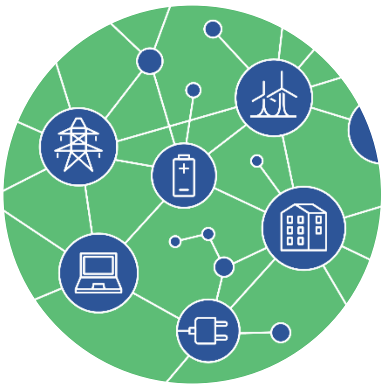
OSMOSE

OPTIMAL SYSTEM-MIX OF FLEXIBILITY
SOLUTIONS FOR EUROPEAN ELECTRICITY

Master control strategies

D4.4



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Executive summary

This deliverable “D4.4: Master control strategies” compiles the developed control strategies for coordinating the different flexibility devices at power system level, accounting for the features of each device (size, performance requirements, operation strategies and controls at system level), as well as the most significant simulation results.

In the context of the OSMOSE WP4 demonstrator of a multi-component flexibility solution (MCFS), the optimal operation of the different flexibility (e.g. storage and FACTS) devices is coordinated by a specific master control system (MC). The MC aims to pursuit twofold objectives at the best performance of each device: the grid reliability and the performance of each specific technology. At the same time, the functionalities and services for the power system that the MC is developed for are identified in D4.1.

First of all, after undergoing a change of the first location of the demonstrator, the Atenea microgrid facilities in Sangüesa became the final site. Therefore, the flexibility solution composition has evolved and finally it is composed by the storage systems in Atenea facilities and a unique hybrid system, consisting of Li-Ion batteries, ultracapacitors and a STATCOM. In the field, these devices will be managed by the MC, which is designed to operate different control strategies and to effectively coordinate the operation of the devices.

In detail, we report the functional description of the MC, the main modules and components and therefore all architecture implemented for the correct real operation based on a MCFS capabilities and communication restrictions.

Additionally, the types of functionalities and services for the grid system that the MC strategies handle that are implemented in the MC are presented. A specific attention is focused on optimization objectives and restrictions that take part at each operating mode. For example, how to be operated so as to provide multiple system services, such as frequency and voltage control and net transfer capacity increase for RES integration, and overall providing flexibility services for the grid. To better understand, a summary of the characteristics of functionalities is collected.

Furthermore, specific operation scenarios are analyzed at the three different levels of MC developed and attending to dispatchability of the control setpoints at device level. The implemented smart algorithms in the MC manage in an efficient way the storage devices so as to accomplish the objective of control strategies. Through simulations are validated the case studies in each scenario with single or multiple functionalities. The results are evaluated showing good accordance with the expected behavior and thanks to the reliability that the developed strategies presented. Accordingly, numerous clarifications are provided to thoroughly understand the procedure to perform the development of the next real test and ultimately to evaluate the effectiveness of the control strategies.

Finally, this deliverable also presents a short user manual that is very understandable from the technical point of view of the flexible SCADA configuration. The developed front end allows operating the plant from the MC that virtually communicates with the REE dispatch centre. This specific SCADA is improved for signal visualization corresponding to the different flexibility devices in real time for control operation.

1 List of acronyms and abbreviations

In the following table are listed the acronyms and abbreviations used in this document.

Acronym	Meaning
BESS	Battery Energy Storage System
BMS	Battery Management System
CA	Consortium Agreement
D	Deliverable
DC	Direct Current
EMS	Energy Management System
ESS	Energy Storage System
FACT	Flexible AC Transmission Systems
HFD	Hybrid Flexibility Device
HMI	Human Machine Interface
HW	Hardware
MC	Master Control
MCFS	Multi-Component Flexibility Solution
P	Active Power
PCC	Point of Common Connexion
PLC	Programmable Logic Controller
PMG	Program management
PFR	Power Frequency Regulation
Q	Reactive Power
RES	Renewable Energy System
SAT	Service Acceptance Tests
SFD	Single Flexibility Device
SC	Supercapacitor
SCADA	Supervisory Control And Data Acquisition
SOC	State Of Charge
SPT	Setpoint Tracking
SSR	Safety SOC Range
SW	Software
TSO	Transmission System Operator
WP	Work Package

2 Introduction

OSMOSE project develops an approach to capture the synergies across different needs and sources of flexibilities, where flexibility is understood as a “power system’s ability to cope with variability and uncertainty in demand, generation and grid, over different timescales. The project aims for the development of flexibilities that can be used for a better integration of renewable energies. A holistic approach is adopted, considering at the same time:

1. The increased need of flexibilities in the system (mainly improved balance of supply and demand in electricity markets, provision of existing and future system services and allowance of a dynamic control of electricity flows).
2. And the sources of flexibilities (RES, demand-response, grid and new storages).” [1]

OSMOSE project addresses all system requirements to capture the synergies proposed by the different solutions in order to avoid stand-alone solutions that might be less efficient in terms of overall efficiency.

In WP4, the Spanish demonstration (see Figure 1) led by REE, which is the Spanish Transmission System Operator (TSO), addresses different flexibility solutions and services by the MFCS[1] that integrates a new hybrid and modular storage solution with the capability to offer multiple system services.

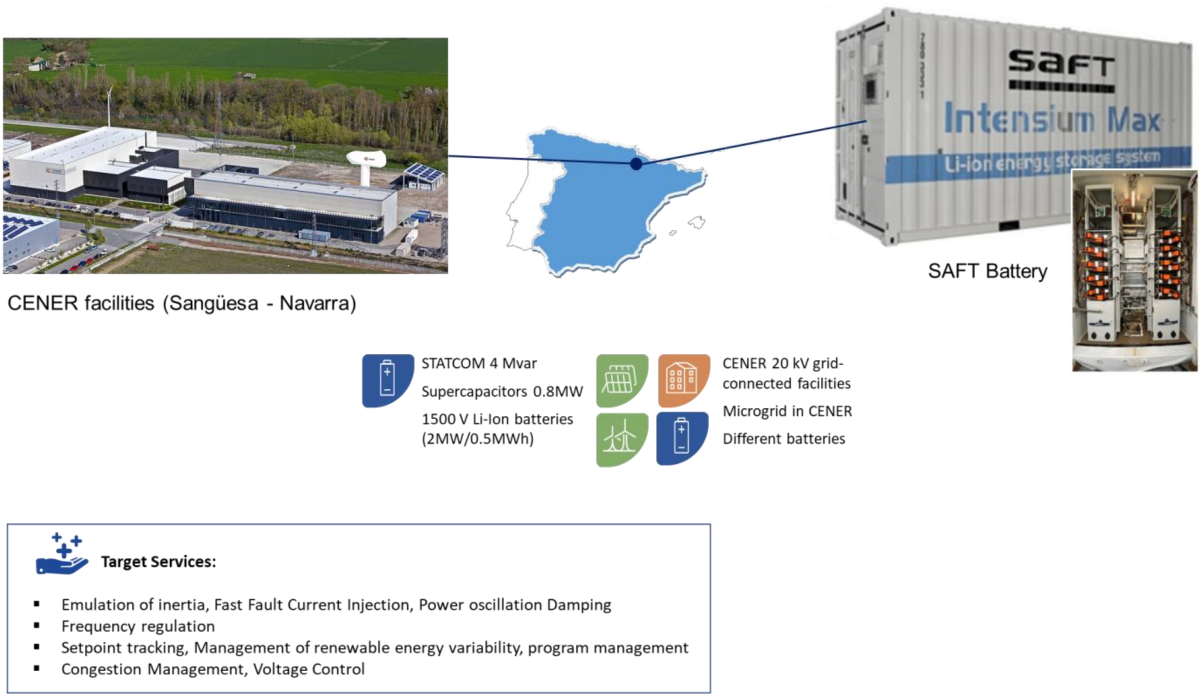

Figure 1: Spanish demo overview developed in WP4. [1]

This document compiles the task 4.4 that covers the design and development of a high-level control that allows implementing different management strategies for the flexibility devices that integrate the MCFS, and that will facilitate the integration of large amounts of renewable

[1] MCFS: portfolio of flexibility solutions at power system level available for the TSO to optimize system operation (consisting of SFDs and/or HFDs with a variety of technologies).

energy through an efficient use of the available resources, taking into consideration the characteristics of each device (power, energy, controls, etc.).

2.1 Spanish demonstration description

A brief description of the Spanish demonstration is presented due to the change of the first planned location in the Canary Islands to CENER facilities in Sangüesa (see Figure 1), which became the final site. Consequently, the flexibility solution composition had evolved in terms of power and energy dimensions to be adapted to the power electric facilities of the new location, as it is described in the "WP4-Proposal of updated project plan" presented and approved by the European Commission. Also, for better understanding the terms to refer to those storage systems are defined in this section.

The point of connection with the distribution grid is done in the 66kV substation point where the substation transformer is placed. Downstreams, at 20kV, there are CENER facilities where the WP4 demonstrator and Atenea microgrid are located. From this point, there are two parallel transformers: one for the Hybrid Flexible Device (HFD[2]) connection and the other for Atenea facilities that conform the single flexible device (SFD[3]).

In Figure 2 a layout of the planned demonstrator in CENER facilities is presented, where Atenea microgrid is located nearby WP4 demonstrator and the connection is indicated.

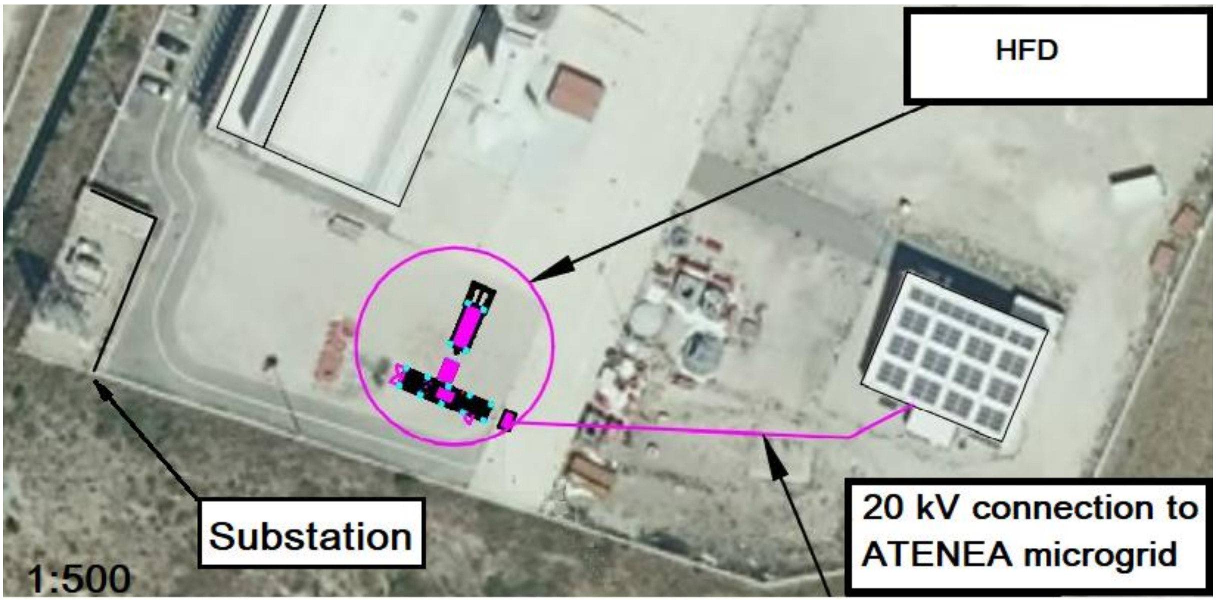

Figure 2: Layout of planned demonstrator in CENER facilities

The components deployed for the demonstrator, without including all necessary wirings and protection systems, are listed for a better understanding:

- A 4 MVAr HFD with:
  - FACTS characteristics based on 12 MMC with 2 Supercapacitors (SC) providing up to 800 kW;

[2] HFD: set of SFDs that share a common connection point through a common power converter.
[3] SFD: equipment capable of providing flexibility solutions at power system level.

- A containerized Li-ion battery with EMS and BMS (HFD-bat) characterized by a rated power of 2 MW and an energy storage capacity of 0,5 MWh.
- DC/DC MP-WD power converter for the integration of the ESS.

- Atenea microgrid components:
  - 25 kWp photovoltaic (PV) installation.
  - Lead acid gel technology battery bank (Pb-bat Atenea), able to supply 50 kW uninterruptedly for 2 hours.
  - Stationary Lithium-ion battery (Li-Bat Atenea) with 43 kWh and 30 kW nominal power in charge/discharge.
  - Vanadium Flow Battery (Redox-Bat Atenea) with capacity to provide 50 kW for approximately 4 hours, with two electrolyte tanks and it is provided by its own bidirectional converter.
- Two transformers for connection to an AC grid of 20 kV through a 0.690/20 kV.
- Ancillary services cabinet.

Therefore, the devices that configure the MCFS are the HFD and the three ESS of Atenea microgrid, which are equipment capable of providing flexibility solutions at power system level operating as SFD.

3 Master control concept

3.1 Objective

The objective in the context of task 4.4 is to develop a modular MC of different storage devices, coordinating different services and optimizing the ageing of the devices. Therefore, the MC objective is to implement a mechanism to provide the system with a series of flexibility services. These flexibility services are functionalities that have been identified as relevant in order to maximize the integration of RES in safe conditions and to optimize the total costs of the system [2].

For that reason, the system developed is able to implement different strategies, services or global operating modes and to provide to the operator the necessary configuration capacity to program a combined response from the managed devices according to the appropriate operating needs at any time.

3.2 Functional description of the master control

Specifically, the aim of the MC is to integrate different flexibility solutions, coordinate their operation and identify possible control strategies. The MC is intended to be a comprehensive storage management system and flexibility tools, independent of the underlying technology, and highly configurable. The MC is conceived as a central control system for the best way to coordinate different flexibility devices.

At a high level, and from the point of view of the end user, the MC allows to the end user to manage the energy storage capacity and power delivered to the grid, as well as a set of services to be provided on the basis of this capacity. Therefore, the system manager will be able, through the relevant configuration interfaces, to configure and activate the services of interest at any time.

In order to offer a functionality of these characteristics, the MC should at least:

- Know the characteristics, capabilities and limitations of the physical devices, both SFDs and HFDs it controls, to conveniently restrict the possibilities offered to the user.
- Communicate with these devices to enable their control and to know in real time their status.
- Know in real time certain information of the electrical grid where the devices are placed.

The intelligence of the system lies in distributing the services configured by the user among the most optimal technologies to provide them, between those that are available, for optimizing the performance of the devices and maximizing the flexibility capabilities provided to the user. This intelligence incorporates device management strategies based on the historical use (and consequent degradation) of the devices, preserving their useful life in case of overuse or intensifying their use otherwise (by requirement). Thus, the intelligent system is able to differentiate and to analyze the type of storage installed and then is capable of determining the functionalities that it could fulfill and optimal levels of security in which it will be working.

In order to implement these intelligent management mechanisms, the MC is able to:

- Distribute the power and energy to be delivered/absorbed among the different energy storage equipment available, according to technical considerations regarding the degradation and lifetime of this equipment. This need arises during the activation of possible functionalities, in order to manage their fulfilment in an optimal way taking into account the constraints of the storage equipment. While certain storage systems allow wide operating ranges in parameters such as power or SOC, operating equipment at the extremes of these ranges on a frequent basis can lead to accelerated degradation of the equipment. Thus, knowing the impact of the equipment operation mode on its lifetime during the covered functionalities to be delivered, the objective of this task is to reach a compromise between the stress caused to the different storage systems and the services to be provided.
- Manage the SOC of the storage equipment over time, so as to maximize the availability of power and energy to be delivered/absorbed in order to respond to the functionalities required. This need arises with the objective that the MCFS is prepared to cover the maximum possible amount of power and energy before the potential activation of functionalities. The requirements of the functionalities proposed are diverse, attending to the Canary Islands grid power problems, and some of them are conflicting, such as the need to be able to absorb energy in "Congestion management" versus the requirement to deliver energy in many other functionalities. Therefore, given the possibility of activation of different functionalities, the MCFS should in principle be kept in an optimal SOC, so that it can respond to positive or negative power demands. Preferably, the system should also consider the probability

of activation of each of them to calculate the optimal SOC point waiting for possible events.

In order to validate the optimal operation of the control, prior to its commissioning, it is required that its functionality can be verified through its connection to models representing the different SFDs/HFDs available. However, the availability of models of these devices developed attending to real parameter values and to an accurate power grid model is difficult. Thus, the control is previously validated based on standard approximate models of CENER's microgrid and the MC will be finally evaluated in field.

3.3 Master control architecture

3.3.1 Master control modules and components

From the point of view of the administration of the MC as a HW-SW tool (HMI), it should have a series of standard modules associated with the usual flexibility technologies (SFDs: in the case of OSMOSE: Atenea microgrid storage, batteries, ultracapacitors and STATCOM), each of which, through the configuration of a series of associated parameters, common between SFDs of the same technology, can be easily linked to existing physical devices.

The HMI must be easily configurable and suitable for additional assets to be added and to run the systems automatically. The final MC/HMI will also allow combining these modules among themselves, although this type of flexible and "customized" configurations will possibly require additional developments, since the HFD will have its own control that will be far from being standard.

The HMI consists of Touch Panel, based on industrial PC, and SW platform that comprises a control module, energy management optimization, SCADA and communication and database (ICTs) focusing on interoperability.

In order to cover the described functionality, the MC is composed of the following functional parts:

- Plant Control Module
- Energy Management /Optimization Module
- SCADA-EMS System
- Communications Modules
    - Modbus TCP/IP
    - IEC 104
- Data Storage, Alarm And Error Management Module
    - Data history
    - Event log
- Access and operating modes:
    - Users and access levels
        - Operator level
        - Administrator level
    - Manual and automatic mode

3.3.2 Methodology approach for MC development

The approach followed to develop the MC as a HMI is schematically described in the Figure 3.

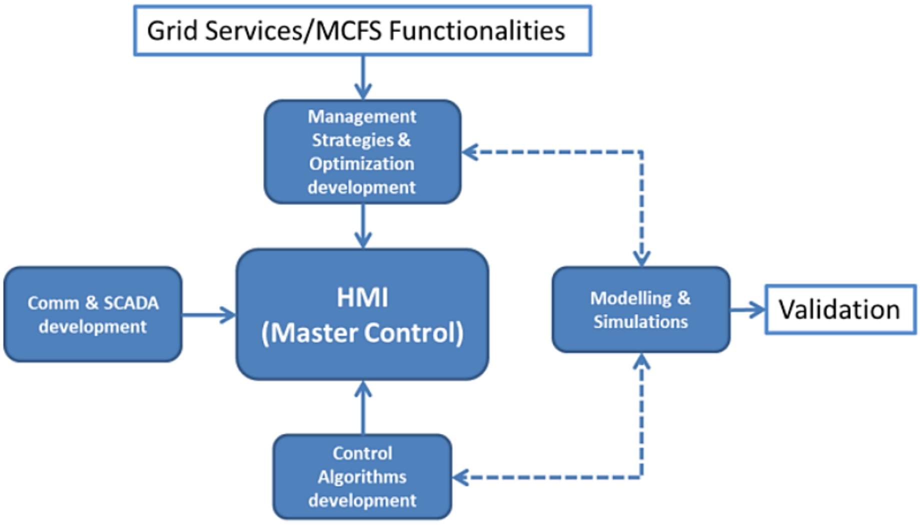

Figure 3 MC/HMI approach

The required flexible functionalities of the system, the management strategy to operate in a coordinate way the flexibility solution are developed following the schematic approach based on simulations.

Besides, an important development of signal coordination is required to be able to connect all different devices of the demo and share the setpoints to run in real time according to prerequisites of the TSO. Thus a dedicated SCADA is developed to fulfil the communication requirements.

3.3.3 MC overall scheme

The purpose of the control module is to establish the operation of the MC for the calculation of the setpoint power, both active and reactive of a global set of storage systems, to correct the power measured at PCC, responding correctly to the power requirements at PCC.

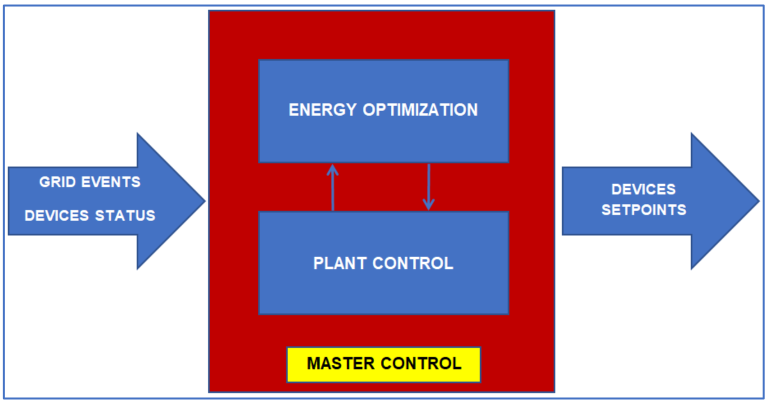

Figure 4: Overall scheme of the MC and its component modules

The objective of using the MC is to establish the setpoints to the MCFS equipment, depending on the grid events and devices status in real time. The plant control module is responsible for the plant operation according to the setpoints at each service in a flexible way. Therefore, the energy management/optimisation module is able to optimise the energy management strategy according to the plant setpoints and taking into account technical criteria based on a conservatory state of health objective. So that the plant responds taking into account both the test plans foreseen in the project and the emulation of grid events or of the services to be provided.

3.3.4 MC flowchart

The operation of the MC during real time-control is presented in the following Figure 5. It shows the flowchart of information handled by the MC to manage the different devices based on the selected functionalities, the grid measurements and the availability of the devices.

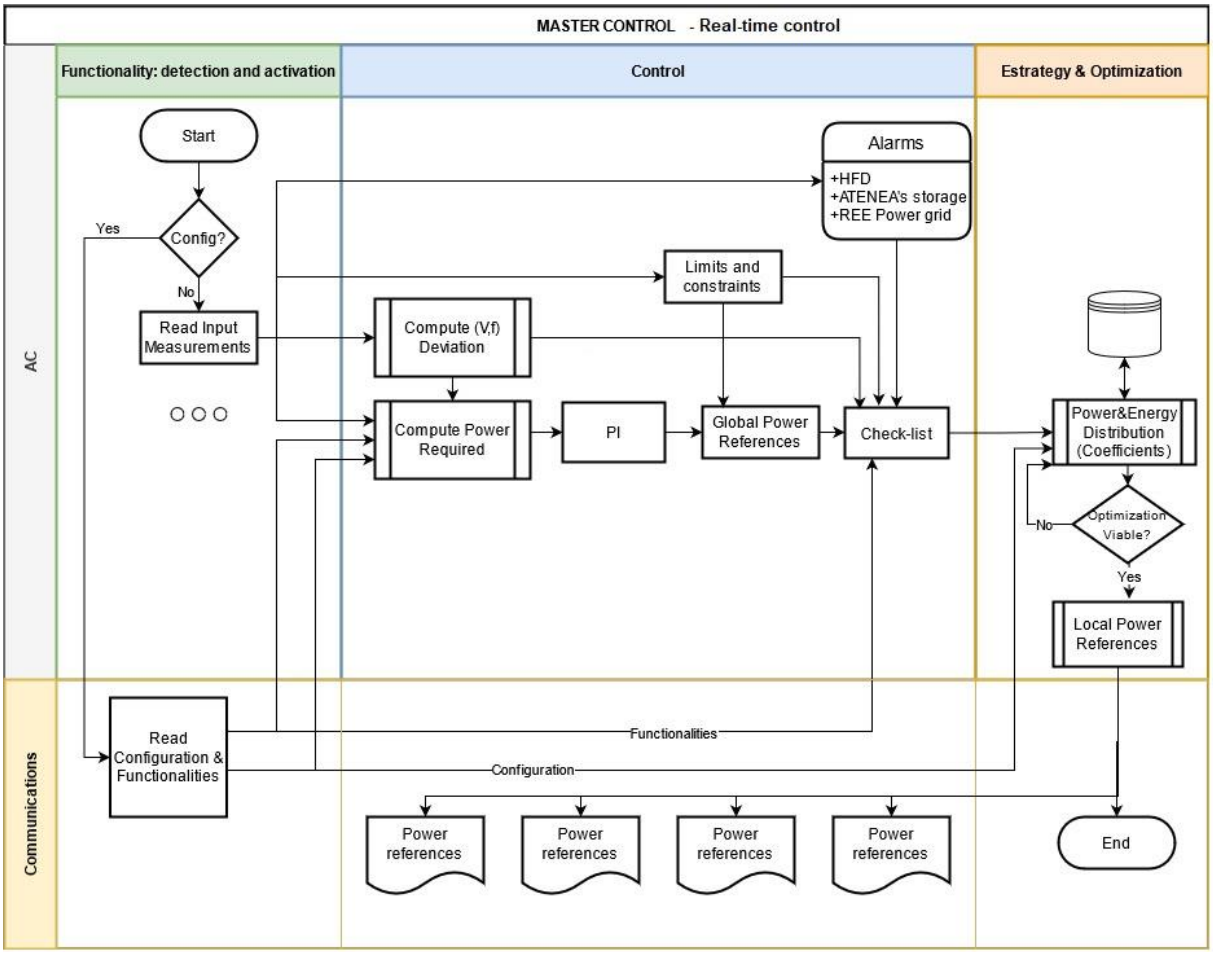

Figure 5: MC flowchart

The process starts with the update of configuration if necessary and then the detection and activation of the active functionalities and continues reading the measurements at PCC or the dedicated configuration in case there is a previous one defined.

Next, in the control level, the required power setpoint is calculated and regulated taking into account the overall performance limits and constrains. The output of this level is a checklist with the total power setpoint and devices to be dispatched; the dispatching power depends on which functionalities are active and their associated devices participation and the status and alarms of the devices.

Afterwards, the checklist is managed on the strategy and optimization level, where the total power setpoint is dispatched between the different devices by assigning an individual setpoint to them.

The next cycle restarts with the status update from all devices and then MC recalculates the next setpoints at that time step.

Since input for the MC is virtually from REE through virtual communications the required data from the MC is read. This means that for each real test, a sequence of functional input data is read from a virtual interface (which emulates the communications) to have the information that the MC requires for testing the flexibility solution and that configures the response for active and reactive power in the power grid.

3.3.5 MC communications

For the purposes of the MC implementation and demonstration, the link should be used to provide the following data:

- Exchange data from the TSO in order to operate as a central MC on each other devices consequently;
- Exchange the information about the setpoint of BESS at the MC interface through the MC SCADA;
- Share other relevant real-time data as electrical measurements or information about security as warnings, alarms, and state of breakers or availability of BESS. This information is only applicable for the interoperability and observable area previously agreed between all local controls of the flexibility devices.

3.4 Types of functionalities

As introduced previously, following the guidelines in “D4.1 Comprehensive report on functionalities and services for the power system” [2] the functionalities to be developed in the MC and in the local controls of the devices can be classified by type. However, the classification of the functionalities has experienced some minor changes, Table 1, which updates the one in deliverable D4.1.

Type	Functionality
A	Inertia Emulation
A	Fast Fault Current Injection
A	POD - Power Oscillation Damping
A	PFR(trapezoidal response)
A	Extraordinary PFR
B	Continuous PFR
C	Setpoint Tracking
C	Program Management
D	Congestion Management
E	Voltage Control
E	Q setpoint Control

Table 1: Planned functionalities

The functionality continuous PFR covers the so-called "Management RES variability" functionality.

The control of the voltage can be addressed by two different functionalities: "Voltage Control" and "Q setpoint Control"

In order to configure the system to provide those services, two limits are determined, referred as Lp and Le. Those values make possible to reserve a dedicated power and capacity for type A and B functionalities from the total capacity of flexibility available.

Following table shows the limits and range of values that can be applied to the configurable parameters:

Variable	Description	Range of change
L_p	Limit that divides the capacity in terms of POWER of the HFD for its distribution among the different functionalities. Indicates the percentage of the nominal power intended for Type B functionality	[0, 100] % P_n
E_{ta}	Energy reserved for the provision of type A functionalities	This will be calculated automatically based on the configuration parameters of the type A
L_e	Limit that divides the capacity in terms of ENERGY of the storage capacity available for its distribution among the different functionalities. The capacity in terms of energy to be distributed will be that which results from subtracting $\boldsymbol{E_{NC}}$, the energy requirement of the type A functionalities ($\mathbf{E_{tA}}$), if these are enabled. The value is referred to as the % associated with the type B applications.	[0, 100] % (E_{NC}-E_{tA})

Table 2: Power and energy system parameters

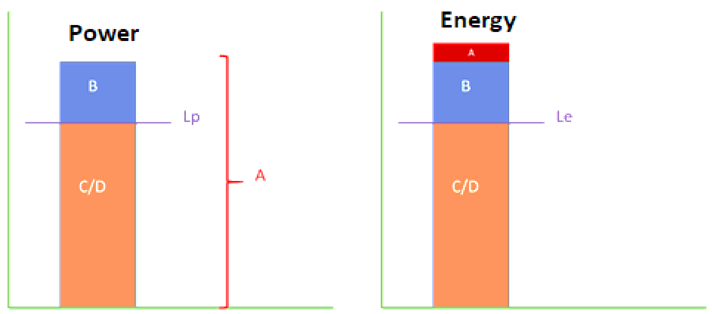

Figure 6: Power and energy distribution according to functionality

It is noteworthy that, in previous figure level Lp and Le look symmetrical just by chance. They are not compulsory to be and can be configured as wish. Besides, in the figure, it is not distinction between charging/discharging. Some examples are shown in sections 5.2 and 5.3.

Besides, the reserves of power and energy done through the parameters of Table 2, do not change during the operation and should be given according to the planned performance of the grid.

3.4.1 Classification of functionalities according to MC operations

Deliverable D4.1 "Functionalities and services for the power system" defines a set of functionalities that, for the purpose of specifying the MC operation, have been classified in first, second and third level. The MC operation makes a special attention to the aim of the controls, from the perspective of grid stability services, and establish three different levels based on that aspect. Therefore, the planned functionalities of Table 1 are classified in these three different levels:

- 1st level for MC operation contains type A functionalities
- 2nd level for MC operation contains type B and E functionalities
- 3rd level for MC operation contains type C and D functionalities

Table 3 below summarizes the objective of each level, if the MC operates each level and classifies the functionalities of Table 1 into execution and control levels.

	1st LEVEL	2nd LEVEL	3rd LEVEL
Objective of the controls at each level	To provide grid stability support services	To provide voltage and frequency control services once grid stability has been guaranteed	To optimize the management of the flexibility devices, taking into account the nature and characteristics of the devices it manages.
Operated by MC	No	Yes	Yes
Functionalities	Inertia emulation (A) Fast Fault Current Injection (A) POD (A) PFR(trapezoidal response) (A) Extraordinary PFR (A)	Continuous PFR (B) Voltage control (E) Q setpoint control (E)	Setpoint tracking (C) Program management (C) Congestion management (D)

Table 3: Classification of functionalities according to MC operation

3.4.2 Compatibility matrix between functionalities

Since the classification of functionalities has changed, the compatibility matrix of functionalities that are governed by the MC is shown in Table 4.

If two functionalities are marked as compatible (YES), they can be active simultaneously. If they are marked as incompatible (NO), they cannot be activated simultaneously.

	Continuous PFR	Voltage control	Q setpoint control	Setpoint tracking	Program management	Congestion management
Continuous PFR	-	YES	YES	YES	YES	YES
Voltage control		-	NO	YES	YES	YES
Q setpoint control			-	YES	YES	YES
Setpoint tracking				-	NO	NO
Program management					-	NO
Congestion management						-

Table 4: Compatibility matrix of functionalities

In general, if the voltage of the grid at PCC is within a certain adjusted range to 0.85 p.u. < V_{PCC} < 1.15 p.u., the system is considered to be in a permanent voltage regime and the functionalities associated with frequency control will have priority.

3.4.3 Device operation by functionality

Table 5 shows the functionalities, governed by the MC, associated with the devices according to the standard operating practices.

	Continuous PFR	Voltage control	Q setpoint control	Setpoint tracking	Program management	Congestion management
Statcom (HFD)	NO	YES	YES	NO	NO	NO
Battery (HFD)	YES	NO	NO	YES	YES	YES
Redox flow battery (Atenea facilities)	YES	NO	NO	NO	NO	NO
Lead battery (Atenea facilities)	NO	NO	NO	YES	YES	YES
Li-Ion battery(Atenea facilities)	NO	NO	NO	YES	YES	YES

Table 5: Functionalities according to standard operating practices

3.4.4 Summary of the characteristics of functionalities

Following Table 6 actualizes the one in D4.1 according to the changes in the functionalities operated by the MC.

	Continuous PFR	Voltage Control	Q setpoint Control	Setpoint tracking	Program Management	Congestion Management
No. of cycles/year	continuous	continuous	continuous	continuous	continuous	<10
Duration of the duty cycle	continuous	continuous	continuous	n.a.	n.a.	minutes
Initial energy content	SOC= 50%	n.a.	n.a.	n.a.	n.a.	SOC= 0%
End energy content	0%<SOC< 100%	n.a.	n.a.	n.a.	n.a.	SOC=100 %
Maximum value of active power output	100% Pn_n	n.a.	n.a.	100% Pn_n	100% Pn_n	0
Maximum value of active power input	100% Pn_n	n.a.	n.a.	100% Pn_n	100% Pn_n	100% Pn_n
Speed of changes in the active power values	Operation in continuous mode	n.a.	n.a.	Each minute	Every 10 minutes	Each minute
Speed of change between states of active power injection/absorption	Maximum possible ramp-rate	n.a.	n.a.	Maximum possible ramp-rate	Maximum possible ramp-rate	n.a.
Maximum partial energy output	ΔSOC=100%	n.a.	n.a.	ΔSOC=100%	ΔSOC=100%	n.a.
Maximum partial energy input	ΔSOC=100%	n.a.	n.a.	ΔSOC=100%	ΔSOC=100%	ΔSOC=100%
Maximum value of reactive power output	n.a.	100%	100%	n.a.	n.a.	n.a.
Maximum value of reactive power input	n.a.	100%	100%	n.a.	n.a.	n.a.
Speed of changes in the reactive power values	n.a.	Maximum reactive ramp-rate.	Maximum reactive ramp-rate.	n.a.	n.a.	n.a.
Speed of change between states of reactive power injection/absorption	n.a.	Maximum reactive ramp-rate	Maximum reactive ramp-rate	n.a.	n.a.	n.a.

Table 6: Characterization of the functionalities

4 Functionalities and services for the grid system

In the document D4.1 the functionalities that the flexible system integrates were defined. In this section, the related 2nd and 3th level functionalities are addressed from the point of view of the operation of the MC to coordinate the operations as well as the modifications experienced in those functionalities since D4.1 publication.

4.1 Master control operation

In the previous section has been presented the classification of the functionalities according the MC operation. All functionalities were divided into three levels and, depending on the settled level and priority, the MC will have flexibility to operate differently the devices that are involved in each one of the defined functionalities.

4.1.1 1st Level

The functionalities of 1st level are focused on providing power grid stability support services. The required response time is under seconds. Therefore, those functionalities are implemented in the primary control of the devices but not in the MC in order to achieve better performance with faster responses. However, it is possible to configure each one of the functionalities from the MC, without the obligation to accessing directly to the local control and/or management system of the devices.

4.1.2 2nd Level

The functionalities of 2nd level are focused on providing voltage and frequency control services once grid stability has been guaranteed. Therefore, those functionalities are implemented in the MC and operation-oriented scenarios are presented in section 6.

4.1.2.1 P-f regulation

According to D4.1 document, the primary frequency regulation was completely achieved by MC. However, due to the continuous work and discussions between the WP team members, this control has been divided into two different ones. In one hand, the continuous PFR that is classified as 2nd level and controlled by the MC. On the other hand, extraordinary PFR that is classified as 1st level and controlled by primary control of the devices. The boundaries to differentiate if the event of frequency variation corresponds to a continuous PFR are:

- $49.75\text{Hz} \leq f \leq 50.25\text{Hz}$
- $|df/dt| <= 0,5$ Hz/s

In case any of previous boundary condition is not achieved, the functionality considered is extraordinary PFR.

4.1.2.2 Voltage control

According to D4.1 document, voltage events were stabilized by voltage control, this control is based on voltage setpoints. The limits of the reactive power according to the voltage at PCC are updated to the following Figure 7.

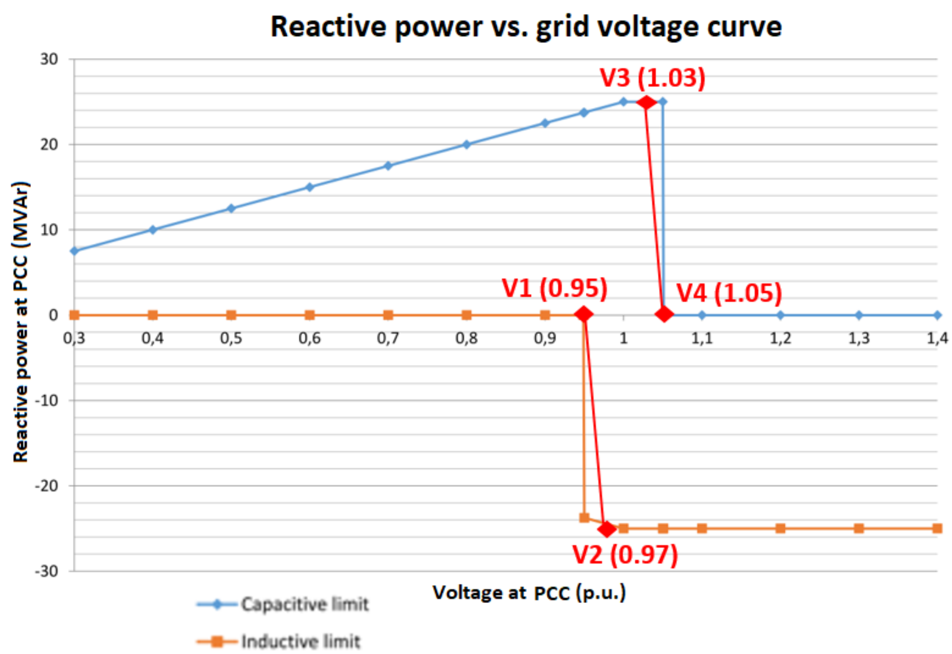

Figure 7: Reactive power limits versus voltage at PCC

4.1.2.3 Q setpoint control

According to D4.1 document, voltage events were stabilized by voltage control, but later that functionality was divided in two due to the need of increasing controllability a new functionality of voltage control based on reactive power setpoint was defined. Therefore, in Q setpoint control functionality, the reactive power provided to the system is directly controlled by the operator by regulating instantaneously the reactive power setpoint.

The limits of the reactive power according to the voltage at PCC are as shown in Figure 7.

4.1.3 3rd Level

The functionalities of 3rd level are focused on optimizing the management of the flexibility devices, taking into account the nature and characteristics of the devices it manages.

At this stage of development the functionality “Management of renewable energy variability” [2] has been updated and finally it is covered by the functionality of continuous PFR.

5 Energy Management Strategies

5.1 Previous development

In order to reduce as much as possible the aging of the storage systems due to their usage time, a genetic algorithm has been designed to find the optimal BESS safety SOC range (SSR) within which the storage systems have the capacity to deliver or absorb the necessary energy to fulfill the priority of functionalities and the requirements of services. Genetic algorithms are random search algorithms that have been developed with the aim of mimicking the mechanisms of natural selection that occur when members of a species compete for limited resources.

It is very important to estimate the right ESS SSR limits because the bigger the range, the fewer the use of storage out of priority functionalities and services operation, but also the bigger the risk of not being able to respond to a possible event.

Figure 8 shows an ESS SOC simulation after being used for auxiliary services during 6 days, where the green band represents the SSR of this storage system. After 3 days of operation for auxiliary services, an “out of safety SOC range” level has been reached (OoSSR-1) and the storage needs to be discharged for a period of time (ΔT1) in order to recover the SSR level to operate without risk.

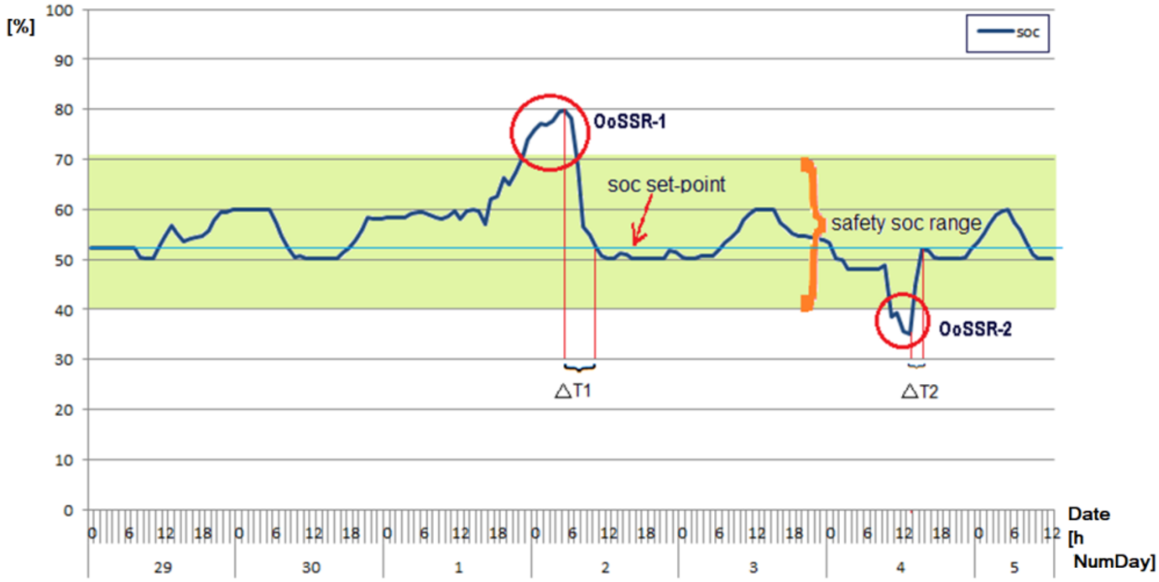

Figure 8: 6 Days ESS SOC simulation for auxiliary services

The time that the ESS has been operated for recovering the SSR (ΔT1 and ΔT2) is the only operation time that can be optimized because it is not related to priority services. In this sense, the objective of the genetic algorithm designed is to optimize both, the SSR limits and the SOC setpoint (SOC level within the ESS safety SOC range that reduce future out of SSR events); This optimization is subject to:

- Maximum coverage of the priority functionalities and services and
- Compliance with the technical and operational restrictions of ESS technologies

During the development and validation of the genetic algorithm use for SSR adjustments, the possibility of establishing different SSR limits according to the priority services demanded during periods with the same characteristics has been considered (for example, on SSR for each season of the year). Although this approach could further reduce the time of use of the different ESS, in the case of the OSMOSE project a more cautious criterion has been chosen under which the ESS are capable of supplying the full range of events for which they have been designed, regardless of the time of year. In this sense, the genetic algorithm will be used to calculate the limits that guarantee the coverage of the events provided in the historical records and these limits will not be automatically updated based on, for example, the last historical events that have occurred.

Most studies and developments that seek to extend the lifespan of ESS for power system services are focused on controlling stress factors as temperature, depth of discharge (DOD), average SOC, charge current and discharge current.

Due to the changes suffered into the project, the MC that will be tested during the project will have to integrate the different storage technologies that are allocated at Atenea microgrid as well as the HFD. Based on the developed simulation platform, the hybrid storage system has been analyzed to include at a simulation level the active power response and SOC evolution. This simulation has allowed CENER to understand how the different devices can respond to the different grid services and functionalities, and tune the energy management strategies to be able to respond to each functionality by coordinating the different elements in the best way in terms of power, energy, as well as taking into account the aging and life extension for the storage devices.

Due to the nature of the OSMOSE project many of the services that will cover the ESSs involved are considered as high priority and, during these services, parameters that could cause stress, such as charge power, discharge power or depth of discharge, will be directly imposed by the requirements of the power system, creating the impossibility of its mitigation.

Unlike others, this project changes the conventional approach and, instead of being focused on the monitoring of the internal parameters of the batteries (already controlled by its BMS), it is oriented to reduce the ESS cycles number not related to automatic responses for priority functionalities and services for the power system.

5.2 Management strategy

The management strategy developed under the OSMOSE project aims to optimise the use of a set of storage systems from the point of view of their SoH, trying to ensure that, while meeting the customer's requirements, the ESSs operate under conditions that minimise the degradation of their components.

Of the parameters that have an impact on the SoH of the storage systems, the strategy developed focuses on minimising 3 aspects:

- Unnecessary use of equipment (operating hours),
- Deviation of their state of charge from the recommended levels according to their technology,
- Operations in aggressive power ranges and/or far from those that minimise degradation.

The objective function of the optimisation problem is described as follows:

$$min \left| \sum_{bat=1}^{n} (Kb_{bat} \cdot S_{bat} + Ksoc_{bat} \cdot |VarSOC_{bat}| + Kpot_{bat} \cdot |VarPot_{bat}|) + K_{pns} \cdot pns \right|$$

Where:

- bat: each of the ESS available
- Kb_{bat}: weight of the idle consumption
- S_{bat}: battery status (on/off)

- $Ksoc_{bat}$: weight of battery degradation due to state of charge variation by technology
- $VarSOC_{bat}$: absolute value of the variation of the state of charge with respect to its ideal state of charge according to technology and design.
- $Kpot_{bat}$: weight of battery degradation per power usage value according to technology
- $VarPot_{bat}$: absolute value of the variation of the absolute power with respect to its ideal power according to the technology and its design.
- Kpns: weight of power not supplied due to ESS technical restriction.
- pns: Power not supplied due to ESS technical restriction.

The different terms of the equation in the above objective function can have a greater or lesser impact on the health of the storage depending on the storage technology. For example, the SOC level of a lead-acid battery has a significant impact on its lifetime; conversely, this same parameter has a significantly lower impact on the lifetime of flow batteries. In order to take these particularities into account, the terms $Ksoc_{bat}$ and $Kpot_{bat}$ have been introduced in the objective function whose values vary depending on the specific technology. The weights used are based on information from manufacturers, articles and own experience gained from working in the ATENEA microgrid. [3] [4]

Kb_{bat}, on the other hand, is related to the no-load consumption of each ESS. However, this parameter also serves to minimise the operating hours of the equipment, as well as the simultaneous operation of several systems when it is not necessary.

The optimization problem restriction is described as follows:

Regardless of the impact of SOC and power level on the health of the battery, the optimization will always establish the necessary restrictions so that its range of possible values remains within the minimum and maximum SOC and power limits established by the manufacturer of each BESS. That is:

$$VarSOC_{bat} = OptSOC_{bat} - SOC_{bat} \;\rightarrow\; SOCmin_{bat} \leq SOC_{bat} \leq SOCmax_{bat}$$

Where:

- $OptSOC_{bat}$: optimum state of charge according to battery technology and design.
- SOC_{bat}: state of charge.

and

$$VarPot_{bat} = OptPot_{bat} - |Pot_{bat}| \;\rightarrow\; Potmin_{bat} \leq Pot_{bat} \leq Potmax_{bat}$$

Where:

- $OptPot_{bat}$: optimum power value according to battery technology and design.
- Pot_{bat}: power.

In turn, the SOC and the power of a BESS are related, in general terms, by the following equation:

$$FinalSOC_{bat} = currentSOC_{bat} - \left({Pot_{bat} * \eta}/{Cap_{bat}} \right) * \Delta T$$

Where the $FinalSOC_{bat}$ is the state of charge of the storage after a time period ∆T, η is the efficiency of the storage system and Cap_{bat} is the total capacity of the battery. The time period ∆T can be interpreted as the time interval during which the storage is committed to maintain the requested power. To ensure that the optimiser's results are met, it is necessary to recalculate in a frequency greater than ∆T, i.e. a new solution must be obtained before the guarantee of the previous solution expires.

Additionally, the optimization problem needs to introduce the conditions and constraints related to the 2nd and 3rd level "functionalities and services for the power system" (see Table 2) that will be covered by the set of storages of the OSMOSE project. The constraints derived from these functionalities are listed below.

1- 2nd and 3rd level set points and compatibilities: the main condition to be applied in both 2nd and 3rd level functionalities is that the sum of the power delivered by the BESS participating in such functionality must equal the global set-point required by the grid operator.

$$SetPointN2 = pnsN2 + PotN2_{bat1} + PotN2_{bat2} + \cdots + PotN2_{batn}$$

$$SetPointN3 = pnsN3 + PotN3_{bat1} + PotN3_{bat2} + \cdots + PotN3_{batn}$$

$$pns = pnsN2 + pnsN3$$

Where SetPointN2, SetPointN3 and pnsN2, pnsN3 are the power required by the grid operator and the power not served in the 2nd and 3rd level functionalities respectively; and $PotN2_i$ and $PotN3_i$ refer to the ESS power served by each ESS for the related functionality.

In the case of the OSMOSE project, one of the batteries exclusively serves 2nd level functionalities, while others only serve 3rd level functionalities and at least one of them can supply both functionalities. In order for the optimization to meet these requirements, place constraints must be created so that if a storage does not participate in a functionality "X", the power value of that functionality is equal to zero ($Pbat_X = 0$).

2- Lp y Le Limits: This restriction delimits how much of the total capacity and power available in the storage pool can be used in each of the functionalities. In this sense, a value of 30% for Lp and 40% for Le means that the storage systems participating in 2nd level functionalities must reserve 30% of the sum of the capacity and power available in all the system's BESS, and consequently, those participating in 3rd level functionalities must reserve the remaining 70%.

5.3 Dispatchability of the setpoints

In order to test the developed optimization algorithm, a congestion management case is considered for preventing PV curtailment when PV composes greater shares of grid capacity [5]. A power profile has been created based on the power difference between a real power generation profile of Sangüesa (Navarre) scaled up to a 15 MW PV system and the predicted average fifteen-minute power for that installation. In this way, the Setpoint for BESSs compensates the deviation of the PV generated power with respect to the expected average power. The power profile to be supplied by the BESS, which has 3 hours duration with a time resolution of 10 seconds, is shown in Figure 9:

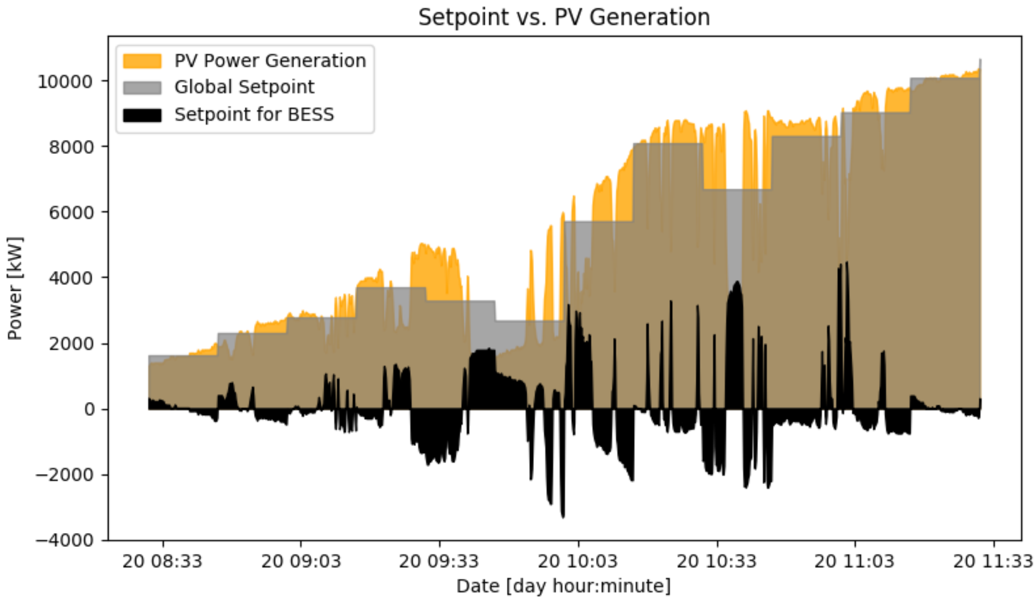

Figure 9: Total Setpoint for BESSs

As can be seen in Figure 9, a positive power to the battery means a delivery of energy and therefore a discharge of energy, while a negative power means a charging of the battery.

The setpoint to be followed with the BESS set (black curve in Figure 7) will be assigned as a 3^{rd} level functionality, using values of 30% for the Lp limit, 40% for the Le limit and taking into account that the batteries must be able to guarantee the assigned power during a time period ΔT of 0.15 minutes. To perform the set-point tracking, we plan to use 3 of the Atenea micro-grid batteries and the lithium battery supplied by SAFT as part of this project. Their main characteristics are listed below in Table 7.

BESS	SAFT HFD	Atenea Redox	Atenea Lithium	Atenea Lead- Acid
Station	**0**	**1**	**2**	**3**
Technology	**Lithium**	**Redox Flow**	**Lithium**	**PB**
Capacity (kWh)	**500.0**	**200.0**	**43.2**	**35.0**
Nominal Power (kW)	**1600.0**	**45.0**	**30.0**	**15.0**
Minimum SOC	**20%**	**10%**	**25%**	**40%**
Maximum SOC	**90%**	**95%**	**90%**	**85%**
Initial SOC	**70%**	**70%**	**70%**	**70%**
Off-load comsumption (kW)	**16.0**	**5.0**	**1.3**	**3.7**
K_B	**12.3**	**3.8**	**1.0**	**2.8**
Optimal SOC level (%)	**60%**	**50%**	**60%**	**80%**
K_{SOC}	**0.5**	**0.1**	**0.5**	**1.0**
Optimal Power level (kW)	**500.0**	**40.0**	**21.6**	**3.5**
K_{POT}	**0.4**	**0.1**	**0.4**	**1.0**
2nd Level func.	✓	✓		
3er Level Func.	✓		✓	✓

Table 7: Characterization of the functionalities

Table 7 includes the initial SOC values used for the simulations in this case study.

The total power (set point) to be supplied by the storages and the results obtained after running the optimization algorithm are shown in Figure 10. A quick glance at this graph shows the presence of intervals in which the power served by the BESSs has not been able to meet the requested set point (grey shading), due to the fact that this set point exceeds the total power of the set of BESSs that can participate in the 3rd level functionality; also, it shows a high use of the SAFT BESS when following relatively high power set points, which is because the nominal power of this battery (1600 kW) is much higher than the nominal power of the other 3 storage systems (45kW, 30kW and 15 kW).

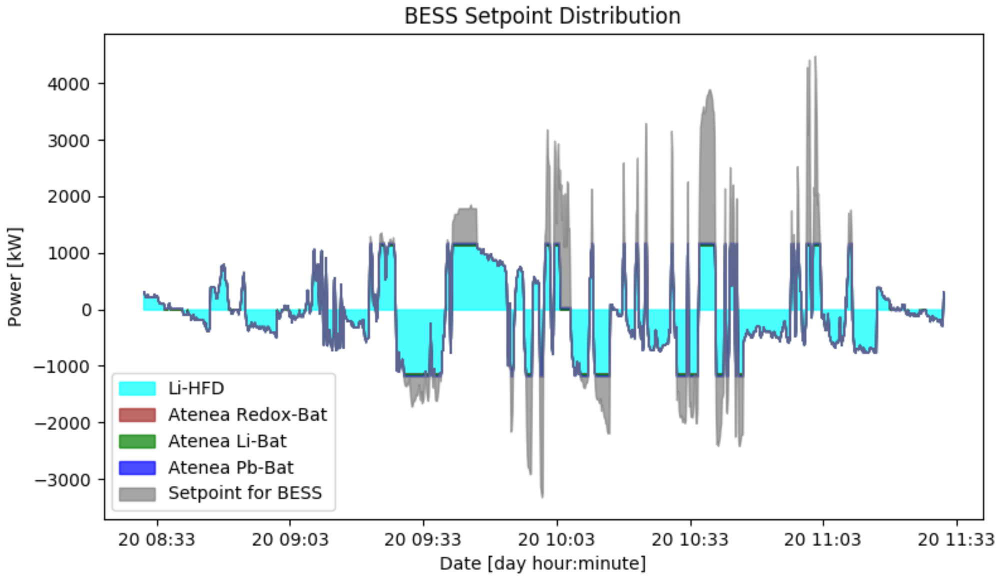

Figure 10: Distribution of the Total Setpoint

In the following, the result obtained in the previous simulation will be examined in more detail to verify that, on the one hand, the objective function is observed and, on the other hand, the constraints imposed on the optimisation problem are satisfied.

As described above, the proposed objective function focuses on acting on three equipment usage factors:

- reducing the unnecessary use of equipment (operating hours) and its off-load consumption,
- maintaining SOC levels close to those recommended by the manufacturer, and
- using charging and discharging power close to the optimum operating power of each equipment.

In order to verify that the hours of use of the equipment are really reduced, the requested set point has been compared with the power distribution performed by optimization, confirming that the lowest possible number of storage systems is used for each case, provided that:

- at the global level, an attempt is made to cover the total required set point using only the storage systems participating in the level 3 functionality and complying with the limits of Lp and Le, and
- at the local level, the minimum SOC, maximum SOC, maximum load power and maximum discharge power limits recommended by the manufacturer are respected.

In cases where more than one BESS can meet the established set point, the optimization covers the requirement with the BESS with the lowest off-load consumption.

In Figure 11 shown below, we can graphically visualize 2 cases in which the solution obtained complies with both the objective function approach and the global and local constraints.

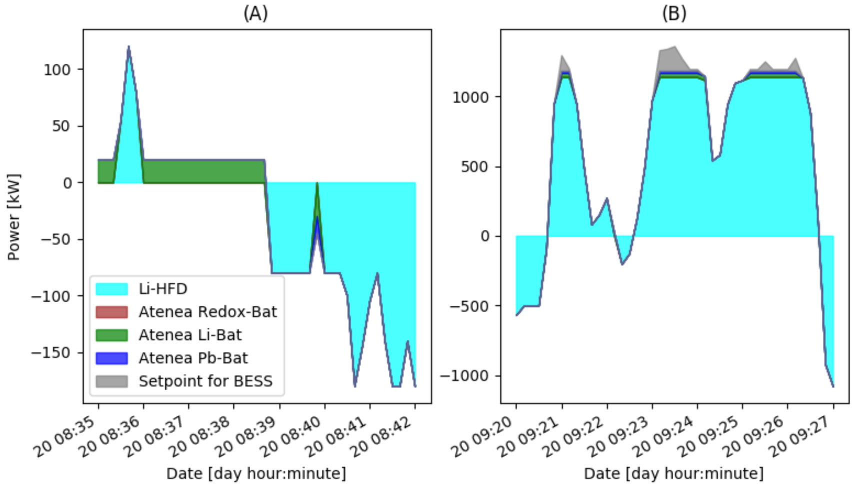

Figure 11: Optimal BESSs Setpoint.

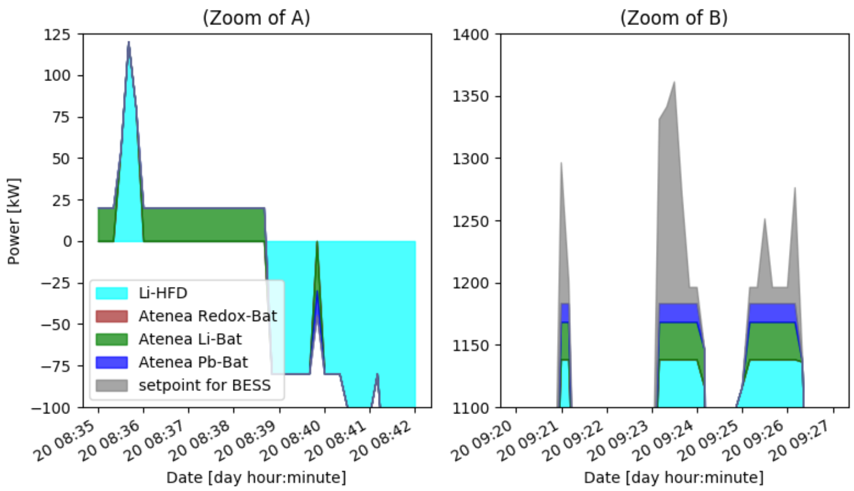

Figure 12: Zoom of BESSs Setpoint.

In case (A), the requested power between 8:36 and 8:39 is 20.28 kW (see detail in Figure 12), which is higher than the maximum discharge power of the lead acid battery (15 kW) and lower than the maximum discharge power of the Atenea lithium battery (30 kW) and the SAFT HFD (1,600 kW). Since the off-load consumption of Atenea lithium battery (1.7 kW) is lower than the one of the SAFT HFD (16 kW), the optimization assigns this requirement to the Atenea battery. Between 8:39:50 and 8:40:00 the required set point was -44.72 kW, being the same assigned to Atenea's lithium and lead-acid batteries since the sum of their maximum charging exceeds the required set point and the sum of its off-load consumption (3.7kW and 1.3 kW respectively) is less than the off-load consumption of SAFT HFD.

For higher setpoints, only HFD is used, as long as the Lp limit is complied with. In this case study, the Le limit establishes that in the batteries that participate in second-level functionalities (SAFT HFD and Atenea redox flow), 30% of all the power available in the system must be reserved. That is:

$$PotN3_{bat1} + PotN3_{bat2} <= (Pot_{bat1} + Pot_{bat2}) - Lp * (Pot_{bat1} + Pot_{bat2} + Pot_{bat3} + Pot_{bat4})$$

$$PotN3_{bat1} + 45 <= (1600 + 45) - 0.3 * (1600 + 45 + 30 + 15)$$

$$PotN3_{bat1} <= 1138\ kW$$

In case (B) of the previous graph we can see how in case of a set point higher than the sum of the nominal power of all the storages, the strategy assigns the maximum possible power to the equipment participating in this functionality, but respecting at all times both the Lp limit and the maximum discharge power recommended by the manufacturer.

In keeping with the Lp limit, the Le limit establishes that in the batteries that participate in second-level functionalities, 40% of all the BESS Useful Capacity in terms of energy (CAP_{useful}) available in the system must be reserved for level 2 functionalities. To evaluate compliance with this limit, we must first calculate the CAP_{useful} of the set of storages, from their nominal capacity values (CAP_{nom}), using the following equation:

$$CAP_{useful_{bat}} = CAP_{nom_{bat}} * \left(SOC_{max_{bat}} - SOC_{min_{bat}}\right)$$

For this case study:

$$CAP_{useful_{bat1}} = 500 * (0.90 - 0.20) = 350.0\ kWh$$

$$CAP_{useful_{bat2}} = CAP_{useful}N2_{bat2} = 200 * (0.95 - 0.10) = 170.0\ kWh$$

$$CAP_{useful_{bat3}} = 43.2 * (0.90 - 0.25) = 28.1\ kWh$$

$$CAP_{useful_{bat4}} = 35 * (0.80 - 0.45) = 12.3\ kWh$$

As mentioned above, in the BESSs participating in the 2nd level functionality, 40% of the BESS Useful Capacity available in the system must be reserved.

$$CAP_{useful}N2 = L_e * \left(CAP_{useful_{bat1}} + CAP_{useful_{bat2}} + CAP_{useful_{bat3}} + CAP_{useful_{bat4}}\right)$$

$$CAP_{useful}N2 = 0.4 * (350 + 170 + 28.1 + 12.3) = 0.4 * 560.4 = 224.2\ kWh$$

In the present case study, the BESSs involved in functionality 2 are SAFT HFD and Atenea Redox Flow. First, the available energy in bat2 (SOC_E) is calculated, which is fully reserved for this functionality.

$$SOC_{E_{bat2}} = CAP_{nom_{bat2}}\left(SOC_{bat2} - SOC_{min_{bat2}}\right) = 200 * (0.7 - 0.1) = 120\ kWh$$

From this calculation, we can derive the remaining energy that needs to be reserved in SAFT HFD for level 2 functionalities:

$$SOC_E N2_{bat1} = CAP_{useful}N2 - SOC_{E_{bat2}} = 224.2 - 120 = \ 104.2\ kWh$$

Taking into account the minimum operating SOC of the SAFT HFD, if 2nd level functionalities are not active and BESS Atenea Redox Flow SOC level remains at 0.7, SAFT HFD SOC level should be:

$$SOC_{bat1} >= SOC_{min_{bat1}} + \left(SOC_E N2_{bat1} / CAP_{nom_{bat1}}\right) = 0.2 + \left({}^{104.2}/_{500}\right)$$

$$SOC_{bat1} >= 0.408$$

That is, the SOC level reserved to 2nd level functionality, after SAFT HFD maintaining the power assigned by the optimization for a period of 0.15 minutes, should be greater than or equal to 40%. In the proposed case study, the Le constraint acts at least during a time interval, shown graphically in Figure 11.

Figure 13 shows how at 10:03 the set of BESS are trying to cover a set point higher than the sum of their nominal power and all BESS participating in 3rd level functionality are delivering power. Shortly before 10:04, SAFT HFD reaches the SOC constraint imposed by the Le limit and stops delivering power, remaining at a SOC level of 0.404.

In this case, the SOC level obtained is slightly lower than the theoretically calculated one due both to the simulation step used and to the fact that the battery model used in this simulation is designed to simulate losses due to equipment efficiency and delays in the execution of the orders, which shows that, in a real application, the accuracy with which the Le limit is met will depend on the refresh rate of the equipment set point and its response speed.

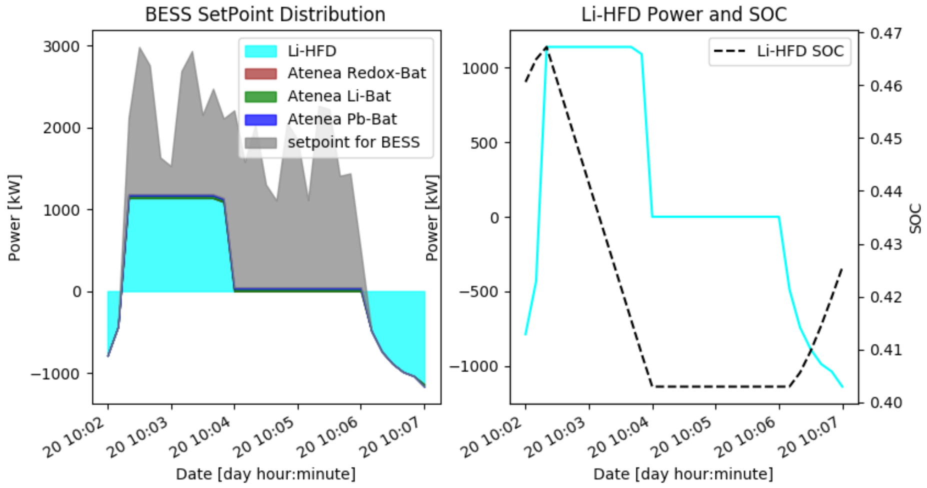

Figure 13: SAFT Battery Power and SOC simulation results

2nd Level function

Finally, to test the optimization against a level 2 functionalities requirement, we will introduce a setpoint to discharge 35kW between 8:35 and 8:37, to charge 300kW between 8:37 and 8:40 and to charge 600kW between 8:40 and 8:42. The result obtained after launching the optimization is shown in Figure 14.

Figure 14: Six days ESS active power simulation for auxiliary services

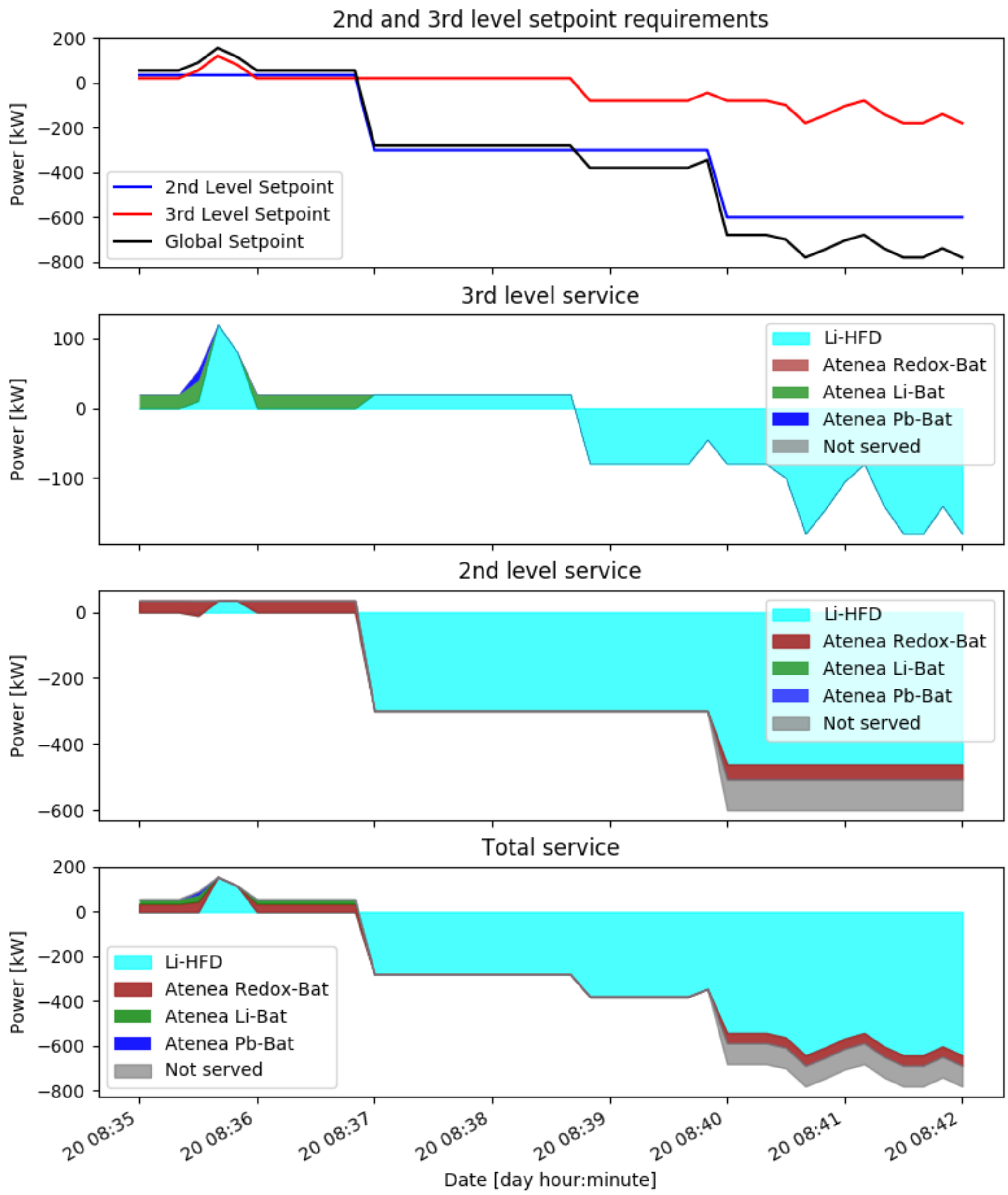

Figure 14: Six days ESS active power simulation for auxiliary services

Figure 14 shows separately the set points assigned to the different BESS according to their functionality and joint behaviour. From the obtained results we consider interesting to describe the following behaviour:

- Between 8:35:00 and 8:37:00 the set point for 2nd level functionality is 35 kW, so the best option to reduce the off-load consumptions and the number of equipment in operation is to supply this functionality with the Atenea Redox flow battery. This is the case between 8:35:00 and 8:35:40; however, between 8:35:40 and 8:36:00, the SAFT battery needs to be in service to supply 3th level functionality, so during this interval the optimization chooses to cover both functionalities with the SAFT battery, reducing the number of BESSs in operation.

- During 8:37:00 and 8:40:00 a charging requirement for 2nd level functionality of 300 kW (higher than the 45 kW of nominal power of the flow battery) makes it necessary the use of the SAFT battery to cover this set point.
- Between 8:40 and 8:42 the set point charging requirement for level 2 functionality rises to 600 kW, which is higher than the power that the Lp limit allows to be used in BESS participating in this functionality. In this case, the optimization assigns the maximum possible power to each one of the participating equipment, being the set points -45 kW and -462 kW for the Atenea redox flow and the SAFT batteries respectively.

With this series of tests, it is considered that the optimisation developed can be validated from these simulations. The next stage of work to be carried out will consist of the field validation of the simulation algorithm in the Atenea microgrid, once the real equipment is operational during the planned test campaign.

6 Operation-oriented scenarios

In the field of grid services, single operation scenarios as well as combined scenarios have been identified (as for example secondary and tertiary control reserves in ancillary services). Thus, artificial flexible operation-oriented profiles based on grid services and functionalities that the MC controls are derived and developed in the following subsections.

The common procedure settles the input signals for the MC and the output power setpoint for the MCFS and the measurements at the PCC: active power, reactive power and voltage.

The verification and validation of the MC control strategies is carried out on the demonstration test system during testing period. This period begins at a near future date, so it is not possible to present these results at the present D.

6.1 Simulation results

6.1.1 2nd Level

The total power and capacity of the storage devices involved in 2nd level functionalities are reserved for performing the following 2nd level simulations. In the reported simulations the energy reserve is set to 0 %.

6.1.1.1 Continuous PFR

PFR simulation is reported and the parameters applied are summarized in Table 8.

Parameter	**Value**	**Units**
Deadband	0.05	Hz
drop	7	%
Limit underfrequency	49.75	Hz
Limit overfrequency	50.25	Hz
Lp	100	%

Table 8: P-f and PMG parameters

The behavior of the control to give the distribution of the instructions is analyzed in terms of active power measures at the PCC. Due to the frequency changes measured at PCC, in, the droop control reacts to them with the corresponding active power setpoint changes. The obtained simulated signals are shown for overfrequency and underfrequency events in 15 and 16 respectively.

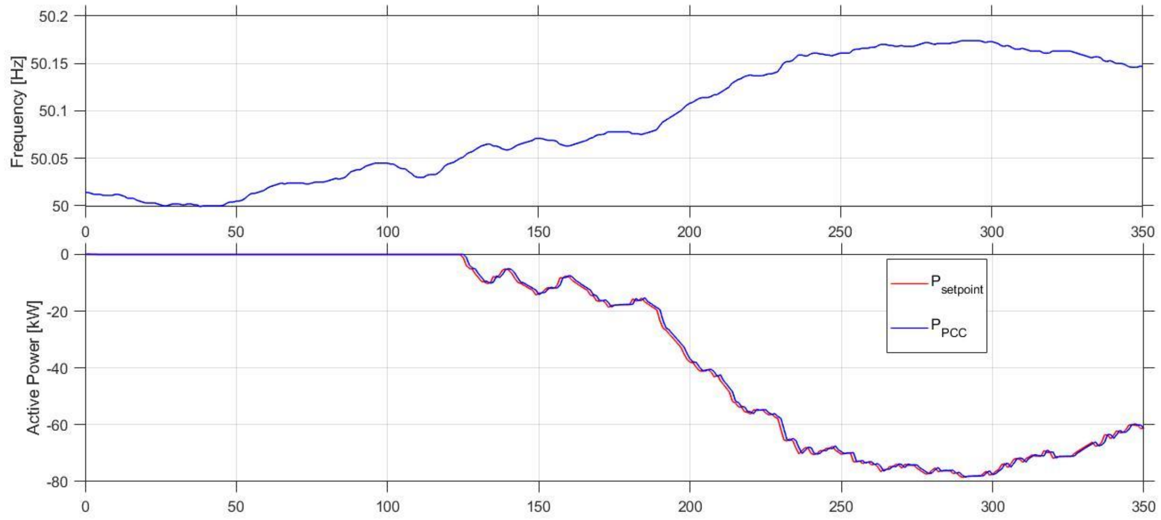

Figure 15: Frequency measurements and PFR profile (overfrequency)

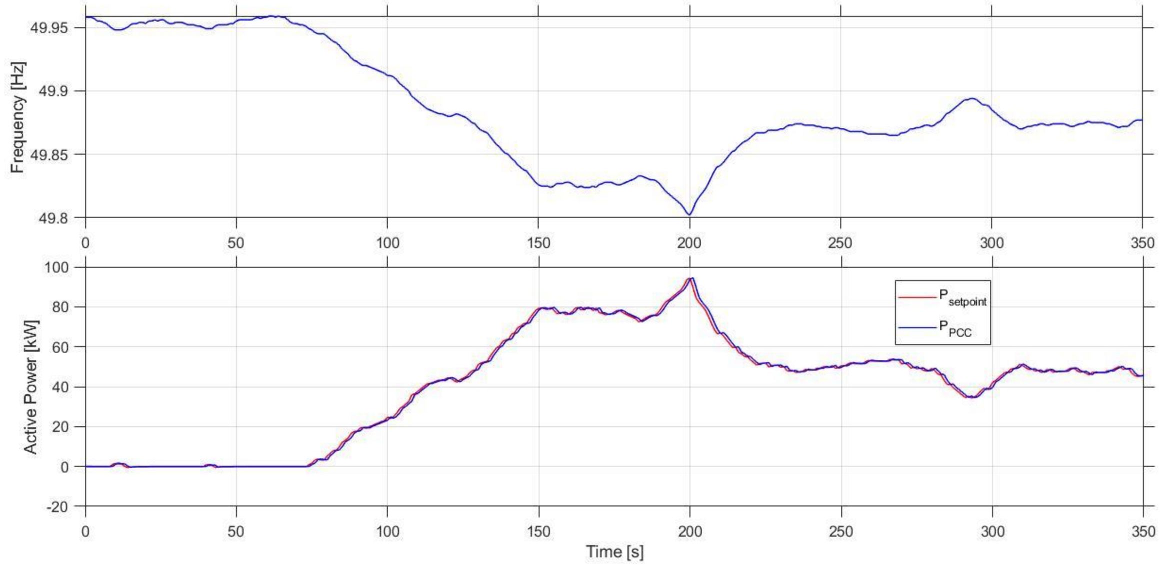

Figure 16: Frequency measurements and PFR profile (underfrequency)

6.1.1.2 Voltage control

Voltage control simulation has been performed by characterizing the parameters of the droop equation and the voltage and reactive power limits of the system. Due to the voltage changes simulated at PCC, in Figure 17, the droop control reacts to them with the corresponding reactive power (Q) setpoint changes, Figure 18.

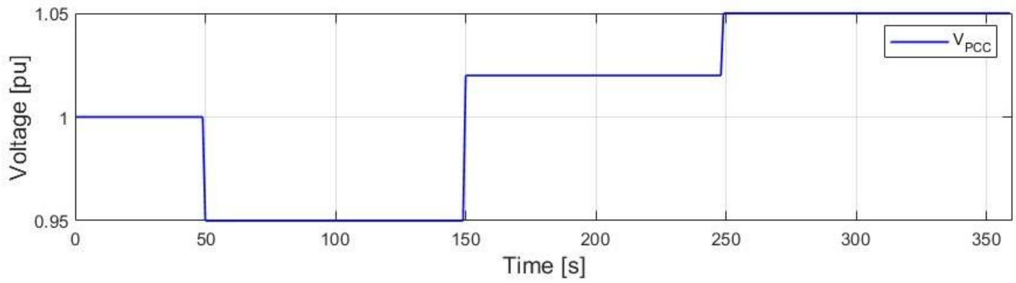

Figure 17: Voltage control variation

In the Figure 18 can be seen the calculated Q setpoint corresponding to the voltage variation according to the droop and the Q measured at PCC. At t=230s the voltage setpoint follows a ramp of 2kV/min, as a consequence, the Q setpoint is ramped.

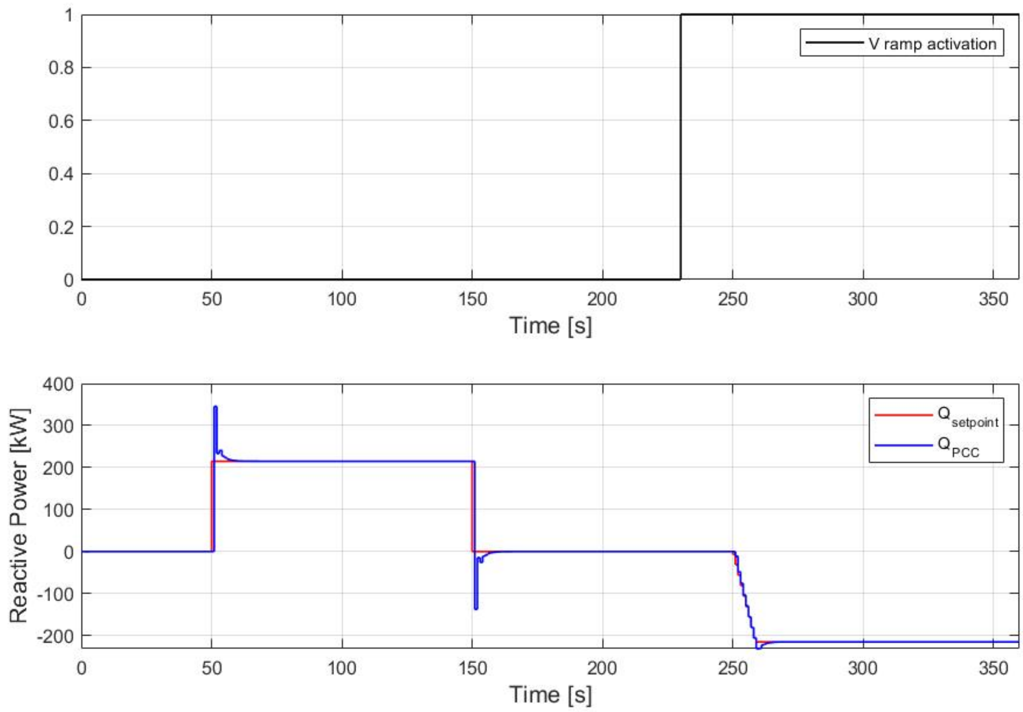

Figure 18: Q setpoint referred to voltage variation at PCC

6.1.1.3 Q setpoint control

Once reactive power is required, the Q setpoints are received at the MC to activate this functionality. The Q measurements at the PCC are following the Q setpoint as given in Figure 19. The ramp applied in this case is 5 [MVAr/min]. Reactive power measured at PCC follows the setpoint during Q ramp activation is on (‘1’ in Figure 19) and with a delay when Q ramp activation is off. The last reference is not followed due to the limitations imposed to the Q response. MFCS response to setpoint allows keeping Q at PCC controlled.

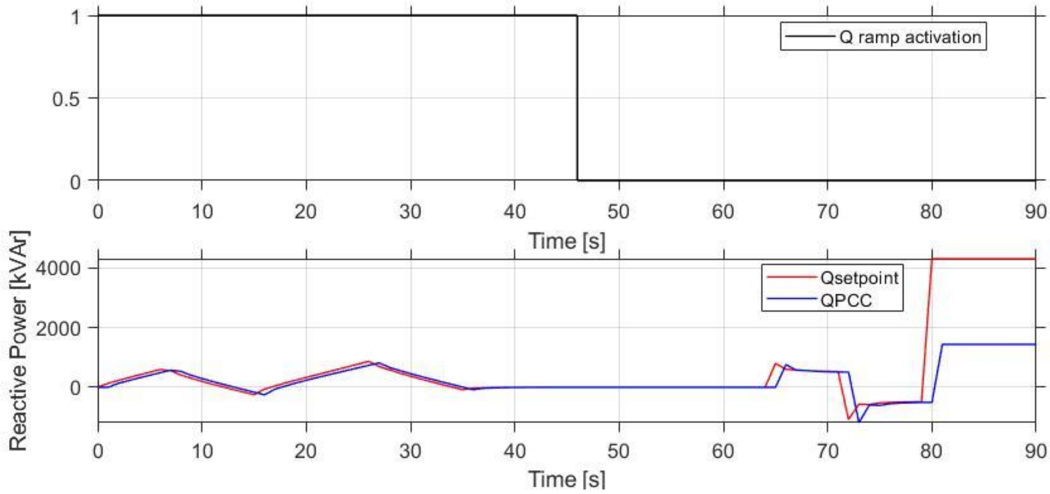

Figure 19: QSPCONT functionality requirement and Q measurement at PCC with Q ramp activation signal over time.

6.1.2 3rd Level

The total power and capacity of the storage devices involved in 3rd level functionalities are reserved for performing the following 3rd level simulations

6.1.2.1 Setpoint Tracking

The applied changes on the P input reference with a reading time tr=1min results in the Setpoint Tracking profile drawn in Figure 20.

Active power ramp up set to 2 MW/min and active power ramp down set to -2 MW/min are parameterized in the MC for calculating the P setpoint, thus the active power changes following the previous ramps.

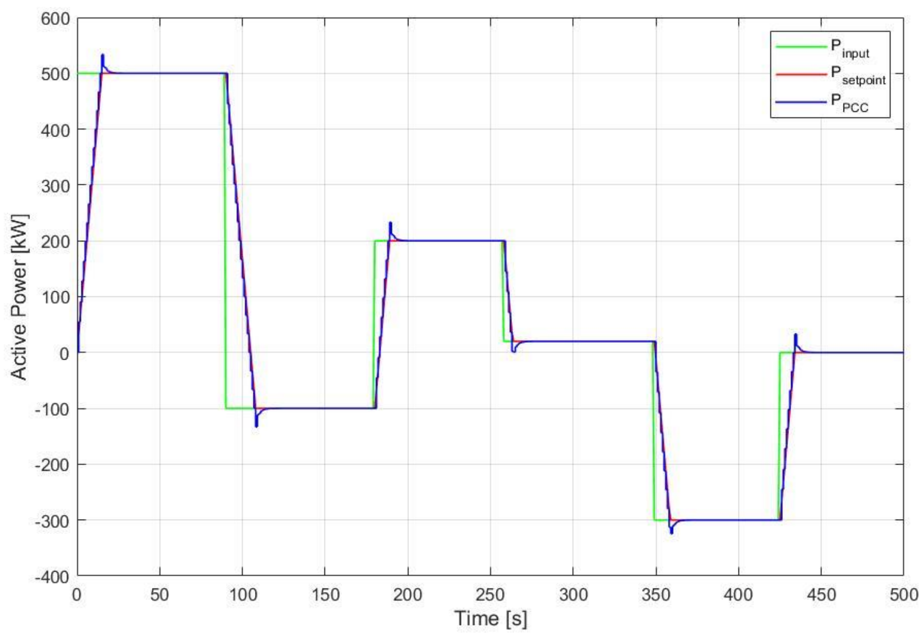

Figure 20: SPT profile

6.1.2.2 Program Management

The Program Management (PGM) defined input profile is as represented in the following Figure 21 active power ramp up of 2 MW/min and active power ramp down of -2 MW/min are parameterized and affect in the rate of P setpoint change, resulting on the P setpoint signal included in Figure 21. Thus, the active power changes follow the previous ramps and the measured power at PCC is ramped, Figure 21.

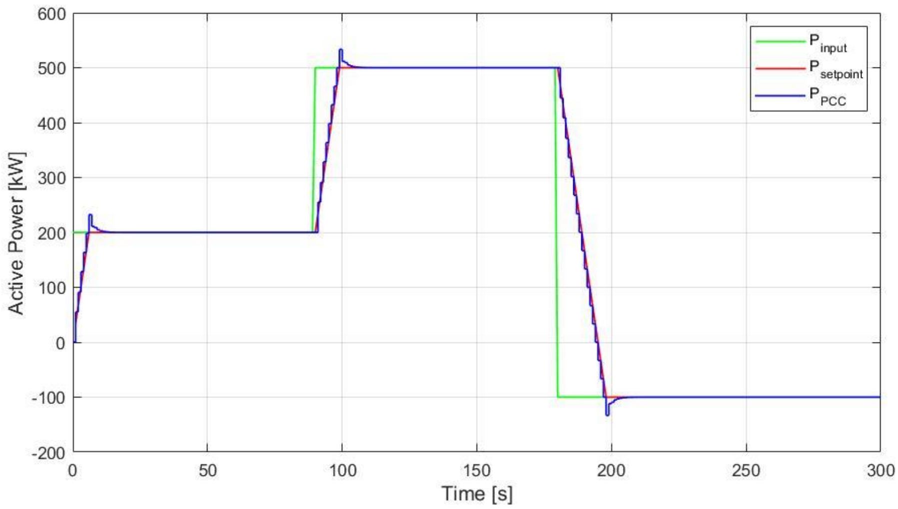

Figure 21: PGM profile

6.1.2.3 Congestion Management

Since the aim of this functionality is to supervise the power in the PCC to avoid congestions in the connection node with the grid, the output power is regulated by taking into account the established limit in the node, that can be dynamically changed, and the renewable energies generation, without curtailing its production. Therefore, the storage devices are controlled to achieve the established power limitation of the node. Next Figure 22 represents the power produced by renewable energies and the power limit in the node, which difference between their active power must be covered by the storage devices. Therefore, the output power in the node respects the established limit, Figure 23.

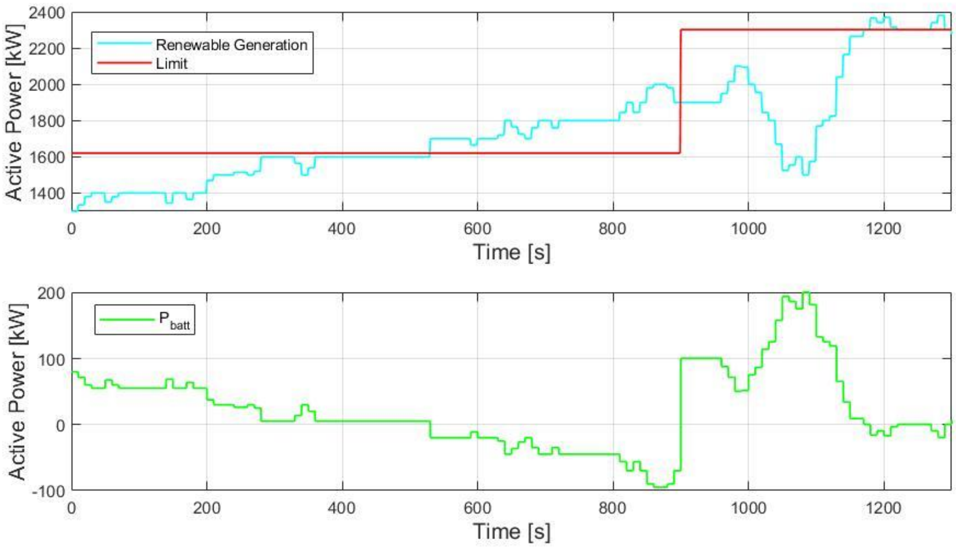

Figure 22: Renewable generation and limit in the node. Power to be compensated by the storage devices

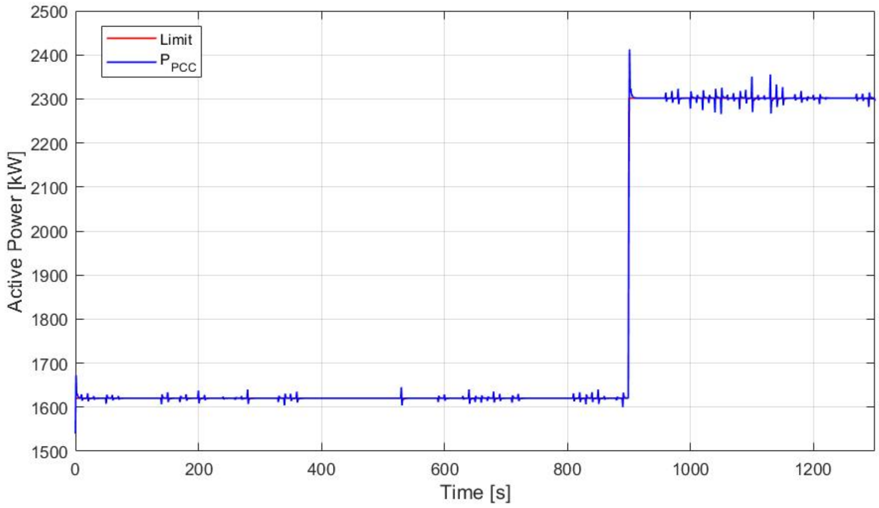

Figure 23: Limit to active power in the node and active power measured

6.1.3 2nd and 3rd Level

6.1.3.1 Continuous PFR and Program Management

In order to be held the alternating current frequency within tight tolerance bounds, PFR is activated at the same time that PGM is also activated. In this case, the parameters applied take the values, see Table 8. The MCFS is operated by the MC for providing this combined functionalities. Frequency measurements vs. time is shown in Figure 24. Therefore the simulated active power signals are represented in Figure 25, where active power at PPC follows PMG setpoint and compensates for the frequency deviations according to see Table 8 parameters.

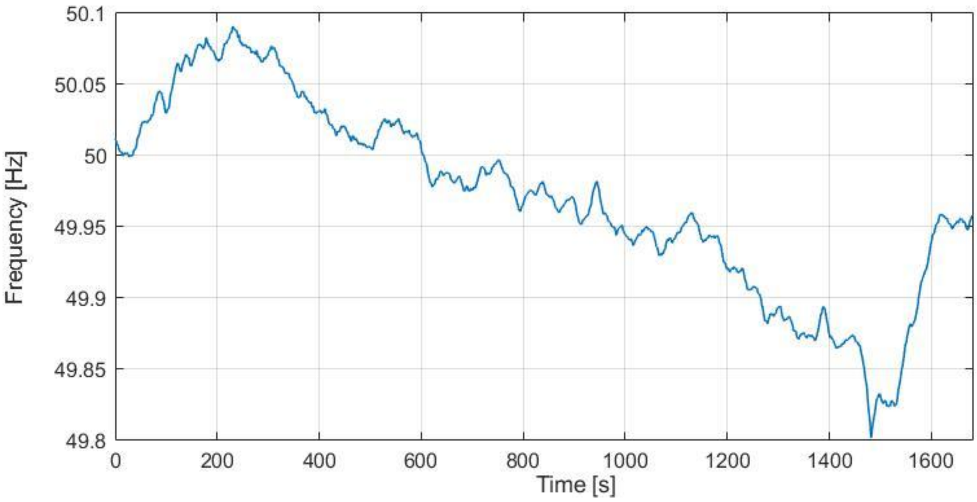

Figure 24: Frequency signal as input measured at PCC

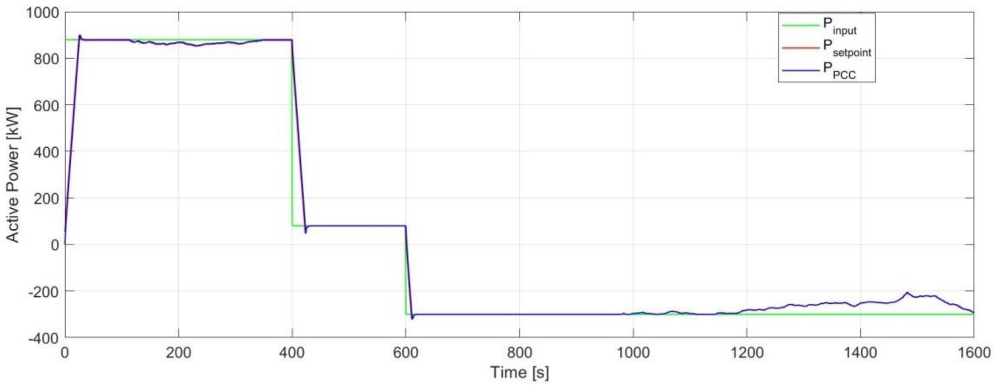

Figure 25: PFR and PMG profile

6.1.3.2 Q setpoint control and Program Management

When a combined occurrence of functionalities is given, in this case Q setpoint and Program Management, the MC receives the corresponding power setpoints. At the same time, from the SCADA the corresponding signals of functionality status are activated and MC starts to compute the power compensation to follow the grid power requirements at the PCC.

In Figure 26 the required active and reactive power set as the PCC power reference, due to TSO requirements (for example voltage droop and load variation), are presented, without ramp. Afterwards, the ramp up/down is to be ±2 MVAr/min, and the measures after controlling over 2500 seconds of simulation are reported in Figure 27.

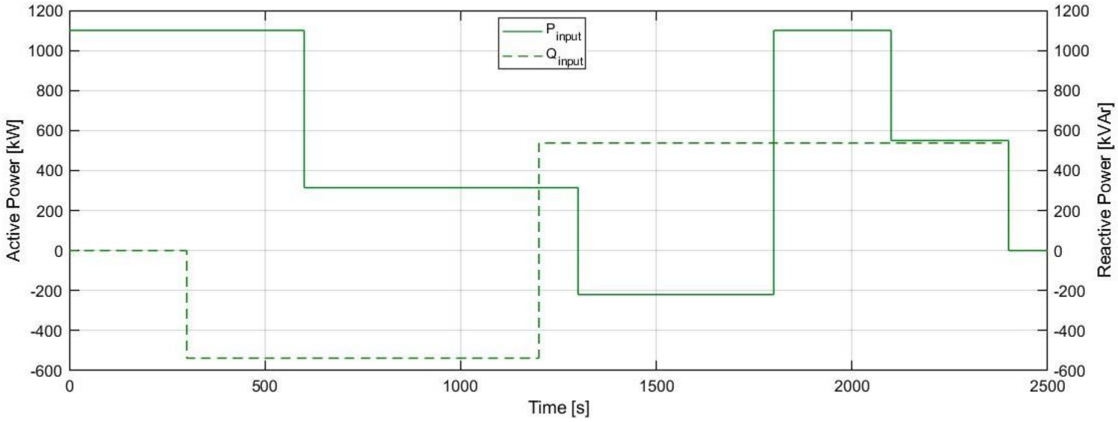

Figure 26: Active and reactive power references without ramp.

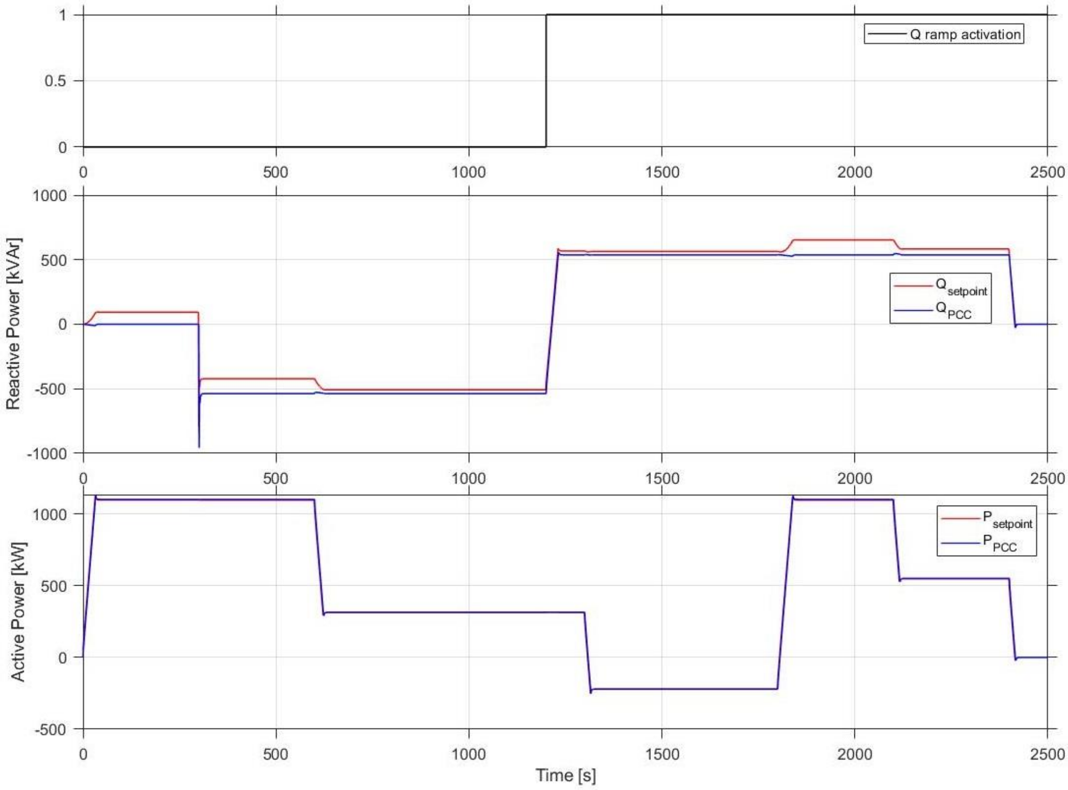

Figure 27: Ramp activation, reactive and active power signals vs. time.

The results show that the control is effective in terms of the adequate following of the response of the system to the setpoints. The reactive response follows the reference and the impact of the PGM requirements causes the increase of Q setpoint.

6.2 Evaluation

In previous sections, it is presented that there is an acceptable accordance between the setpoint and the measures at the PCC in all simulated scenarios. That indicates that all scenarios confirm the controllability of the MC.

Once the MC model is ready and connected it needs to be enriched for data and used to achieve its goal. Besides, according to an update scheme of the MC based on test results, possible improvements, etc. can be performed. This brings us to the face of enrichment and utilization.

In order to receive data from the physical devices it is important to establish the communication between the HFD and SFDs and the MC/ HMI. The collected data needs to be stored, analysed and visualized in order to fulfil the services and degree of flexibility for the MC. Hence, in this face the following has to be considered. Connectivity protocols and standards, security, middleware, data storage and required data science based on the service needs.

7 Master control SCADA

7.1 Description

MC SW is developed under HMI-EMS architecture. The HMI is based on a touch screen panel PC that runs the control algorithms; the optimization strategies for storage management, as well as the SCADA, communications and database (see Figure 28).

Figure 28: Scheme concept

The MC SCADA system is developed associated to what is required for the purpose of testing the flexibility system, as well as to its configurability based on the main performances of the HMI:

- Easy and configurable Front End for plant elements selection
- Integrates Standardize industrial communication protocols
- Integrates MC strategies for power plant energy optimization
- Integrates power plants elements control
- SCADA, Strategies and Control embedded into the same HW and SW Platform
- Power Plant Alarms and Warnings for safety shutdown
- WEB interface for remote monitoring
- Different users configurations and access

Functionalities selection is configured for user manual selection in Figure 29.

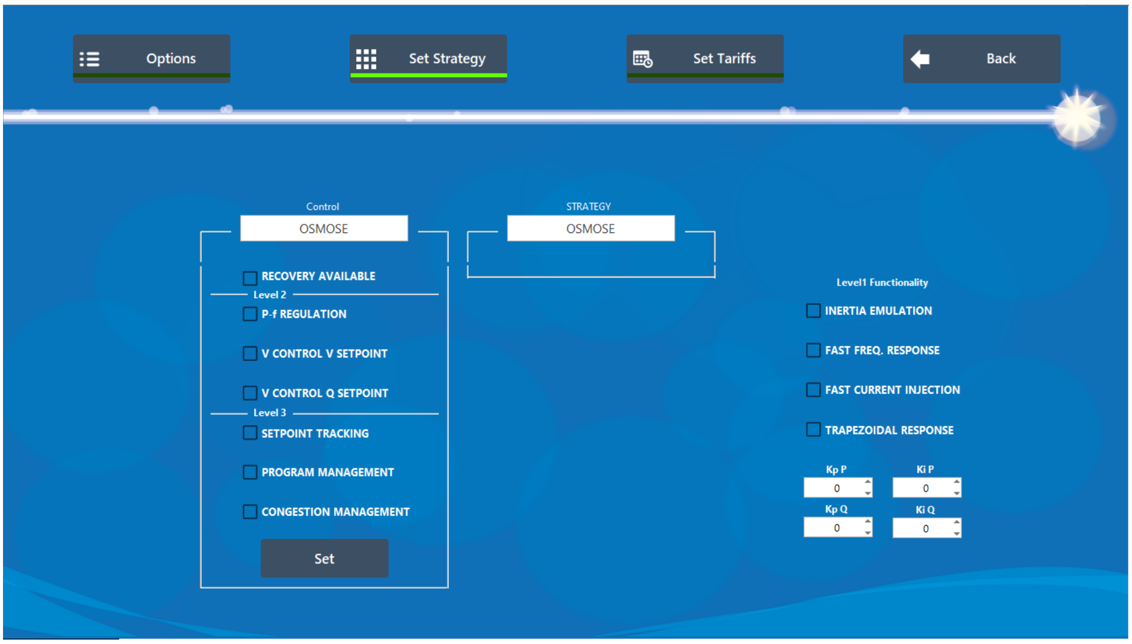

Figure 29: Functionalities selection

7.2 MC SCADA front-end

Each component has its own monitoring graphic display. The configuration and most relevant signals are presented through the client of each of the MCFS component. In Figure 30 and Figure 31 the front end with measured signals in two different situations (Case I and Case II) is shown. The components that appear are listed above:

1. HFD
   Integrate the communications with the HFD to be able to send and receive data to be managed by the HMI.
   1.1. STATCOM
   1.2. SC
   1.3. BESS
2. Atenea microgrid with SFD
   2.1. PV generation
   2.2. Pb battery
   2.3. Li-battery
   2.4. Redox Flow battery
3. PCC

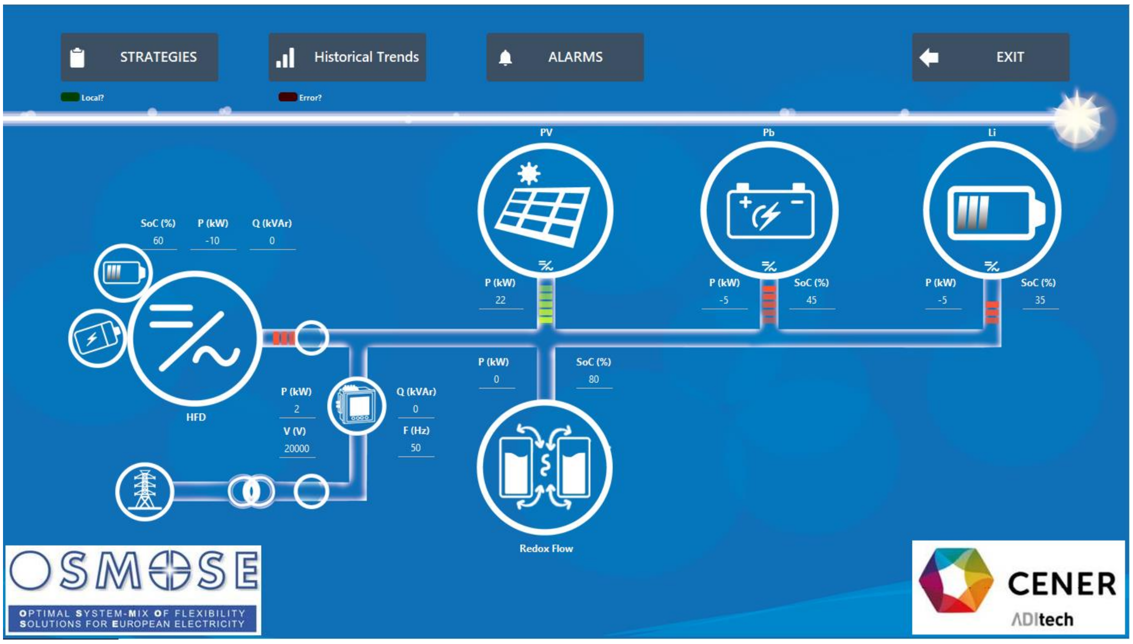

Figure 30: SCADA, Case I

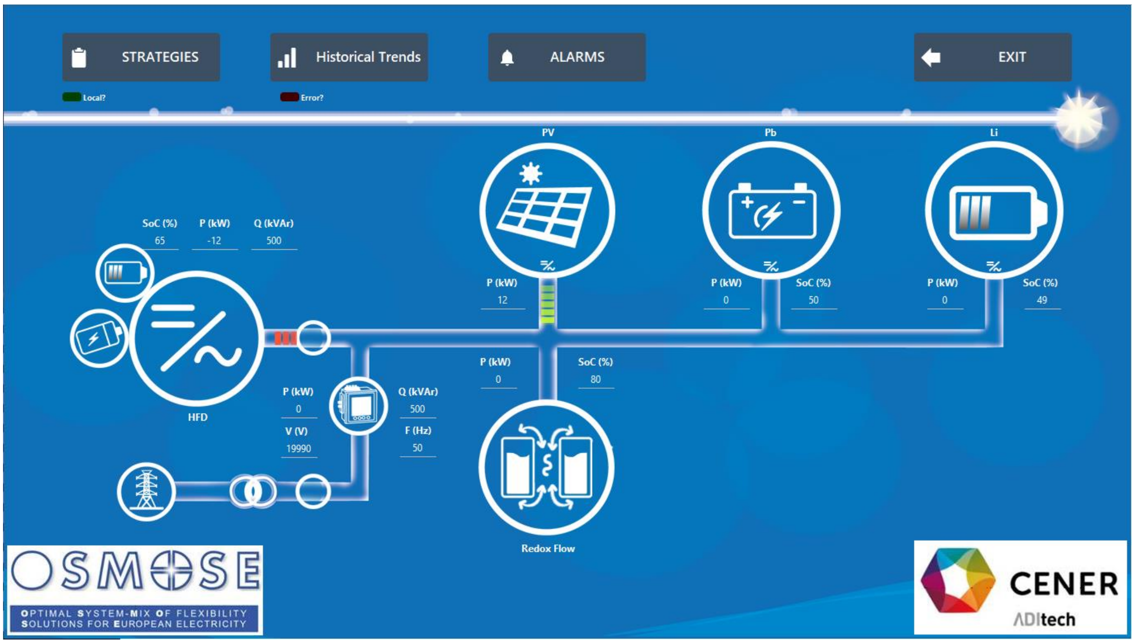

Figure 31: SCADA, Case II

8 Conclusion

OSMOSE Spanish demonstration tries to integrate an Hybrid Flexibility Device (HFD) solution to provide different flexibility services,

Atenea microgrid enables increasing hybridization and performance of HFD working as SFD in MCFS.

Master control development implies a supervisory control, energy management system and SCADA for MCFS and to assure the provision for flexibility services stablished by the TSO.

The energy strategy developed focuses on minimising degradation in terms of:

- Unnecessary operating hours, deviation of their recommended SOC and preventing aggressive power ranges operations.
- And respecting the technical limits stablished by the manufacturer and the grid connection.

A case study is presented to recall the maximisation of PV integration in a congestion management service based on flexibility storage solution.

Evidence of flexibility is presented in terms of multiple services (2nd and 3rd level) provided by the MCFS. Indicate that all scenarios confirm the controllability of the MC.

Future work is proposed to fulfil master control objectives aligned with WP4 and the OSMOSE project aims, as well as to improve scalability capabilities of control strategies. In this regard, control algorithms improvement will be reached through test development with real signal database evaluation. MC will be updated with the parameters deduced from the signal registered during real tests of the demo. Also, models extraction for optimal control degradation are lines of work of interest. Scalability and interoperability of the solution are feasible thanks to the design. Nevertheless, it should be noted that further studies concerning performance evolution and the ageing of BESS are of interest as for WP7. Accordingly, for further research projects involving different storage technologies and RES integration in grid/off-grid applications, all extracted lessons learnt will help to feed partners knowledge and to overcome new challenges including control strategies and optimization with tightest restrictions and improvements.

9 References

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