid following the Madeira Island grid code. The system architecture diagram is shown in Figure 13Figure 13, where each stack interfaces with a common DC bus of 350 V through five parallel DAB converters.

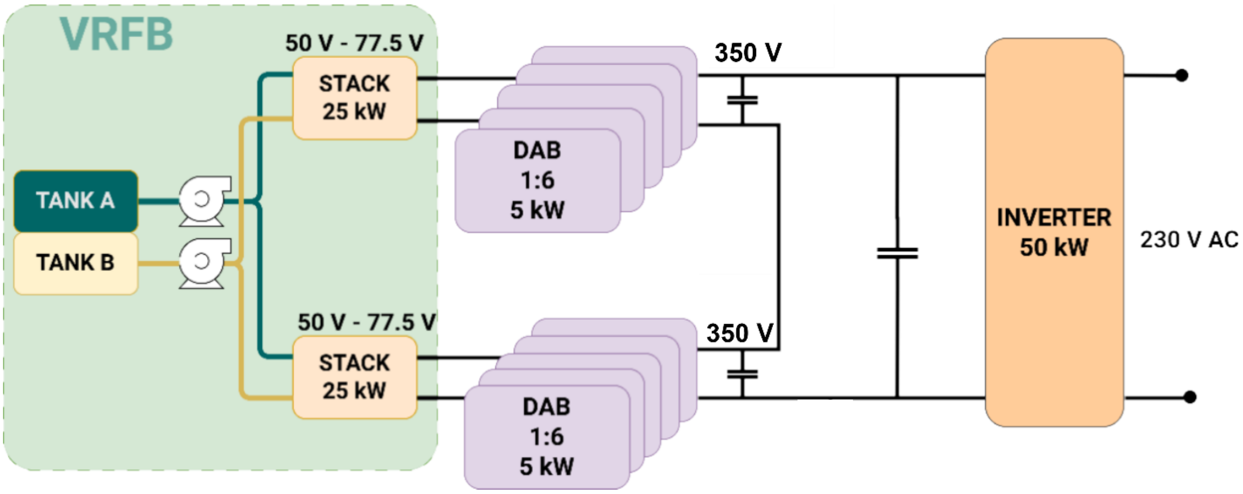


FIGURE 13: VRFB SYSTEM ARCHITECTURE

5.2.1.1.2 Lab-Scale Development

The lab-scale prototype includes the full assembly of the lab-scale VRFB, including the design of the piping circuit, sensorisation, BMS, etc., and the additives' development.

5.2.1.1.3 Additives

One limitation of the VRFB is the operational range of the temperature, generally between 10 and 40ºC. Temperatures above these limits may lead to a precipitation of the vanadium species and consequently decrease the battery's performance. A way to contour this limitation is to use additives added to vanadium electrolytes. Hence, inorganic additives have been selected, and the tests have started. The tests involve electrochemical characterisation (cyclic voltammogram), temperature resistance, and the influence of battery performance (charge/discharge). The additive with better performance will be tested on the lab-scale prototype 4 kW/8 kWh.

5.2.1.1.4 Lab-Scale Construction

Figure 14 shows the development state of the 4 kW/8 kWh VRFB Lab-scale ready for calibrating pumps, ensuring tightness of the piping system, and proper pressure drop according to the preliminary calculations.

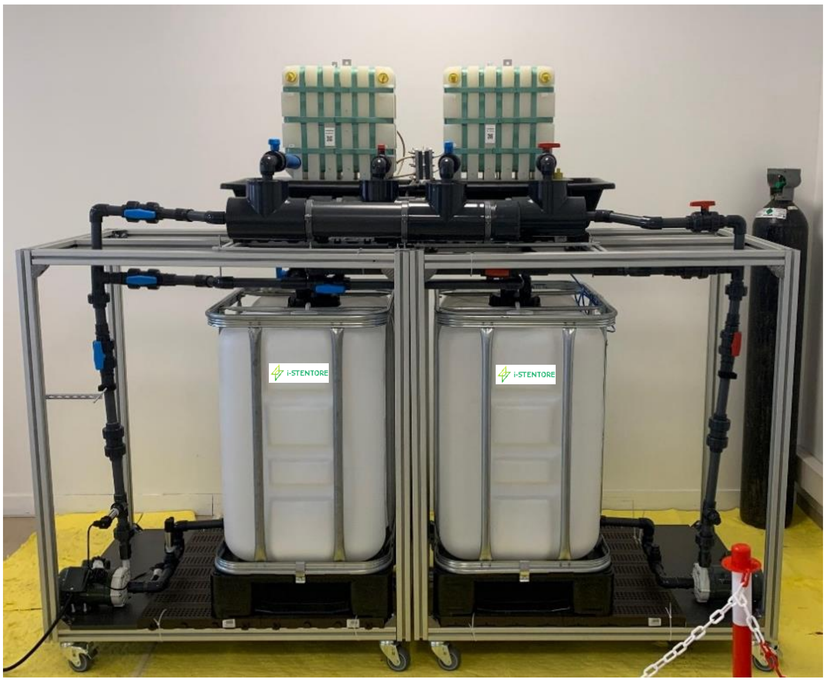


FIGURE 14: VRFB LAB-SCALE PROTOTYPE 4KW/8KWH

Figure 15 illustrates a descriptive hydraulic scheme of the VRFB that shows all possible electrolyte paths:

- A main pressure line connecting tanks to the feeding manifold and reactors/stacks.
- A bifurcation to create on each tank a close-loop path for self-priming the pump and allowing the change of electrolytes or adding additives.
- A bifurcation to create a path to the opposite tank for electrolyte rebalancing purposes (due to cross-over on stacks).

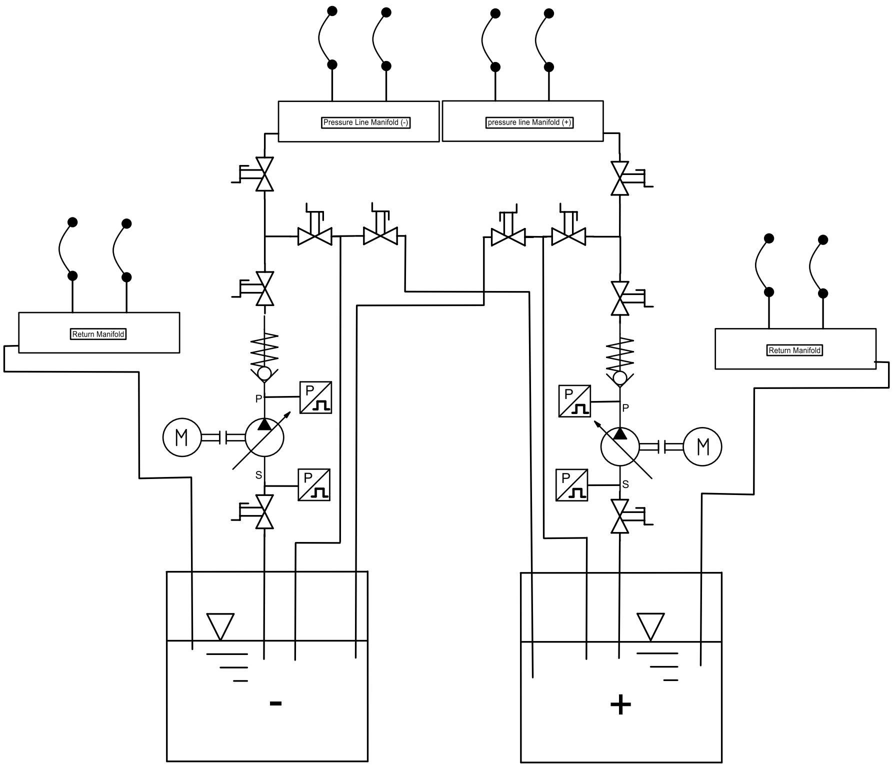
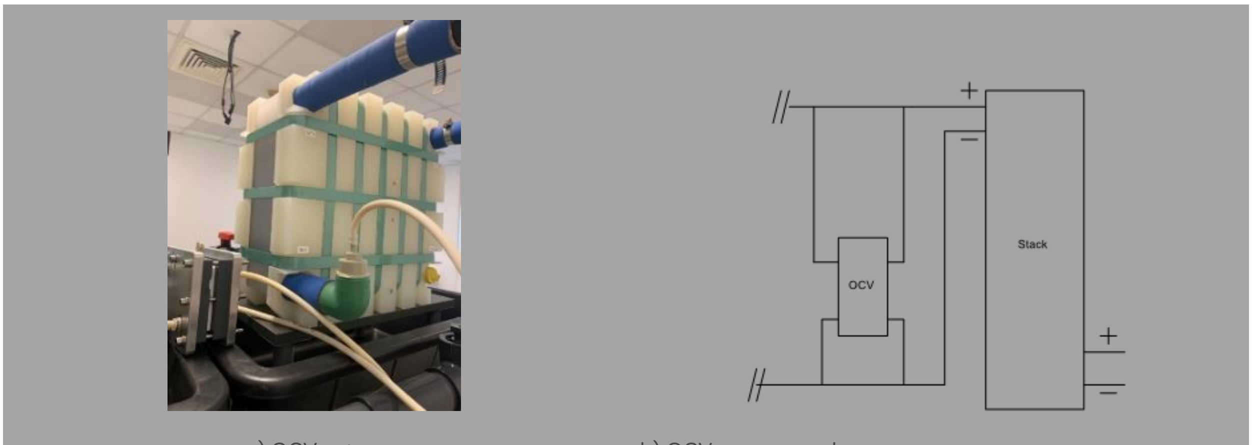


FIGURE 15: HYDRAULIC SCHEME

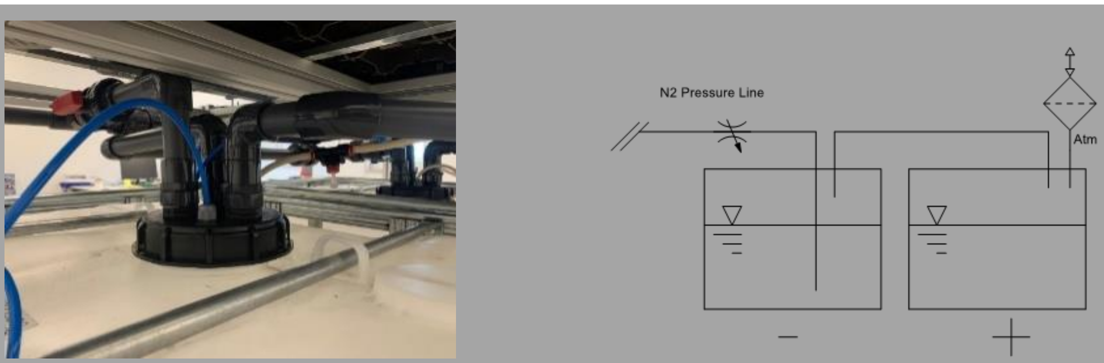
An Open circuit voltage measurement cell is being implemented so that we have an accurate SOC measurement. Figure 16**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** depicts the implementation of the measurement cell and the respective scheme.



a) OCV setup. b) OCV measure scheme.

FIGURE 16: OCV MEASUREMENT CONSTRUCTION

To mitigate active species O_2 contamination, which leads to side reactions, a N_2 pressure line was inserted to ensure an inert atmosphere throughout the two tanks. Figure 17 shows the insertion of the pressure line and the respective scheme.



a) N_2 pressure line.   b) N_2 pressure line scheme.

FIGURE 17: A) PRESSURE LINE B) N2 PRESSURE LINE CONSTRUCTION

5.2.1.1.5 Battery Management System (BMS)

To ensure proper functioning and system safety, it is necessary to select sensors to monitor the system and develop the sensor's conditioning boards as well as the BMS board.

In Figure 18**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, the developed BMS board is shown. The BMS software as well as the BMS board were successfully tested and the sensors were calibrated ensuring correct measurements.

The tests conducted prove the good performance and correct operation of the BMS.

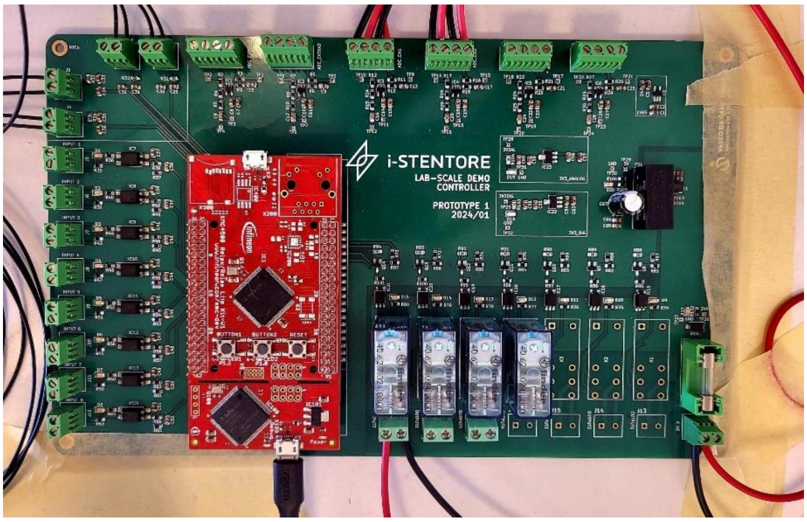


FIGURE 18: LAB-SCALE DEMO BMS CONTROLLER

5.2.1.2 Power Electronics Development

To connect the vanadium redox flow battery (VRFB) to the grid, it is necessary to elevate the voltage to achieve a DC bus that allows to generate a three-phase bus, as depicted in Figure 19. In the following subsections, the development of the main power electronics elements (inverter and the DAB modules) is reported.

5.2.1.2.1 Inverter

Figure 19 shows the inverter CAD model. Currently, the design phase is being finished, and we are in the process of acquiring the passive elements to proceed with the testing and validation.

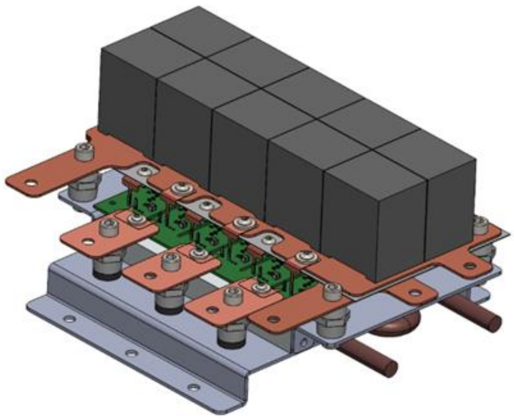


FIGURE 19: INVERTER CAD MODE

5.2.1.2.2 Isolated DC/DC converter – Dual Active Bridge

The solution to be implemented is ten DABs with 5 kW each, organised in two groups of five in parallel.

The power electronics will be stored in a cabinet and each rack will have two DABs.

Figure 20 shows the preliminary CAD model of each DAB rack, which is almost completed. Currently, we are working on each subsystem assembly. Figure 21 and Figure 22 depict two DAB subsystems, namely, the heatsink and high-frequency transformer. Currently, we are finishing its assembly to proceed then with the testing phase.

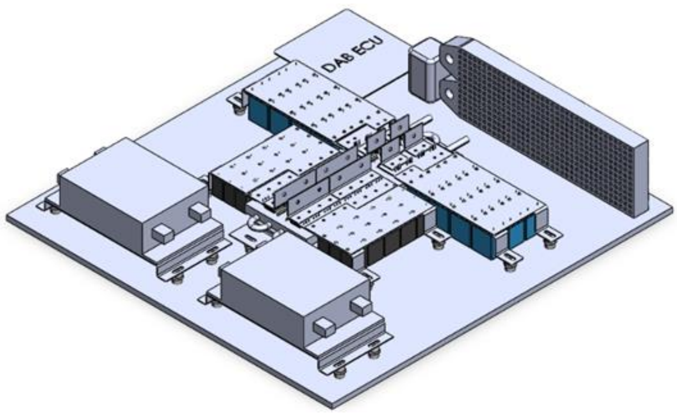


FIGURE 20: DUAL ACTIVE BRIDGE CAD MODEL

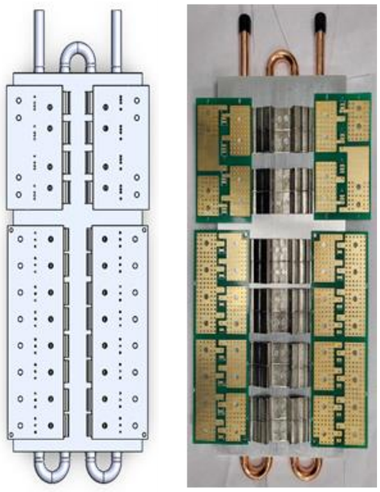


FIGURE 21: HEATSINK

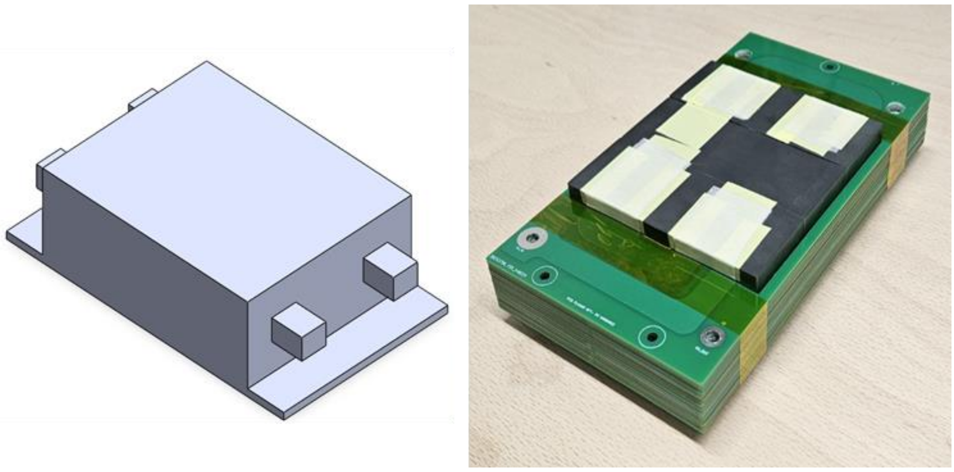


FIGURE 22: HIGH FREQUENCY TRANSFORMER

5.2.1.2.3 Grid Code Compliance

To ensure compliance with the expected requirements for plants connected to Madeira's electrical grid, a review of the existing grid code was carried out to evaluate the required operation characteristics.

Hence, considering that the requirements are divided by increasing the output power level, the proposed plant falls within the designation of type A (i.e. nominal power above 2.5 kW and below 100 kW). Therefore, the plant must:

- Modulate locally the reactive and active power output to ensure that the voltage does not exceed or fall below 10% of its nominal value.

- Modulate the active power output within 1 second, in response to grid frequency variations in excess + 0.3 Hz, via a droop characteristic.

Additionally, similarly to all other plant classification types, it must also operate continuously within the acceptable grid frequency and voltage deviations.

5.2.1.3 Tests and Preliminary Results to the VRFB

5.2.1.3.1 Electrolyte preparation containing additives and experiments involving half-cells (three electrodes)

Figure 23 presents cyclic voltammetry experiments obtained in a solution of $V^{3.5+}$ (V^{3+} + V^{4+} 1:1 M/M) containing different additives. In Figure 23A, we see the redox reaction to the V^{4+}/V^{5+} pair around 0.8 - 1.1 V vs. Ag/AgCl (sat. KCl) and to the V^{3+}/V^{2+} pair around -0.4 - -0.8 V as expected. Similar behavior was found when the experiment used a diluted electrolyte containing a higher concentration of sulfate ions and phosphates presented in Figure 23B. However, the current was lower because of the lower $V^{3.5+}$ concentration (1.43 mol/L).
Different behaviors were observed in Figure 23C and D where PVP+$(NH_4)_2HPO_4$ and $(NH_4)_2HPO_4$+ $MgCl_2$ were added, respectively. A possible explanation is that the presence of the additives shifted the potential where the electrochemical reactions of the pair redox the V^{3+}/V^{2+} were supposed to happen. To evaluate the potential shifted supposition, the potential window in Figure 23C was increased, and we can see the current increasing, probably related to the redox reaction of the V^{3+}/V^{2+} pair.

Co-funded by the European Union

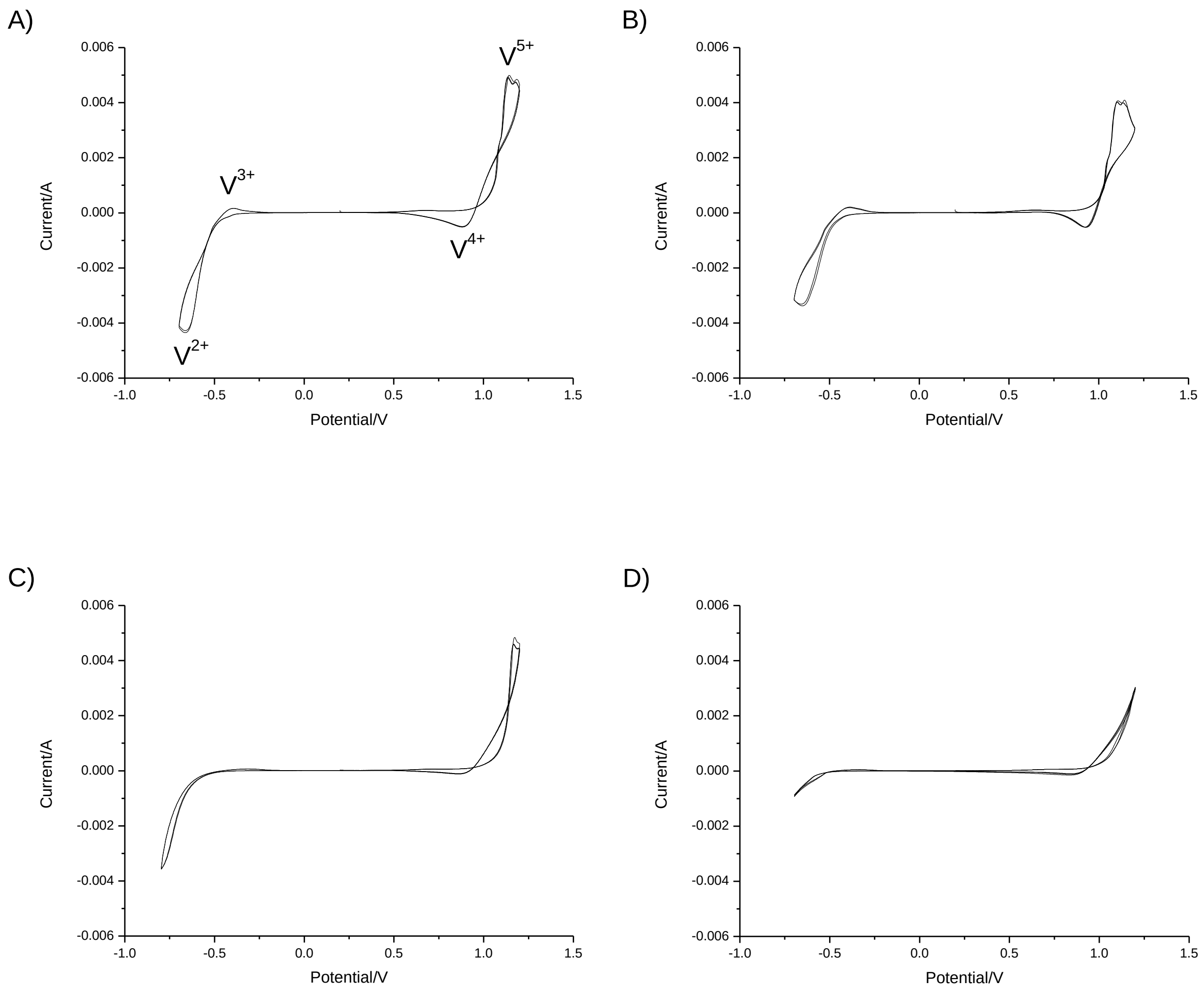


FIGURE 23: CYCLIC VOLTAMMOGRAMS IN SOLUTIONS OF V3.5+ (V3+ + V4+ 1:1 M/M) CONTAINING DIFFERENT ADDITIVES: A) 1.6 MOL/L V3.5+ + 4.3 MOL/L SO4-2 + 0.05 MOL/L PO4-3(COMMERCIAL); B) 1.43 MOL/L V3.5+ + 0.1 MOL/L H3PO4 + 4.9 MOL/L SO4-2; C) COMMERCIAL + PVP 0.025 WT% + (NH4)2HPO4 0.25 WT%; D) COMMERCIAL + 0.15 MOL/L (NH4)2HPO4 + 0.05 MOL/L MGCL2

The experiments showed the electrochemical behavior of electrolytes containing different additives. However, experiments involving a redox flux battery system must be conducted to evaluate the influence of the potential shift.

Some missteps occurred in the pipping assembly process, namely leakage problems (Figure 24) during the pumping tests to validate the system (without the battery stacks) and procurement of acid-resistant components.

FIGURE 24: AN EXAMPLE OF A LEAKAGE PROBLEM IN THE PIPING SYSTEM

5.2.1.3.2 Dual Active Bridge – Simulation Results

To validate the design parameters defined and to guarantee the system stability, we simulated two DABs with the output in series to achieve the 700V DC.
Figure 25 shows a simulation result regarding the DC bus voltage control with load variation.

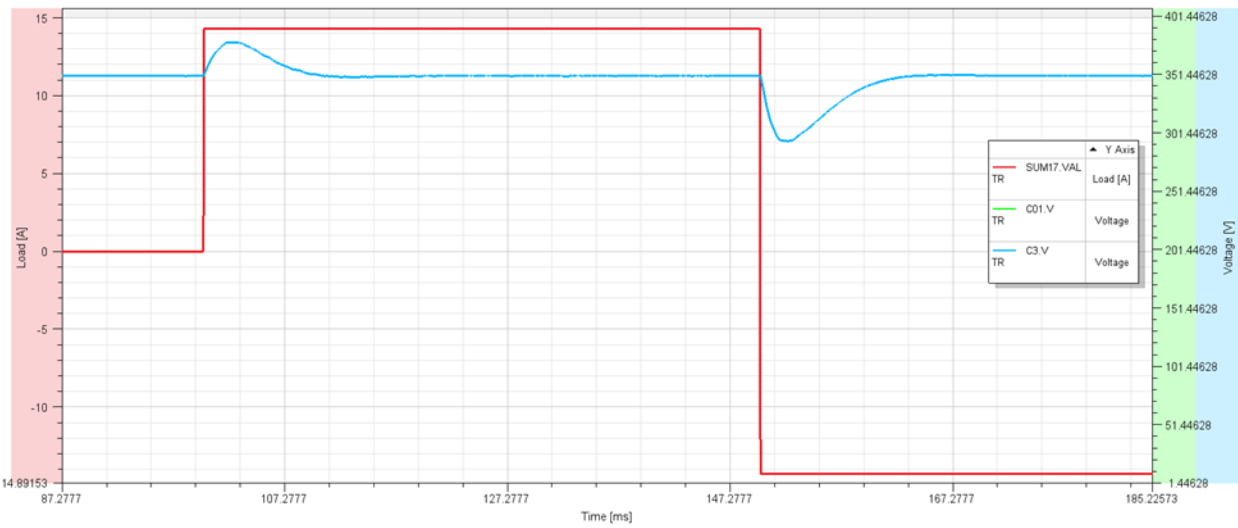


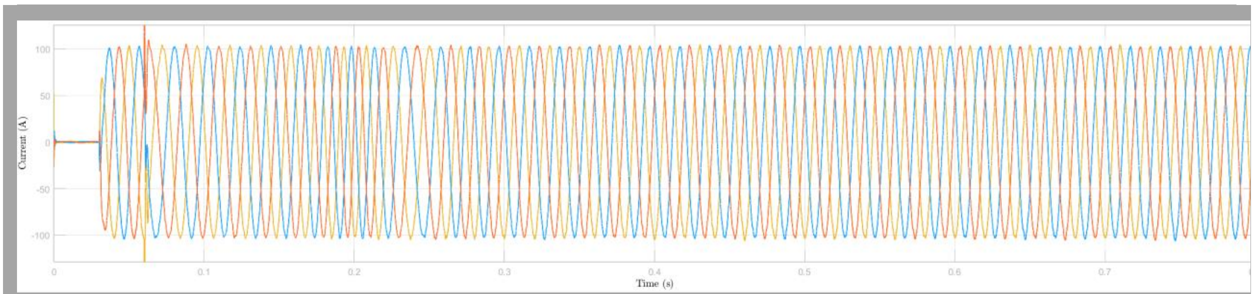
FIGURE 25: DUAL ACTIVE BRIDGE SIMULATION RESULTS

As it can be seen, the system is stable under maximum load variation, responding within 10 *ms* with a maximum overshoot <50 V.

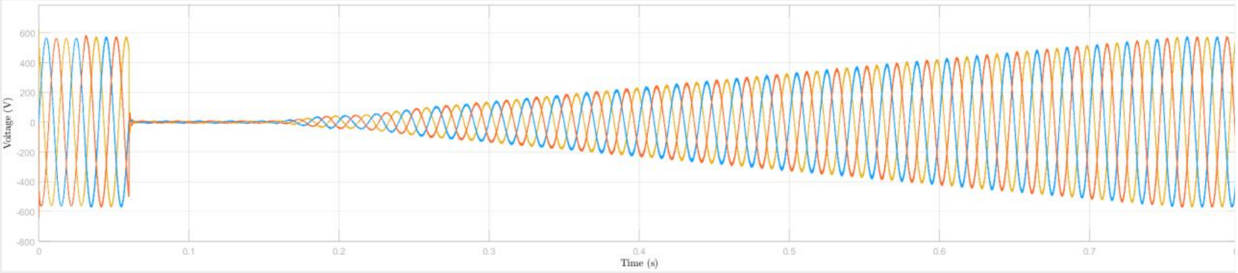
5.2.1.3.3 Inverter – Simulation Results

The inverter simulation results were performed considering uncertainties on filter parameters, the semiconductor conduction models, and discretised control loops. The Inverter simulation was carried out considering a regulated DC bus voltage.

Figure 26 illustrates the converter current dynamics during a voltage sag by the Madeira grid code[1], where times were scaled down by a factor of 10. The results shown represent the most demanding test when it comes to the controller's stability and performance evaluation, making it possible to validate its design.



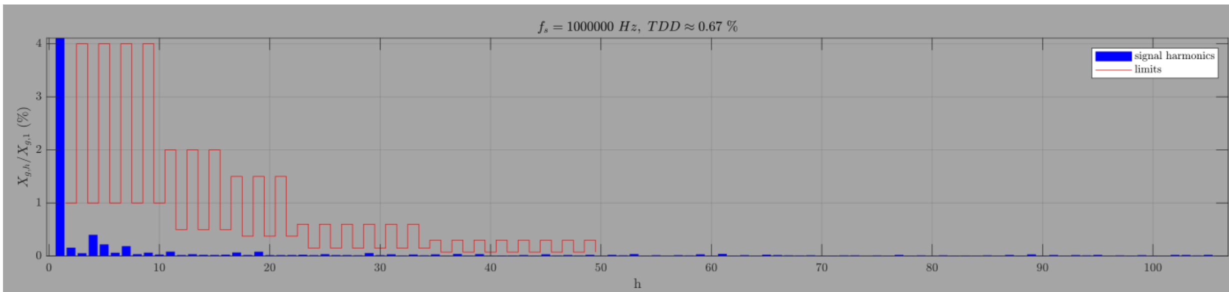
a) Three-phase current waveforms



b) Three-phase voltage waveforms

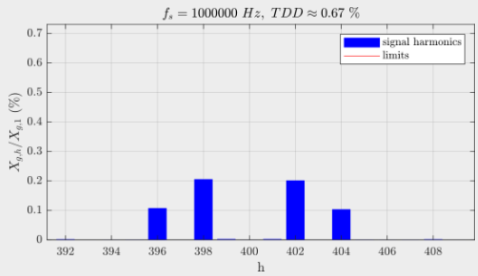
FIGURE 26: VOLTAGE SAG TO 0 V FOLLOWING MADEIRA ISLAND GRID CODE

Figure 27**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** a and b, show the current harmonics content, following the IEEE-519 standard in steady-state conditions. The individual and total demand distortion (TDD) is respected with a considerable margin, though high order harmonics, at switching frequency h=[396; 404], can be further attenuated if needed by placing an LC trap filter.



a) Harmonics within IEEE 519 standard defined range. Limits in red and harmonics in blue.

[1] https://joram.madeira.gov.pt/joram/1serie/Ano%20de%202019/ISerie-175-2019-11-06.pdf (in Portuguese)



b) Harmonics at switching frequency (20 kHz).

FIGURE 27: STEADY-STATE CURRENT INDIVIDUAL HARMONICS AND TDD FOLLOWING IEEE 519 STD

5.2.1.4 Hydro cascades modelling and water inflow forecasts

There are two main ways that streamflow prediction has been done in the past. The first category includes process-driven or dynamical hydrological models, which can be as simple as a conceptual model or as complex as a physically-based, distributed one. Machine learning methods like autoregressive models and Artificial Neural Networks (ANNs) are a part of the second strategy that uses data-driven statistical models. Ensemble Streamflow Prediction (ESP) systems, which use ensemble with a numerical weather prediction model to improve prediction accuracy, are ideal for using these methodologies. Deep learning algorithms provide a potential alternative to explicit data types, including soil properties, and may thus handle these issues. Because of their strength in learning long-term dependencies within time series data and their ability to handle sequential data, Long Short-Term Memory (LSTM) networks have become a popular deep learning model in hydrology. This makes them ideal for streamflow forecasting, a field where these dynamics are common.

To obtain the result needed, LSTM neural networks have been implemented for forecasting water inflow into hydrological reservoirs using accurate rainfall forecast data from a meteorological radar as input, after training it with hindcast data of rainfall and water inflows. This requires detailed representation of complex, changing systems that are affected by time-based patterns and potentially unpredictable natural processes, for which LSTM are particularly well suited. The method uses rainfall forecast data for a specific catchment area as an input. However, it is necessary to understand that rainfall alone as an input can be limited in terms of justifying water inflow, since on the one hand it cannot account for all water inflow and on the other hand not all rainwater is collected. It is therefore crucial to create an artificial feature (to be called "spring_water_contribution" for simplicity, though it gathers other factors) in the data preparation phase. This characteristic is intended to measure the constant baseflow that contributes to the total water inflow, which is expected to remain relatively steady regardless of current weather conditions. In order to calculate this, a moving average of the water input is determined over a specific time period. The length of this moving average can be altered depending on the period of prediction needed. This method captures the consistent contribution from underground or continuous water sources successfully, while implying that value inputs should be updated regularly.

To make sure that the best possible results are achieved, outliers must be handled. This is a crucial process for guaranteeing the integrity of data. The analysis is conducted by applying the Interquartile Range (IQR) approach to each relevant parameter to detect and resolve any anomalies that may distort the results. This procedure entails computing the IQR for the dataset and adjusting any outlier values that lie above predetermined thresholds, hence maintaining the integrity of the data utilised for model training.

Afterwards, a normalisation technique is implemented, using Min-Max scaling to convert the dataset into a standardised range. The normalisation process involves incorporating all characteristics, including the spring_water_contribution, to guarantee uniform data magnitude, which is crucial for optimising the efficiency of neural network training.
In Figure 28 there's a simplified explanation of the data preparation.

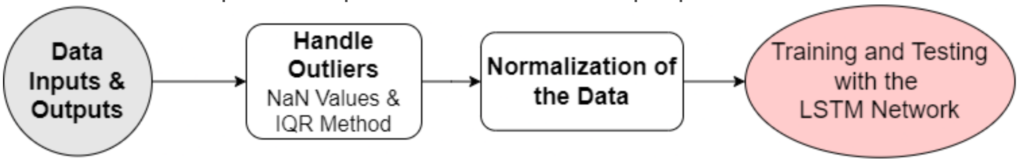


FIGURE 28: DATA FLOW SCHEMA

The second part of the proposed methodology is the training of the network and testing. The training of the LSTM network is systematically conducted by creating an architecture, specifically designed to accommodate the temporal and sequential characteristics of hydrological data. This architecture consists of an input layer, which represents the number of features, LSTM hidden layers that are configured with an appropriate number of units to capture data dependencies, and a regression output layer for predicting continuous water inflow.
In this case, the LSTM model is trained using the Adam optimisation algorithm, with carefully adjusted hyperparameters including the number of epochs, mini-batch size, gradient threshold, initial learning rate, and learning rate schedule. Adam Optimisation is straightforward, computationally efficient, and intuitive tool for non-convex optimisation problems, making it suitable for large data and parameters, non-stationary objectives, noisy/sparse gradients, and minimal tuning, which makes it a good match for the problem in hand. These adjustments are made to optimise the network's learning and predicting accuracy. The training process is continuously improved, with an emphasis on avoiding overfitting by using early stopping and validation tests, to guarantee that the model can be applied to new data circumstances.
The first tests were already made using the data provided by EEM for the use case of Socorridos. The results are fairly good, but the model has difficulty in predicting some of the inflow spikes, as it can be seen in Figure 29.

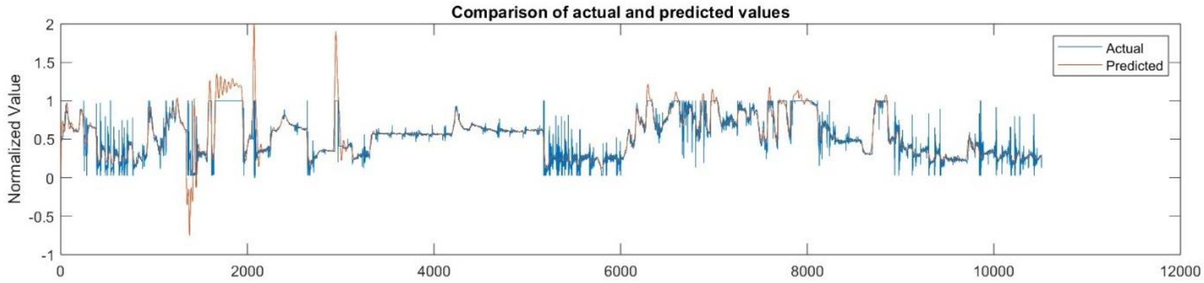


FIGURE 29: ACTUAL VS PREDICTED VALUES OF SOCORRIDOS

This model resulted in a normalised RMSE of 0.128 which implies that the methodology is effective but the model still has room for improvement.

5.2.1.5 ED/UC optimisation algorithm

The algorithm was developed with the following considerations:

- Generator and Reservoir Constraints: All generators have a maximum power limit, and all reservoirs have a maximum water storage capacity. Water flows and stored water are described in terms of power/energy, considering conversion factors that relate water content to potential energy production when turbined.
- Optimisation Tools: Python and PuLP were used to build and solve the optimisation problem.
- Simplified Thermal Generators: For simplicity, thermal generators were aggregated into a single generator with the combined capacity of all individual units.
- Spinning Reserves: Only thermal generators and batteries are considered for spinning reserves (both upward and downward), implementing an n-1 criterion. The maximum power includes only the power of the generators that are online, and the minimum power is the technical operational minimum of the online generators.

The model aims to optimise energy dispatch at minimum cost while increasing renewable penetration, meeting electricity demand, satisfying spinning reserve requirements, and ensuring water needs for human consumption, agriculture, and environmental purposes.

In order to test the algorithm, study cases were created utilising EEM's real data from 2022. The data from EEM includes weather, load and generation forecasts. Primary reserve both upward and downward were set to 15 MW which is the peak power provided for the largest thermal generator operating.

Each storage reservoir is initially set at 30% of its capacity, and the model ensures that the reservoirs end at the same level, maintaining a balance between the water used and recovered. The model will solve the dispatch problem for three scenarios and compare the results with the actual dispatch/load of January 2022:

- Standard Scenario (STD): The same conditions as January 2022 are considered.

- Increased Renewable Energy Scenario (REW): This scenario considers a 33% increase in wind power and a 100% increase in solar power compared to the STD scenario.
- Increased Renewable Energy Scenario + Battery Reserve (BAT): The conditions of the REW scenario are maintained, but the impact of using batteries for primary upward and downward reserve is evaluated.

The first 10 days of the year are shown in Figure 30, where the behaviour of the model in different scenarios can be compared to the actual data. The model is able to dispatch the available resources, follow the load and use the reservoir hydro resource in the periods of lower availability of renewable resources, while avoiding its use otherwise. A significant reduction in thermal generation occurs in all the scenarios with reduction of renewables curtailment and improvement on storage usage. Thermal generation is also reduced in scenarios where the battery can provide synthetic spinning reserve.

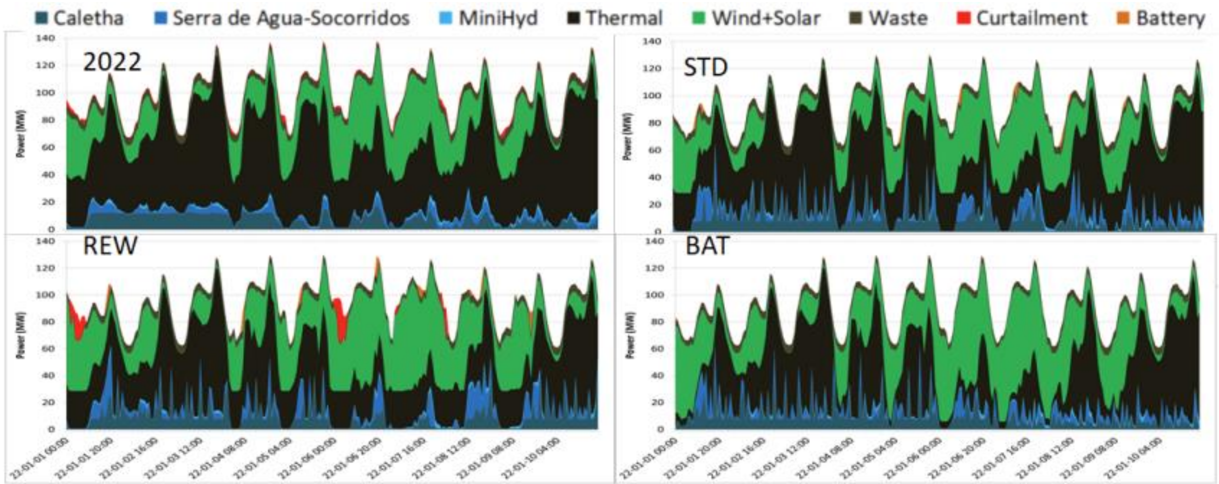


FIGURE 30: ENERGY DISPACH FOR THE FIRST 10 DAYS OF THE MODELLED PERIOD

5.2.1.6 ED/UC Dynamic Security Assessment

For the purposes of this study, the electrical system of Madeira Island was represented in terms of the network infrastructure and the power generation system according to the single-line diagram presented in Figure 31. The modelling of the system included the synchronous base generation systems, and the renewable park projected for this year, two energy storage systems, and an additional synchronous compensator to be installed.

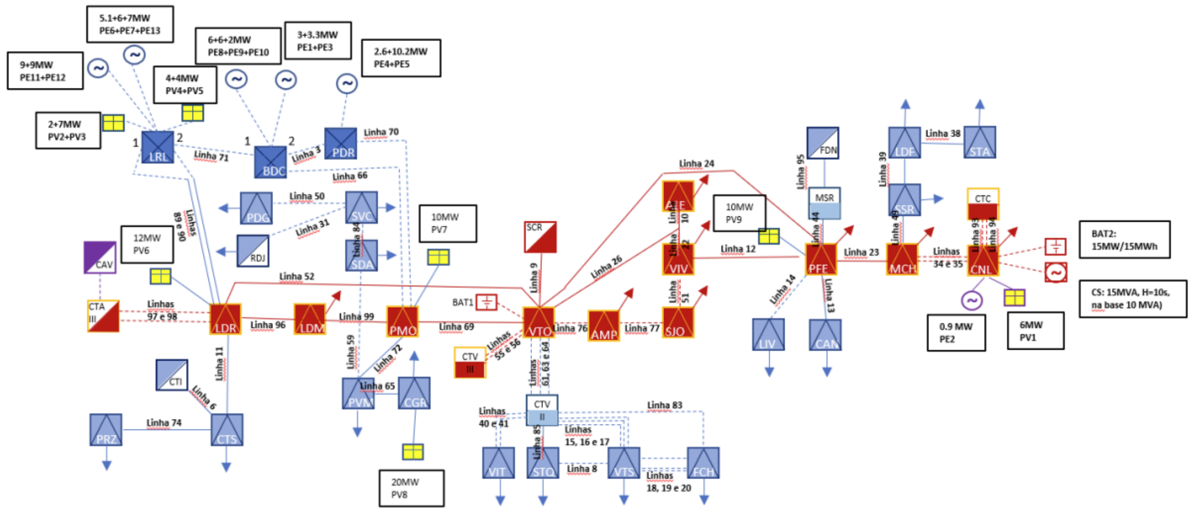


FIGURE 31: MADEIRA ISLAND ELECTRICAL GRID SCHEMATICS

To conduct the stability analysis, numerical simulation models of the various elements that make up the power generation system were used. The PowerFactory (DigSILENT) simulation software was utilised, involving typical options that reflect the current state-of-the-art knowledge. There was a concern around making appropriate adjustments to the different model parameters to better reflect the behaviour of the existing units in Madeira. A brief description of the models adopted for the various technologies is presented below. The simulation model is shown in Figure 32.

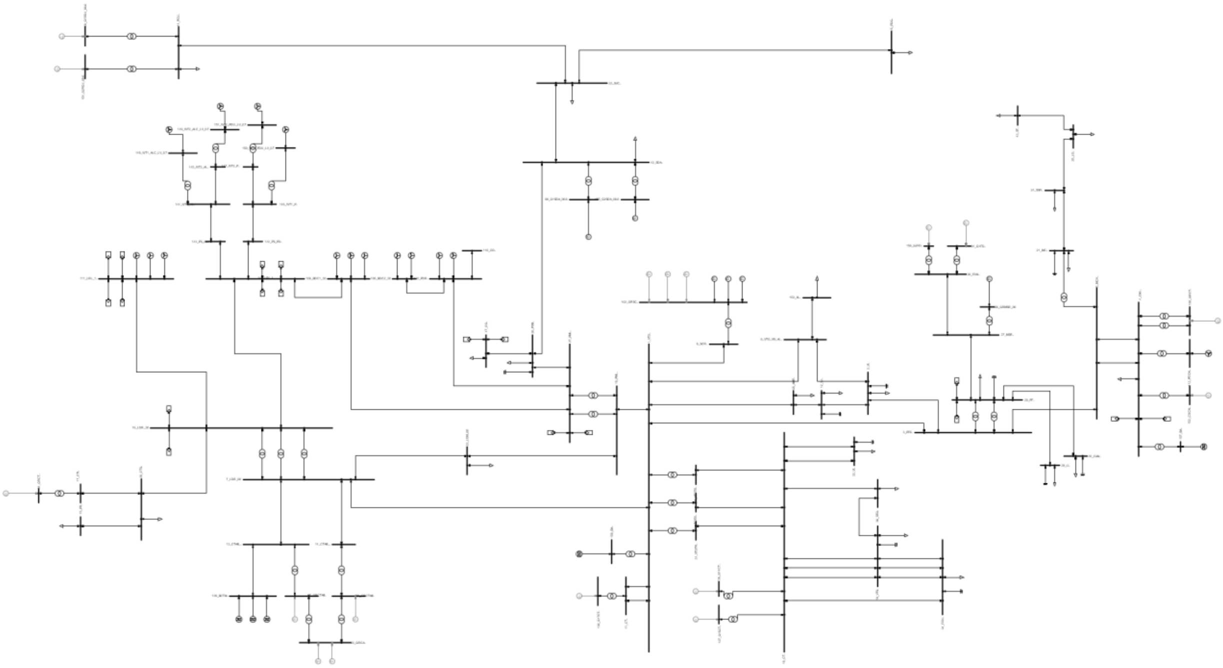


FIGURE 32: MADEIRA ISLAND POWER FACTORY MODEL

Synchronous Generation: For the synchronous units (thermal and hydro), the base model available in PSS/E was considered, and it was appropriately transposed to the generator models available in PowerFactory. Regarding the representation of the excitation system, the IEEEX1 model was adopted. The parameterisation of these models was based on information provided by EEM, particularly the inertia of each unit (H, in seconds), here referred to their nominal power (Sn).

Solar and Wind Power Plants: In most cases, a generic model (REGCA1) was used to represent the behavior of the electronic converter connecting these units to the grid, the REECA1/REECB model for representing electrical control, and the REEPCA1 model for representing the power control mechanism. These models were appropriately parameterised for each park to reflect their characteristic behavior in terms of response to short-circuit situations on the grid. Each aggregate of such installations, which does not comply with the current grid code, is generally subdivided into two parts:

- A power volume that does not have fault ride-through (FRT) capability.
- A power volume with fault ride-through capability but, due to the technological specifics of the equipment used, it was considered unable to inject current (active or reactive) during the fault, referred to as Zero Power Mode (ZPM).

Additionally, the power recovery ramps for wind parks operating in ZPM were adjusted according to the fault duration (as recommended by EEM). It should be noted that for the Alecrim and Pico da Urze units, both compliant with the current grid code, specific models provided by the manufacturer of the wind turbines installed there (ENERCON) were adopted.

Different amounts of photovoltaic solar generation without FRT were considered for each generation aggregate (depending on their current or future existence within the study horizon – 2024). Thus, it was assumed that 40% of the existent aggregate would not have FRT capability for the Loiral and Caniçal solar parks, while for the remaining ones that are yet be installed, only 25% was considered (to reflect the lack of fault ride-through capability in smaller units – types “A special” and “A” according to the current grid code designation).

Energy Storage Systems: Both battery systems were assumed to be characterised by the same technical requirements, being capable of operating in both grid-forming (GFM) and grid-following (GFL) modes. For GFM operation, it is considered that:

- The control follows a Virtual Synchronous Machine (VSM) type philosophy, similar to those presented in [5] [6].
- The virtual inertia (base value of 4s) varies with voltage, based on a logic that increases its base value when terminal voltage drops, thereby improving the GFM's transient response.
- The virtual damping (D) is 100.
- The dynamic current limit (Imax) is 1.5 p.u. (limited via virtual impedance).

It should be noted that the model used is based on the current state-of-the-art knowledge, without reflecting any specific supplier model, whether for the currently implemented battery solution in Vitória or the one to be installed in Caniçal.

For GFL operation, it was considered that:

- The control follows an operation philosophy based on grid support, combining an active power-frequency regulation characteristic based on a droop (P(f)) and a constant reactive power support characteristic to the grid (Q fixed), along with the capability of injecting reactive current during voltage sags.
- The droop (R) was parameterised to a value of 0.01 (p.u Hz/p.u. MW).
- The dynamic current limit (Imax) is 1.3 p.u. (limited via a saturation block acting directly on the reference current to be injected).
- The maximum power gradient (dP/dt max) is 10 p.u./s.

Synchronous Condenser: For this device, the basic generator model provided by PowerFactory was adopted, as well as the AC7B excitation system model. Both models were parameterised according to a document provided by EEM [7], highlighting the power of 15 MVA and an inertia constant of 6.798 s (referred to the nominal power base of the machine).

Pumping Systems: For the Socorridos pumps, a generic induction motor model was assumed, with instantaneous protection tripping for voltages below 0.8 p.u. For the Calheta case, it was considered that the pumps were connected to the grid via an electronic converter and entered "kinetic buffering" mode (similar to ZPM from the grid's perspective) for voltages below 0.8 p.u. After the fault was cleared, it was assumed that the pump power recovered quickly, as this represented the most demanding situation for the system in the moments following the fault clearance. The assumptions made here are based on information described in a document provided by EEM [8].

5.2.1.7 Data Pipeline

Data is obtained directly from an SFTP server created by EEM. This data is already pre-processed from a SCADA server. Inside our network we have a data pipeline that follows the schema in Figure 33.

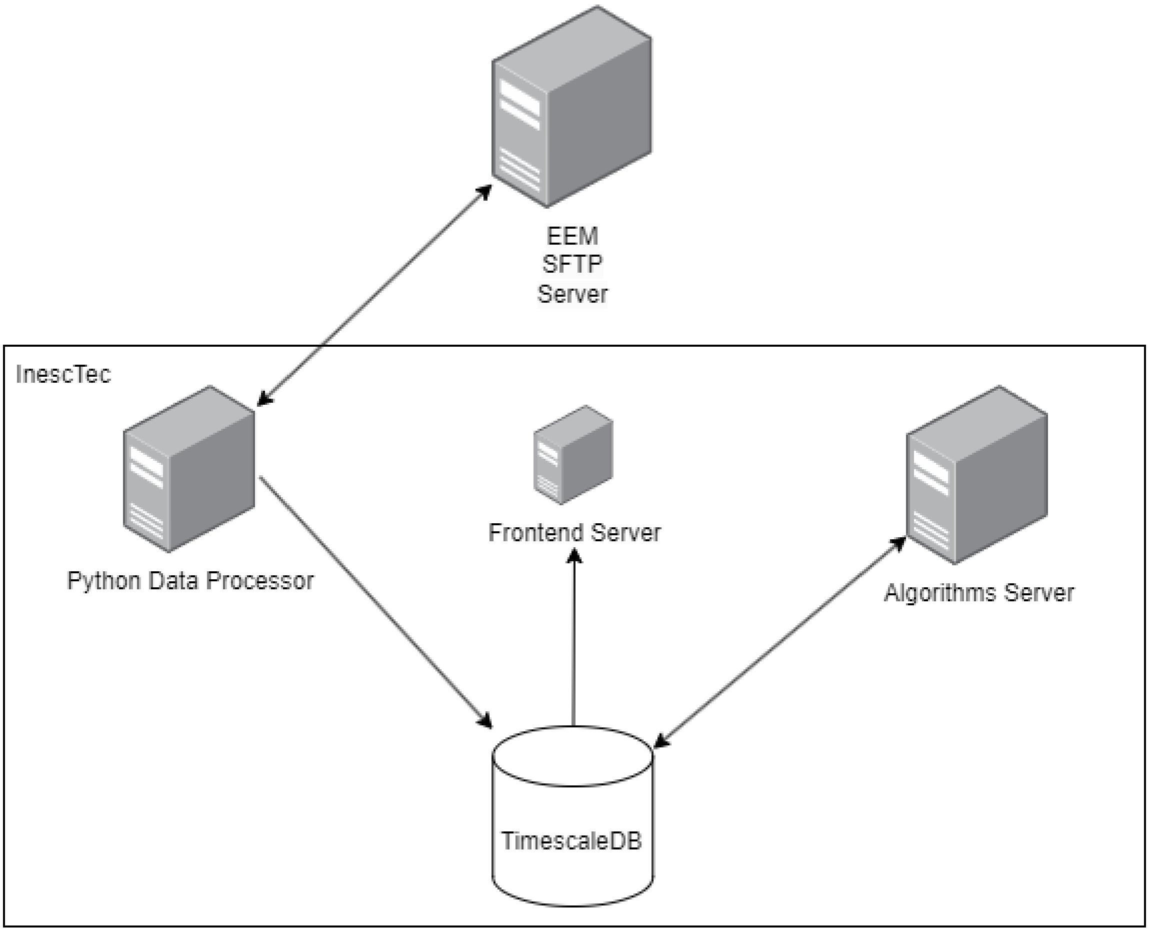


FIGURE 33: DATA PIPELINE

INESC created a Python script that fetches data from the SFTP server and processes it so that it fits the schema of the database created in the INESC virtual machine. This database is in Timescale DB, which is an extension to PostgreSQL. A frontend server is also being developed – currently, it is only used for data visualisation and is based in Grafana. The algorithms server is a representation of how the data will be processed using the machine learning/optimisation models being developed.

5.2.2 Lessons Learnt and Next Steps

As mentioned above, the Demo 2 implementation plan covers different areas. The lessons learnt and the next steps from the implementation plan are described in the following subsections.

5.2.2.1 VRFB development

The influence of the additives on the electrochemical response to vanadium electrolytes was obtained in cyclic voltammogram experiments. The results showed that the presence of these compounds on electrolytes influences the cyclic voltammogram profile obtained compared to the commercial one. Further experiments are needed to understand the influence of this compound on charge/discharge experiments. In the following steps, experiments will be carried out at different temperatures and in the presence of carbonaceous materials in commercial electrolytes and diluted solutions. An improvement of the operational temperature range and current density in the electrochemical response is expected.

In the Lab-scale prototype, the next steps include cleansing the system of any impurities with distilled water in a few weeks and making it fully operational to receive the vanadium electrolyte solution.

In the upcoming months, the subsystems assembly activities will be concluded, and testing will start. As soon as the validation of the DAB subsystems is finished, the full system assembly and testing will begin.

The results of the inverter design have validated the filter, and converter control design and are ready to advance for an implementation phase with the final prototype. Several tests will be performed following a stepwise approach to ensure that the converter in the end can perform safely and following the Madeira grid code.

5.2.2.2 Water inflow forecasts

Considering the Hydro cascades modelling and water inflow forecasts, the solution has been tested with real data from EEM, yielding valid results. In the future, this solution needs to be tested with more data from EEM. There's lack of sensors in the water cascades; flow sensors are necessary instead of volumetric sensors.

5.2.2.3 ED/UC optimisation algorithm

The ED/UC optimisation algorithm is expected to increase renewable integration and system's stability. Future work will consider expanding the time frames of the current study and consider additional scenarios with focus on increasing renewable energy sources and storage systems. After conducting more tests with additional scenarios, it is expected to integrate the algorithm with the water inflows predictive tool. Furthermore, the whole solution will then be applied to the Madeira Island power system.

5.2.2.4 ED/UC dynamic security assessment

To create a resilient neural network for dynamic security assessment, several simulations need to be performed, requiring the definition of study cases and contingencies. The development of this neural network must be done thoroughly since it is a complex process. Integrating the neural network with the optimisation algorithm increases the problem's complexity due to non-linearities. Therefore, the problem has been divided into two parts: the algorithm iteration and the dynamic security assessment.

5.2.2.5 Data pipeline

Relating to the technological choices for the data pipeline, since the data given by EEM is structured and follows time-series events, the best open-source solution is timescale to store data in INESC TEC's virtual machine.

Since there is not yet a discussed way on how the data should be returned to EEM, the next step involves choosing one of the following 3 options: 1) pushing the results to EEM's SFTP server; 2) EEM makes an API request to the INESCTEC servers; 3) deliver results through a frontend website.

The development of the VRFB and its power electronics should be completed before the end of 2024, along with the grid code compliance studies. In 2025, large scale tests in Madeira Island should be conducted, which includes tests with the VRFB fully operational in the power system integrated with the optimisation algorithms and neural networks.

Considering the development of demo 2 the next steps are as follow:

- Development of the VRFB and its power electronics, to be completed by the end of October 2024
- Grid code compliance tests for the VRFB to take place in INESC TEC's laboratory. This task should be completed by the end of 2024
- Solve convergence problems in the optimisation algorithm by the end of 2024
- Increase the accuracy of the water inflows forecasts by the end of 2024
- Create multiple scenarios for dynamic security assessment simulations to create neural networks. This task should be completed by the end of 2024
- Development of an API to analyse data and make requests, to finalised by mid-2025
- Push the results to EEM's SFTP server, by the end of 2024
- Large scale tests on site with the VRFB, optimisation algorithms, dynamic security assessments should be executed in 2025
- An API to make request to the INESC TEC server and a frontend website will be developed, by mid-June 2025
- Integrate the solutions in the i-STENTORE platform, by the end of the project

6 DEMO 3 - VIRTUAL ENERGY STORAGE SYSTEM FOR RENEWABLE ENERGY INTEGRATION

Demo 3, entitled "Virtual Energy Storage System for Renewable Energy Integration", takes place in Spain. During the Pre-demo Phase, progress has been made on various aspects of the demonstrator, such as the development and testing of the optimisation algorithms, the control architecture, the development of the digital platform, the on-site specifications definition, and the LIB provisions, among others. This progress is outlined in the sections "Demo Deployment" and "Operation, Testing, and Preliminary Results".

Following the completion of various assessments, several refinements have been proposed. Additionally, during the Pre-demo Phase, a significant risk related to the withdrawal of the VRFB provider had to be managed. This issue was already presented in D4.1, section 4.4.7: "Appendix for Demo 3 - VRFB Supplier Withdrawal - Update to Current Demo Status." At the time of writing, this issue is still being addressed, and various mitigating measures have been thoroughly explored. Further details on this are provided in the subsequent sections, specifically in sections "Risk Analysis", "Exploration of one of the potential mitigating measures for the withdrawal of E22" and "Deployment of the first stage of the solution during the Pre-Demo Phase".

6.1 DEMO STATUS UPDATE

An update to the contents of the Baseline Assessment Report for Demo 3 is presented in the following paragraphs.

6.1.1 Context and Objectives

The Context and Objectives of Demo 3 were detailed in D4.1. Essentially, the primary objective of the demonstrator encompassed the integration of two energy storage technologies, LIB and VRFB, into a distribution grid with a high share of renewable energy, operating them in a coordinated manner as a Virtual Energy Storage System (VESS). Thus, considering the generation from renewable plants within the same distribution grid, the identified business scenarios are leveraged to optimise the joint operation of the assets, participating in energy markets, while also providing different services to the DSO and TSO.

If necessary, this scenario will be refined once the definitive mitigating action has been determined, following the situation facing the demo concerning the VRFB. However, the scenarios analysed, maintain the overall objectives of exploring coordinated and optimised operation of assets, taking into account renewable generation to provide various services, generate economic benefits, support grid resilience, and drive renewable integration.

6.1.2 Stakeholders

At the time of delivering this document, the stakeholders involved in the development of Demo 3 are, as reported in D4.1, section 4.4.2. UC3M leads the demo and is responsible for developing its real-time control structure. CUERVA (MECSA) acts as the Distribution System Operator, owner, and end-user of the distribution grid where the demo will be implemented. CEN Solutions is responsible for developing and providing the Li-ion battery, while AGG is in charge of developing the cloud-based digital platform for the demo and integrating the optimisation engine. As an update to D4.1, it is worth mentioning that the optimisation algorithms are being developed by UMA.

Additionally, other partners of the i-STENTORE project, who perform horizontal tasks, are also involved in various activities related to the demo.

6.1.3 Services, Data and Infrastructures

During the Pre-demo phase, ongoing analysis was conducted to refine the services that could be provided by the assets of Demo 3, taking into account both their technical limitations and Spanish regulatory constraints. Additionally, different business scenarios were considered. The results of this in-depth analysis led to few modifications to the services reported in D4.1. However, some refinements were considered with regard to the provision of balancing services to the TSO, which will be restricted to mFRR (Manual Frequency Restoration Reserve), given the capabilities of the demo assets.

Aligned with the i-STENTORE conceptual catalogue, Demo 3 will focus on three main services:

- Energy Arbitrage
- mFRR as a frequency regulation service provider
- Mitigation of congestion and overvoltage events as a flexibility provider to the DSO.

The input/output data required for the provision of these services were outlined in D4.1 and are detailed for Energy Arbitrage and mFRR in the section "Optimisation Strategies for the Implementation of the Business Use Cases" of this document. Additionally, the data requirements for the real-time control of the demo are outlined in the section "Demo Control Architecture.

Regarding the equipment, tools, and assets, the information reported in D4.1 remains consistent concerning the central controller (designated as the HOCS controller in D4.1), the Li-ion battery, and the digital platform for the demo. The procurement of the central controller has been completed, and the procurement of the Li-ion battery is proceeding as planned, except that some components will be received firstly at CEN's facilities instead of the installation site. Similarly, the cloud-based optimisation platform, which includes the optimisation engine, is being developed as scheduled.

However, in the section "Services, Data and Infrastructures" of D4.1, the Vanadium Redox Flow Battery was reported. As mentioned, the demo is facing the potential withdrawal of E22, so the possibility of incorporating a controlled power source or a battery emulator to emulate its behaviour is under analysis. More details on this issue are addressed in the section "Exploration of one of the potential mitigating measures for the withdrawal of E22" of this document.

6.1.4 Key Performance Indicators

The table from D4.1, which outlines the Key Performance Indicators (KPIs), is included herein with slight modifications. While all previously introduced KPIs are featured in this table, it is important to note that the inclusion and definition of certain KPIs, especially those related to the VRFB, are heavily dependent on the resolution of the situation following the potential withdrawal of the VRFB supplier. Consequently, some KPIs are still awaiting full definition. Detailed and definitive specifications of the demo's KPIs will be provided in future interactions.

TABLE 10: DEMO 3 KPIS

ID	Name	Description / Definition (formula)	Unit	Baseline Value	Target Value (estimated)	Comments
Axis I. Demo's Implementation Progress & Outcomes						
9	Implementing two large-scale virtual energy storage systems (VESS) based on VRBF+BESS+Hydropower in both an island and a distribution grid with high share of RES	Implement two VESS using a HESS (VRFB + BESS + Hydro power) The name of the KPI is as defined for the entire project. Specifically, for the Spanish demo, it involves the implementation of a VESS in a distribution grid with high share of RES	- Nº of VESS implemented	0	For Demo 3: One fully operational VESS able to provide services	
16	Flexibility and ancillary services provision to the system operator from energy resources coordination (VRFB, Li-ion BESS, hydro-power) as a virtual ESS (VESS) (congestion management, contingency relief, voltage/frequency regulation, new grid-forming functions)	Nº of events of congestion and voltage problems solved and sum of kWh through flexibility provision	%	0	TBD	
18	Deployment of digital platforms for operating and managing new functionalities in wide-are multi-user energy storage systems	Integration of the communications and services into the DEMO and i-STENTORE platforms	-	-	Effective integration into the platform	As an initial step, the services and communication between the assets, optimisation algorithms, and controllers will be developed on the demo platform. As the i-STENTORE platform progresses and

ID	Name	Description / Definition (formula)	Unit	Baseline Value	Target Value (estimated)	Comments
						certain services/data are implemented through it, the demo will incorporate these communications and services into the platform
24	New collaborations between SMEs, industry and academia in the energy storage sector	New collaborations between SMEs, industry and academia in the energy storage sector	Nº of contacts established (partners involved)	0	5	
27	Nº of multi-use business models evaluated in detail	New business models reachable through this Demo	Nª of business models	0	3	
29	Efficient integration of storage technologies in demo sites	Storage technologies involved in this Demo: Li-ion batteries and Vanadium Redox Flow batteries	Number of ESS deployed	0	2	
35	No of storage-centric grid supporting services proposed and validated through the demos	Evaluate storage-centric services to support the grid that can be evaluated and validated through the demos	Number of services	0	2	
Axis II. Novel stand alone or Hybrid Energy Storage Systems (HESS)						
2	Energy density increase of VRFB	kWh discharged energy	%	TBD	3% of improvement	
3	Lifetime increase of VRFB	Lifetime increase = New Lifetime-Baseline Lifetime	Years	20 years of operation	Increasing lifetime of battery at 25 years (5 years increase)	
4	LCOS reduction of VRFB	LCOS reduction = (Baseline LCOS – Target LCOS)/Baseline LCOS	Target LCOS (€/kWh)	-	-	Information to be provided by the VRFB supplier

ID	Name	Description / Definition (formula)	Unit	Baseline Value	Target Value (estimated)	Comments
			LCOS reduction (%)			
5	Potential increase of renewable-based power generation without jeopardising system security	TBD	kW / %	TBD | Depends on Connection Point	TBD | Depends on Connection Point	
6	Decrease the Li-ion average depths of discharge, by coordinating its operation with the VRFB	TBD	TBD	TBD	TBD	
7	Energy generation cost decrease, through avoidance of renewables spillage	TBD	€	TBD	TBD	
20	Energy saving in terms of volume of reduced fossil fuel consumption	Equivalent kg of fossil fuel needed to solve the problems mitigated by flexibility	kg/ t	TBD	TBD	

6.1.5 Risk Analysis

The evaluation of the primary risks that this demo is facing, remains consistent with the one presented in D4.1. However, this section provides an update on their status.

Risk 3.1 pertains to the possibility for some services not to be implemented due to regulatory issues and technical constraints of the assets. Following an exhaustive examination, the feasibility of the demo assets' involvement in various use cases, has been thoroughly assessed, resulting in the identification of three viable services: energy arbitrage, mFRR, and flexibility services for the DSO. The analysis determined that the characteristics of the assets are suitable for the implementation of these three services. However, when considering a larger pool of services, others, such as aFRR, had to be discarded due to technical and regulatory barriers. A comprehensive analysis of this assessment is provided in the "Pre-demo Phase Scenarios" section. To address this issue, mitigating activities have included the design of a comprehensive optimisation algorithm tailored to the provision of these services which takes into account renewable generation. Additionally, a real-time control framework has been devised to coordinate real-time asset operation effectively, alongside the integration of these services into a digital platform. Therefore, the main objectives of the demo remain intact with the services that can be provided. Additionally, it is possible to analyse other services with different tools. Thus, this risk can be considered mitigated.

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Regarding risk 3.2 about potential delays in the execution of the demonstrator due to Spanish regulatory permitting processes, all feasible steps in the permitting procedure up to this moment have been completed. However, some aspects of the permitting process are on hold, as they are dependent upon the resolution of the situation with the VRFB, including the payment of the guarantees related to the connection point by the DSO, which may result in delays. These procedures will be triggered once the situation is clarified. However, all activities that can be completed prior to resolution will be advanced.

In relation to risk 3.3 concerning a potential increase in the cost of Li-ion battery racks, the information presented in D4.1 remains consistent, as this risk has already been effectively mitigated.

Finally, in accordance with what has been presented previously, risk 3.4, concerning the withdrawal of suppliers of critical components, such as the VRFB and LIB, has materialised with the intention of E22, the VRFB supplier of the demo to withdraw. At the time of writing this deliverable, various solutions are being evaluated to continue with the main objectives of the demo, one of which involves integrating a controlled power source to emulate its behaviour. Considering the importance of this risk, a full section has been dedicated to analysing this potential mitigating solution and its deployment.

6.1.5.1 Exploration of one of the potential mitigating measures for the withdrawal of E22

During the pre-demo phase, Demo 3 faced the challenge of the potential withdrawal of one of the demo partners. At the end of the first year of the i-STENTORE project, E22, the consortium partner responsible for supplying the VRFB to the demo, announced its intention to discontinue its participation in the project due to the closure of the VRFB production line for internal reasons. .

In response to this scenario, efforts have been made to explore an alternative solution that would preserve the core objectives of the demo while awaiting further clarification. Although it is not known whether the alternative solution to the VRFB will ultimately be implemented, it is considered important to report on the work that was conducted, as it was one of the major challenges during the Pre-Demo Phase.

The original implications of this issue were reported in D4.1; however, an overview of what was presented in that deliverable is included here, along with the subsequent deployment steps that have been taken towards this solution after its submission.

It is important to note that the proposed solution was developed with several constraints in mind. Primarily, the budget allocated to E22 within the i-STENTORE project does not allow for the purchase of a new manufactured VRFB of significant power. Secondly, the acquisition of a new VFRB would require an excessively long period of time, given the time available in the project. Finally, the DSO's requirements regarding certifications and qualifications for the equipment to be installed in the distribution grid must be met.

Considering these limitations, a solution was identified that would allow the overall objectives of the demonstrator to be maintained, which involved replacing the original asset with a controlled power source or a commercial battery emulator that would be used to emulate the response of a VRFB. This solution would make it possible to demonstrate the value of coordinated operation of the assets in the distribution grid along with the generation of various renewable power plants, and to explore the planned use cases while respecting the budget, time, and DSO constraints.

The proposed solution was designed in two steps: the first includes development and testing tasks in a controlled environment, and the second, a validation in the field within the distribution grid, preserving the original architecture of the demo. Please refer to D4.1 for further details on these phases.

Figure 34 and Figure 35 show the setup of the demonstrator in both phases. Comparing the second figure with the original configuration of the demo, it can be seen that the architecture of the pilot remains unaltered, replacing the VRFB with the controlled power source or the battery emulator that emulates its response, reproducing the injection or absorption of current that the VRFB power converter would have performed. In this way, all the management layers of the demonstrator, including the optimisation tool, the demo platform, the controls implemented in the central controller, the integration of the demonstrator with the i-STENTORE digital ecosystem and all the real-time communications involved, would remain unaffected.

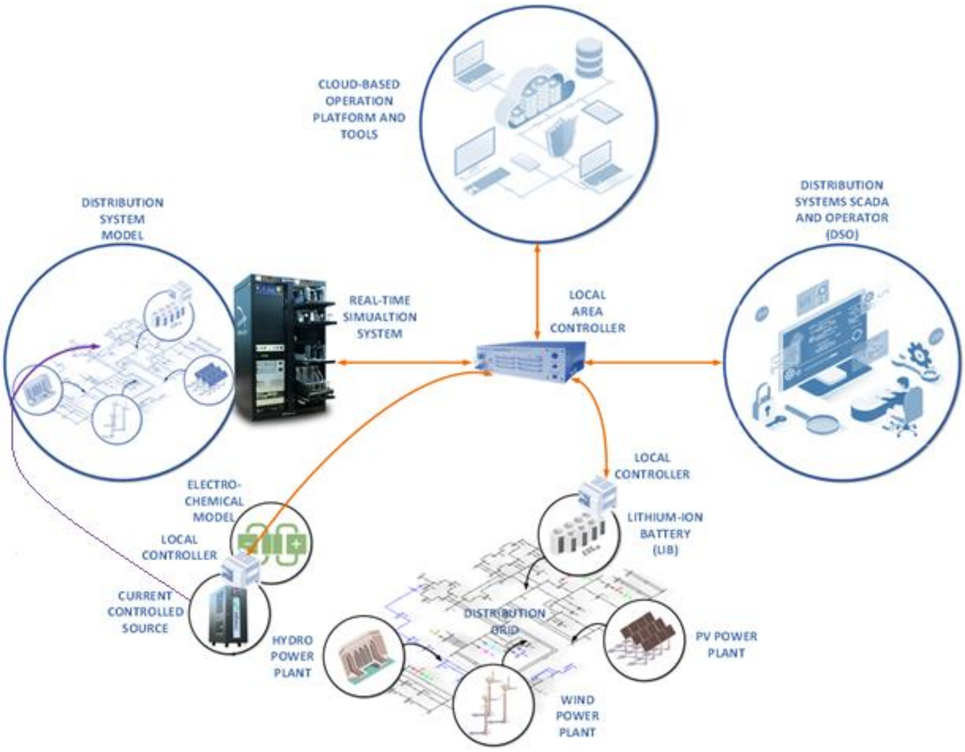


FIGURE 34: SYSTEMS OF DEMONSTRATOR 3, STEP I OF THE PROPOSED SOLUTION

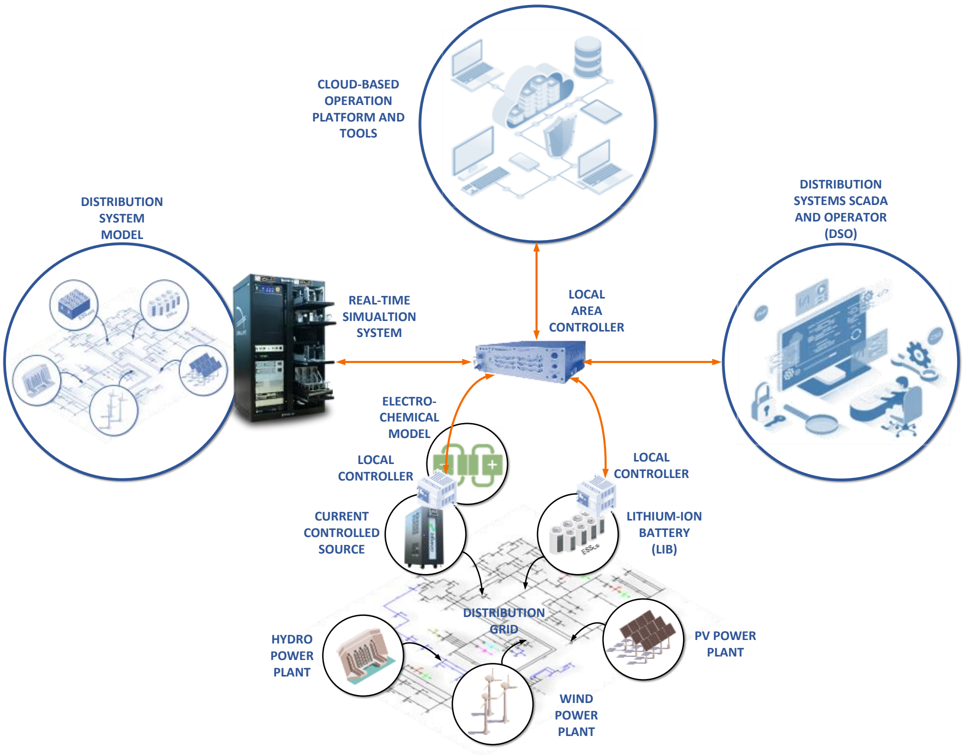


FIGURE 35: SYSTEMS OF DEMONSTRATOR 3, STEP II OF THE PROPOSED SOLUTION

The proposed schedule for the alternative solution extends the first step until the end of the Full Demo Operation Phase and plans to execute the second step during the Large-Scale Demo Operation Phase.

6.1.5.2 Deployment of the first stage of the solution during the Pre-Demo Phase

While the situation remains unresolved at the time of writing, efforts have been made to advance the tasks associated with this alternative solution as much as possible in case it ultimately needs to be implemented.

Controlled power source specifications

During the Pre-Demo the specifications of the controlled power source were determined and the Pacific Power Source 3450AZX was selected. This equipment (shown in Figure 36) is a 45-kW switching power source capable of handling AC, DC, and AC+DC with regenerative capabilities to support both current and power sourcing, as well as sinking.

FIGURE 36: CONTROLLED POWER SOURCE

The main characteristics of the power source include:

- Fully programmable electronic power source with advanced controller functions.
- Bidirectional power flow operation with energy recovery to the AC grid.
- Multiple output modes including AC, DC, and AC+DC.
- Diverse operating modes, such as AC, DC, and AC+DC Voltage Source, AC, DC, and AC+DC Current Source, Optional AC or DC Load Operation, and Hardware in the Loop Amplifier.
- Compatibility with single, split, and three-phase modes.
- Fully remote control of all settings and metering read back.

The voltage/current operation ranges in AC and DC modes are illustrated in Figure 37.

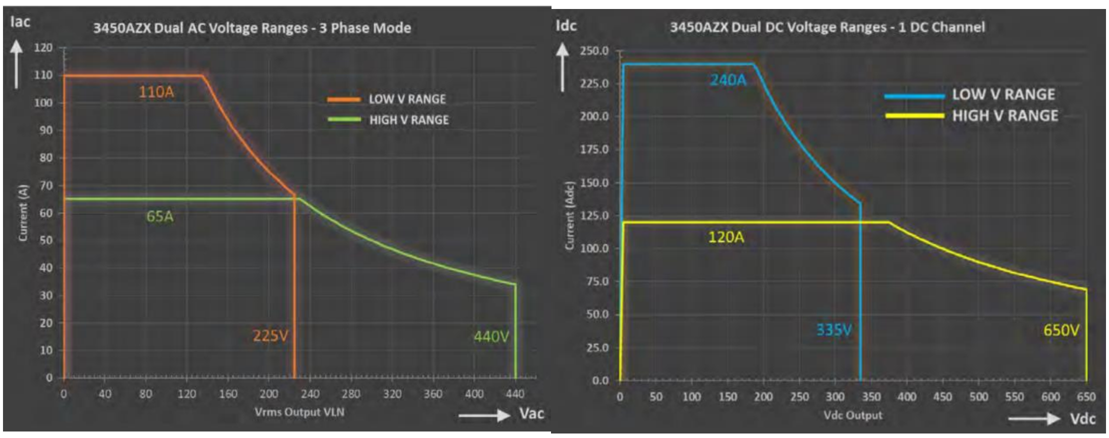


FIGURE 37: OPERATION MODES OF THE CONTROLLED POWER SOURCE

The first phase of the solution will utilise a controlled power source available at UC3M to develop and test all models and control algorithms. The second phase will involve the deployment of an identical unit at a low-voltage connection point within the MECSA distribution grid in Granada.

Pre-procurement of the power source for the second phase

During the Pre-Demo Phase, the source intended for installation during the subsequent phase of the proposed solution was pre-procured. In this second phase, an identical source to the one used during the development stage will be rented. To accomplish this, a study was conducted on potential suppliers, and a formal offer was ultimately obtained from the selected supplier, who committed to delivering the power supply to the installation site within two weeks from the date of order.

First Phase Deployment Design and Initial Implementation

During the Pre-Demo Phase, a detailed design of the implementation actions for the first phase was conducted. This phase is being developed at one of the UC3M laboratories where a controlled power source with the specified characteristics is already available.

The integration details of the source within the demo architecture were defined. Accordingly, as originally planned, the demo platform will communicate with the central controller via MQTT, which will be responsible for transmitting the setpoints to the assets and adapting them to real-time operating conditions using the Modbus protocol. Since the central controller consists of a PLC and an industrial PC, the industrial PC will be utilised to implement the controller of the emulated VRFB, encompassing the following functionalities:

- Implementation of a Modbus server to incorporate the mapping of the operational variables of the controlled power source and the variables of the VRFB model.
- Implementation of the VRFB model.
- Control of the power source by sending operational setpoints through SCPI commands.
- Datalogging of the operational variables of the power source and the VRFB model.
- HMI to visualise the operation of the emulated VRFB.

The initial steps regarding the deployment of the development phase have already been completed. Therefore, the power loop has been set up in one of the UC3M laboratories, connecting the power source to a 400-V connection point. This arrangement would be replicated in a low voltage connection point in the MECSA distribution grid.

Additionally, communication tests have already been conducted within the architecture described above, sending power absorption/injection commands into the laboratory's grid, which were executed correctly.

6.1.6 Engagement and Implementation Plan

All activities have been executed as planned, except for those impacted by the situation with the VRFB, which has led into putting some activities on hold until the issue is resolved. These activities include "B3: Vanadium Redox Flow Battery" in the Gantt Chart presented in D4.1, as well as those related to the on-site installation and integration of the assets and the processing of certain permits.

However, all horizontal tasks have progressed according to schedule, and all possible tasks have been advanced. This includes those related to the Li-ion battery, the cloud-based digital platform, the integration of optimisation algorithms, and the design of the control structure.

Additionally, alternative work plans have been developed based on the different solutions explored. Subsequent documents will include a final version of the Engagement and Implementation Plan.

6.2 DEMO DEPLOYMENT

This section starts by offering a detailed overview of the on-site components of the demonstrator. This is followed by a description of the platform being custom-built for this specific pilot. Finally, integration aspects with the i-STENTORE digital platform (Virtual Power Plant) are presented.

6.2.1 On-Site Demo Deployment

The Virtual Power Plant will consist of three different generation technologies (a PV plant, a hydropower plant, and a wind plant) along with a Li-ion Battery and a Vanadium Redox Battery. The description of the assets and the grid connection of the Li-ion Battery is provided in the following paragraphs.

6.2.1.1 PV Plant

The PV plant, located in Granada, has a nominal power of 1.8 MW and a peak power of 2.077 MW, with an average production of 4,198 MWh/year. The structures are configured with single-axis trackers.

6.2.1.2 Hydropower Plant (Bermejales)

The hydropower plant is situated at the foot of the dam of the Bermejales Reservoir, Arenas del Rey, and incorporates essential infrastructure for power evacuation. The evacuation line, approximately 340 meters long, uses aluminium cables consisting of three conductors with a 3x54 cross-section.

Concerning transformers, the primary transformer, denoted as CT Power, has a capacity of 3000 KVA and operates at a voltage of 21/6 kV. Commissioned in 1988, it contains approximately 1637 kg of insulating fluid. Additionally, the auxiliary transformer, known as CT Auxiliary, operates at a voltage of 21/220 kV with a capacity of 30 kVA.

6.2.1.3 Wind Plant

The wind turbine installation is located at Cerro de Taventa, Padul, Granada. The site features a single wind turbine group from manufacturer VENSYS, model VENSYS/GOLDWIND 2.5MW/121, with an installed capacity of 2,500 kW and a nominal power of 2,400 kW. This wind turbine stands 90 meters high and utilises wind power through a direct drive system with permanent magnet generators.

The aerial evacuation line for this wind turbine connects to the Dúrcal substation, operating at a nominal voltage of 20 kV. The external protection system includes a main switch manufactured by Ormazabal, model CGMCOSMOS V-24 RELÉ EKOR RPS-DD, with a nominal voltage of 24 V, a nominal current of 400 A, and a breaking capacity of 16/20 kA. Additional protections consist of various overcurrent, ground fault, and voltage protections to ensure stable and safe operations.

Measurement equipment for high-voltage monitoring comprises three voltage transformers and three current transformers manufactured by Arteche, guaranteeing precise monitoring and operational safety. Metering equipment, supplied by Landis+Gyr, model ZMG405CTSRE.32S1-6 from 2019, ensures accurate measurement of electrical parameters. These setups significantly contribute to the efficient management and distribution of the generated wind energy.

6.2.1.4 Li-ion Battery

In addition to the generation assets, a Li-ion Battery will be installed in the distribution grid operated by MECSA. The main characteristics of this battery are as follows:

TABLE 11: LI-ION BATTERY SPECIFICATIONS

Parameter	Value
Installed Capacity	0.479 MWh
Load rate	2C
Module Type	76.8NESP160
Number of modules	39
Number of Racks	3
Modules per rack	13
Dimensions (m^2)	6 x 3.5

1. Connection and Siting

The Li-ion Battery will be situated within MECSA's distribution area (see Figure 38). The planned storage installation will have a nominal power of 1,000 kW. The system design is based on a modular and scalable configuration, consisting of a power modular unit and an energy modular unit.

FIGURE 38: LI-ION BATTERY PRE-DEMO PHASE SITING IN THE DISTRIBUTION GRID

Each power modular unit will have an associated capacity of 1,000 kW and one direct current input, comprising the power conversion system, a power transformer, and an MV switchgear.

Each modular unit will have a capacity of 497.7 kWh DC and will consist of battery racks, ancillary equipment and a container.

An energy modular unit will be associated with three battery racks connected in parallel, each with a capacity of 159.9 kWh, for a total of 497.7 kWh.

Each battery rack will have 13 direct current energy modules connected in series with a capacity of 12.3 kWh each, for a total of 159.9 kWh. The maximum operating voltage of each rack will be 1,123.2 V, with 998.4 V being the nominal operating voltage.

2. Electrical Installation

General Description

This type of installation comprises two distinct sections from an electrical perspective. Firstly, there is the DC section operating at low voltage, responsible for module interconnection and their connection with the power conversion system. Secondly, there is the AC section, which can be further divided into a low-voltage section connecting the output of the power conversion system with the low-voltage panel situated in the Transformation Centre, and a medium-voltage section linking the medium-voltage side of the Transformation Centre with the Protection and Measurement Centre, as well as the grid interconnection point.

In summary, the following configurations can be found:

TABLE 12: ELECTRICAL INSTALLATION CONFIGURATIONS

Sections	Channelling	Interconnection
DC in LV	Overhead ducting (inside the rack and beneath the tube)	Energy modules – Power conversion system
AC in LV	Underground ducting directly buried	Power conversion system – Low voltage panel in the Transformation Centre
AC in MV		Switching, Transformation, Protection and Measurement Centre – Grid interconnection point

Low Voltage Installation in DC

The conductors to be used in the DC section will be made of copper, unipolar, with an assigned voltage rating of 1.8/1.8 kV, Class II, and with halogen-free reticulated compound insulation.

The modules will be connected to form the different racks using the same cable that comes with the energy module.

The connections between the racks and the power conversion systems will utilise sections of the previously mentioned conductor, calculated according to their current carrying capacity and length. These calculations are designed to ensure voltage drops of less than 1.5% at the maximum power point.

These cable runs will be channelled in two different stretches. One section will be in overhead ducting within the rack itself, while the second section will be in overhead ducting beneath the tube, extending to its connection with the power conversion system that will be located inside the container.

To determine the allowable current, appropriate correction factors will be applied for each stretch of the channelisation, with the most restrictive factor used to determine the appropriate conductor size.

Low Voltage Installation in AC

The AC low voltage installation section spans from the output of the power conversion system to the input of the Switching, Transformation, Protection, and Measurement Centre. More precisely, it connects to the respective output of the low voltage panel housed within the centre.

The conductors used will be made of aluminium, unipolar, with an assigned voltage of 0.6/1 kV, featuring reticulated polyethylene insulation and halogen-free thermoplastic polyolefin covering.

This stretch will be directly placed in underground ducting.

To calculate the allowable current, appropriate correction factors will be applied.

Medium Voltage Installation in AC

This section of the installation comprises:

- A Transformation Centre equipped with a 1,250 kVA transformer.
- A Switching, Transformation, Protection, and Measurement Centre (STPMC) housed in a prefabricated building. The medium voltage installations for evacuating the power of the plant associated with this project will be located inside the building and will be exclusive to the owner of the project.
- An underground evacuation line: simple circuit extending to its connection in the Transformation Centre.

The conductors used will comply with the requirements of standard UNA HD 620 and ITC 06 from the Regulation on Technical Conditions and Safety Guarantees in High-Voltage Power Lines.

To calculate the allowable current, appropriate correction factors will be applied.

3. Protections

The installation will be equipped with necessary and appropriate protections and connection panels to ensure the safety of individuals and prevent equipment damage.

i. DC Installation

Direct contacts

Protection against direct contacts is based on the ICT-BT-24 regulations for low voltage, and the following measures will be taken for its implementation:

- Insulation of the active parts. All elements in the installation will have double insulation or Class II. Positive and negative poles will be run separately and protected according to the current regulations.
- Out of reach through distancing protection. The storage plant will have a perimetral closing made of fence preventing fortuitous contacts with active sections of the installation.

- The storage plant will be enclosed by a perimeter fence to prevent any unintentional contact with the active parts of the installation.

Indirect Contacts

In accordance with the low-voltage regulation, the utilisation of equipment with Class II insulation would be sufficient to ensure protection against indirect contacts. Nevertheless, an inspection device has been incorporated, which remains isolated and monitors the installation, detecting any defect to earth and promptly notifying the plant for repair.

Overcurrent

It should be noted that photovoltaic strings operate at values close to their short circuit current.

In order to protect the string against overcurrent, either overloads or short circuits, fuses will be installed in both the positive and negative poles. These fuses will be 30 A, 1500 V cylindrical gPV fuses.

Overvoltage

Protection against surges originating from atmospheric conditions will be implemented using surge arresters, as described in ITC-BT-23 regarding transient overvoltage.

ii. AC Installation

Overvoltage

The power conversion system itself incorporates protection against overvoltage through Type 2 Arresters.

Upstream of the Power Conversion System

Each power conversion system will be equipped with a protection panel in AC equipped with an automatic switch.

Low voltage panel

The low voltage panel located at transformation centres will be equipped with a load break switch.

Insulation Monitors

In the low voltage side of the Transformation Centre, a general ground fault monitoring system with alarm for the first fault condition is implemented.

iii. Power Conversion System Protections

- Protection against short circuits and surges in the output
- Anti-islanding protection with automatic disconnection
- Protection against insulation fault
- Protection against AC surges with Type 2 arresters
- Protection against DC surges with Type 2 arresters

In addition, it will have a DC disconnector for each MPPT.

iv. Earthing

All non-active metallic masses of the storage facility must be earthed to a single earth, which should be independent of the neutral of the distribution company.

Specifically, the energy modules support structures will be earthed to the main earthing system through aluminothermic welding. This conductor will be a 35 mm^2 copper insulated cable.

The energy modules will be earthed through direct contact of its frames within the support structure and through its anchor points to the structure. The main earthing electrode will be a 35 mm^2 bare copper wire, placed at the bottom of the underground ducting used for the channeling of electric circuits.

As previously mentioned, the support structures will be connected to this main electrode. Similarly, each of the power conversion systems will be connected to this electrode.

The permanent insulation monitor will be connected to the earthing system to allow the detection of any insulation fault.

Regarding active parts insulation, all installation elements will present double or Class II insulation. Positive and negative poles will be run separately and protected in accordance with the current regulations, appropriate for outdoor installation.

4. Expected Contracted Power for Ancillary Systems Consumption

A 10 kVA power supply is expected to provide the necessary power to support the ancillary systems group for the proper functioning of the battery storage installation.

6.2.1.5 Controlled Current Source

At the time of writing, Demo 3 is currently facing the potential withdrawal of E22, the partner responsible for providing the VRFB to the pilot project. This issue is outlined in detail in section 5.3. However, while this matter is being clarified, an alternative solution is being considered. This solution entails installing a controlled power source to simulate the behaviour of the VRFB. This power source would be connected to the low-voltage grid at one of MECSA's secondary substations. An alternative solution is also being examined that considers the use of a commercial battery emulator which includes pre-programmed models and can be seamlessly connected to the grid.

6.2.2 Demo Digital Platform Overview

A HOCS enables real-time coordination among renewable power plants, VRFB, and LIB. This system ensures efficient grid support services while managing battery degradation. Three control layers facilitate effective energy asset management, integrating advanced technology tools for real-time interactions.

As illustrated in Figure 39, the demo platform architecture includes four different databases for storing component definitions, real-time data, historical data, and forecasts. VESS components measure variables in real time, transmitting data for optimisation processes and energy trading. SQL, NoSQL, and timeseries database technologies are employed for efficient data management.

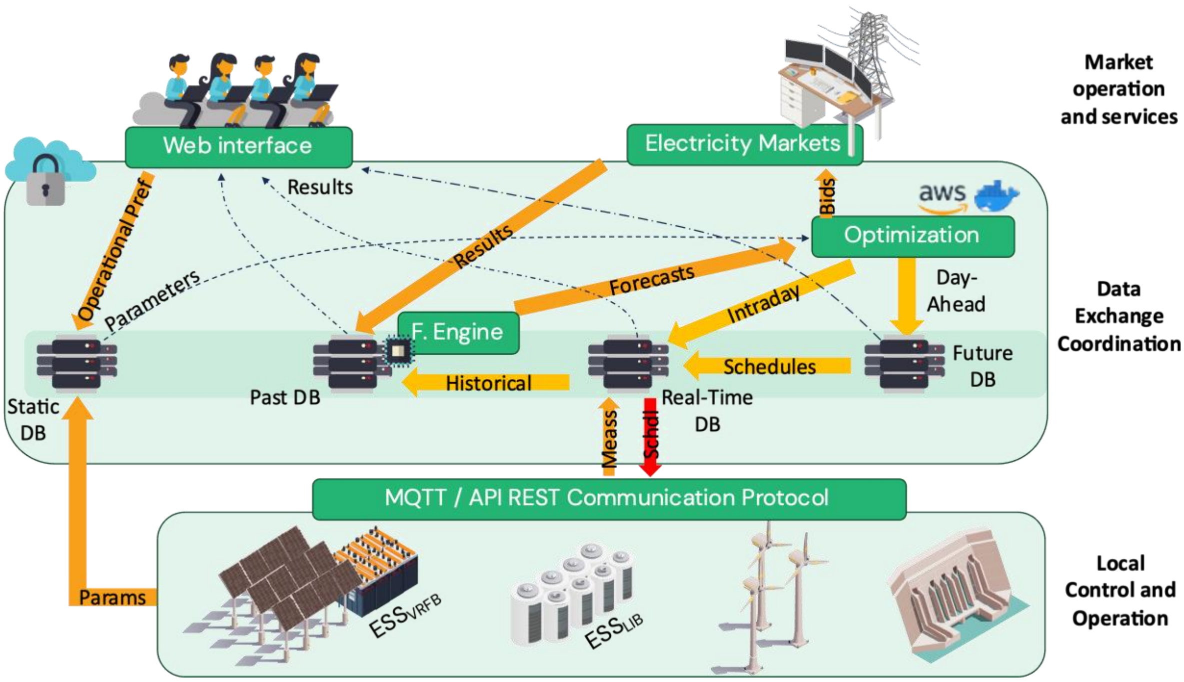


FIGURE 39: DEMO PLATFORM ARCHITECTURE AND INTERACTION WITHIN THE CONTROL SYSTEM

Mathematical optimisation processes will be hosted on AWS, facilitating energy trading and data analysis. A web interface provides real-time data visualisation and user interaction for informed decision making.

Demo 3's integration of energy storage, innovative control systems, and cloud-based platforms promotes interoperability, data trust, and grid flexibility, aligning with the i-STENTORE Reference Architecture. This initiative represents a significant step towards an integrated, efficient, and consumer-centric European energy system, fostering sustainability and responsiveness for all stakeholders.

6.2.3 Integration with the i-STENTORE Digital Platform

The communication exchanges between the demo and the i-STENTORE platform encompass various data transmissions and requests. Data sent to i-STENTORE includes results of optimisation algorithms/battery schedules, static data such as component definitions and user account details managed via SQL, NoSQL, and HTTP requests. Past data, including historical weather conditions and market results, is updated approximately every 15 minutes for forecasting.

Data requested from i-STENTORE comprises asset attributes for optimisation, such as static parameters for wind generators, PV plants, run-of-river hydroelectric plants, and battery energy storage systems, as well as dynamic parameters and market prices. Ideally, JSON format obtained through HTTP requests is used every 15 minutes.

The services requested from i-STENTORE encompass weather, renewable production, and market price forecasts, updated ideally every hour or quarter-hour for the next 24 to 72 hours. These forecasts can be probabilistic or based on expectancy values, formatted as JSON through HTTP requests.

Regarding communication with the i-STENTORE platform, a cloud server, possibly AWS, will oversee the process. There are no limitations regarding communication protocols, data formats, or accessibility, and it will be possible to reconfigure it to use the final protocols decided by i-STENTORE. The cloud service communications will be fully programmable by demo partners, allowing for modification requests, if needed.

6.3 PRE-DEMO PHASE SCENARIOS

During the Pre-demo Phase, the capabilities of the demo assets were assessed together with the Spanish regulatory framework, in order to identify the business scenarios in which the demo can be engaged, considering both the technical and the regulatory constraints.

Firstly, a pool of scenarios was considered, and after analysing the market regulations and the interests of the demo in terms of alignment with the i-STENTORE concept, three main scenarios were selected: energy arbitrage, tertiary balancing reserves, and provision of flexibility services to the DSO.

Energy Arbitrage

Initially, it was noted that the participation of standalone energy storage systems in the day-ahead and intraday markets is not regulated within the rules approved by the National Commission of Markets and Competition (CNMC). However, in a resolution dated February 23, 2023, the CNMC mentioned the possibility of incorporating storage as a separate entity within the existing market rules. This clarification implied that energy storage, including battery-based systems, could participate in the market under the current regulations, provided they are appropriately registered.

The initial planned use case focused on the participation of a Virtual Energy Storage System (VESS) in the day-ahead and intraday markets. It involved offering hourly/quarterly scheduling based on production forecasts from various generation plants and managing storage systems. The optimisation of the support provided by the storage system through participation in intraday markets, along with a market arbitrage strategy, was also initially outlined. The initial proposal for the programming process was as follows: Firstly, energy bids would be submitted in the day-ahead market, considering forecasts of renewable generation and market prices, as the initial phase of the optimisation process.

Subsequently, adjustments could be implemented in the intraday markets to rectify any deviations or further optimise the battery operation, considering the energy prices for these markets.

In the final scenario, a service optimised a VESS for market participation only in day-ahead markets for the sake of simplicity and to leave room for the participation in tertiary balancing reserves, which are better remunerated. Leveraging renewable generation from PV, wind and hydro plants, the VESS strategically offers energy to maximise benefits across different applications and processes. Operating at a wholesale market scale, this service adheres to market rules to efficiently manage the VESS's participation, utilising predictions of renewables output and wholesale market prices. Notably, the service is designed to react at least 12 hours before market commitment, aligning with the Gate Closing Time at 13:00 pm.

Tertiary Balancing Reserves

The initial plan involved integrating management capabilities into the control system (HOCS) to participate jointly in the first use case with day-ahead market and provide balancing services to the TSO. Spanish regulations posed challenges for small plants like the VESS to participate in aFRR (secondary regulation) services due to requirements for participation in regulation zones managed by large companies exceeding 200 MW, which is not possible for the partners. Hence, the focus shifted to studying mFRR (tertiary regulation) services, where compliance criteria could be met, since there is no control zone requirement in the regulation. The establishment of reserves for frequency-power regulation indicated the VESS's potential to meet qualification tests based on its characteristics.

Optimisation efforts were deployed to incorporate equations and constraints associated with participation in this market, since it requires for day-ahead optimisation of the availability of the VESS and real-time update once the uncertainty is realised. The optimisation problem's proposal was generated by UMA and is being validated by the rest of the partners. Real-time information exchange between the plant's market representative and optimisation algorithms was essential for efficient operation, with simulations planned in case real-time exploitation posed challenges.

The final service focuses on positioning the VESS for tertiary balancing reserves to support the mFRR of the Spanish TSO. Operating within Spain's frequency regulation framework, the VESS, particularly leveraging the Lithium battery, contributes to tertiary reserves with a 30-minute duration and 15-minute reaction time. The service, examined under various scenarios, addresses sector-specific energy demands and constraints. In the end, it was determined that the most suitable participation scheme for the VESS is through the so-called "scheduled offer scheme" where the participants submit their reserve availability up to 25 min before activation, and the TSO can only activate the offer up to 15 min. This was due to size requirements of the battery. Conditional links are also to be used in an effort to participate in the market within the limited size of the Lithium battery.

DSO Services

The initial plan focused on participating in local flexibility markets, which unfortunately do not exist in Spain. However, tests and simulations were to be conducted to explore VESS participation in flexibility markets offering services to the DSO for mitigating over-voltage events and congestion. These actions aimed to derive the price range that would interest a VESS in facilitating such services.

In an ongoing effort to explore the VESS's potential in providing ancillary services and flexibility to the DSO, this new service use case evaluates the VESS's capabilities in alleviating grid congestions and over-voltages. Operating at the site level, this service establishes bilateral contracts between the DSO and VESS to add flexibility to the grid. Ongoing analysis incorporates marginal costs and market values for VESS services to fully understand their potential. With approximately a 15-minute discharge time and near real-time reaction time, this service is envisioned as a smart energy and services trading formula within the digital platform, representing an exploratory step towards leveraging VESS capabilities for grid support.

Services That Will Not Be Demonstrated

aFRR

One of the services explored in the Spanish demo was managing the storage capacities of the VESS to participate in secondary regulation services. However, this was discarded mainly due to two factors:

- Regulatory Barrier. The aFRR services can only be provided in Spain by agents belonging to a regulation zone. The necessary processing to join these zones requires significant time and would jeopardise the demonstration phase of the project.
- Technical Barrier. To participate in secondary regulation, the physical unit, which in this case would be the VESS, should be capable of providing 1 MW of power for 15 minutes both for increasing and decreasing with a 15-second notice. The main issue here is the limitation of our Lithium battery, which could not offer symmetric bids due to its power limitation, which is just the minimum required to participate in balancing services.

Flexibility Markets

While the use of storage as a service to the DSO will be covered, the orientation of this use case as a real market service was discarded. The main reason why this business case will not be demonstrated, is because Spain lacks regulation that enables prosumers to participate in a regulated flexibility market, which would make demonstration in a real environment impossible.

6.4 OPERATION, TESTING AND PRELIMINARY RESULTS

6.4.1 Demo Control Architecture

The control of the demo operation is organised as a Hierarchical Operation and Control System (HOCS). A schematic of the control system is depicted in Figure 40, where the main controllers and assets are shown.

The operation and control algorithms are organised in three levels with different scopes:

1. **Top level layer**, which is responsible for:
   a. Scheduling the optimisation tasks
   b. Gathering information to and from external services, such as the i-STENTORE platform, forecast providers, market representative, HMI, etc.
   c. Acting as a gateway / broker for demo internal communication and data logging to databases
2. **Real-Time execution layer**, which is responsible for:
   a. Gathering the power schedules from optimisation results, market results, service activations and direct DSO commands.
   b. Executing the final operation power schedule.
   c. Retrieving real-time measurements and current status from the assets and forwarding them to the data broker.
3. **Local controllers** for power assets. These devices receive the power setpoints from the Real-Time execution layer and provide the local measurements for each asset.

This hierarchical structure and separation of concerns allows for a robust and fail-safe operation.

The top-level layer can leverage the flexibility of a cloud-based implementation to provide advanced optimisation services and an interface to most external services for non-time-critical tasks. High-availability communication gateways ensure a secure data flow between the demo elements.

The Real-time controller and the local controllers are based on state-of-the-art PLC controllers to guarantee robust operation for time-critical tasks. The main Real-time controller also includes an industrial PC to add flexibility regarding communications and to add the possibility of implementing real-time local optimisation algorithms. This controller will always have a copy of the most recent operation schedule to ensure safe operation in the event of temporal failure in the top control level.

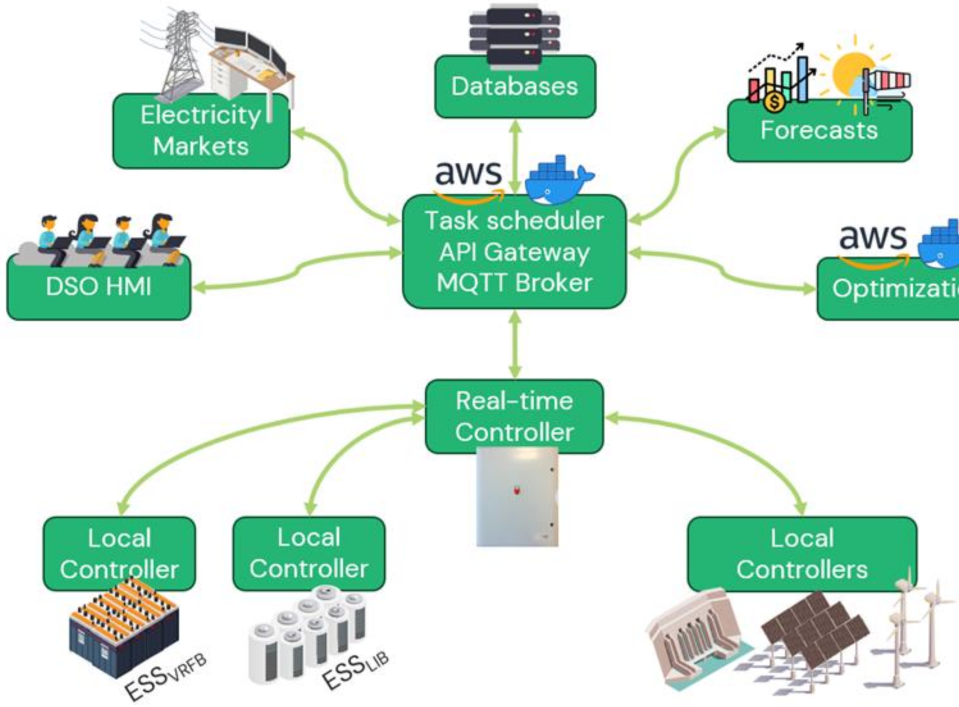


FIGURE 40: DEMO CONTROL SYSTEM

The control of the demo at these three levels has been organized into various tasks, ensuring efficient coordination between higher-level control areas, such as obtaining optimal setpoints for market participation, and lower-level control areas, such as real-time control of the different assets in the demo.

To achieve this, the tasks have been defined by specifying the trigger mechanism, the controller responsible for its execution, the required inputs, and the actions to be performed. The detailed organization of this control structure, including specifics for each task, is presented in the appendix at the end of this document. Additionally, this appendix provides information on the necessary variables in the different demo databases for implementing this control structure, as well as details on internal communication within the demo and with the i-STENTORE system.

6.4.2 Optimisation Strategies for the Implementation of the Business Use Cases

This section presents the optimisation strategies developed for the business use cases to be demonstrated and the preliminary results of their application.

6.4.2.1 Overview of the Business Use Cases

This Business Use Case will optimise the participation of the VESS in the day-ahead market considering the forecasts of the non-controllable renewable energy plants (PV, Wind and Run of the river power plants).

The timeline of the proposed BUCs is as follows:

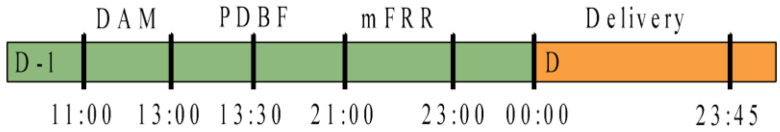


FIGURE 41: TIME FRAMEWORK FOR THE FIRST BUSINESS USE CASE: ENERGY ARBITRAGE.

As shown in Figure 41, the Gate Opening Time (GOT) is settled at 11:00 while the Gate Closing Time (GCT) is set to 13:00 considering Operation Procedure 3.1. of the Spanish Day-Ahead Market. During this time the Market Representative (MR) upload the offer computed by the optimiser to be cleared.

The results are published at 13:30 in the "Programa Diario Base de Funcionamiento" or Basic Daily Program of Functioning. At that time, the MR will communicate the VESS the cleared setpoints for the next day and the price of the energy imports/exports.

With this information, it is possible to compute the tertiary reserve available for the next day. Following the Operation Procedure 3.1., the VESS must offer **all the available tertiary reserve** for the next day. Nevertheless, Market Participators (MPs) can modify their offers up to 25 min before the quarter-hourly period T.

Given the size of the Li-ion Battery (0.491 MWh) the VESS could participate in the tertiary reserve market using the offer type: "Scheduled Activation" in which the System Operator (SO) will ask for the activation of maximum 15 minutes of tertiary reserve with 15 minutes of anticipation. There is another type of offer, called "Automatic Activation", but the duration of the activation could reach 30 minutes, and given the minimum size of 1 MW, the Li-ion lacks capacity to provide this type of offer.

Considering this restriction, the type of the link between offers is forced to be "Conditional", which enables to retire the availability of the linked offer given the activation of offers up to two periods before. Being intended for "Automatic Activation" offer types, the "Technical Link" cannot be used for the BUC at hand.

Lastly, the third service, DSO asks the VESS for real-time services, given the remaining capabilities of the Li-ion battery. This service encompasses congestion management and overvoltage mitigation.

6.4.2.2 Service 1: Energy Arbitrage in Day-Ahead Markets

Considering the timeline proposed in Figure 41Figure 41, every day from 11:00 to 13:00 the day-ahead market offers for the next day are computed based on the forecasts of the renewable energy of the non-controllable sources.

The energy exchanges for this case study are showed in Figure 42.

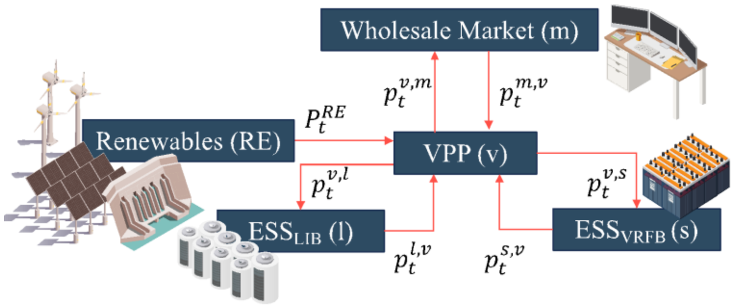


FIGURE 42: ENERGY EXCHANGES FOR THE BUC 1 – ENERGY ARBITRAGE

The problem is defined in (1) where the optimisation problem maximises the profits obtained from the participation of the VESS in the DAM.

Sets

$t \in \Omega_t$: Set of periods in the scheduling horizon.

$m \in \Omega_m$: Set of segments for the degradation model of the BESSs.

Parameters

λ_t^{DAM}: Forecast of the day-ahead price in period t (€/MWh).

$C^{DEG,LIB}, C^{DEG,VRFB}$: Degradation cost of the LIB and VRFB BESSs (€/MWh).

P_t^{RE}: Forecast of the renewable energy production (MWh).

η^{CH}, η^{DIS}: Mean charging and discharging efficiencies for the batteries (%).

Δt: Timestep between periods (h).

$SOC0^{LIB}, SOC0^{VRFB}$: Initial state of charge for the LIB and VRFB batteries (MWh).

$\underline{P}^{LIB}, \underline{P}^{VRFB}$: Power of the converter for the LIB and VRFB BESSs (MWh).

$\underline{SOC}^{LIB}, \overline{SOC}^{LIB}, \underline{SOC}^{VRFB}, \overline{SOC}^{VRFB}$: State of Charge Limits for the LIB and VRFB BESSs (MWh).

a_m^{LIB}, a_m^{VRFB}: Slope of the segment m to compute the calendar degradation of the LIB and VRFB BESSs (p.u.).

b_m^{LIB}, b_m^{VRFB}: Interception of the segment m to compute the calendar degradation of the LIB and VRFB BESSs (MWh).

c_m^{LIB}, c_m^{VRFB}: Slope of the segment m to compute the cyclic degradation of the LIB and the VRFB BESSs (h).

d_m^{LIB}, d_m^{VRFB}: Interception of the segment m to compute the cyclic degradation of the LIB and VRFB BESSs (MWh).

Decision variables

$z_t^{LIB}, z_t^{VRFB} \in \{0,1\}$: Binary variables indicating the charging (1) or discharging (0) status of the LIB and VRFB BESSs.

$p_t^{v,m}$: Power flow from the VPP (v) to the market (m) at time t (MW).

$p_t^{v,l}$: Power flow from the VPP (v) to the LIB BESS (l) at time t (MW).

$p_t^{v,s}$ Power flow from the VPP (v) to the VRFB BESS (s) at time t (MW).

$p_t^{m,v}$: Power flow from the market (m) to the VPP (v) at time t (MW).

$p_t^{l,v}$: Power flow from the LIB BESS (l) to the VPP (v) at time t (MW).

$p_t^{s,v}$: Power flow from the VRFB BESS (s) to the VPP (v) at time t (MW).

$soc_t^{LIB}, soc_t^{VRFB}$: State of charge of the LIB and VRFB BESSs at time t (MWh).

$\Delta b_{loss,t}^{cal,LIB}, \Delta b_{loss,t}^{cal,VRFB}$: Calendar degradation for the LIB and VRFB BESSs lost at time t (MWh).

$\Delta b_{loss,t}^{cyc,LIB}, \Delta b_{loss,t}^{cyc,VRFB}$: Cyclic degradation for the LIB and VRFB BESSs lost at time t (MWh).

The optimisation for the DAM is then:

$$\sum_{t} \lambda_t^{DAM}(p_t^{v,m} - p_t^{m,v}) - \sum_{t} C^{DEG,LIB}(\Delta b_{loss,t}^{cal,LIB} + \Delta b_{loss,t}^{cyc,LIB}) - \sum_{t} C^{DEG,VRFB}(\Delta b_{loss,t}^{cal,VRFB} + \Delta b_{loss,t}^{cyc,VRFB}) \tag{1a}$$

Subject to,

$$p_t^{v,m} + p_t^{v,l} + p_t^{v,s} = p_t^{m,v} + p_t^{l,v} + p_t^{s,v} + P_t^{RE}, \qquad \forall t \tag{1b}$$

$$soc_t^{LIB} = soc_{t-1}^{LIB} + \eta^{CH} p_t^{v,l} \Delta t - \frac{p_t^{l,v} \Delta t}{\eta^{DIS}}, \qquad \forall t > 1 \tag{1c}$$

$$soc_0^{LIB} = SOC0^{LIB} \tag{1d}$$

$$\underline{SOC}^{LIB} \le soc_t^{LIB} \le \underline{SOC}^{LIB}, \qquad \forall t \tag{1e}$$

$$0 \le p_t^{v,l} \le z_t^{LIB} \underline{P}^{LIB}, \qquad \forall t \tag{1f}$$

$$0 \le p_t^{l,v} \le (1 - z_t^{LIB}) \underline{P}^{LIB}, \qquad \forall t \tag{1g}$$

$$soc_t^{VRFB} = soc_{t-1}^{VRFB} + \eta^{CH} p_t^{v,s} \Delta t - \frac{p_t^{s,v} \Delta t}{\eta^{DIS}}, \qquad \forall t > 1 \tag{1h}$$

$$soc_0^{VRFB} = SOC0^{VRFB} \tag{1i}$$

$$\underline{SOC}^{VRFB} \le soc_t^{VRFB} \le \underline{SOC}^{VRFB}, \qquad \forall t \tag{1j}$$

$$0 \le p_t^{v,s} \le z_t^{VRFB} \underline{P}^{VRFB}, \qquad \forall t \tag{1k}$$

$$0 \le p_t^{s,v} \le (1 - z_t^{VRFB}) \underline{P}^{VRFB}, \qquad \forall t \tag{1l}$$

$$\Delta b_{loss,t}^{cal,LIB} \ge a_m^{LIB} soc_t^{LIB} + b_m^{LIB}, \qquad \forall m, t \tag{1m}$$

$$\Delta b_{loss,t}^{cyc,LIB} \ge c_m^{LIB} \frac{p_t^{v,l} + p_t^{l,v}}{\underline{P}^{LIB}} + d_m^{LIB}, \qquad \forall m, t \tag{1n}$$

$$\Delta b_{loss,t}^{cal,VRFB} \geq a_m^{VRFB} soc_t^{VRFB} + b_m^{VRFB}, \qquad \forall m,t \tag{1o}$$

$$\Delta b_{loss,t}^{cyc,VRFB} \geq c_m^{VRFB} \frac{p_t^{v,s} + p_t^{s,v}}{\underline{P}^{VRFB}} + d_m^{VRFB}, \qquad \forall m,t \tag{1p}$$

$$z_t^{LIB}, z_t^{VRFB} \in \{0,1\}, p_t^{v,m}, p_t^{v,l}, p_t^{v,s}, p_t^{m,v}, p_t^{l,v}, p_t^{s,v} \geq 0 \ \forall t \tag{1q}$$

The objective (1a) maximises the revenues obtained for the participation in the Day-Ahead Market, while minimising the calendar and cyclic degradation for the LIB and VRFB batteries. Energy balance of the VESS is ensured by (1b). State of charge update for the LIB is stated in (1c) and (1d), while (1e) set bounds for the SOC. The charging and discharging limits are enforced by (1f) and (1g) using z_t^{LIB} to indicate charging status. Similarly, equations (1h) to (1l) enforce the same operational constraints for the VRFB. Calendar and cyclic degradation for the LIB are computed in (1m) and (1n), for the LIB and in (1o), (1p) for the VRFB. Lastly, (1q) define the domain of the decision variables of the problem.

6.4.2.3 Service 2: Tertiary Reserve Markets

After the definition of the set points ($p_t^{v,m*}, p_t^{v,l^*}, p_t^{v,s*}, p_t^{m,v*}, p_t^{l,v^*}, p_t^{s,v*}$) defined by the PDBF the availability of the LIB BESS to provide tertiary reserve is computed using (2).

Sets

$t \in \Omega_t$: Set of periods in the scheduling horizon.

$m \in \Omega_m$: Set of segments for the degradation model of the BESSs.

Parameters

λ_t^u, λ_t^d: Forecast of the upward u and downward d prices for the mFRR services at time t (€/MWh).

p_t^{v,l^*}, p_t^{l,v^*}: Charging and discharging commitments in the DAM from problem (1) (MWh).

$\underline{P}^{LIB}$: Power of the converter for the LIB BESSs (MWh).

$C^{DEG,LIB}$: Degradation cost of the LIB and VRFB BESSs (€/MWh).

η^{CH}, η^{DIS}: Mean charging and discharging efficiencies for the batteries (%).

Δt: Timestep between periods (h).

$SOC0^{LIB}$: Initial state of charge for the LIB BESS (MWh).

$\underline{SOC}^{LIB}, \underline{SOC}^{LIB}$,: State of Charge Limits for the LIB BESS (MWh).

P^{MIN}: Minimum offer in the mFRR market (MW) [$P^{MIN} = 1\ MW$].

M: Big enough number, for this case: $M = 2\underline{P}^{LIB}$ (MW).

a_m^{LIB}:Slope of the segment m to compute the calendar degradation of the LIB BESSs (p.u.).

b_m^{LIB}: Interception of the segment m to compute the calendar degradation of the LIB BESSs (MWh).

c_m^{LIB}: Slope of the segment m to compute the cyclic degradation of the LIB BESSs (h).

d_m^{LIB}: Interception of the segment m to compute the cyclic degradation of the LIB BESSs (MWh).

Decision variables

z_t^{LIB}: Binary variables indicating the charging (1) or discharging (0) status of the LIB BESSs.

y_t^u, y_t^d: Binary variables that ensure minimum bid requirements of the mFRR market in the upward u and downward d directions.

$p_t^{dis,u}, p_t^{ch,u}$: Discharging and charging power of the LIB BESS contributing to the upward u mFRR product (MW).

$p_t^{dis,d}, p_t^{ch,d}$: Discharging and charging power of the LIB BESS contributing to the downward d mFRR product (MW).

soc_t^{mFRR}: State of charge of the LIB BESSs at time t for the MFRR market (MWh).

$\Delta b_{loss,t}^{cal,LIB}$: Calendar degradation for the LIB lost at time t (MWh).

$\Delta b_{loss,t}^{cyc,LIB}$: Cyclic degradation for the LIB lost at time t (MWh).

Then the problem is formulated as follows:

$$\sum_t \left[\lambda_t^u\left(p_t^{dis,u} + p_t^{ch,u}\right) + \lambda_t^d\left(p_t^{dis,d} + p_t^{ch,d}\right)\right] - \sum_t C^{DEG,LIB}\left(\Delta b_{loss,t}^{cal,LIB} + \Delta b_{loss,t}^{cyc,LIB}\right) \quad (2a)$$

Subject to,

$$p_t^{v,l^*} + p_t^{ch,d} - p_t^{ch,u} \leq \underline{P}^{LIB} z_t^{LIB}, \quad \forall t \quad (2b)$$

$$p_t^{v,l^*} + p_t^{ch,d} \leq \underline{P}^{LIB} z_t^{LIB}, \quad \forall t \quad (2c)$$

$$p_t^{v,l^*} - p_t^{ch,u} \geq 0, \quad \forall t \quad (2d)$$

$$p_t^{l,v^*} + p_t^{dis,u} - p_t^{dis,d} \leq \underline{P}^{LIB}\left(1 - z_t^{LIB}\right), \quad \forall t \quad (2e)$$

$$p_t^{l,v^*} + p_t^{dis,u} \leq \underline{P}^{LIB}\left(1 - z_t^{LIB}\right), \quad \forall t \quad (2f)$$

$$p_t^{l,v^*} - p_t^{dis,d} \geq 0, \quad \forall t \quad (2g)$$

$$soc_t^{mFRR} = soc_{t-1}^{mFRR} + \left[\eta^{CH}\Delta t\left(p_t^{v,l^*} + p_t^{ch,d} - p_t^{ch,u}\right) - \frac{\Delta t}{\eta^{DIS}}\left(p_t^{s,l^*} + p_t^{dis,u} - p_t^{dis,d}\right)\right], \forall t \quad (2h)$$

$$SOC_0^{mFRR} = SOC0^{mFRR} \quad (2i)$$

$$\underline{SOC}^{LIB} \leq soc_t^{mFRR} \leq \underline{SOC}^{LIB}, \quad \forall t \quad (2j)$$

$$p_t^{ch,u} + p_t^{dis,u} \geq P^{MIN} y_t^u, \quad \forall t \quad (2k)$$

$$p_t^{ch,u} + p_t^{dis,u} \leq M y_t^u, \quad \forall t \quad (2l)$$

$$p_t^{ch,d} + p_t^{dis,d} \geq P^{MIN} y_t^d, \quad \forall t \quad (2m)$$

$$p_t^{ch,d} + p_t^{dis,d} \leq M y_t^d, \qquad \forall t \tag{2n}$$

$$\Delta b_{loss,t}^{cal,LIB} \geq a_m^{LIB} soc_t^{mFRR} + b_m^{LIB}, \qquad \forall m, t \tag{2o}$$

$$\Delta b_{loss,t}^{cyc,LIB} \geq c_m^{LIB} \frac{p_t^{v,l^*} + p_t^{ch,d} - p_t^{ch,u} + p_t^{l,v^*} + p_t^{dis,u} - p_t^{dis,d}}{\underline{P}^{LIB}} + d_m^{LIB}, \qquad \forall m, t \tag{2p}$$

Objective (2a) maximises the benefits from the participation in the mFRR market based on the price forecasts λ_t^u and λ_t^d, while minimising the degradation of the LIB battery. Equations (2b) to (2g) ensure the operation of the LIB in the mFRR, avoiding simultaneous charging and discharging. Then (2h) to (2j) update the SOC of the LIB after the market participation. Equations (2k) to (2n) ensure that the bid provided by the LIB comply with the minimum size set by the market P^{MIN}. Lastly, calendar and cyclic degradation are computed in (2o) and (2p), respectively. Note that this problem needs to be solved every time there is an activation of the mFRR products for the remaining scheduling horizon.

Regarding the conditional links between the offers, given the limited size of the battery, an analysis is provided in Table 13. Based on the activation of the upward and downward products in T-2 and T-1 periods, the submitted upward and downward offer at time T is enabled to be activated (YES) or disabled to be activated (NO) by the TSO.

TABLE 13: EVALUATION OF THE POSSIBLE CONDITIONAL LINKS BETWEEN THE OFFERS GIVEN THE LIMITED SIZE OF THE BATTERY

	Upward Activated		**Downward activated**		**Upward offer**	**Downward offer**
Period	**T-2**	**T-1**	**T-2**	**T-1**	**T**	**T**
Case 1	Yes	No	No	Yes	Yes	No
Case 2	Yes	No	No	No	No	Yes
Case 3	No	Yes	Yes	No	No	Yes
Case 4	No	Yes	No	No	No	Yes
Case 5	No	No	Yes	No	Yes	No
Case 6	No	No	No	Yes	Yes	No
Case 7	No	No	No	No	Yes	Yes

These conditions can be visualised in Figure 43:

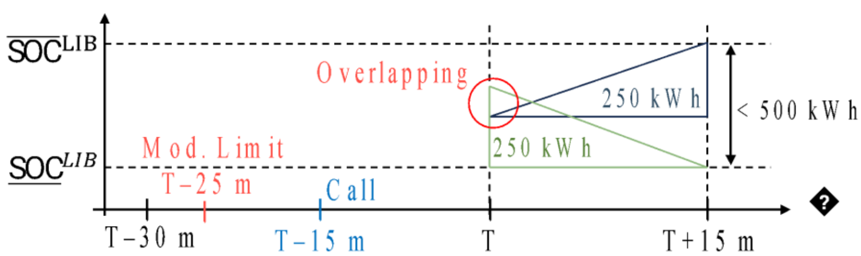


FIGURE 43: VISUALISATION OF THE CONDITIONAL LINKING OF THE TERTIARY OFFERS. PERIODS T-30 AND T-15 INFLUENCE IN THE AVAIABILITY OF ENERGY FOR PERIOD T. THE SOC SHOULD BE OVER 300 KWH TO PROVIDE UPWARD ACTIVATION, WHILE IT SHOULD BE LESS THAN 190 KWH TO PROVIDE FULL DOWNWARD ACTIVATION IN PERIOD T

Co-funded by the European Union

Given this conditional linkage of the offers, the availability of tertiary reserves, should be sequentially updated every time the SO activate it. The following data workflow is implemented.

6.4.2.4 Preliminary Results

Simulation algorithm

The simulation algorithm is built on a multi-step optimisation approach, where the VESS operation is firstly optimised for the Wholesale Market, and then for the mFRR market on a day-ahead basis. The real-time corrections of the mFRR market are considered in the algorithm in real-time, considering the conditional links between the offers and the information available at each moment. The algorithm is outlined in Figure 43.

begin
  for $d \in \mathcal{D}$ **do**
    VESS Schedules $\leftarrow$Solve DAM (1)
    VESS mFRR availability $\leftarrow$Solve mFRR (2)
    for $t \in \Omega_t = [1, 2, \cdots, \mathcal{T} - 2]$ **do**
      $p_t^{u,act}, p_t^{d,act} \leftarrow$ Dir(t), Link($t-1, t-2$)
      $p_{t+1}^{u,act}, p_{t+1}^{d,act} \leftarrow$ Dir($t+1$), Link($t, t-1$)
      $p_{t+2}^{u,act}, p_{t+2}^{d,act} \leftarrow$ Link($t+1, t$)
      $p^{ch}, p^{dis}, soc_t^{RT} \leftarrow p^{u,act}, p^{d,act}$
      if $\|soc_t^{LIB} - soc_t^{RT}\| > 0$ **then**
        for $\tau = [1, 2, \cdots, t+2]$ **do**
          Fix $p_\tau^u, p_\tau^u \leftarrow p_\tau^{u,act}, p_\tau^{d,act}$
        end
        $p_t^u, p_t^u, soc_t^{LIB} \leftarrow$ Solve mFRR (2)
      end
    end
    Log market participation results for day d
  end
end

FIGURE 44: MULTI-STEP DAY-AHEAD AND MFRR SIMULATOR ALGORITHM

Preliminary results

The Granada demonstrator integrates renewable assets including a WT, alongside a PV and a small run-of-the-river hydropower plant. These renewable energy sources serve as the primary generation capacity for the system, providing the necessary energy input for the VESS operation and grid support services. Managed by MECSA, the local Distribution System Operator (DSO) and Electricity Supply Company (ESCO), the VESS coordinates storage services comprising a Li-ion BESS of 1 MW/0.5 MWh and a VRFB with 250 kW/625 kWh, connected to different nodes of the grid. To evaluate the system's performance, renewable energy profiles are obtained from historical data in 2022. Simulations are performed using Gurobi 9.5.1 and Python 3.9.18 on an Apple M1 Processor with 16 GB of RAM. The simulation for the wholesale market considers an hourly time resolution for the next three years, while the mFRR market considers a 15-minute time resolution for the next 24 hours. The total number of the continuous and binary variables is 672 and 288 for the wholesale market model, 1,056 and 192 for the mFRR market model. The number of constraints is 960 and 1,248 for the former and latter models, respectively. The solver takes less than one second to solve each problem considering a MIP gap of 5%.

The VESS operation in the wholesale market is shown in Figure 45. This figure is drawn after step 3 of the simulation algorithm, where the VESS operation is optimised for the wholesale market. As it can be seen, the VESS store as much energy as possible during the low-price periods (using the LIB as the VRFB is fully charged) and discharges it during the high-price periods.

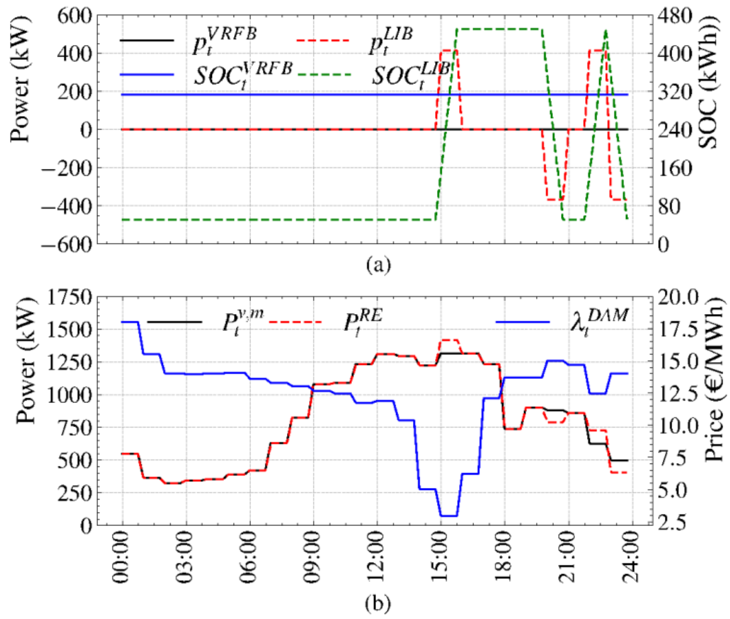


FIGURE 45: VESS EXCHANGES WITH WHOLESALE MARKET FOR ONE REPRESENTATIVE DAY OF THE SIMULATION.

The VESS stack of products is shown in Figure 46. The battery effectively provides energy arbitrage and mFRR services, capitalising on the activation of the mFRR products, while providing previously compromised offers in the wholesale market in real-time. The profits obtained in the wholesale and mFRR markets for the year under study are 874.292 k€ and 14.695 k€, respectively. This results in a total profit of 888.987 k€ increasing the profits by 3.261% compared to the case without VESS, where the profits are only sold in the wholesale market without any possibility of energy arbitrage or mFRR services. In the latter case, the profits are 860.911 k€.

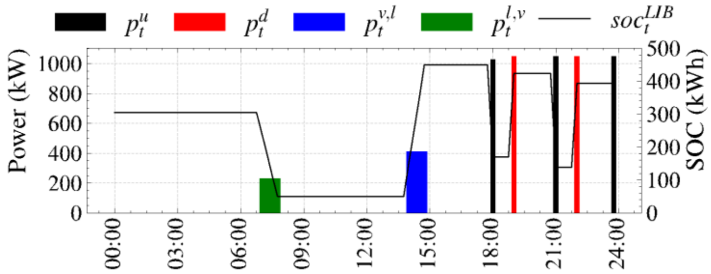


FIGURE 46: STACKING OF MFRR AND WHOLESALE ENERGY PRODUCTS FOR A TYPICAL DAY OF OPERATION. THE LIB PROVIDE ENERGY ARBITRAGE SERVICES IN THE WHOLESALE MARKET (GREEN AND BLUE BARS), WHILE CAPITALISING THE REMAINING POWER IN THE MFRR MARKET (RED AND BLACK BARS).

A more detailed operation of the VESS in the mFRR market is shown in Figure 47. This figure is drawn after step 17 of the simulation algorithm, where the VESS operation is being optimised in real-time given the calls of the TSO, the direction of the event - which is unknown at step 4 of the algorithm - and the conditional links presented in the previous table. In this figure, filled black and red bars represent the activation of the upward $p_t^{u,*}$and downward $p_t^{d,*}$ products, respectively. The bar with strips represents the offers submitted that were not activated in each direction. Blue and green bars represent the previously compromised offers in the charging p_t^{v,l^*} and discharging p_t^{l,v^*} directions in the wholesale market, respectively. Arrows over the bars indicate the final direction of the activated mFRR event.

This figure showcases how the VESS capitalise on the activation of the mFRR products, while providing previously compromised offers in the wholesale market in real-time, ensuring that the VESS can provide the required tertiary reserves by the TSO. It is possible to see that the VESS effectively provides the mFRR services when the TSO activates the products in the direction where the VESS has energy available.

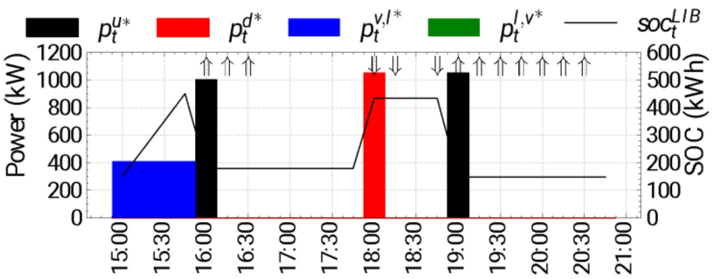


FIGURE 47: REAL-TIME CORRECTIONS FOR THE MFRR MARKET

6.4.3 Progress on KPIs

To conclude this section, the previously presented KPIs in which progress has been made during the Pre-Demo Phase, are listed in Table 14**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**. Those not indicated here, do not apply during this period as they are related to the effective operation of the demos. As mentioned earlier, the KPIs will be finally delineated in a future iteration.

TABLE 14: DEMO 3 PROGRESS ON KPIS

ID	Name	Baseline Value	Pre-Demo Phase Value
Axis I. Demo's Implementation Progress & Outcomes			
18	Deployment of digital platforms for operating and managing new functionalities in wide-are multi-user energy storage systems	-	Development and integration are in progress
24	New collaborations between SMEs, industry and academia in the energy storage sector	0	5
27	Nº of multi-use business models evaluated in detail	0	3

6.5 LESSONS LEARNT AND NEXT STEPS

As seen in the preceding sections, significant progress has been made in various areas of the demo during the Pre-demo Phase. This includes the study of business scenarios and the subsequent selection of the business use cases and services that best fit the characteristics of the demo, the development and testing of the optimisation algorithms, the design of the demo architecture, the development of the digital platform, and the definition of the on-site specifications.

However, during this period, the demo faced the potential withdrawal of the VRFB battery supplier. As of the writing of this document, this situation has not yet been clarified, although various mitigating solutions have been explored. While several aspects presented are horizontal to the demo and will not change significantly pending the final resolution, others are awaiting the definitive solution to this situation, such as a more detailed specification of the KPIs or the final on-site specifications.

In this context, the next steps will depend on the final solution. Nonetheless, in any case, they include the refinement of the optimisation, the integration of the different parts into the demo architecture, permitting and installation, and the definition of the remaining pending aspects, such as the definitive KPIs.

7 DEMO 4 - COOPERATIVE MODULAR MULTI HYBRID ESS FOR E-MOBILITY SERVICES

The Italian demo project envisages a radical transformation of the regional transportation industry, leveraging electric vehicles (EVs) and battery-powered charging infrastructure. This ambitious initiative encompasses a holistic approach to stimulate EV adoption, expand charging networks, and integrate renewable energy.

At its core, the project focuses on establishing Multi-Charging Hubs (MCHs) strategically positioned in key touristic areas. These hubs will serve as centres for EV sharing, providing convenient access to EV's renting for visitors exploring the region. Accompanying the MCHS are "destination chargers" installed at popular tourist spots, ensuring easy access to charging facilities for EV drivers.

To address gaps in fixed charging infrastructure, the project will deploy mobile chargers, offering on-demand charging services even in remote locations.

Utilising energy storage systems (ESS) and renewable sources like solar panels will ensure a reliable electricity supply for the charging infrastructure. ESS will store surplus energy from solar panels, effectively managing supply and demand, even during periods of low solar output. Integrating the Multi Charge Hubs with renewable energy communities (recs), will further bolster sustainability by tapping into local renewable resources, reducing reliance on the main power grid.

In addition, Demo 4 will employ optimal management of smart grid strategies, utilising optimal power flow algorithms to emphasise energy flexibility through storage devices. This approach aims to reduce energy costs and prolong the lifespan of ESSs.

7.1 DEMO STATUS UPDATE

An update to the contents of the Baseline Assessment Report for Demo 4 is presented in the following paragraphs.

7.1.1 Context and Objectives

The demo aims to showcase various ESS applications to enhance Electric Vehicle (EV) charging services and supply energy to the grid when needed. It focuses on improving EV Ultra-Fast Charging performance with stationary hybrid energy storage, reducing charging time and distribution grid impact. It also introduces the concept of delivering energy to vehicles exactly where and when it is needed, addresses range anxiety with a portable, swappable battery charger, and promotes increased PV grid penetration along with the sharing of surplus energy from stationary hybrid storage plants and Mobile Chargers for EV mobility service.

7.1.2 Stakeholders

The stakeholders involved in Demo 4 are UNINA, SAMSO, REEF and NIO. Table 15 summarises the roles of each partner:

TABLE 15: DEMO 4 STAKEHOLDERS

Actor	Role(s) in the demo	Stakeholder group
University of Naples Federico II (UNINA)	Leader of Demo 4 (Italy)	Academy institution
SAMSO	Italian Demo activities provide the energy management tools	Energy stakeholders
Reefilla (REEF)	Provide mobile EV-chargers	Storage Operators, Aggregators
NIO	Provide V2G charging stations and EVs	Manufacturer

7.1.3 Services, Data and Infrastructures

Demo 4 focuses on smart management of the EV multi-charge hub through advanced algorithms that optimise power flow. This extends the lifespan of energy storage systems (ESS) and reduces energy costs. A central server acts as the brain of the system, acquiring data from each charging point via the OCPP protocol. It also fetches real-time data on VESS from the i-STENTORE platform. This data is then used to monitor and evaluate the performance of the power flow algorithms, ensuring optimal functionality.

The Lithium-Ion Capacitor (LIC) in the HESS for the Ultra-Fast Charging Station will be replaced with a Lithium Titanate Oxide (LTO) battery. This substitution enhances the system's performance and reliability while ensuring compatibility with the designed DC/DC converter. To validate the compatibility and functionality of this system adaptation, rigorous testing will be conducted at the UniNa Lab before the installation at the site. This comprehensive testing phase at UniNa Lab will encompass various scenarios to assess the performance, stability, and safety of the LTO battery integrated with the DC/DC converter.

For a deeper dive into Demo 4 services, refer to deliverable D4.1 section 4.5.3.

7.1.4 Key Performance Indicators

No alterations have been made to the Demo 4 KPIs as documented in deliverable D4.1, section 4.5.4.

7.1.5 Risk Analysis

Referencing the risk list presented in deliverable D4.1, section 4.5.5, the identified risk R4.4 regarding potential disruptions to the implementation activities of the charging hub on the i-STENTORE platform due to the withdrawal of ENG has been mitigated. This mitigation has been achieved through an agreement with ED, which will assume responsibility for the implementation tasks.

Furthermore, it's important to note that the remaining risks listed in the deliverable D4.1 remain unchanged.

7.1.6 Engagement and Implementation Plan

The i-STENTORE project in Italy is finalising details for its demonstration site. While a previous location was discussed, the project team is currently focusing on a public tender with a new municipality. This tender involves a photovoltaic plant for electric bus charging, potentially offering a better fit for the project's goals. Additionally, mall parking projects are being evaluated as backup options. A final decision on the site is expected by September.

Finding a V2G charger supplier that complies with Italian regulations is another ongoing task. If a suitable supplier isn't identified, the project might need to proceed with a previously found supplier whose charger lacks a CE mark, potentially limiting its use in certain situations.

The project is also moving forward with the development of a Hub Energy Management system through a partnership with a software company. Quick charging stations are on hold until the final project details are confirmed, at which point they will be purchased.

Italy recently implemented exciting new regulations promoting Renewable Energy Communities (RECs) in January 2024. These communities allow citizens to join forces and benefit directly from renewable energy sources like solar power. This translates to increased energy efficiency in their homes and businesses, along with lower electricity bills. The i-STENTORE project plans to establish a REC involving the Hub charging stations, the host municipality, and potentially neighbouring residents.

The Hub's Energy Management Policy will be designed considering the REC regulations, energy consumption forecasts, electricity prices, and insights from the i-STENTORE Reference Architecture. This collaboration has the potential to create a model for sustainable energy use within communities.

7.2 DEMO DEPLOYMENT

Demo 4 deployment is following the Gantt chart of Table 16 below:

TABLE 16: DEMO 4 DEPLOYMENT GANTT CHART (LEGEND: PROCUREMENT (P), DEPLOYMENT PLAN (D) AND TESTING (T))

N	Equipment	Plan	Quarters											
			2023				2024				2025			
			1	2	3	4	5	6	7	8	9	10	11	12
1	E-Cube Ultrafast Charger (E-UFC)* *(* testing in UniNa Lab)*	P												
		D								X	X			
		T							X	X				
2	HESS LTO Storage *(* testing in UniNa Lab)*	P				X	X							
		D						X	X	X				
		T								X				
3	PV –Shelter Power Plant	P					X	X						
		D							X	X				
		T									X			
4	Mobile Battery Charger	P								X				
		D									X			
		T									X	X		
5	AC Normal Charger	P					X	X						
		D							X					
		T								X				

N	Equipment	Plan	Quarters											
			2023				2024				2025			
			1	2	3	4	5	6	7	8	9	10	11	12
6	Hub E-Station	P					X	X						
		D							X	X				
		T									X	X	X	
7	V2G Charger & EV	P					X	X						
		D								X				
		T									X			

The i-STENTORE project in Italy is building a cutting-edge microgrid system at its demonstration site. This system aims to be a model for efficient and sustainable energy management, integrating various components to optimise power usage and minimise strain on the local grid.

Here's a breakdown of the key elements and their functionalities:

- E-Cube Ultrafast Chargers (E-UFC): These high-powered chargers will be the workhorses for electric vehicles (EVs), enabling rapid charging. Before installation, the site will undergo a thorough assessment to ensure the electrical infrastructure can handle the E-UFC's demanding power requirements. This might involve upgrading transformers or power lines to guarantee a reliable connection. Once the electrical infrastructure is ready, the E-UFC units will be securely mounted and connected to the grid. This process will involve qualified technicians following strict safety protocols to ensure a safe and functional charging station. The EV charger will be Connected to the local power grid and SCADA system to be monitored and controlled by Energy Management System (EMS) energy optimisation purposes. The EMS acts as the brain, dynamically adjusting the controllable power references based on real-time data to avoid overloading the grid during peak demand periods and guarantee maximum ESS lifetime at minimum costs. This congestion management is achieved through sophisticated algorithms that analyse forecasting data.

- Hybrid Energy Storage System (HESS): This innovative system will be directly integrated with the E-UFC to maximise the overall battery lifespan. This upgraded version will not only store excess energy generated during low demand periods but will also use that extra capacity to provide additional services to the grid. These services include helping to manage congestion during peak demand times and smoothing out power fluctuations. Before integrating the new HESS, thorough site preparation will be conducted. This includes installing the necessary cooling systems to ensure optimal performance.

- PV-Shelter Power Plant: This solar panel array harnesses the power of the sun, generating clean and renewable energy. The EMS plays a central role again, ensuring optimal energy harvesting and usage. By intelligently controlling the distribution of solar energy, the system minimises peaks that could overload the grid and distributes power efficiently when needed. Optimisation algorithms based on forecasting data allow the EMS to make these decisions in real-time.

- Mobile Battery Chargers: These versatile chargers offer flexible charging options for EVs on the go. They seamlessly integrate with the EMS for optimised charging, minimising stress on the grid. The EMS schedules charging to occur during off-peak times, when there's less demand on the grid. Additionally, the mobile chargers can leverage stored energy from the HESS to provide a steady power supply, mitigating fluctuations and ensuring a smooth charging experience.

- AC Normal Chargers: These slower chargers provide a readily available option for everyday EV charging needs. The EMS manages the charging loads to ensure efficient power distribution and prevent overloading the grid. Similar to the E-UFCs, congestion management is achieved through optimisation algorithms that analyse forecasting data.

- V2G Charger & Electric Vehicles (EVs): This pioneering technology takes things a step further. V2G chargers allow EVs to not only be charged but also act as mobile energy sources. During peak demand periods, EVs can actually feed energy back into the grid, further reducing strain on the system. Similar to the E-UFC chargers, the site might require electrical infrastructure upgrades to handle the bidirectional power flow of the V2G system. This could involve installing new transformers or power lines. Strict safety protocols need to be followed during installation, including proper grounding, ventilation, and fire safety measures. The V2G charger needs to be integrated with the Energy Management System (EMS) to ensure safe and efficient communication between the EV, the charger, and the grid. The intelligent EMS manages this bidirectional flow of energy, ensuring a smooth and balanced operation.

By intelligently integrating these advanced components and leveraging the power of the EMS, the i-STENTORE demonstration site aims to showcase a robust, efficient, and sustainable energy model. This microgrid system has the potential to revolutionise how we manage energy grids, paving the way for a future with smoother power supply, reduced reliance on fossil fuels, and a significant decrease in grid congestion.

7.3 PRE-DEMO PHASE SCENARIOS

Four scenarios have been developed for the Pre-demo Phase for managing energy resources, focusing on photovoltaic (PV) generation, storage state of charge (SoC), and electricity consumption.

- 1st Scenario: No PV Generation & Low Storage SoC vs. Low Electricity Price
    a. Objective: Use storage charging to assist in balancing the electricity grid.
    b. Action: If the storage SoC is low, initiate storage charging during periods of low electricity prices, e.g. during the night.
- 2nd Scenario: Low PV Generation vs. High EV Consumption
    a. Objective: Reduce electricity withdrawal from the grid.
    b. Action: Turn off a few electric vehicle (EV) chargers to balance the available PV generation and storage capacity.
- 3rd Scenario: High PV Generation vs. High REC Consumption Forecast
    a. Objective: Exploit the REC operation mode (i.e., energy sharing) to support grid balancing.
    b. Action: Turn off all EV chargers and stop storage charging to direct electricity towards REC consumption.
- 4th Scenario: External Input from DSO
    a. Objective: Manage energy based on directives from the Distribution System Operator (DSO).
    b. Action: Adjust EV chargers and storage charging to modify hub consumption as needed to implement DSO services.

These scenarios aim to optimise the use of renewable energy sources, manage storage systems effectively, and maintain grid stability through strategic energy management.

7.4 OPERATION, TESTING AND PRELIMINARY RESULTS

The Pre-Demo Phase has been characterised by an extensive study aimed at defining the best control strategy for the optimal dispatching of the micro-grid. Additionally, activities have focused on determining the suitable technical specifications for both the power converter and the energy storage system to realise the hybrid energy storage systems.

7.4.1 Grid Operations

Grid operations are significantly affected by the randomness associated with the variable nature of EV charging load and PV power production.

The micro-grid to be realised within Demo 4 resembles an Active Distribution Network (ADN), hosting several EV Charging Stations (EVCSs) and heterogeneous Distributed Energy Resources (DERs), such as Battery Energy Storage Systems (BESS) of different technologies and uncontrollable PV power plants. Consequently, the dispatching framework is organised into two layers:

1. Determining a day-ahead schedule based on the forecast of stochastic injections and available flexibility from EVCSs and BESS.
2. Controlling the EVCSs and BESS power profiles during real-time operations to track the day-ahead reference profiles.

In the day-ahead stage, the Distribution System Operator (DSO) designs a dispatch plan, which is a power schedule to be followed by the ADN's grid connection point during the next day's operations. This stage involves two processes: forecasting and dispatch plan creation. The forecasting process uses stochastic models for EV charging demand and PV power production to predict the power demand and production curve for the upcoming day. These forecasts are used to design a 24-hour dispatching plan with a time resolution of a few minutes (e.g., 5 minutes).

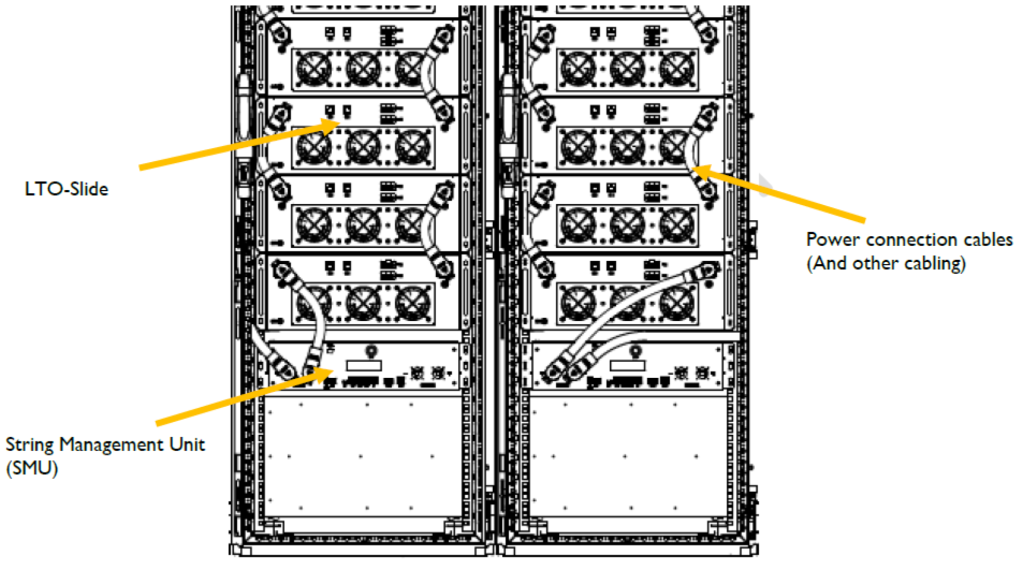
In the real-time stage, a Model Predictive Control (MPC) is solved with a time resolution shorter than the day-ahead stage one (e.g., 30 seconds). The MPC utilises flexible resources (i.e., EVCSs and BESS) in real-time to compensate for power mismatches at the ADN's grid connection point between the optimal day-ahead dispatch plan and the actual conditions during the day of operation. It is important to note that these operations require a suitable communication platform through which the controller implementing the MPC problem exchanges information with all distributed units and delivers setpoints to them.

Currently, the research activities are focusing on the first point, namely the day-ahead stage. The primary objective is to develop a suitable optimisation framework to define the dispatch plan. In this context, the problem is formulated as a stochastic optimal power flow, where power flow constraints are linearised to simplify the problem and enhance its convergence rate.

7.4.2 Integration of the Hybrid Energy Storage System

In the upcoming months, the converter along with the battery will be installed at the UNINA Lab, where an intense test campaign will be carried out to primarily check the compliance of the new device with existing UFCS and complete the integration of the hybrid storage system with UFCS. The new LTO system in Figure 48 acquired by NIO offers 30 kWh of energy capacity, operates at 360V, and can deliver a maximum discharge power of 100 kW.

A)



B)

FIGURE 48: LTO MODULE (A) AND RACK (B) FOR HESS DEVELOPMENT INTEGRATED INTO THE UFCS

The new DC/DC converter module in Figure 49, designed and acquired by UNINA, is compatible with the new LTO system. This module utilises two IGBT chopper converters to adjust voltage between the UFCS DC bus (510-720V) and the LTO system and control the current and power delivered for vehicle charging. The module will also include system protection and a Modbus interface for communication between the LTO's Battery Management System (BMS) and the existing charging infrastructure.

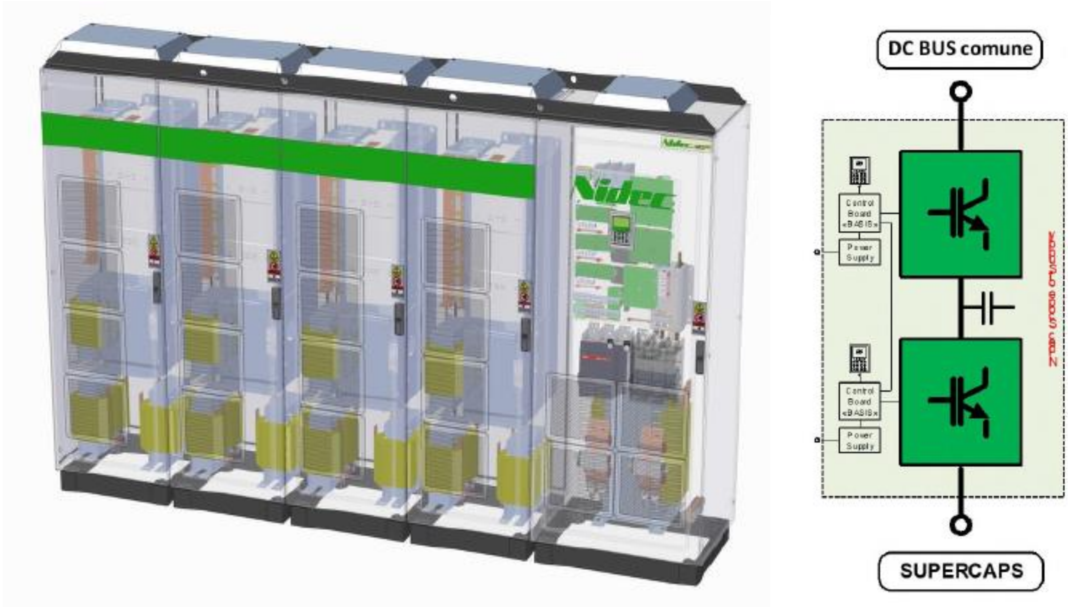


FIGURE 49: CAD REPRESENTATION AND CONCEPTUAL SCHEME OF THE DCDC CONVERTER DESIGNED TO INTERFACE THE NEW LTO SYSTEM WITH THE UFCS

The upgraded UFCS software will be enhanced to set power levels for each storage system based on an optimal power flow algorithm developed by UNINA. This ensures efficient utilisation of both systems, maximise the lifespan of the combined storage systems while minimising operational costs.

To conclude this section, the KPIs that have shown progress during the Pre-Demo Phase are listed below in Table 17. The KPIs not listed here do not apply to this period, as they are related to the effective operation of the demos. As mentioned earlier, the KPIs will be fully delineated in a future iteration.

TABLE 17: DEMO 4 KPIS

ID	Name	Baseline Value	Pre-Demo Phase Value
Axis I. Demo's Implementation Progress & Outcomes			
1	Integration of multi-charger hub	0	20 %
12	Design and integration of hybrid supercapacitor/battery storage system in Ultra-Fast charger	20%	60%

7.5 LESSONS LEARNT AND NEXT STEPS

As outlined above, a deep twofold research activity has been carried out until now to determine the optimal grid operations and integrate the hybrid storage system within the UFCS. The next steps will be devoted to finalising the design of optimal control strategies for the microgrid and performing tests and measurements on the UFCS architecture, which will then be moved to the actual demo site.

8 DEMO 5 - AGRI-PV FARM WITH ENERGY STORAGE CAPABILITIES

Demo 5 is entitled "Agri-PV Farm with Energy Storage Capabilities" and takes place in Kielen, Luxembourg. Relevant updates regarding the work and progress conducted during the pre-demo phase are described in the following paragraphs.

8.1 DEMO STATUS UPDATE

An update to the contents of the Baseline Assessment Report for Demo 5 is presented in the following paragraphs.

8.1.1 Context and Objectives

As described the previous D4.1, the scope of the Luxembourgish demonstrator is an Agri-photovoltaic plant combined with high-performance energy processes provided by a hybrid energy storage system, composed by utility-scale Li-ion battery and green hydrogen. The objective of the demonstrator is to evidence the availability, robustness, and safety of an APV farm that includes a hybrid energy storage system (HESS) to optimise the use of its local renewable resources when meeting the farm's production needs, at the same time providing services to the grid operator.

8.1.2 Stakeholders

There are no changes to report neither on the composition of the stakeholder list nor on their participation roles. The stakeholder and their respective roles in Demo 5 are described in the sub-section 4.6.2 of D4.1.

8.1.3 Services, Data and Infrastructures

There are no notable changes on the infrastructures, legacy tools, and assets to be reported. The status of the utility scale Li-ion BESS (1MW/0.5kWh) is still under manufacturing. The power converter enclosure is currently being assembled and prepared for modules integration. The PLC and PMU units have been installed for testing in the RT-HIL Laboratory, using emulation methods.

8.1.4 Key Performance Indicators

The Demo 5" Key Performance Indicators" presented in D4.1 remain adequate without significant changes for the pre-demo phase.

8.1.5 Risk Analysis

There are no new items to be included in the Risk Analysis of Demo 5. For the existing risk analysis please see D4.1, sub-section 4.6.5.

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8.1.6 Engagement and Implementation Plan

There are no changes to the engagement and implementation plant presented in D4.1. Between M14 and M17 the activities were mainly focused on the finalisation of the modelling of demo 5 assets for real-time simulations and in the development and testing of the communication interfaces for the fog (area) control and edge (local) control components. Work regarding the flexibility energy services has also started.

8.2 DEMO DEPLOYMENT

The cloud platform is hosted in AWS and consists of 3 subnets: two private and one public as in Figure 50Figure 50. Within these subnets the various resources are provisioned for running the databases, optimisation and forecast engines, APIs, etc. The databases are launched within a secure subnet with a highly granular network access control list (NACL) for setting the policies and traffic to minimise potential threats. This NACL is continuously being revised to continuously improve the data security. The platform communicates with the fog control through MQTT messages that are handled by an ETL pipeline executed by lambda functions. These are designed to handle both downstream and upstream messages.

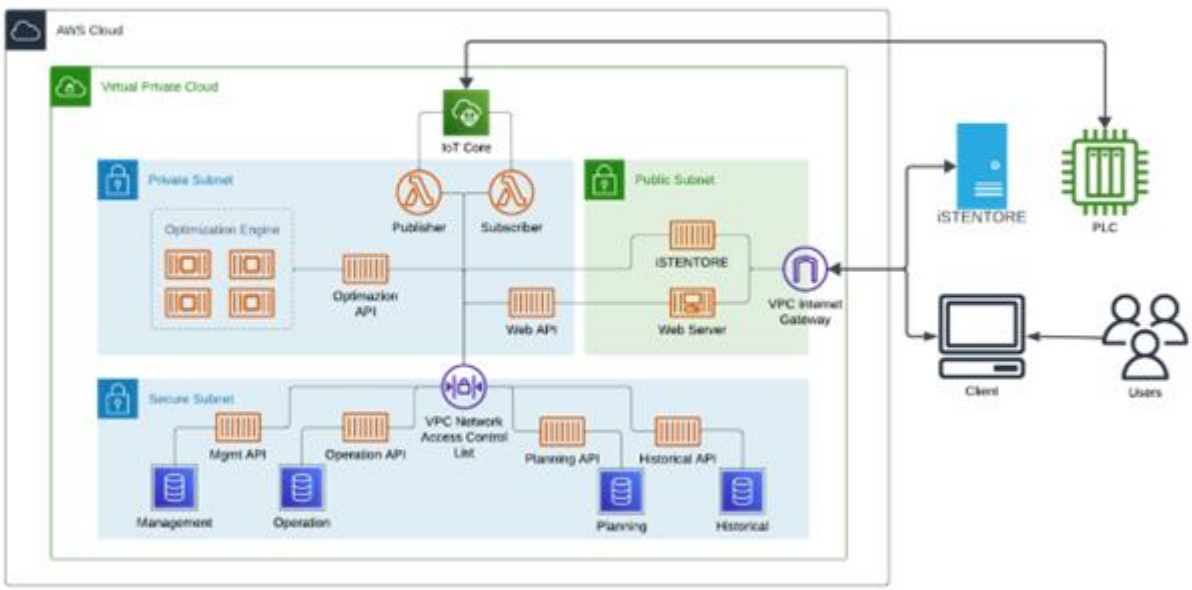

FIGURE 50: DEMO 5 CLOUD PLATFORM

An overview of the hierarchical control structure is shown in Figure 51 illustrating the three main components i.e. cloud, fog (Area) control and edge (local) control. As mentioned, the communication between the cloud and area control is done via MQTT messages while the communication between area and local control is done via ModBus TCP/IP. The area control receives measurements from PMUs via a Phasor Data Concentrator (PDC) through an ADS link.

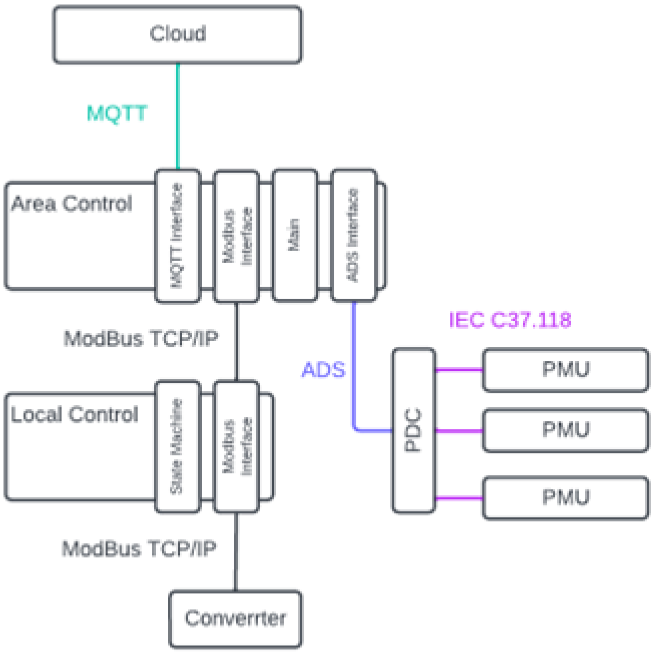

FIGURE 51: DEMO 5 HIERARCHICAL CONTROL STRUCTURE

8.3 PRE-DEMO PHASE SCENARIOS

The main driver of this demonstration is the availability of renewable energy from the Agri-PV and wind farms, which determines the operation of the electrolyser, supported by the availability of the trailer at the off-take. For this reason, a pool of scenarios is created based on wind and PV production, taking into account the impact of the weather for typical months of the year. In these scenarios, the amount of energy sold to the grid is added as an additional constraint to assess the impact of BESS on the overall profitability of the scenario. As an example, the following results are from a scenario that considers varying PV and wind production over a 28-day period for the month of January, with most of the electrolyser's needs met by wind production. Specifically, Figure 52 shows the available PV and Wind power against the power bought to cover hydrogen demand over that 28-day period. The evolution of hydrogen demand is depicted in Figure 54 while the actual hydrogen stored in the tanks is shown in Figure 53. Finally, the electrolyser's power needs for producing the hydrogen to cover the demand is illustrated in Figure 55. Notice that the peak power needed by the electrolyser during the entire period can be covered entirely by the PV and Wind production of Figure 52.

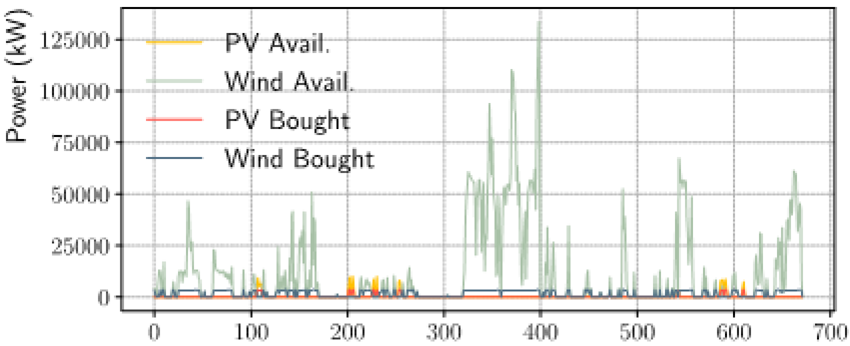

FIGURE 52: RENEWABLE POWER SOURCES FOR COVERING HYDROGEN PRODUCTION

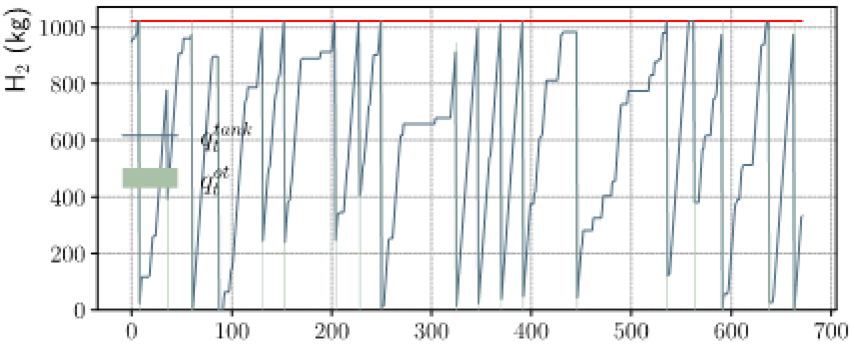

FIGURE 53: HYDROGEN STORAGE

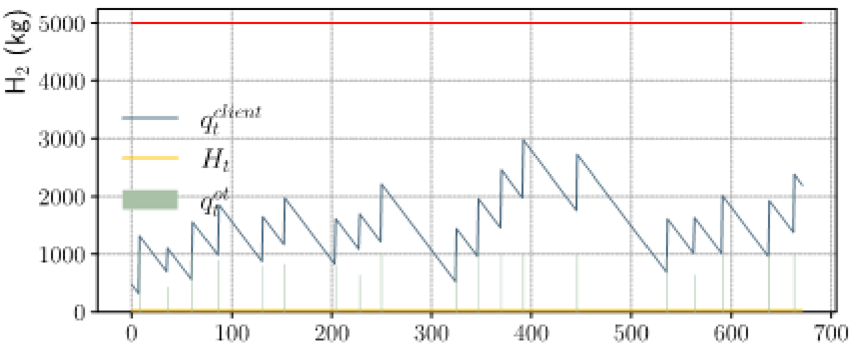

FIGURE 54: HYDROGEN DEMAND

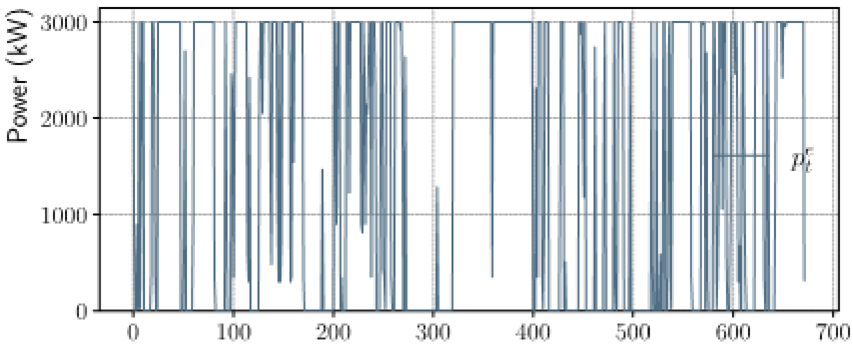

FIGURE 55: ELECTROLYSER DEMAND

8.4 OPERATION, TESTING AND PRELIMINARY RESULTS

The assets of demo 5 are modelled in the RT-Simulator. A snapshot of the modelling software interface is shown in Figure 56 below which depicts some of these assets including the PV, BESS and Electrolyser. These models are used to execute contingency scenarios for analysing the dynamic response of the plant assets in real-time. Such an example is a shown in Figure 57Figure 55 and Figure 58, which show the dynamic response of the plant after a three-phase short circuit has occurred at a nearby transmission line with a duration of 80ms.

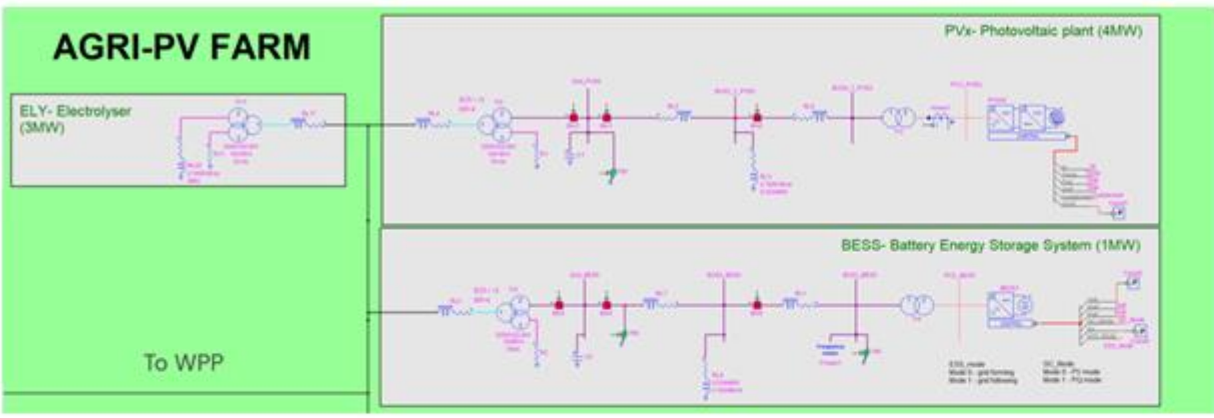

FIGURE 56: AGRI-PV FARM ASSETS HYPERSIM MODELS

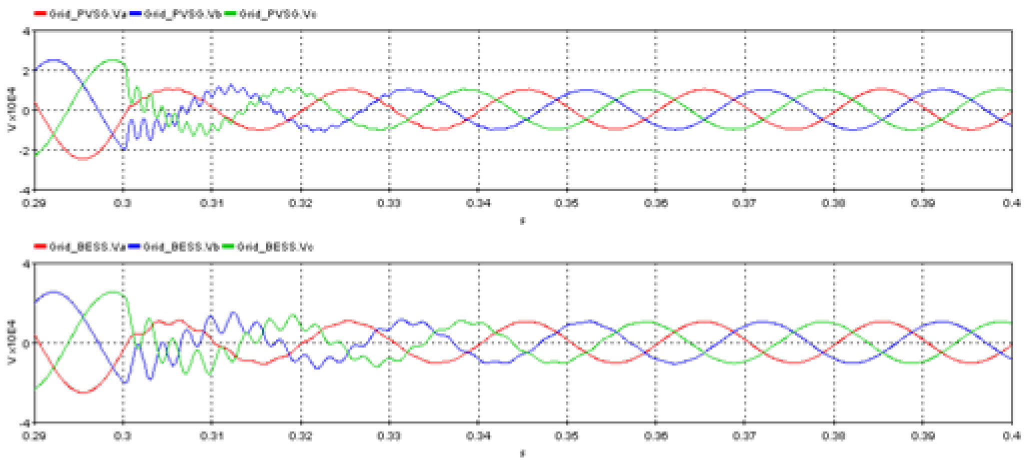

FIGURE 57: SIMULATION RESULTS DEPICTING THE PHASE VOLTAGES AT PV OUTPUT (TOP) AND BESS OUTPUT (BOTTOM)

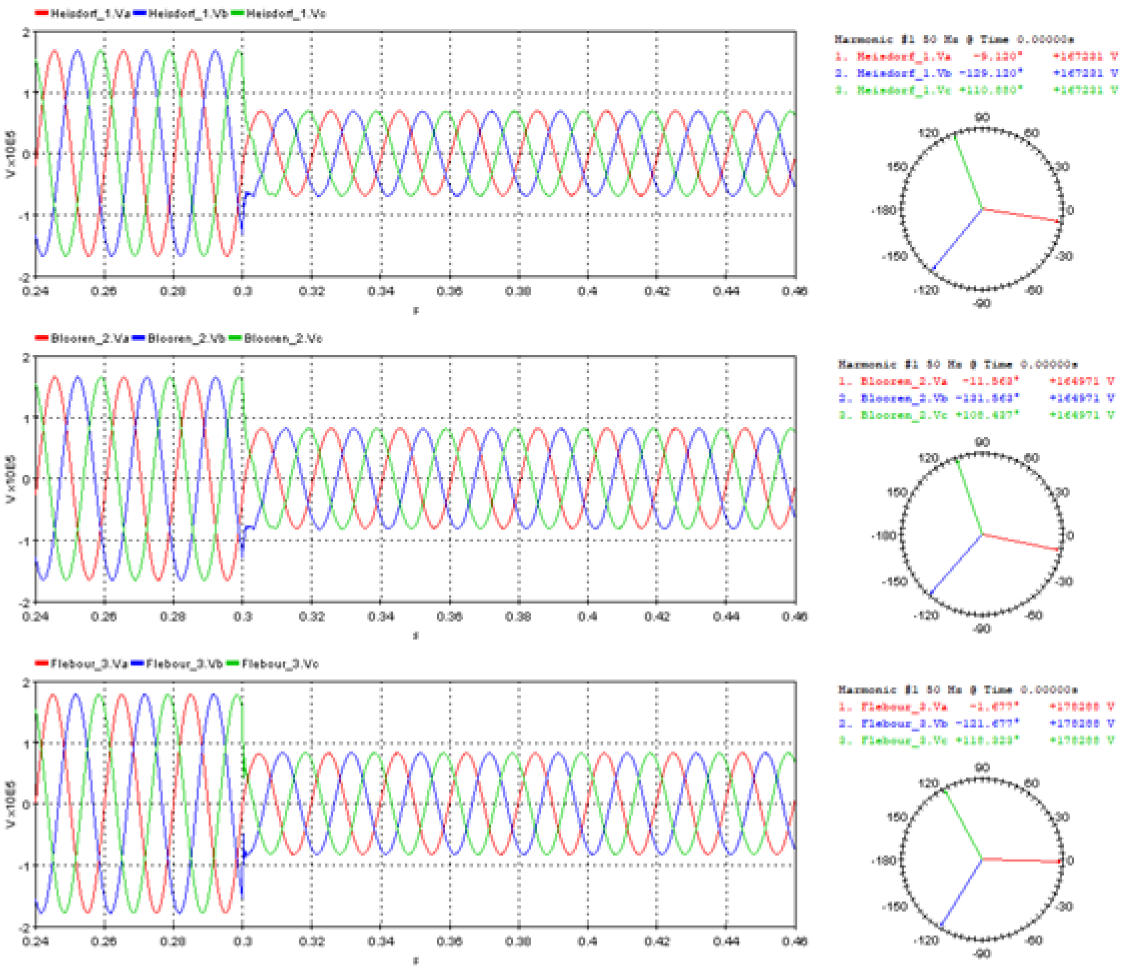

FIGURE 58: INTERCONNECTION BUSES VOLTAGE MEASUREMENTS

The integration of the PMUs in the LIST RT-HIL lab is complete and are used to transmit phasor measurements from the RT simulator to the PMU PDC and from there to the WAMSTER platform. The PMUs are connected with the OPAL simulator using analogue connections of ±10 V. The PMUs are virtually "installed" at high voltage buses of the Luxembourgish network, including the interconnection buses with Germany and Belgium. In the snapshot below, the geolocation of one of the six PMUs is shown as presented in the WAMSTER platform. For the same contingency described above, the PMUs were able to record and transmit their measurements in the WAMSTER servers as in Figure 59.

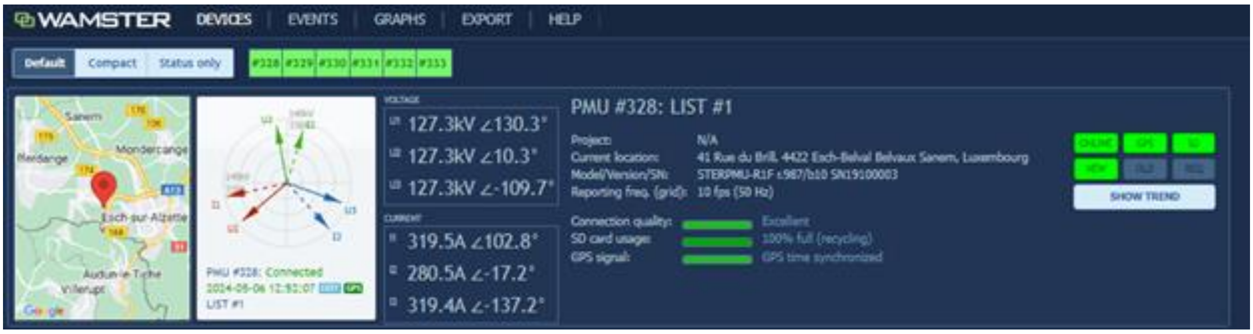

FIGURE 59: LIST PMUS AS SHOWN IN WAMSTER PLATFORM

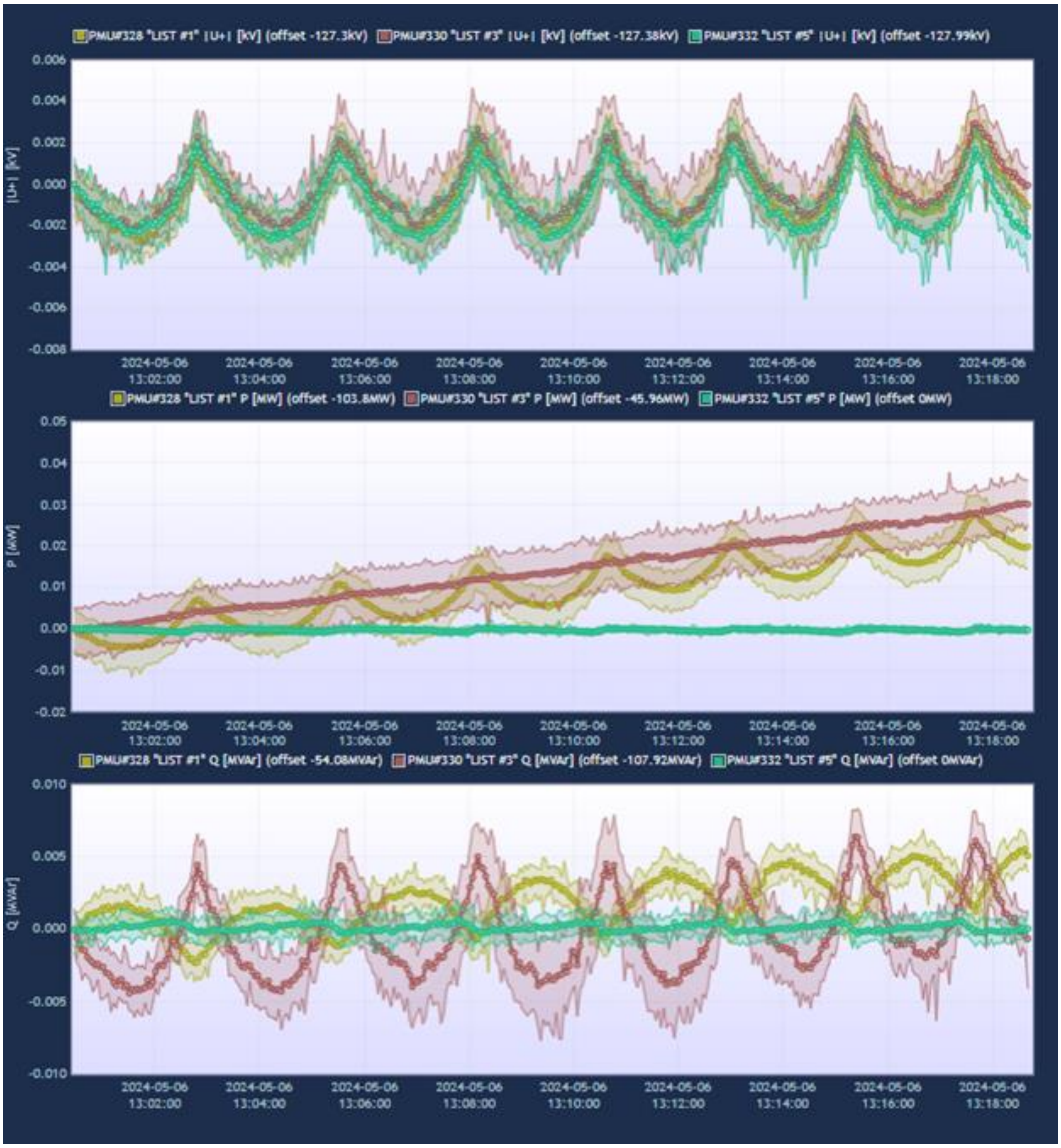

FIGURE 60: PMU READINGS OF RT-SIMULATIONS AT INTERCONNECTED BUSES

TABLE 18: DEMO 5 PROGRESS ON KPIS

ID	Name	Baseline Value	Pre-Demo Phase Value
Axis I. Demo's Implementation Progress & Outcomes			

ID	Name	Baseline Value	Pre-Demo Phase Value
10	Implementing a large-scale energy storage system in an agri photovoltaic (APV) farm based on hydrogen (1MW) and Li ion BESS (1MW/1MWh)	0	0.3
15	Flexibility and ancillary services provision from an agriculture PV farm (congestion management, contingency relief, voltage/frequency regulation, new grid-forming functions)	None	N/A
18	Deployment of a digital platform for managing energy and services	0	0.5
25	No. of single-use business models defined and validated	0	N/A
29	Efficient integration of storage technologies in demo sites	0	0
35	No of storage-centric grid supporting services proposed and validated through Demo 5	0	N/A
Axis II. Novel stand alone or Hybrid Energy Storage Systems (HESS)			
40	Energy density	0	N/A
41	Power density	0	N/A
42	Energy efficiency (energy losses)	0	N/A
43	Storage capacity	0	N/A
44	Discharge rate	0	N/A
45	Discharge time	0	N/A
46	Discharge losses	-	N/A
47	Lifetime	0	N/A
48	Technological Maturity (TRL)	5	N/A
54	Renewable integration	0	0

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8.5 LESSONS LEARNT AND NEXT STEPS

In the previous section an update of the KPIs was presented based on D4.1. It is important to comment on these updates. Firstly, most of the KPIs (especially in axis II) are declared as N/A because they are linked to the assets and the next phase of the demos. For KPI 10, the value 0.3 is attached to the progress of BESS development. For KPI 18, the 0.5 value indicates that there was significant progress with regard to the cloud development, but there is still work to be done mostly in the integration of the flexibility services and integration with the middleware, which has not been considered thus far. Finally, the 0 value for KPI 29 is justified because the BESS has not yet been delivered to the demo site for the integration.

As it has been documented in other Deliverables the Luxembourgish pilot is facing certain challenges. The Luxembourgish pilot was originally designed to include innovative infrastructure and equipment, including a large photovoltaic (PV) plant, a lithium-ion battery, an electrolyser, a small wind turbine, and other assets. These components were intended to demonstrate the integration of various renewable energy sources and storage technologies in a comprehensive energy solution.

The funding for some critical components of the Luxembourg pilot, such as the electrolyser and wind turbine, was supposed to come from a national project funded by the Luxembourgish government. However, following the Ukrainian war and the ensuing energy crisis, the Luxembourgish government revised its strategy and ultimately did not fund this project. As a result, the project was left without these key components, significantly impacting the pilot's planned activities and scope. The consortium is currently assessing different options the most favourable of all being to move the pilot to a different site. Actions towards this solution are already being examined and potential candidates have been identified. This will have an impact on the demo activities, but not a significant one. As it was already presented all activities concerning the software development are progressing well and will be applicable in any demonstration site with no or minor modifications.

9 CONCLUSIONS

This document is the first part of three consecutive and evolutive rounds of deliverables that aim at capturing the demos' implementation progress during the pre-demo, full demo and large-scale demo operation phases. As such, it covers demo developments carried out in the context of Tasks 4.2 to 4.7 during the pre-demo phase, with an emphasis on the timeframe between months 14 to 17.

The activities documented in this deliverable involve procurement procedures, technical specification, development and implementation tasks as well as extensive scenario development, algorithmic design, modelling, simulation and preliminary testing efforts that have allowed for a set of initial yet promising assumptions to be reached and have laid the foundations for the work to be conducted during the full demo operation phase. Such assumptions indicatively include the replicability potential of the LL case study, positive trends in the capability of the developed models to predict system behaviour and thereby optimise its performance in the case of demo 1, encouraging outcomes regarding the performance of electrolyte composites and the developed water inflow forecasting and optimisation models in the case of demo 2, profitability opportunities generated by the services of demo 3, highly transformative prospects in the case of demo 4, as well as the potential of Agri-PV renewable energy (PV, wind) production to cover the electrolyser power needs in the case of demo 5.

Planned activities for the upcoming months entail for several demos the continuation and/or completion of infrastructure development tasks, integration work, as well as further model refinement and testing efforts. In particular, next steps for the Living Lab include the replication of the case study built and thereby the development of additional what-if scenarios in cooperation with the rest of the demo partners.

For Demo 1 already planned activities involve the evaluation of the system's response to increased power input (full electric boosting ramp up), the consequent refinement and validation of the developed furnace models and flexibility service based on additional data, as well as the continuation of data and component integration efforts.

The action plan of Demo 2 foresees more experiments on the influence of additives on the electrochemical response of vanadium electrolytes, finalisation of the assembly of the VRFB power electronics, as well as further refinement of the demo's water inflow forecasting model and optimisation algorithm, to be followed by their integration and the application (later) of the whole solution to the Madeira Island power system. Different choices around the dispatch of the data to the system operator are also planned to be explored and implemented.

Then, Demo 3 prioritises for the upcoming period the elucidation of any pending unclear aspects, impacted by the VRFB supplier withdrawal, and in this regard, further work in the directions of optimisation algorithms refinement, component integration, permitting and installation.

For Demo 4 accordingly the devised work plan entails deploying the involved HESS within the lab environment and proceeding with intense testing to validate its compatibility with the demo's Ultra-Fast Charging Station, but also finalising the design of the optimal control strategies for the demo's microgrid and conducting tests and measurements on the UFCS architecture. Final decisions around the demo installation site and the V2G charger supplier will be reached.

Last but not least, upcoming work for Demo 5 involves progressing with the development of the BESS, and accordingly with the integration of the components involved at the demo site, as well as with the development of the demo cloud platform, basically in terms of the flexibility services and middleware integration. The pilot will prioritize the resolution of the issue that appeared concerning the lack of electrolyzer and the wind turbine. Solutions are currently being examined a soon a decision will be reached.

10 APPENDICES

10.1 APPENDIX I. DEMO 3: PRELIMINARY IMPLEMENTATION OF THE CONTROL SYSTEM

In this section, the latest version of the control systems and communication is shown. This control system is currently being implemented, and therefore substantial changes are expected.

As a first step, the control is being implemented as a system completely independent of the i-STENTORE platform. However, the modularity of the design is such that, as the i-STENTORE platform becomes available and services are implemented, the demo can progressively off-load certain tasks and services to the platform by replacing the local services with the i-STENTORE provided ones. This stand-alone mode is also very useful to test the platform operation and to troubleshoot any problem, especially in these early stages of design.

10.1.1 Optimisation of market participation

The control system is structured as a set of tasks (Table 19 to Table 26Table 26) that are being executed by each of the controllers. Tasks can be executed either as a result of a time schedule or can be triggered by other tasks. The control design tries to be as modular as possible, minimising the coupling between tasks.

Tasks executed in the cloud will usually get the data they need and save their results to the databases and trigger other tasks if needed. All tasks will log their execution to the database.

TABLE 19: TASK FOR CREATING ESS POWER SCHEDULES FOR THE NEXT DAY

Task: Create next day ESS power schedules	
Trigger	Time, everyday at 12:00h
Controller	Cloud
Description	Entry point for the execution of the tasks leading to ESS power schedules.
Required	None
Actions	Trigger *Retrieve forecasts for next day* to start the process

TABLE 20: TASK FOR RETRIEVING NEXT DAY FORECASTS

Task: Retrieve forecasts for next day	
Trigger	On demand
Controller	Cloud

Description	Retrieve the day-ahead forecasts for electricity price, PV and Wind power plants from forecast services and store them to the database.
Required	None
Actions	Success: - Post forecasts to database. - Trigger DAM optimisation. Failure: - Schedule itself to retry, until DAM is closed. - After market is closed, post failure to database.

TABLE 21: TASK FOR OPTIMISING DAY AHEAD MARKET PARTICIPATION

Task: Optimise day ahead market participation	
Trigger	After success of *Retrieve forecasts for next day*
Controller	Cloud
Description	Compute the optimal day ahead market participation for the VPP as described in the corresponding section.
Required	RES & price Forecasts Current day program to forecast next day initial SOC
Actions	Success: - Post bids to database. - Send bids to market. Failure: - Schedule itself to retry, until DAM is closed. - After market is closed, post failure to database.

TABLE 22: TASK FOR RETRIEVING MARKET RESULTS

Task: Retrieve market results	
Trigger	Time, every day at 14:00h
Controller	Cloud
Description	Retrieve the market results for the following day and store them to the database.
Required	None
Actions	Success: - Post market result to database. - Notify ESS schedule availability via MQTT topic. Failure: - Schedule itself to retry, until end of day. - After end of day, post failure to database.

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TABLE 23: TASK FOR OPTIMISING MFFR PARTICIPATION FOR THE NEXT DAY

Task: Optimise mFFR participation for next day	
Trigger	Time, every day at 22:00h
Controller	Cloud
Description	Optimise the mFFR market participation for the following day.
Required	ESS schedule for next day ESS schedule for current day to forecast initial SOC for next day
Actions	Success: - Post next day mFFR availability to database. - Send availability to mFFR market. Failure: - Schedule itself to retry, until market is closed. - After market is closed, post failure to database.

TABLE 24: TASK FOR UPDATING MFFR PARTICIPATION

Task: Update mFFR participation	
Trigger	Time, 30 min before each quarter-hourly period. Whenever there is an activation of mFFR service.
Controller	Cloud
Description	Check ESS status and update the mFFR market availability if needed.
Required	Current mFFR availability for the remaining of the day Current ESS SOC and schedule.
Actions	Success: - Post next day mFFR updated availability to database. - Send updated availability to mFFR market. Failure: - Schedule itself to retry until mFFR update deadline is reached. - After update deadline is reached, post failure to database.

10.1.2 Real Time Operation

The Real-time controller is in charge of executing the ESS power schedule and monitoring the assets operation.

TABLE 25: TASK FOR MONITORING ESS SCHEDULES AND RENEWABLES

Task: Monitor ESS schedules & Renewables	
Trigger	Time, each 30 seconds.
Controller	Real-time controller

Description	This task checks the status of the assets, gathers measurements, and issues alerts in case of malfunction, unavailability, or any significant divergence from the schedule that is happening or will likely happen. It also keeps track of the ESS energy exchanges and adjusts the power setpoints to compensate for any unexpected event, to ensure that the market commitments and any other ESS schedules are fulfilled at the end of each period.
Required	Current ESS schedules
Actions	- Get measurements from assets via Modbus. - Post measurements to MQTT topic. - Post any anomaly to MQTT topic. - Send updated power setpoints to ESS via Modbus.

TABLE 26: TASK FOR UPDATING ESS SCHEDULES

Task: Update ESS schedules	
Trigger	On demand, via MQTT topic
Controller	Real-time controller
Description	This task reads the updated ESS schedules for the rest of the current day and for the next day if available. A copy of the schedule is stored locally. The ESS schedules include the market results, the mFFR activations, and manual overrides. The local copy will be the source used to generate the final setpoints. The task also checks for failures posted to the database and brings the ESS to a safe state if needed.
Required	None
Actions	- Update local copy of ESS schedules

10.1.3 Future Database tables & columns

The Future Database (Table 27 to Table 29) holds the results of the day ahead optimisation. Some of these results will later be transferred to the Real-time Database for the execution of the schedules. Some of these results will later be transferred to the Past Database for logging purposes.

TABLE 27: HOURLY VALUES FOR FUTURE DATABASE: VARIABLES, FORMAT AND DESCRIPTION

Future Database hourly values		
DateTime	ISO datetime	Time and date of the start of the hourly period.
Forecast_PV_Dayahead	float	Forecasted value for time DateTime, retrieved the previous day

Future Database hourly values		
Forecast_Wind_Dayahead	float	Forecasted value for time DateTime, retrieved the previous day
Forecast_Hydro_Dayahead	float	Forecasted value for time DateTime, retrieved the previous day
Forecast_Price_Dayahead	float	Forecasted value for time DateTime, retrieved the previous day
Opt_LIB_P_Dayahead	float	Optimal power for time DateTime, as computed by the DAM optimisation
Opt_VRFB_P_Dayahead	float	Optimal power for time DateTime, as computed by the DAM optimisation
Opt_VPP_P_Dayahead	float	Optimal power for time DateTime, as computed by the DAM optimisation
Mkt_VPP_Dayahead	float	Power for time DateTime, as a result of DAM participation
Mkt_Price_Dayahead	float	Energy price for time DateTime as a result of the DAM
Schedule_LIB_P_Dayahead	float	Scheduled power for time DateTime to fulfil market results, assuming the forecasted values are true
Schedule_VRFB_P_Dayahead	float	Scheduled power for time DateTime to fulfil market results, assuming the forecasted values are true

TABLE 28: QUARTER-HOURLY VALUES FOR FUTURE DATABASE: VARIABLES, FORMAT AND DESCRIPTION

Future Database quarter-hourly values		
DateTime	ISO datetime	Time and date of the start of the quarter-hourly period.
mFFR_availability	float	Available power for the mFFR service in the DateTime period.

TABLE 29: DAILY VALUES FOR FUTURE DATABASE: VARIABLES, FORMAT AND DESCRIPTION

Future Database daily values		
DateTime	ISO datetime	Time and date of the start of the hourly period. Time is 00:00h since the period is the day.

Future Database daily values		
SOC0_LIB	float	Expected SOC at the start of the DateTime period.
SOC0_VRFB	float	Expected SOC at the start of the DateTime period.
DAM_Failure	bool	Indicates a failure in the DAM optimisation and bidding process leading to no participation for the next day
mFFR_Failure	bool	Indicates a failure in the mFFR optimisation process leading to no participation for the next day

10.1.4 Real-time Database tables & columns

The Real-time Database (Table 30 to Table 32) holds the values needed for the real-time operation during the current day, as well as the measurements performed every 30 seconds. Some of these results will later be transferred to the Past Database for logging purposes.

TABLE 30: REAL-TIME DATABASE HOURLY VALUES: VARIABLES, FORMAT AND DESCRIPTION

Real-time Database hourly values		
DateTime	ISO datetime	Time and date of the start of the hourly period.
Mkt_VPP_Dayahead	float	Power for time DateTime, as a result of DAM participation
Mkt_Price_Dayahead	float	Energy price for time DateTime as a result of the DAM
Schedule_LIB_P_Dayahead	float	Scheduled power for time DateTime to fulfil market results, assuming the forecasted values are true
Schedule_VRFB_P_Dayahead	float	Scheduled power for time DateTime to fulfil market results, assuming the forecasted values are true

TABLE 31: REAL-TIME DATABASE QUARTER-HOURLY VALUES: VARIABLES, FORMAT AND DESCRIPTION

Real-time Database quarter-hourly values		
DateTime	ISO datetime	Time and date of the start of the quarter-hourly period.

Real-time Database quarter-hourly values		
mFFR_availability	float	Updated available power for the mFFR service in the DateTime period.
mFFR_activation_request	float	Power requested by the system operator for DateTime period
mFFR_activation_executed	float	mFFR power executed for the DateTime period
Correction_LIB_P_manual	float	Additional power that will be added to the other schedules (DAM & mFFR) as a manual correction.
Correction_VRFB_P_manual	float	Additional power that will be added to the other schedules (DAM & mFFR) as a manual correction.
Override_LIB_P_manual	float	Manual power setpoint that will override all schedules. This will be the final applied power setpoint.
Override_VRFB_P_manual	float	Manual power setpoint that will override all schedules. This will be the final applied power setpoint.

TABLE 32: REAL-TIME DATABASE 30-SECOND VALUES: VARIABLES, FORMAT AND DESCRIPTION

Real-time Database 30-second values		
DateTime	ISO datetime	Time and date of the start of the 30-second period.
P_LIB	float	Measured power for the DateTime period.
P_VRFB	float	Measured power for the DateTime period.
P_PV	float	Measured power for the DateTime period.
P_Wind	float	Measured power for the DateTime period.
P_Hydro	float	Measured power for the DateTime period.
P_VPP	float	Measured power for the DateTime period.
SOC_LIB	float	SOC reported by the BMS for the DateTime period.
SOC_VRFB	Float	SOC reported by the BMS for the DateTime period.
Online_LIB	Bool	The asset is reachable during the DateTime period.
Online_ VRFB	bool	The asset is reachable during the DateTime period.
Online_PV	bool	The asset is reachable during the DateTime period.

Real-time Database 30-second values		
Online_Wind	bool	The asset is reachable during the DateTime period.
Online_Hydro	bool	The asset is reachable during the DateTime period.

10.1.5 Past Database tables & columns

The Past Database (Table 33) will hold a log of all the activity of the system.

An hourly-value table, a quarter-hourly-value table and a 30-second-value table will store all the values from the Future and Real-time Databases. The columns will not be repeated here, as they will be the same.

A daily task will transfer the data from the Future and Real-time Databases to the Past Database and remove the transferred data from the source.

An additional table will be created to log all activity for debugging and analysis purposes.

TABLE 33: EXECUTION LOG FOR PAST DATABASE

Past Database execution log		
DateTime	ISO datetime	Timestamp of the logging
log_data	JSON string	JSON string containing the source of the data (task name, MQTT topic, etc..) and the activity or data being logged.

10.1.6 MQTT Topics

The following MQTT topics are required:

i-stentore/demo3/measurements

This channel will stream the measurements in real-time. Current format for the message is: {name : value , name : value , name : value, …. } where "name" is a string containing the name of the measurement as specified in the database definition, and the value is of the type specified in the database definition.

i-stentore/demo3/alerts

This channel will be used to send alerts regarding any malfunction. Current format for the message is {"type": string, "details": string}. Current alert types are "asset-unreachable", "SOC-unsuitable", "setpoint-not-applied", where the "details" string contains info about which asset is involved.

i-stentore/demo3/commands

This channel will be used to issue commands to the Real-time controller. Format is {"command": string, "payload": json string}. Only one command is currently available: "update-schedules" that requires no payload.

10.1.7 API Specification

The API specification is still under definition. After the i-STENTORE API is defined, a final specification will be created.

For the time being, a simple API will be setup as an interface to the database:

- A POST request with a JSON payload of column/time/value to post data.
- A GET request to query the database, specifying the requested columns and a time range.

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