OSMOSE

OPTIMAL SYSTEM-MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY

Hybrid Flexibility Device implementation

D4.3

Contact: www.osmose-h2020.eu

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Document Responsible	Joaquin Alvarez (GPTECH)
Author(s)	Joaquin Alvarez (GPTECH), Faisal Bouchotrouch (CENER), Alberto Escalera (REE)
Reviewer(s)	Leonardo Petrocchi (TERNA), Nathalie GRISEY (RTE)
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List of acronyms and abbreviations

You can find in the table below the list of the acronyms and abbreviations used in this document.

Acronym	Meaning
APCS	Advanced Power Conditioning Station
ASN	Advanced Supervision Node
AVCS	Advanced VAr Compensator Station
BPCS	Battery Power Converter System
BESS	Battery Energy Storage Station
DAQ	Data Acquisition Module
DSM	Dynamic System Monitor
EMS-MM	Energy Management System – Monitoring Module
ESS	Energy Storage System
FAT	Factory Acceptance Test
FPA	Fast Power Analyzer
GW	Gateway
HFD	Hybrid Flexibility Device
IPP	Independent Power Producer
MMC	Multi Modular Converter
MTR	Minimum Technical Requirements
PCC	Point of Common Coupling
POI	Point of Interconnection
PPC	Power Plant Controller
PPS	Plug & Play Storage System
RTU	Remote Terminal Unit
RTAC	Real Time Automation Controller
SCADA	Supervisory Control and Data Acquisition
SS	Substation
STATCOM/SVC	Static Var Compensator
WAN	Wide Area Network
A.O	Analog output

0 Executive summary

One of the main objectives in the Spanish demonstrator within Osmose project WP4 is the design and development of a hybrid flexibility device able to provide multiple flexibility services to the transmission system. This hybrid flexibility device integrates a container including a modular multilevel STATCOM and supercapacitors, another container with a high voltage lithium-ion battery system and a DC-DC converter that allows the connection of the two previous containers. The STATCOM and supercapacitors containers and the DC-DC converter has been manufactured by GPTECH, while the lithium-ion battery system has been developed by Saft.

Intensive works has been conducted to design, manufacture, test and validate the STATCOM, the battery and the DC-DC converter. Main characteristics, schematics, dimensions, connections and installation requirements have been defined and are reported in this deliverable. Apart from this, communication and control systems required for the correct performance of the demonstrator has been properly implemented.

All these elements that constitute the hybrid flexibility device developed has been properly installed on field in CENER facilities and connected to a 20 kV substation. More information of the works done, equipment used for this purpose and its characteristics is also provided in this deliverable.

1 Introduction

The Spanish demonstrator in Osmose project, developed by Red Electrica de España, CENER, GPTECH, Saft and University las Palmas de Gran Canaria, aims to develop and validate a novel hybrid flexibility device (HFD) for provision of multiple flexibility services to the power system. The HFD integrated a new lithium-ion battery, supercapacitors and a modular multilevel STATCOM, all of them optimally coordinated by a master control.

Among the different works conducted for the demonstrator development, tasks for the engineering, manufacturing and installation of the HFD represent one of the key activities in the project. This deliverable describes the work conducted in the project for this purpose and compiles the main results obtained from these engineering, manufacturing and installation process.

2 Hybrid Flexibility Device

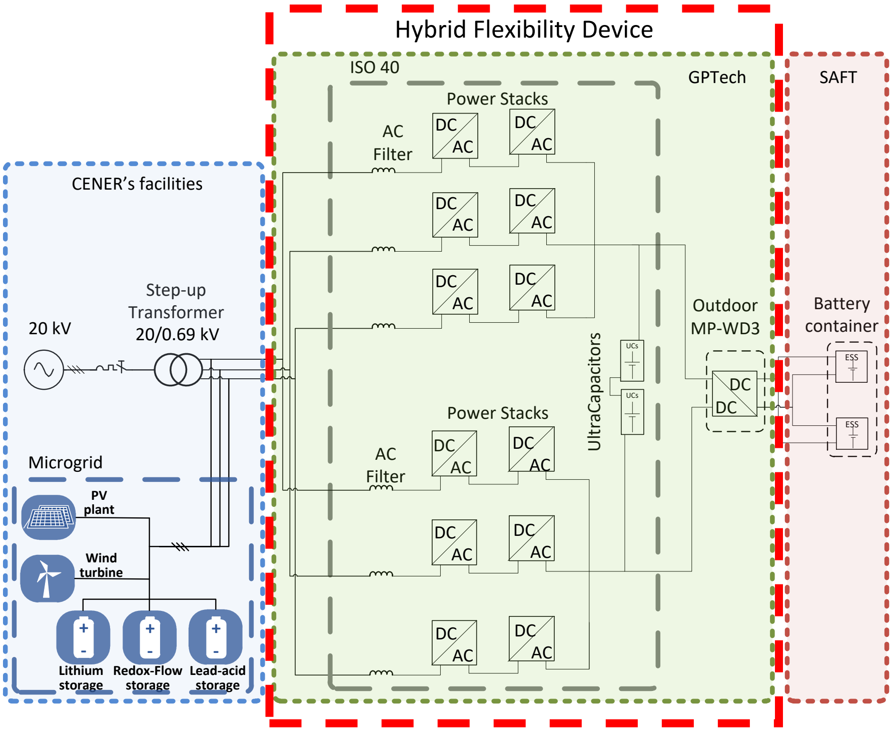
Figure **1** show a simplified diagram of the different components that constitute the hybrid flexibility device developed in the project. The main features of these components are:

- A 4 MVAr STATCOM based on 12 modular multi-level converters
- 2 Supercapacitors providing up to 800 KW (the STATCOM and the supercapacitors are integrated in a single container)
- Lithium-ion battery with 2 MW rated power and an 0,5 MWh energy storage capacity.
- A DC-DC converter that interconnects the STATCOM with the battery

The HFD is connected to the 20 kV AC substation in CENER facilities through a 20/0,69 kV power transformer and also to the existing ATENEA microgrid located also in CENER facilities.

Each of these elements that integrates the HFD are described in detail, with figures, schemes, layouts, etc., in the next sections.

Figure 1. Diagram of the HFD, including components and connection to existing CENER facilities.



2.1 STATCOM plus supercapacitors container

Previous to its manufacturing, STATCOM, including the supercapacitor elements, were redesign after the project location modification. As a result, the final Multi Modular Converter (MMC)-STATCOM was defined with two stages (DC/AC Modular Converters) per phase, obtaining two STATCOM connected between each other through the supercapacitors (check Figure **1**).

While initially, MMC-STATCOM and supercapacitors container integration was separated. Because of the smaller size of the system, both components were considered to be installed in the same container. As a consequence, electrical, mechanical as well as hydraulic cooling systems, among others, needed to be rethought.

The final results of the STATCOM + Supercapacitor redesign are explained in detail in next sections, taking as a guide pictures, schemes and description of the main elements: mechanical par, electrical connection, control and communications links, etc.

Finally, section 2.1.4 shows the manufacturing process followed for the STATCOM + Supercapacitor container.

2.1.1 GENERAL ARRANGEMENT

This section focuses on the mechanical part and the optimal location of the different components taking into account weight, size as well as safety and security of operation.

2.1.1.1 Internal and weight distribution

For the internal distribution of the container, all the elements showed in Table 1 were considered.

Estimated Weights HVPS				
		Weight	Qty	Subtotal
Item	Equipment	kg	Uds	kg
A	Container			
1	Container Enclosure	5125	1	5125
2	Stacks and Structure	1000	2	2000
3	Ucaps+Structure.+Incoming DC	1060	1	1060
4	Inductances+Structure+aux.	2500	2	5000
5	Incoming AC Panel	200	2	400
6	PPC & Aux Panel	800	1	800
7	Transformer 100kVA	360	1	360
8	Copper Bars	250	1	250
9	Container Wiring & Auxiliary Material	600	1	600
10	HVAC	1075	1	1075
11	HVAC Supports	175	1	175
12	Air Ducts	150	1	150
	Total			**16995**

Table 1. Main components and Weight distribution of STATCOM & Supercapacitors container

2.1.1.2 External distribution

Considering external connections -AC auxiliary, AC from transformer and DC from DC-DC converter-, container inputs and outputs, including required elevations, were specified.

Regarding equipment, it is important to highlight the HVAC placed at the top of the container. It is a bulky element that needs to be safely integrated and operated taking into consideration containers height. In fact, disassemble was considered necessary for its transportation from the factory site to CENER.

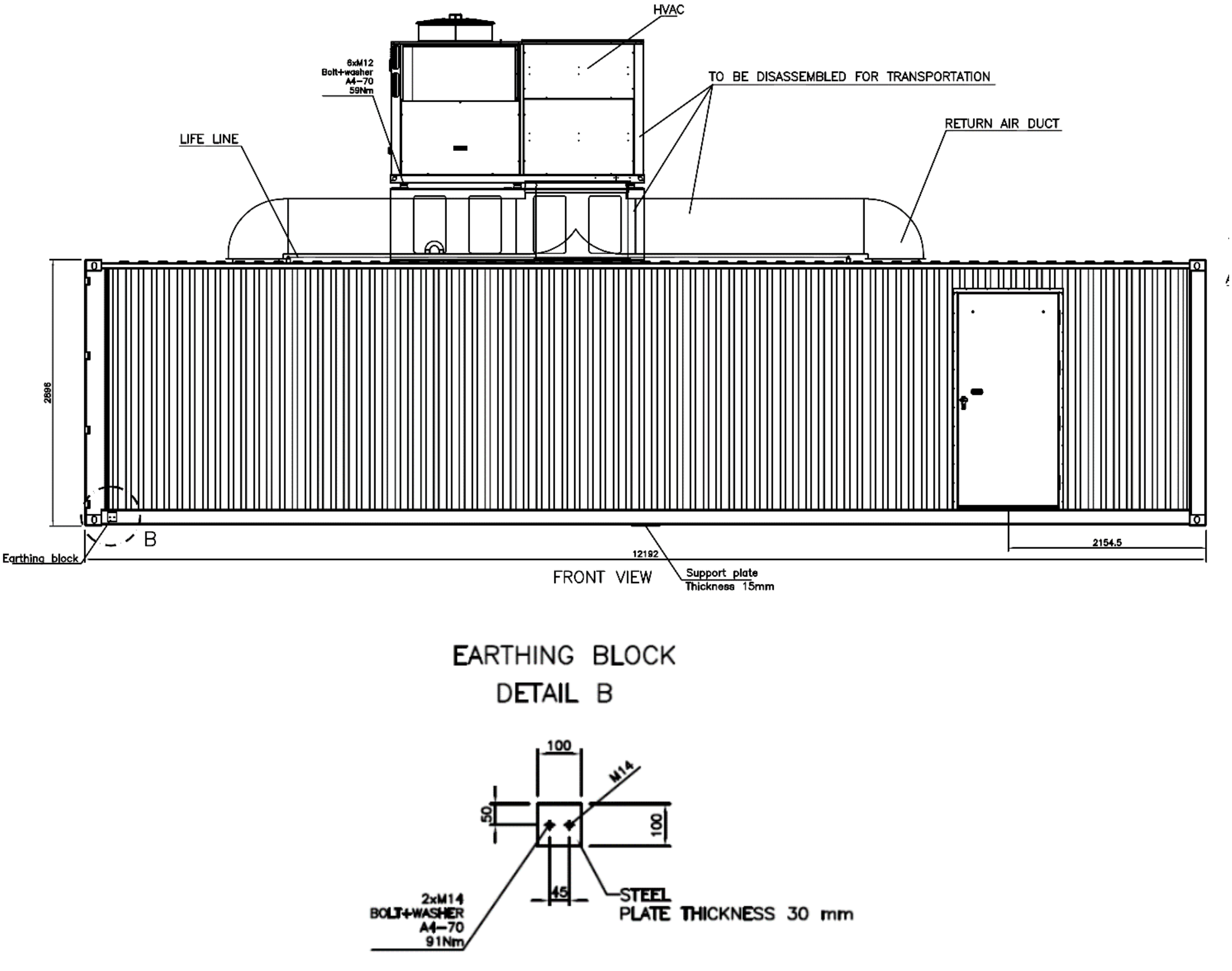


Figure 2. Front view and earthing block of STATCOM & Supercapacitors container

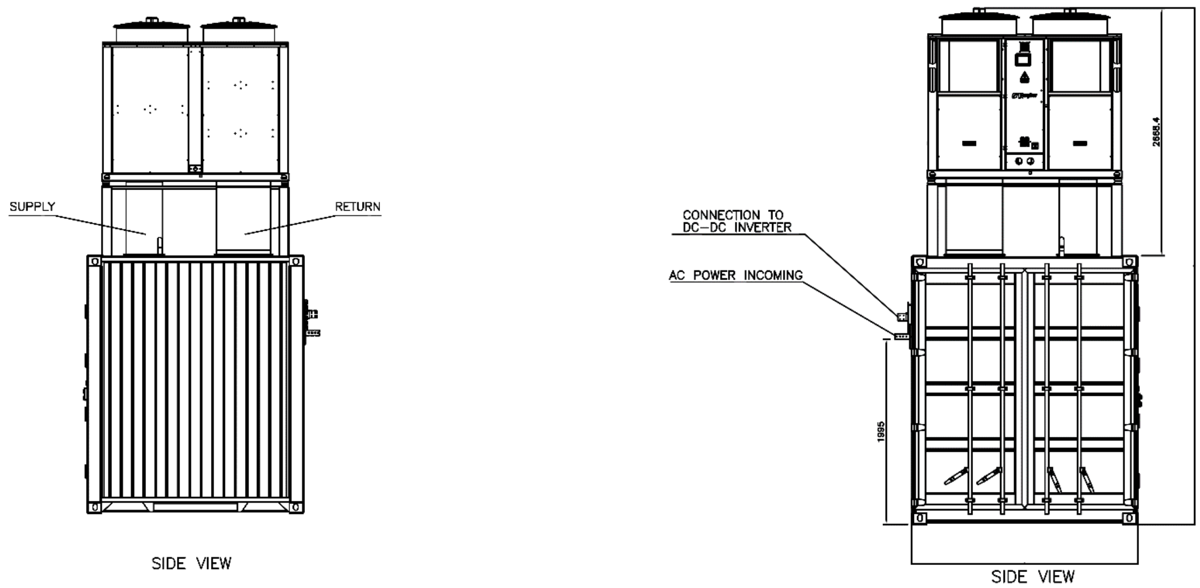


Figure 3. Side Views of STATCOM & Supercapacitors container

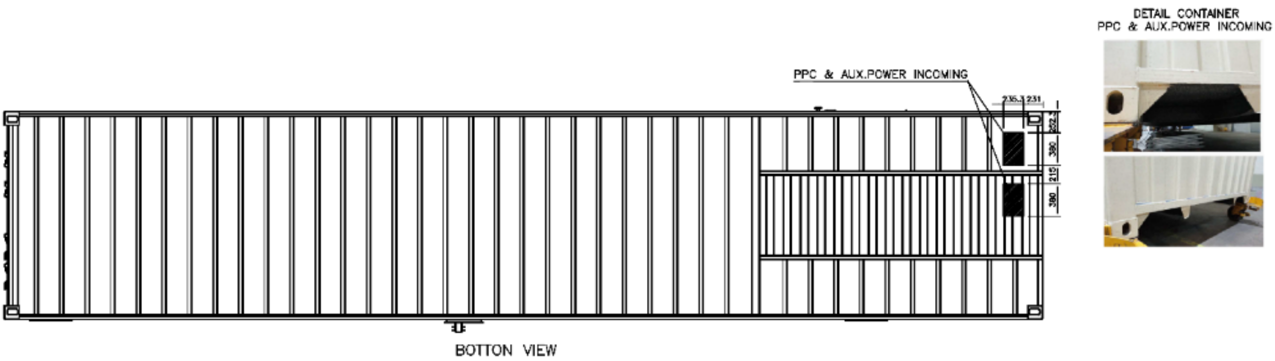


Figure 4. Bottom view of STATCOM & Supercapacitors container

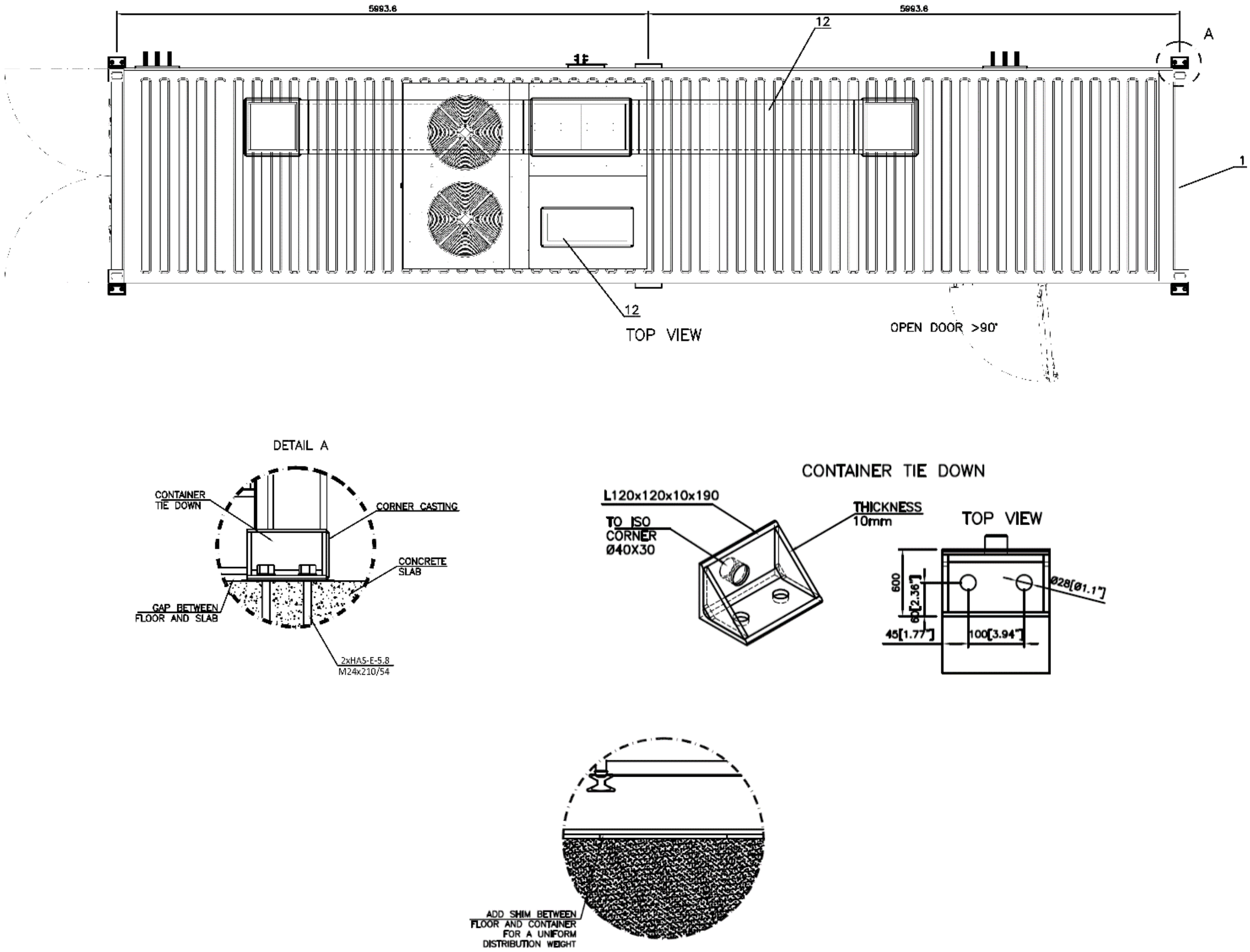


Figure 5. Top View and Tie Down details of STATCOM & Supercapacitors container

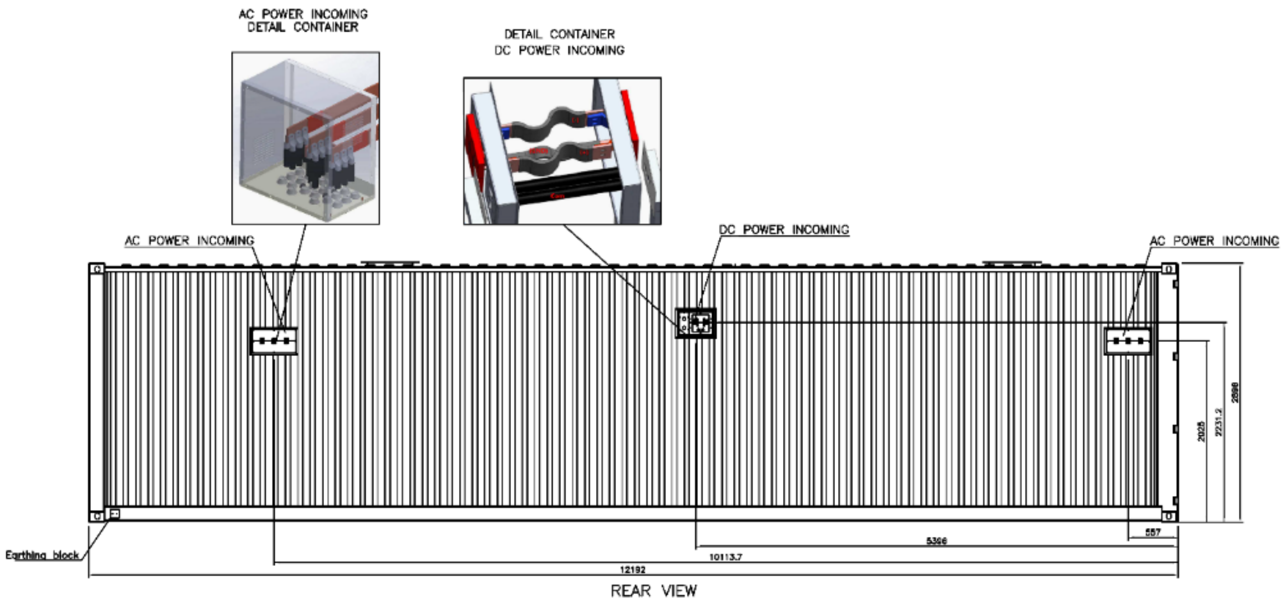


Figure 6. Rear view and AC and DC Power Connections of STATCOM & Supercapacitors container

2.1.1.3 Lifting Requirements:

The main requirements for transportation and lifting of the container are as follows:

- Road transport:

  Road transportation of containers must be carried out in accordance with the regulations of the countries concerned. The transport equipment must be suitable for this usage and have all the safety guarantees in terms of load bearing capacity and of the securing devices.

  Driving should also be on truck roads of enough quality not to damage the equipment set on board.

- Container Unloading Maneuver

  Container handling must be done in accordance with the regulations of the countries concerned, following the approved procedures for these works, and managed by qualified personal.

✓ **Correct container Lifting Methods.**

According to ISO3874 regulation, 40' HC container is allowed to be lifted as follows:

- From upper corner castings using spreader or slings. If container will be lifted in that way, slings must be installed vertically (see images below).

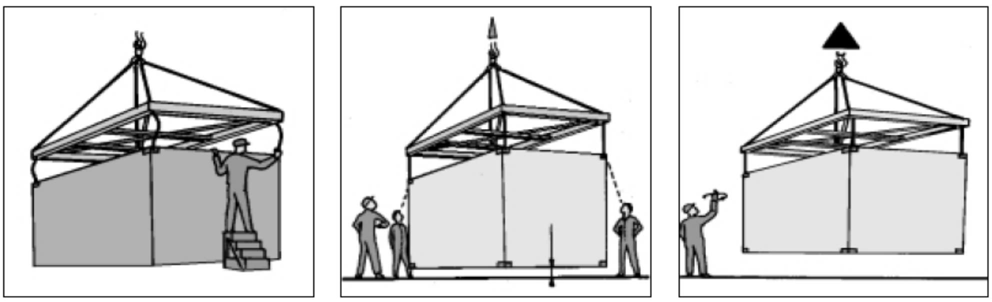


Figure 7. Correct container Lifting Methods from upper corner castings

- From bottom corner castings using sling hooked to a transversal spreader. Slings must have at least 30 degrees from horizontal line. Transversal spreader must be above 500 mm from the top of container.

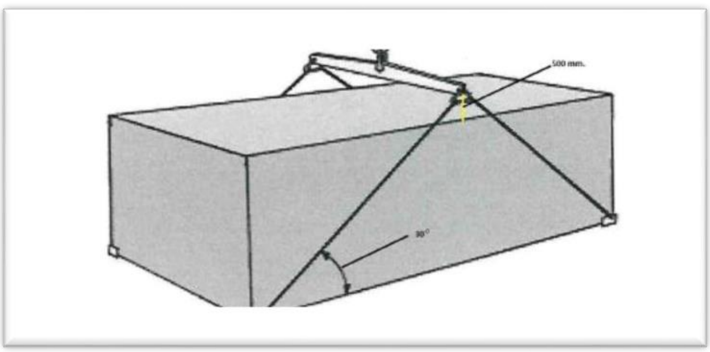


Figure 8. Correct container Lifting Methods from upper corner castings

× Wrong Container Lifting Methods

Some examples:

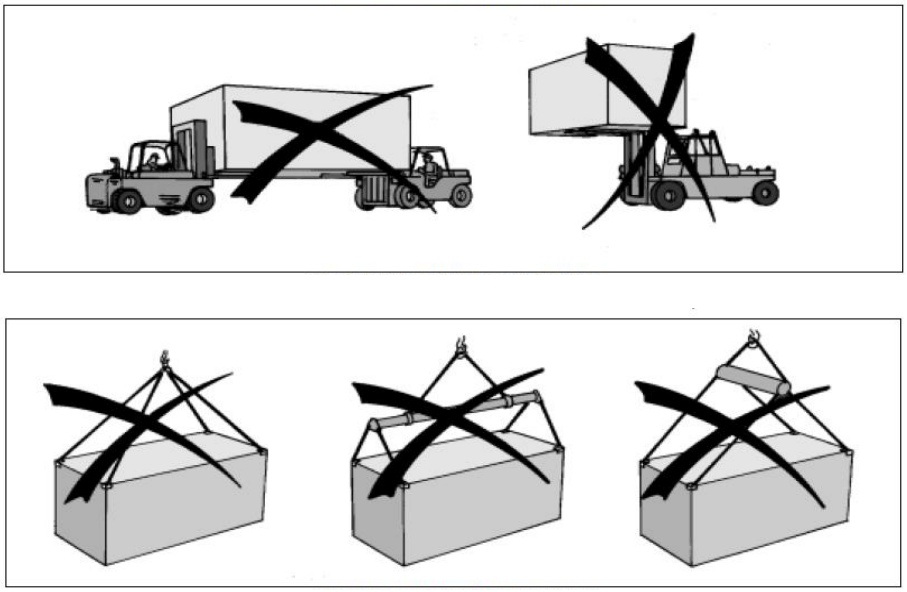


Figure 9. Wrong Container Lifting Methods

2.1.2 POWER CONNECTIONS

With regards to electrical connection as well as control and communication links, an update was implemented taking into consideration AC feeding from 690 V_{AC} and the auxiliary interconnection values. As a results, schemes were generated as can be observed in next sections.

2.1.2.1 AUXILIARIES CONNECTIONS

Auxiliary system took into consideration the features of HVAC and cooling system, apart from the already known control (PPC) and communications boards, sensors as well as all the emergency systems involved. Main aspects considered were:

- Voltage requirements: 400VAC – 3 phases
- Power needed: 50-100KVA
- Grounding: 50 mm2

2.1.2.2 POWER CONNECTIONS & PROTECTIONS

For the power connection, AC and DC sides were differentiated. Connections main features for AC and DC feeders are:

- AC power supply characteristics (ACOM_AC):
  - Voltage: 690 VAC – 3phase
  - Power needed: 2,5MW – 690VAC
  - Two Power Outputs
  - Each output with Copper Plate includes 6 terminals with contained palm 240mm, M12
  - Protections: LSis-IEC AC Breaker WITH KEYLOCK and Button lock (D frame) 1150Vac 1600A
- DC power supply characteristics (ACOM_DC):
  - Voltage: 1500 Vdc
  - Maximum Current: 1600 A
  - Terminal/ Connectors type: Copper Plate.
  - Protections: LSis- Breaker 1500 Vdc 1600A(IEC)

With the MMC topology and the supercapacitor connection chosen (Figure **1**), electrical schemes were generated, as can be observed in:

- Figure 10: Focus on the AC input
- Figure 11: With emphasis on inductance and modules connecton
- And finally, Figure 12 showing ultracapacitors connections.

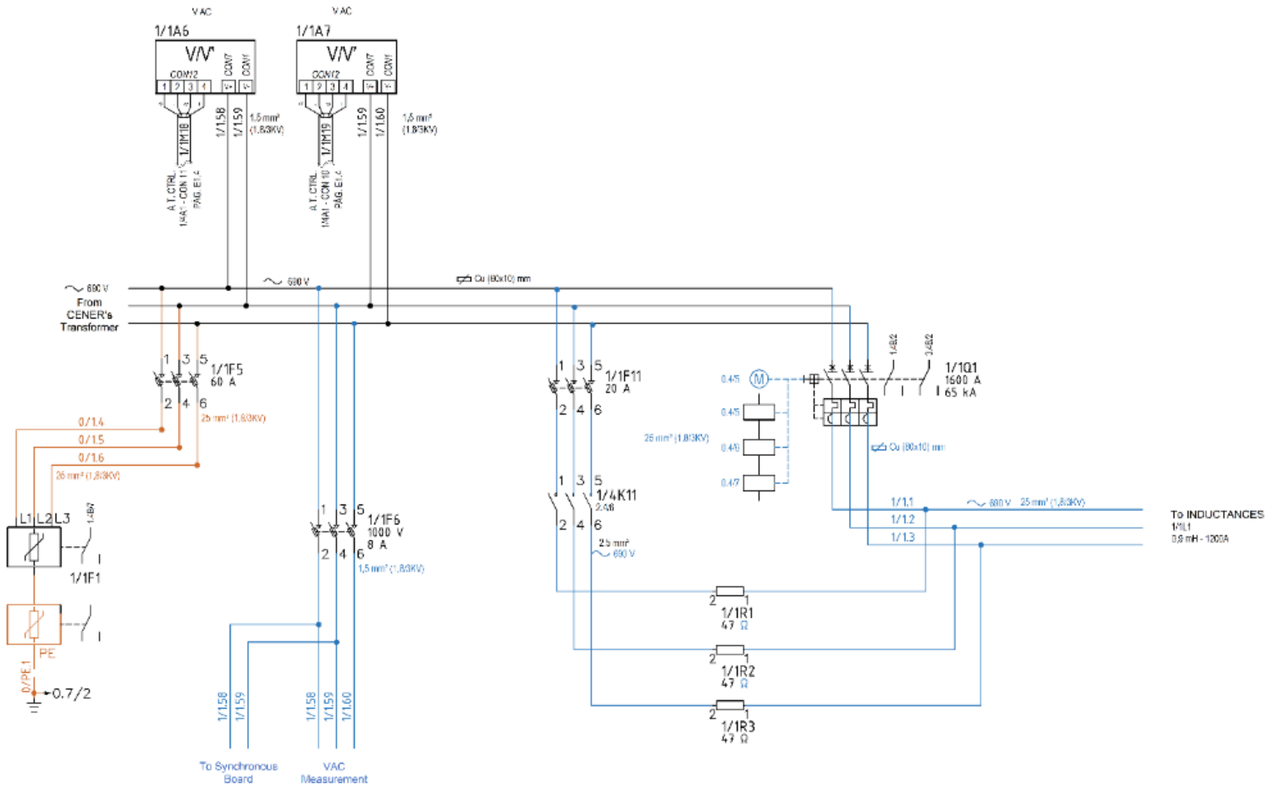


Figure 10. Electrical inputs from 690 V_{AC} power supply external connection

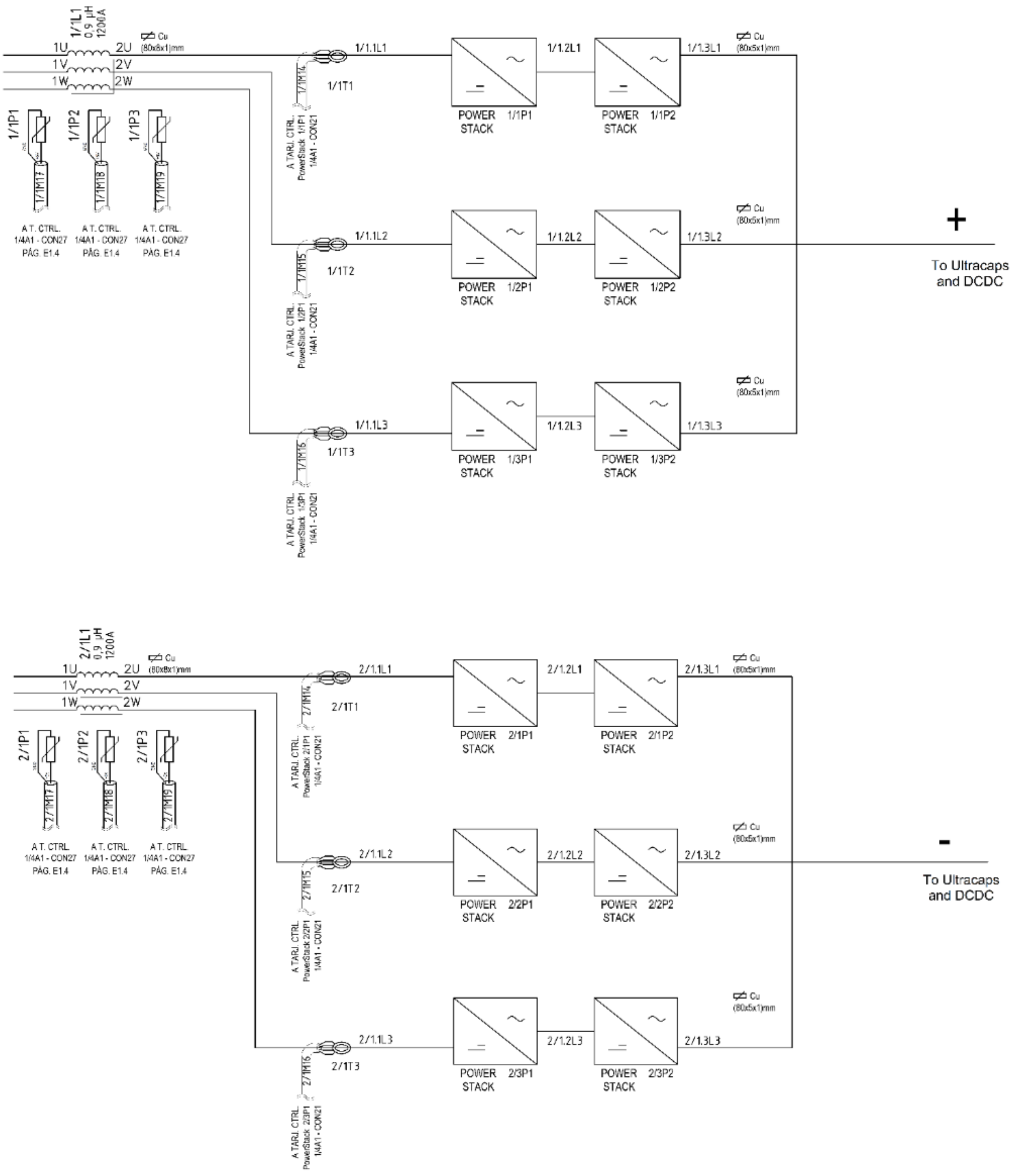


Figure 11. Power stacks and inductances connection

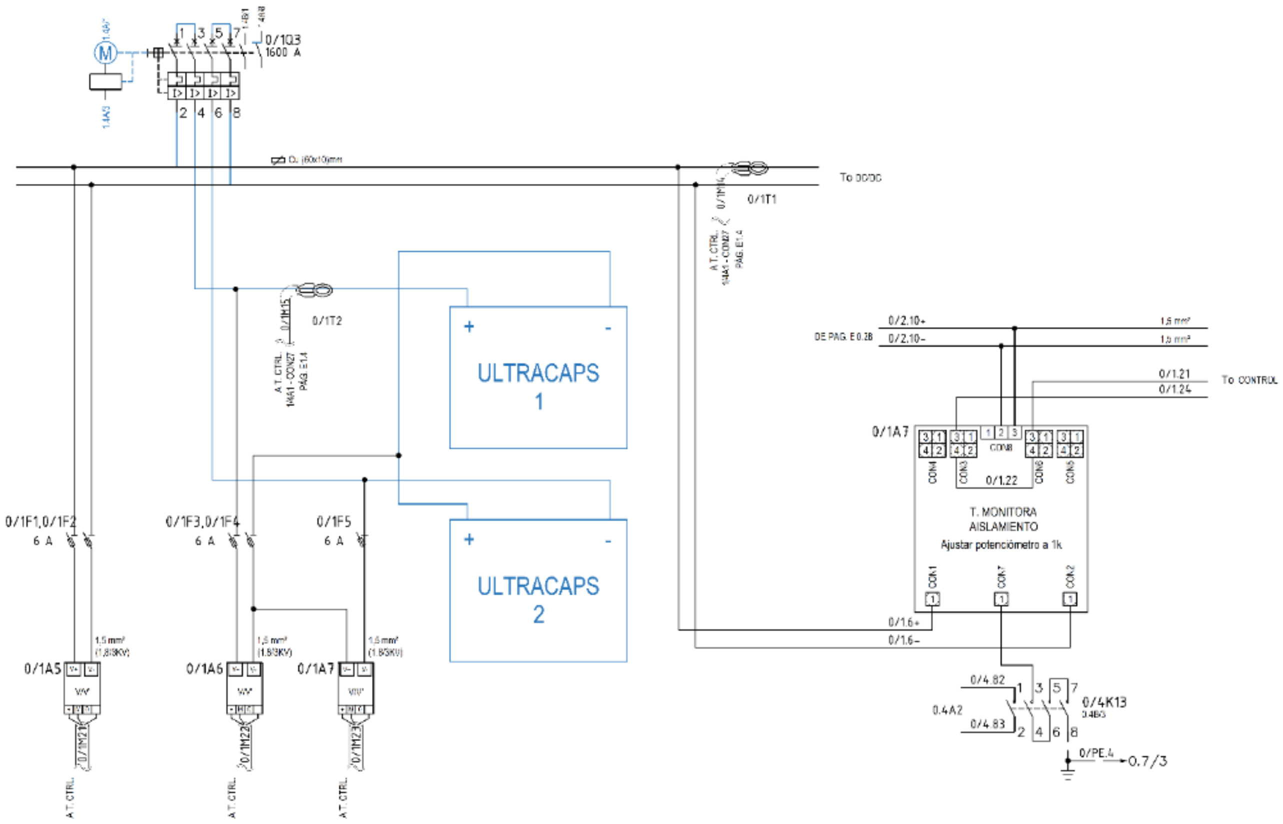


Figure 12. Supercapacitors Connections

2.1.2.3 GROUNDING CONNECTIONS

Grounding is a very important element to consider in this kind of projects working with High Voltages. In HFD case is even more important due to the IT connection required for working. Therefore, STATCOM & Supercapacitors container grounding was defined according to Figure **13** and next description:

- M14 threaded plates
- Cable Metric (mm2): 70 mm2
- 2 external earthing points

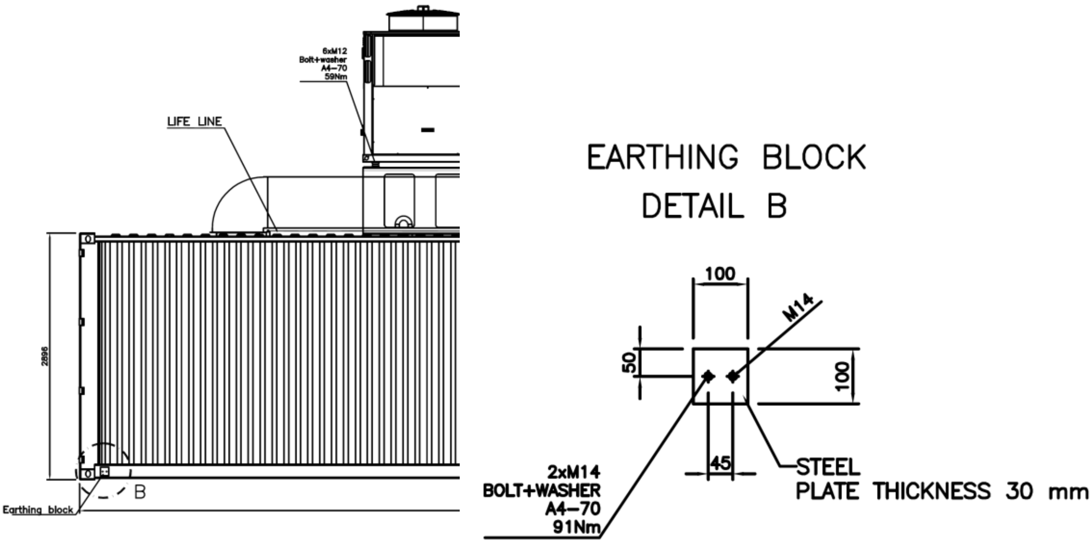


Figure 13: Earthing Block Detail – STATCOM & Supercapacitors container

2.1.3 HYDRAULIC CICUIT

The high power and high operating currents of the modules that constitute the MMC-STATCOM imply enormous amounts of heat release. As a consequence, it requires from a cooling system based on liquid refrigerant. These types of cooling systems are not usually installed in power electronics solutions because of the difficulties and risks of mixing water and electricity, being the air cooled (forced or natural) systems the most common ones. However, one of the innovations of the project and the future of the HFD is related with its capability to work with high currents levels, implying a liquid cooling solution for the refrigeration of the power stacks.

Considering the designed power system and the expected losses, and once all the elements were placed in the container, the hydraulic circuit was generated. Figure 14 show all the elements outside the container, including pipelines, temperature and pressure sensors, heat exchangers or pumps, among others. Both cool and hot water pipes are represented.

It is important to note that water is very corrosive to copper elements. Therefore, inox steel or adequate plastic material was required. However, a balance between cost and estimated corrosion during the expected operation time was considered in order to obtain the optimal option, selecting inox steel and best materials for critical elements.

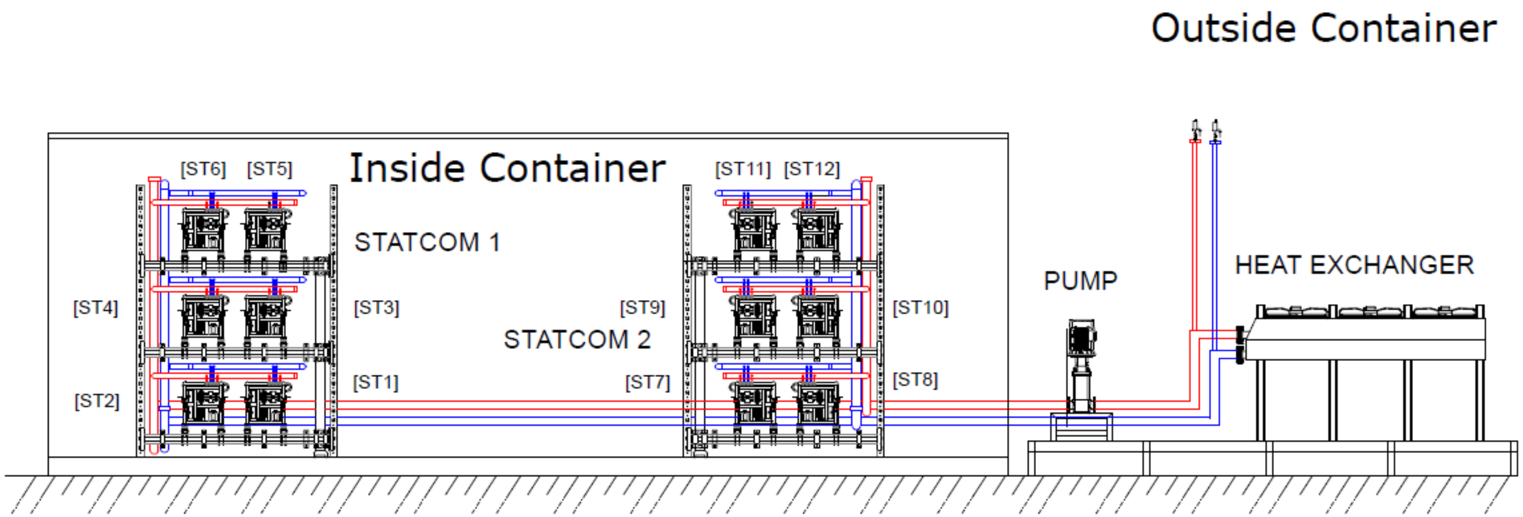


Figure 14. Hydraulic Circuit General Layout for the STATCOM & Supercapacitors container

2.1.4 INTEGRATION STAGE AT FACTORY

After final design and engineering of main parts, described in previous sections; manufacturing and integration phase took place. Next figures show the main stages during the construction of the STATCOM and supercapacitors container:

- **Internal Container Adequacy**

Figure 15. Container Adequacy

- **Assembling of the inductances, protections and power electronics stacks**

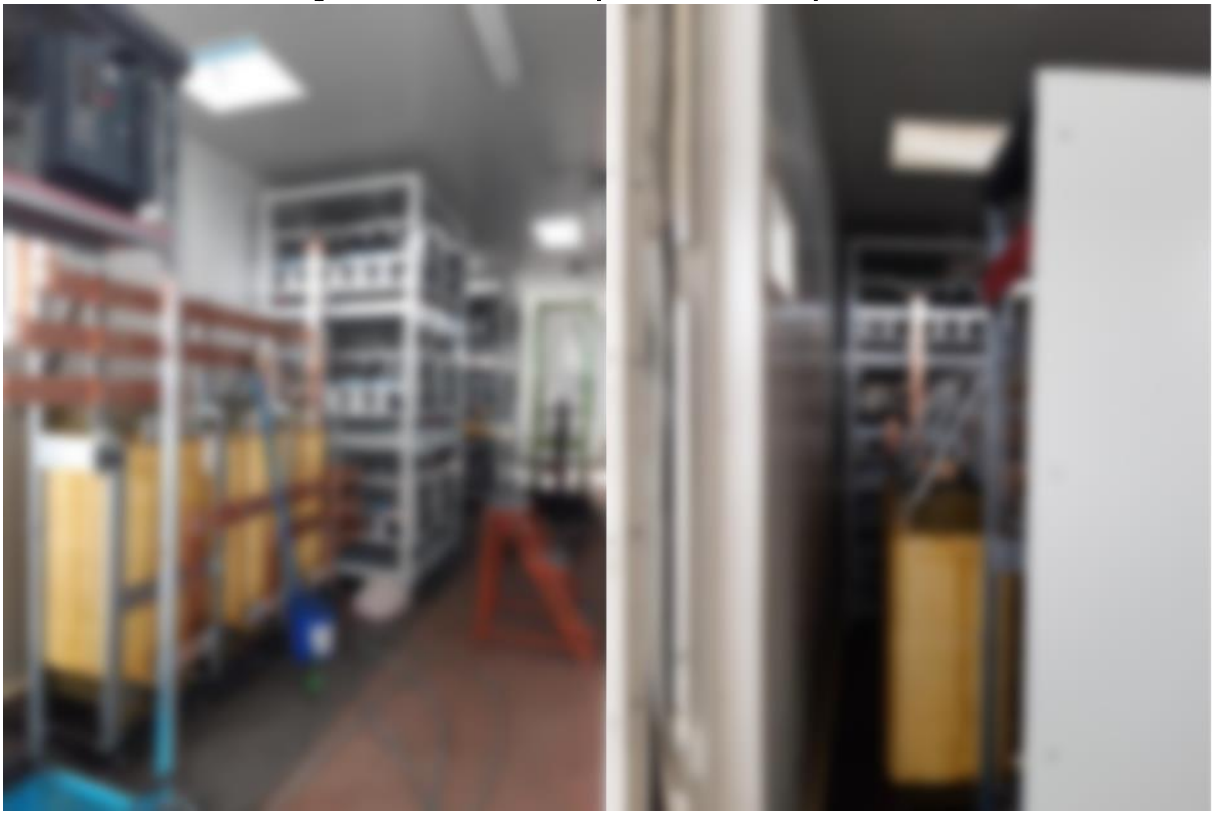


Figure 16. Inductance, Protections and stacks installation

- **HVAC**

Figure 17.HVAC of the STATCOM & Supercapacitors container

- **External liquid cooling system and heat exchanger**

Figure 18. Pumps and pipelines

- **Internal liquid cooling system**

Figure 19. Internal Cooling Systems

- **External electrical connection (DCDC and AC)**

Figure 20. DC-DC connection

Figure 21. AC output connection

2.2 DC-DC converter

Figure 22 illustrates the real picture of DC-DC converter developed as a component of the HFD. Cabinet design and power connections of the DC-DC converter implemented are described in next sections.

Figure 22. DC-DC converter developed in the project and its connection at the test bench for the factory acceptance tests

2.2.1 DESIGN AND GENERAL CHARACTERISTICS

Figure **23** and **Figure 24** shows the schematic of the DC-DC converter cabinet that integrates the HFD. Dimensions and structural characteristics are also included. The converter has a weight of 2800kg, elevation height equal to the inverter outlet height plus 200mm.The container will be placed over metal pillars and it must be anchored to these pillars.

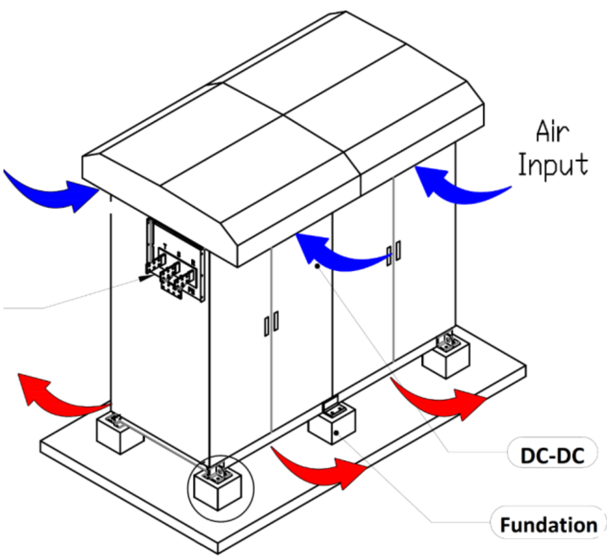


Figure 23: DC/DC Architecture.

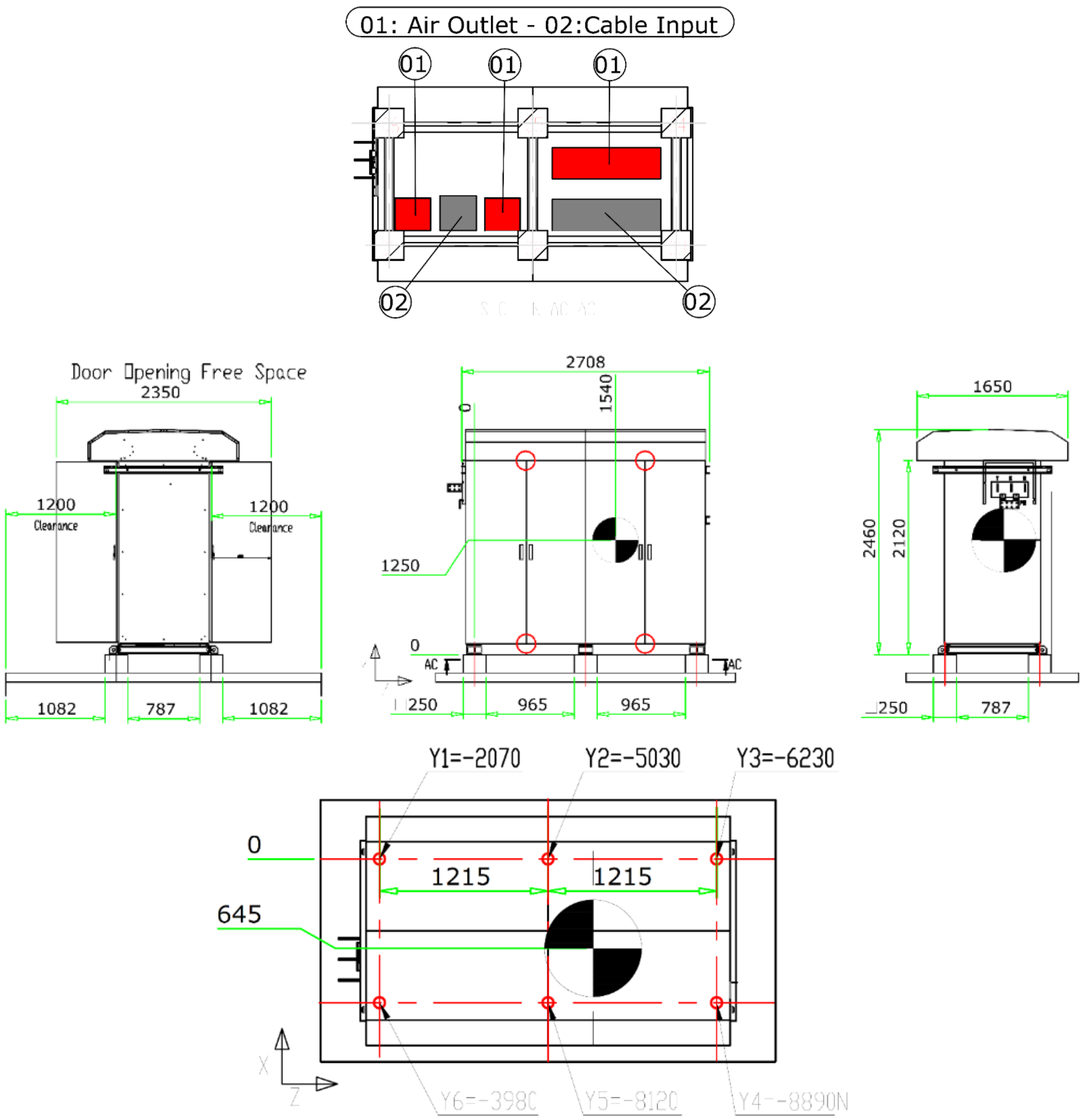


Figure 24: DC/DC – MP WD Cabinet

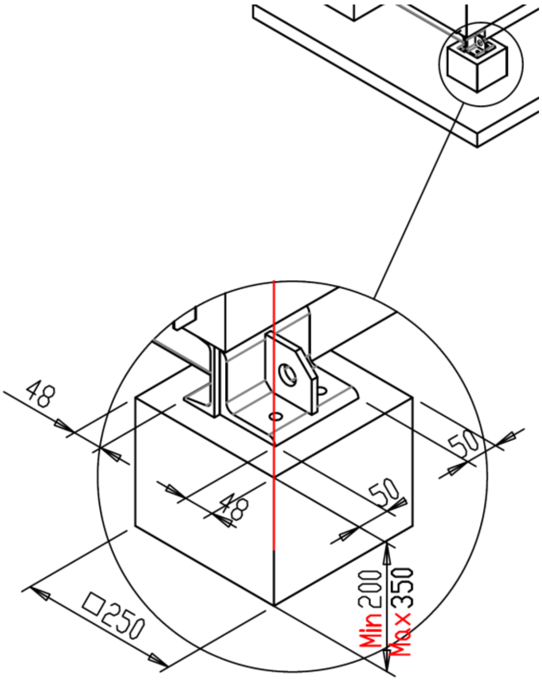


Figure 25. Foundation Position Detail

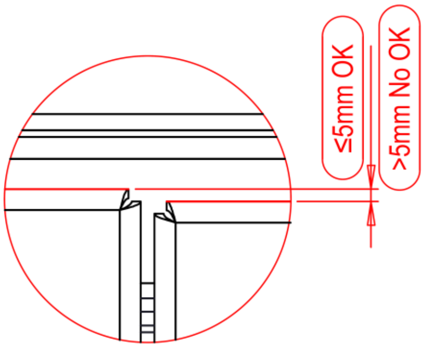


Figure 26. Door Level Check Detail

Notes:
- Installation site requires minimum clearance distances to guarantee proper ventilation at the bottom part of at least 200 mm
- The shown foundation is a proposal.
- The mounting surface must be levelled. The evenness of the foundation must be better than 0.1 %.
- The diference of height between every anchoring points must be less than ±3mm
- The DC input wiring must be perpendicular to the WD3 bottom how it is indicated in the document: WD3_15_065_Wire Cable Input Detail.

2.2.2 POWER CONNECTIONS

Main characteristics of the power connections of the DC-DC converter are:

- Maximum Voltage level: 1300 V_{DC} Input- 1500 V_{DC} Output
- Maximum Current (Input and Output): 1600 A
- Terminal/ Connectors type: Copper Plate terminals with contained palm 240mm, M12
- Up to 6 pair of cable per DC line (2 DC lines). Check Figure 27.
- 4 cables for grounding. Cable Metric (mm2): 50 mm2

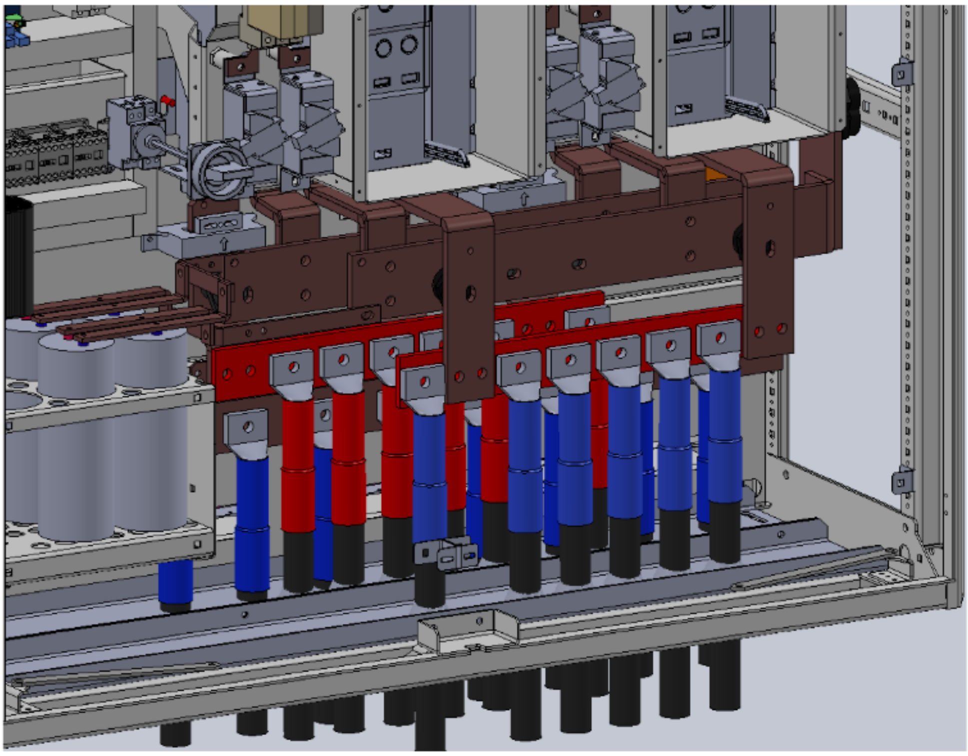


Figure 27. DCDC input and connectors for DC battery side

2.3 HFD and DCDC

Once HFD container and DC-DC converter was defined, implementation on field was considered. Figure 28 to Figure 31 show the layout of the “STATCOM + Supercapacitor’s container” and the DC-DC converter, including the heat exchanger and other hydraulic systems. The required zones for working, installation and maintenance access are also represented.

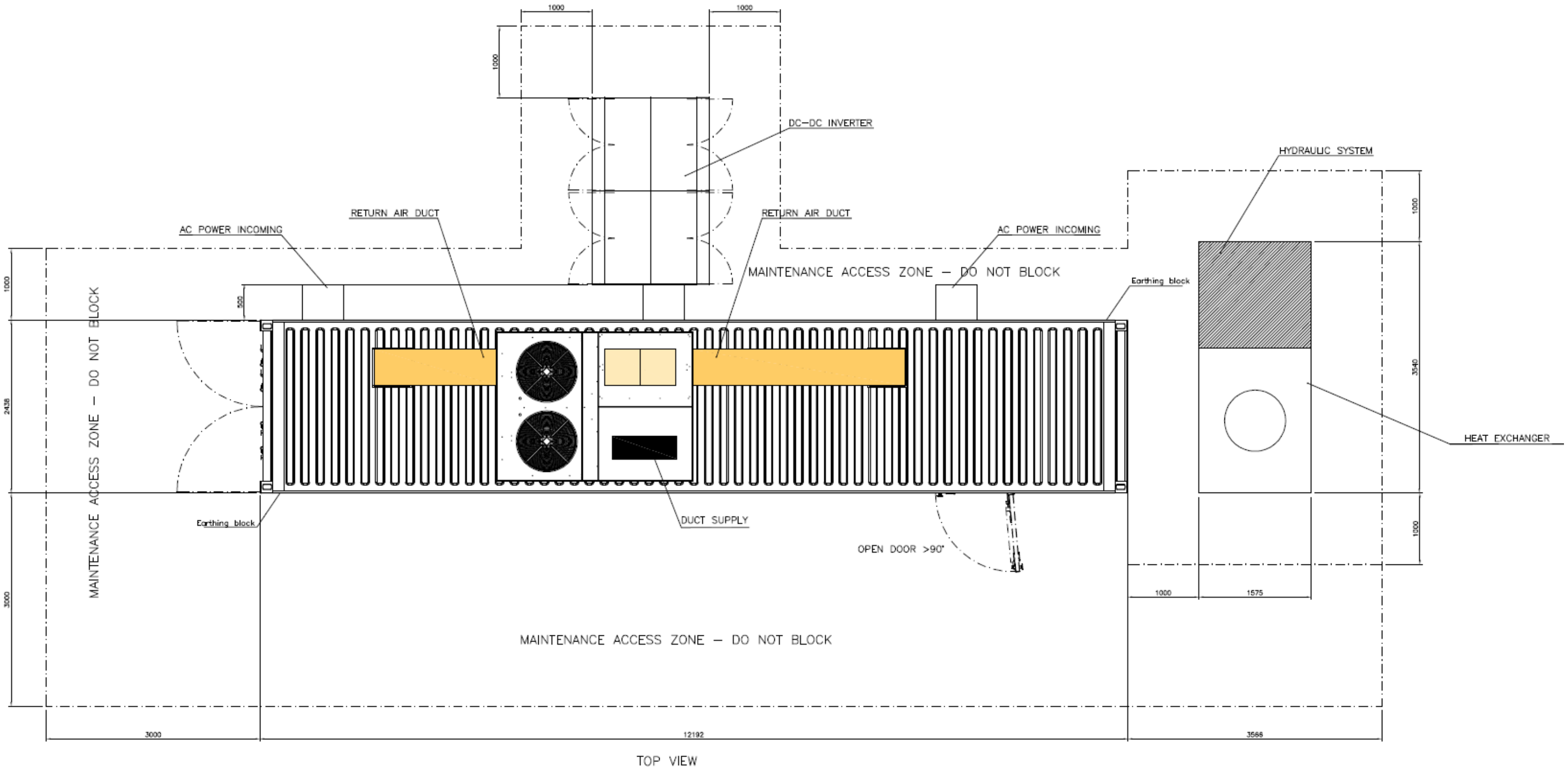


Figure 28. All components Top View.

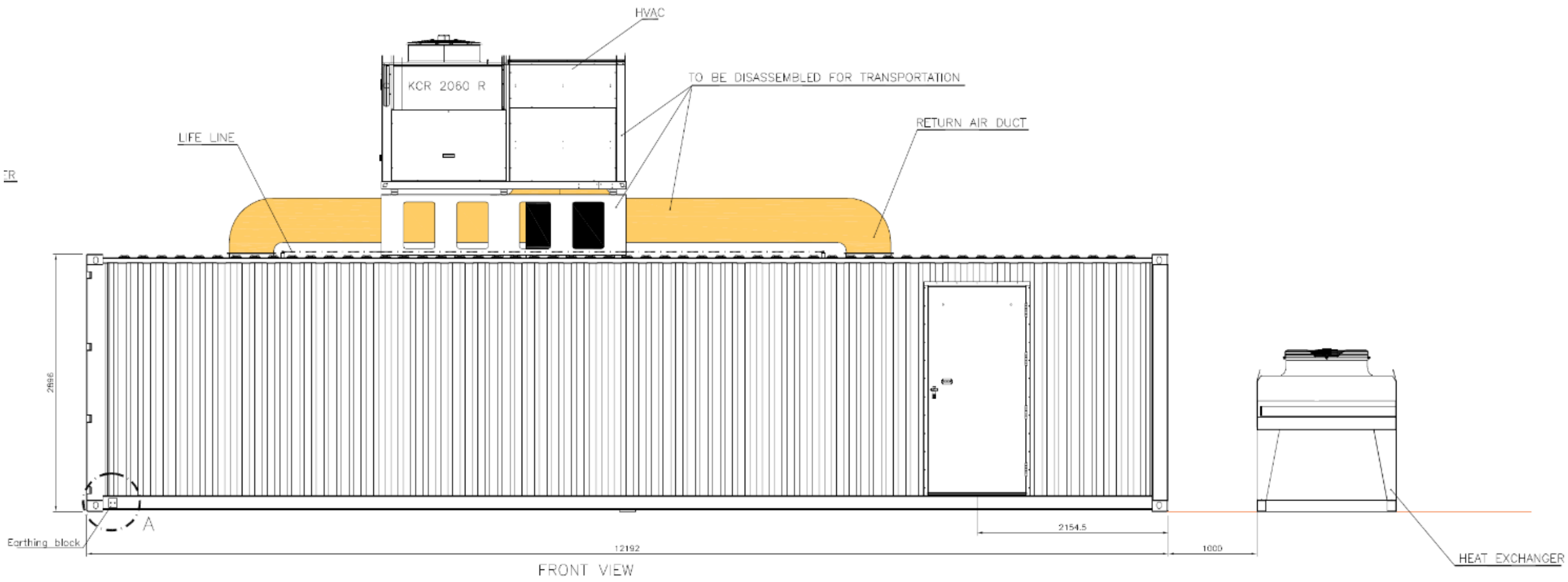


Figure 29. All components Front View

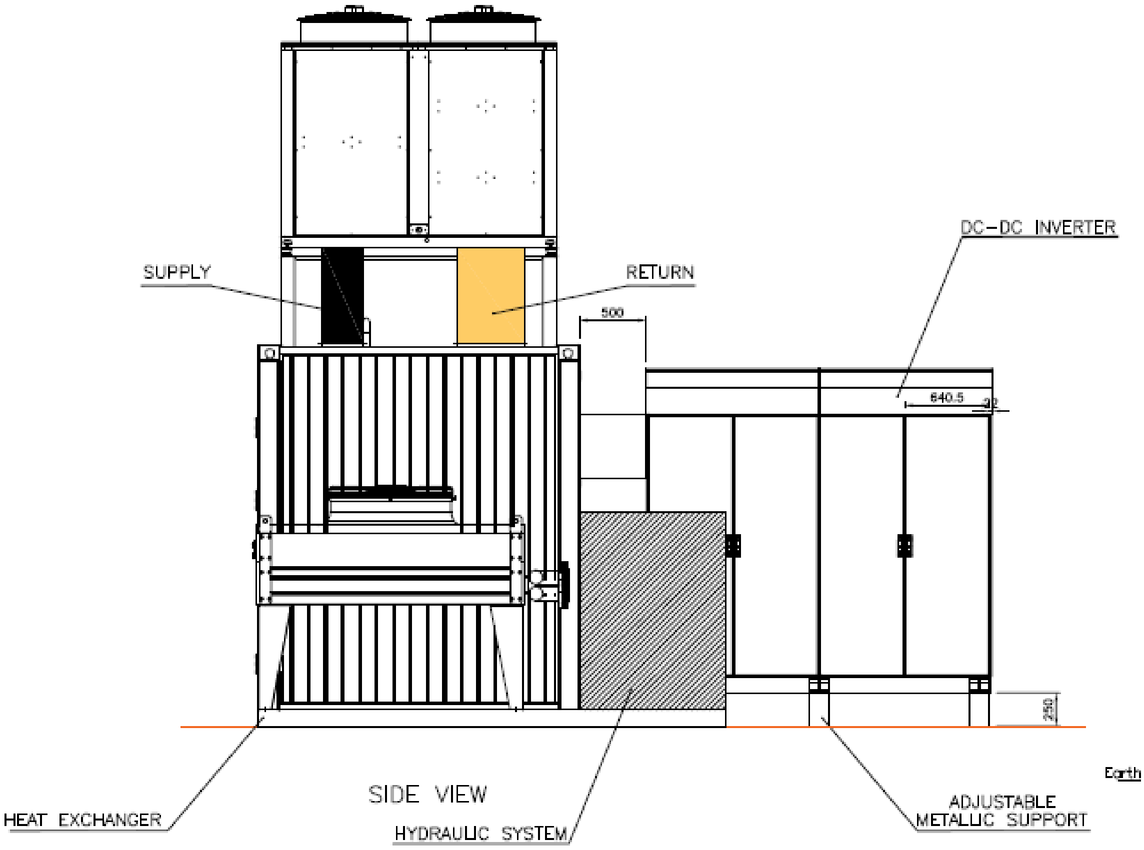


Figure 30. All components Right Side View

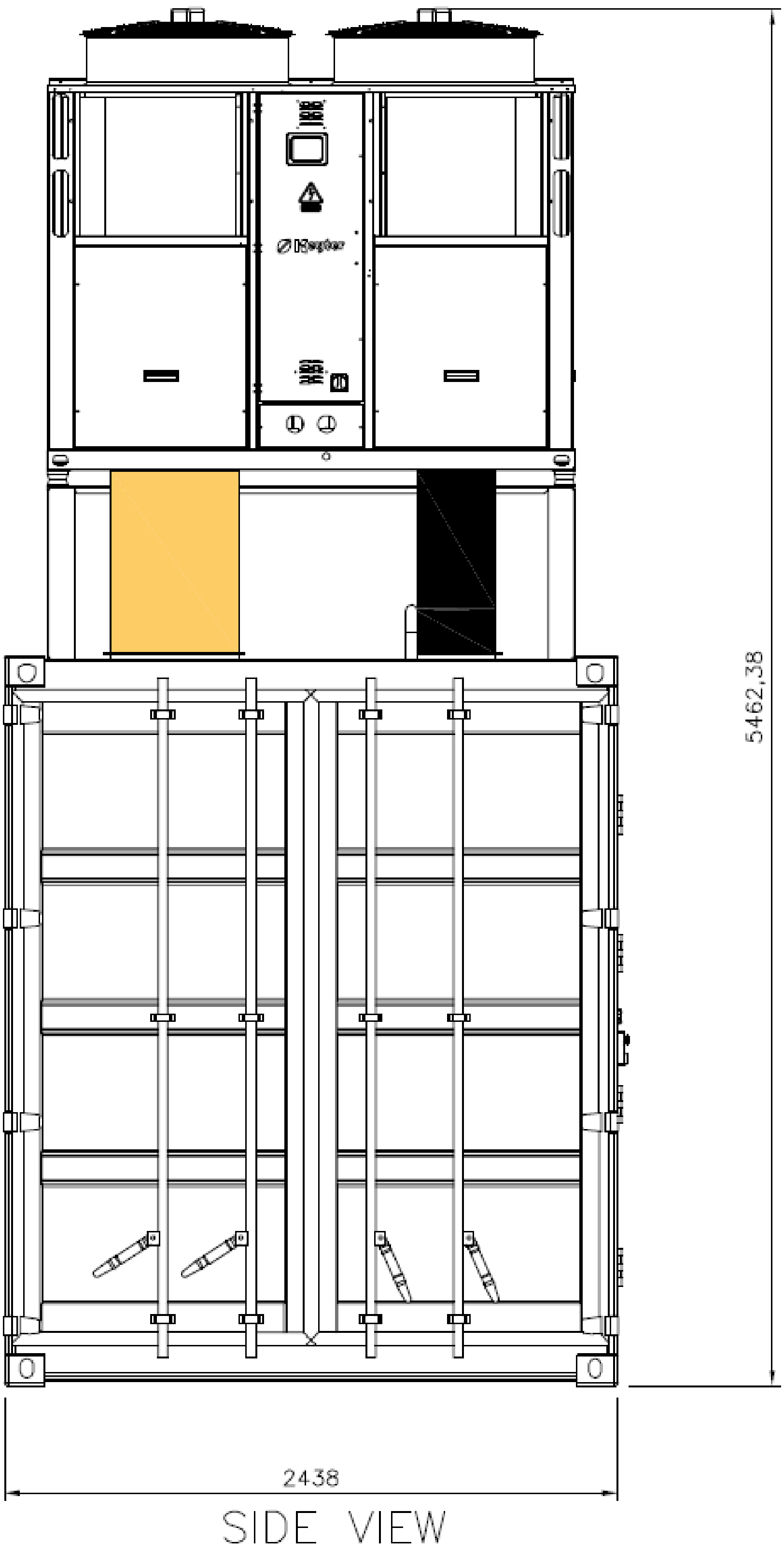


Figure 31. All components Left Side View

3 High Voltage lithium-ion battery

The lithium-ion battery system is another of the key devices that constitutes the HFD. Characteristics, equipment, layout, and architecture of this battery system are described in Deliverable D4.2 FAT High voltage lithium-ion battery. The manufacturing process and the factory acceptance tests conducted are also available in this deliverable. To consult this information the reader is referred to this deliverable published in the following link of the project website

4 Control and Communications

The communication and control diagram defined for the HFD is illustrated in Figure 32. Three PLCs are considered for the project:

- **HFD PLC**: it has the general objective of managing of the whole HFD (STATCOM+ DC-DC converters + supercapacitors +battery).
  This PLC is the only one that should receive write requests. This device will ensure the transmission of references and enabling controls to the others two PLCs.
- **SFD_1 PLC:** A PLC to manage the container with the STATCOM capabilities and the ULTRACAPs.
- **SFD_2 PLC:** A PLC to manage the DCDC and the SAFT battery.

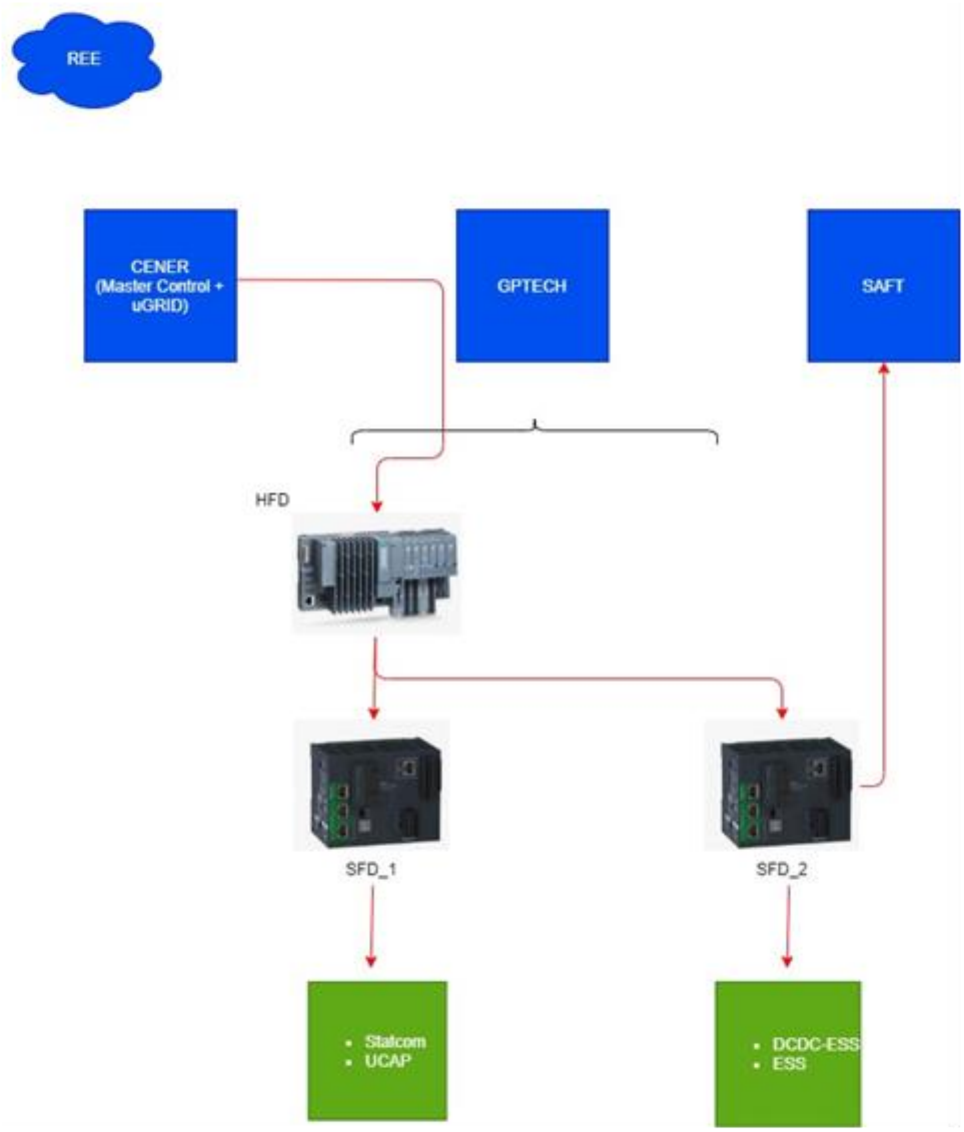


Figure 32. HFD and DCDC Communication&Control scheme

For reading the particular data of the different HFD components (STATCOM, supercapacitors, DC-DC converter, battery system), managed by the SFD_1 and SFD_2 PLCs, there are no limitation of Modbus clients. However, written processes are not possible on any them, since that is only possible on the HFD-PLC.

In the case of the HFD-PLC, it only allows one client per Modbus server. For this reason, it has three ports available:

- 502: Manual: This is used for maintenance performed by GPTech.
- 10502: Local: This is generally used for SCADA
- 10503: Remote: This is used for an external connection, in this case REE or CENER Master Control

Therefore, there is a variable in the HFD that, depending on its value, indicates which port control the plant.

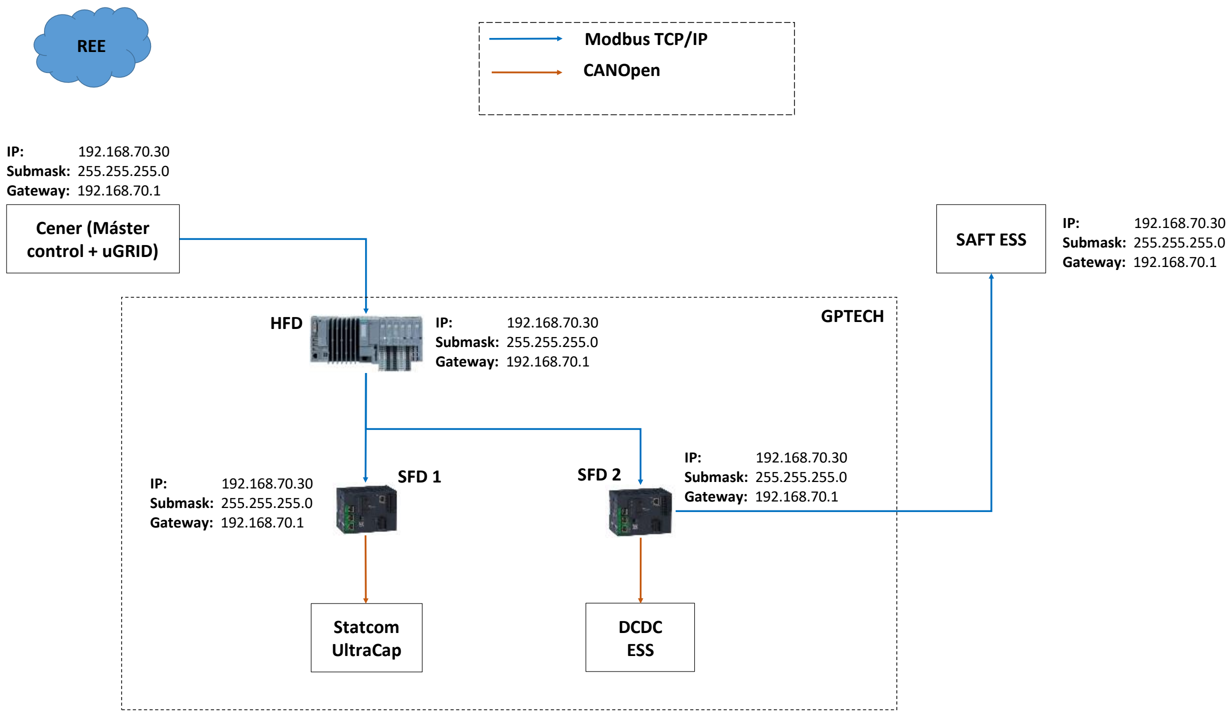


Figure 33. Network Schematic

5 Factory acceptance test of the Hybrid Flexibility Device

This section described the Factory Acceptance Test (FAT) procedure applied and main results obtained for the STATCOM and supercapacitors container as well as the DC-DC converter. FAT results for the high voltage lithium-ion battery are not included in this section as they are already described in Deliverable 4.2 FAT HV lithium-Ion battery already elaborated in the project.

5.1 Test bench overview

The test bench has been designed specifically for OSMOSE project to work with the HFD and DC/DC. It is compound of a grid emulator (E1) to which the HFD is connected through transformer T1, and a rectifier (E2) that supplies system losses and maintains DC bus. Both converters are GPTech PV100. This test bench is simplified in Figure 34.

First, the rectifier E2 is started using a preload system consisting of a diode bridge. It increases DC voltage up to 950 V due to PV100 limitation. Then, inverter E1 is started and set AC voltage to 400 V due to PV100 limitation. Finally, OSMOSE DC/DC and HFD can be started following normal operation.

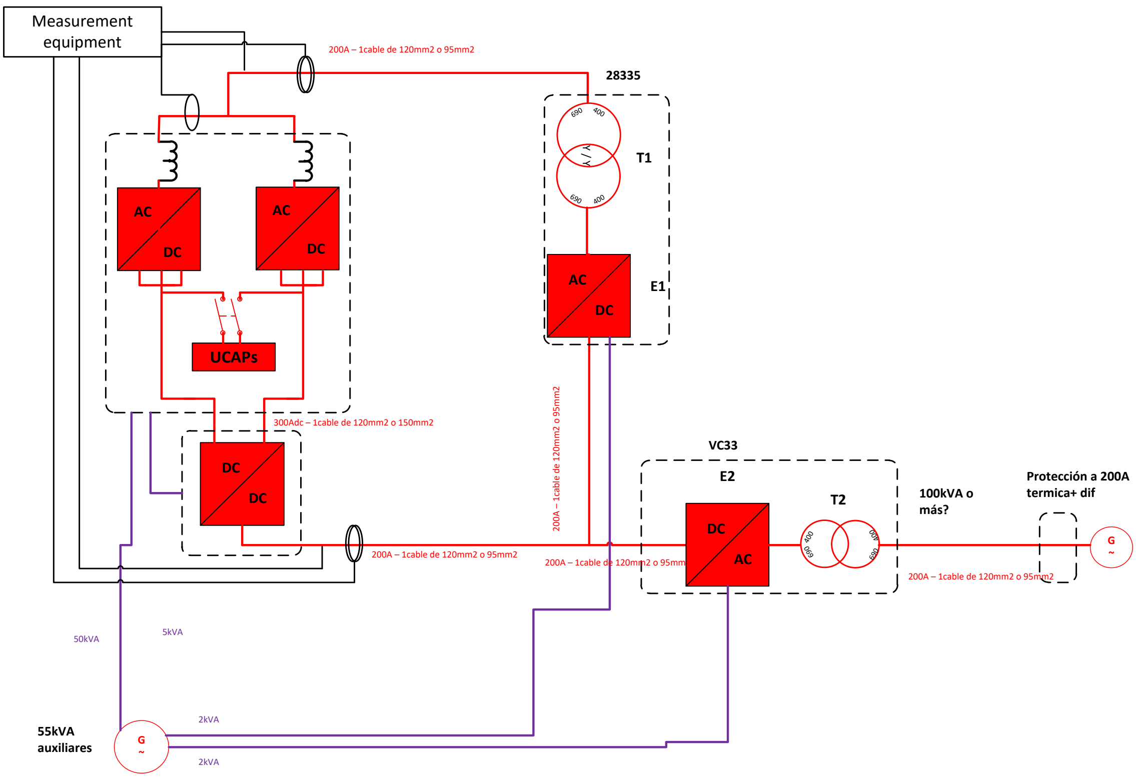


Figure 34. Simplified scheme of the HFD test bench

Figure 35. Test bench during REE visit

5.2 Description of the FAT conducted

The FAT was fully described in and internal document, next description shows a summary of the needed resources and test implemented.

The equipment required is listed and described below:

- Personal computer with Windows operating system with Ethernet port.
- 6-pin JTAG-USB FPGA programmer from Diligent (only if it's necessary to program the control board).
- Oscilloscope with isolated channels.
- Multimeter with AC/DC voltage and current function (with at least 0.5% accuracy).
- Current sensor up to 2000A with male BNC connector to oscilloscope. It is recommended a flexible Rogowski current sensor.
- Voltage test probe up to 2000V ac/dc.
- Grid analyzer with probes that allow DC / AC measurements up to 2000 Arms. It is recommended Yokogawa WT 3000 or 1600 and current sensors CURACC 1.0 (version c40-5) or others with a similar accuracy. (see also)

- Infrared camera.
- Datalogger with inputs intended for DC voltage, thermocouples and 3-wire RTD. It is recommended Yokogawa WT100 with accessories for at least 30 inputs, similar equipment could be used, please address GPTech staff for approval.
- Thermocouples. It is recommended thermocouples type K with at least 3 m length.
- Megger isolation tester. It is recommended model C.A. 5445 from Chauvin Arnoux or similar equipment, please address GPTech staff from approval.
- 25Vdc adjustable power supply.
- Adjustable current source (capable to supply at least 25A).
- User interface for control & monitoring power inverter (sFoto).
- SW-Kit program provided by GPTech.
- Spray nozzle or hose nozzle, it is recommended those indicated in section 14 of the IEC 60529 standard. A water source able to provide at least 1 bar pressure using this nozzle.
- Yokogawa configuration file. See for more details.

To measure efficiency, THD and power factor, the installation of a grid analyzer was required. As shown in Figure 34, AC magnitudes are measured at HFD output, where the two output connections join. DC magnitudes measurement for the power analyzer was done at the input of DC/DC. This connection applied for the whole routine tests.

To record the measurements, an Ethernet connection was used between Yokogawa and a PC using WTViewer software.

The tests performed during the FAT check were the following ones:

- Cold component Validation:
    - Test 1: Validation of component feeds under no-loads conditions.
    - Test 2: Validation of the Off state of the IGBTs.
    - Test 3: IGBTs switching validation.
- Protections Validation:
    - Test 1: Overcurrent protection validation.
    - Test 2: Network overvoltage protection validation.
    - Test 3: Validation of continuous overvoltage protection in module.
    - Test 4: Validation of overtemperature protection module.
- Losses Validation:
    - Test 1: Validation of losses without load.
    - Test 2: Validation of losses with reactive power.
- Steady State validation.
    - Test 1: Validation of components with inductive reactive power.
    - Test 2: Validation of components with capacitive reactive power.
- Enclosure IP test

5.2.1 Cold component test

The first validation of the system are power supplies and trigger signals inspection. For that purpose, next will be checked:

- Local power supplies of the modules
- Power module's ability to keep the semiconductors IGBTs off
- Correct addressing of the switching references through the fiber optic communications network

All these tests are carried out without power voltage, but with auxiliary voltage.

The following procedure will be carried out.

Title	**Test 1.1: Validation of component feeds under no-load conditions.**	
Parameter	**Description**	
Auxiliary Power Supply	**Objective**	Check the correct operation of components with just auxiliary voltage.
	Procedure	The batteries of the modules will be charged. Later they will be activated by the operator and the supply voltages will be checked in the different nodes of the auxiliary circuit.
	Acceptance criteria	Battery voltage 24 V ±30% UPS output voltage 24 V ±30% DC/DC converter output voltage15V ±10%

Title	**Test 1.2: Off state validation of IGBTs.**	
Parameter	**Description**	
Off state of IGBTs	**Objective**	Verify that IGBTs maintain the open state while at rest.
	Procedure	The gate voltage of the IGBT will be measured with the module feed by the auxiliary battery power.
	Acceptance criteria	Gate-emitter voltage between -9 V and -12 V.

Title	**Test 1.3: IGBTs switching validation**	
Parameter	**Description**	
Off state of IGBTs	**Objective**	Verify that the IGBTs are capable of switching.
	Procedure	The switching of each module will be verified. For this, a 24V DC voltage source must be connected to the DC bus. Then, a modulation index setpoint equal to 0.875will be sent.
	Acceptance criteria	Switching frequency = 2000 Hz ± 2% Pulse width equal to 75%.

5.2.2 Protections Test

Before proceeding with the start-up and nominal operation, it is important to check that its self-protection system works correctly in order to avoid future breakages during the tests.

The following procedure will be carried out:

Title	**Test 2.1: Overcurrent protection validation**	
Parameter	**Description**	
Current Limit	**Objective**	To verify that the equipment has the capacity to stop when it measures a current higher than the maximum set by the operator.
	Procedure	A current limit equal to 0.5 p.u. of the nominal value will be established. Then, the equipment is taken to the stationary regime with a reactive power setpoint equal to 0.05 p.u. of the nominal value to later assign a setpoint of 1 p.u. of inductive reactive power.
	Acceptance criteria	Equipment shutdown Shutdown Iac = I limit ±20%.

Title	**Test 2.2: Network overvoltage protection validation**	
Parameter	**Description**	
AC voltage limit	**Objective**	To verify the equipment has the ability to stop when it measures a network voltage higher than the maximum established by the operator.
	Procedure	A voltage limit equal to 1.4 p.u. of the nominal value will be established. The equipment is started with a reactive power reference equal to 0.5 p.u. of the nominal. Then, the network voltage will be increased to 1.41 p.u. of the nominal value.
	Acceptance criteria	Equipment stops Stop Vac = V limit ± 20%

Title	**Test 2.3: Continuous overvoltage protection in module.**	
Parameter	**Description**	
DC voltage limit	**Objective**	To verify that the equipment has the capacity to give error when measuring a continuous voltage higher than the maximum established by the operator.
	Procedure	A voltage limit equal to 0.7 p.u. of the nominal value shall be established. Then, the equipment shall be supplied with grid voltage up to its rated grid voltage.

	Acceptance criteria	Change to error status.

Title	**Test 2.4: Validation of overtemperature protection module.**	
Parameter	**Description**	
Temperature limit	**Objective**	To verify the equipment has the capacity to give error when it measures a temperature higher than the maximum set by the operator.
	Procedure	With the equipment stopped and at rest state, the temperature limit protection shall be changed to a value -5ºC of the lowest temperature measured in the modules.
	Acceptance criteria	Change to error status.

5.2.3 Losses Test

It is important to check system losses and efficiency in order to detect manufacturing or design anomalies. The failure of a component will be associated with a high consumption or lack of it with respect to the expected, being a clear failure indication. Results will be validated against theoretical calculations obtained during the design stage.

For this purpose, the following tests are carried out:

Title	**Test 3.1: Validation of losses with capacitive reactive power.**	
Parameter	**Description**	
Losses with Reactive Power control (steady state)	**Objective**	To verify losses of the equipment in steady state with capacitive reactive power control.
	Procedure	With the equipment in operation and controlling its DC voltage in each module at its nominal value, a capacitive reactive setpoint at 1 p.u. will be given and maintained for 5 minutes, counting from the time the setpoint is achieved.
	Acceptance criteria	Active power < 135 kW

5.2.4 Steady state Test

In order to validate the design of the different components of the system, it is important to carry out a thermal test, with the objective of characterizing their heating. The aim is to check if values are within the ranges established by the manufacturers and the design.

Therefore, the temperature jump will be verified in order to extrapolate to the real conditions of the final installation.

Thus, the tests performed will be:

Title	**Test 4.1: Validation of components with inductive reactive power.**	
Parameter	**Description**	
Reactive control (steady state)	**Objective**	To verify the thermal behavior of each component in steady state under conditions of inductive reactive injection.
	Procedure	With the equipment in operation and controlling its DC voltage in each module at its nominal value, an inductive reactive set point will be given.
	Acceptance criteria	Delta temperature of the components < 2ºC AC voltage ±10% nominal value AC current ±10% nominal value

Title	**Test 4.2: Validation of components with capacitive reactive power.**	
Parameter	**Description**	
Active control (steady state)	**Objective**	To verify the thermal behavior of each component in steady state under conditions of capacitive reactive injection.
	Procedure	With the equipment in operation and controlling its DC voltage in each module at its nominal value, a capacitive reactive set point will be given.
	Acceptance criteria	Delta temperature of the components < 2ºC AC voltage ±10% nominal value AC current ±10% nominal value

5.2.5 Enclosure IP test[1]

Title	**Test 5.1: Validation of IP.**	
Parameter	**Description**	
IP	**Objective**	To verify liquid ingress test to the equipment enclosure
	Procedure	Conditions: ▪ Ambient temperature ▪ No load ▪ AC voltage: no voltage ▪ DC voltage: no voltage ▪ Auxiliary services fed externally. ▪ Test duration: 0,6 hours ▪ Measuring conditions: Unit fully assembled For general checks, IP test are performed with the EUT cooling system stopped. For other checks, IP test must

1 In case an inverter fails this test, the root cause of the specific failure will be investigated and a corrective mitigation plan will be established in coordination with GPTech engineering staff.

		be carrying out with and without EUT cooling system fully functional. Connect the spray or hose nozzle to a water source and verify that the water pressure is around 1 bar. During the test, the nozzle device must be at around 1 meter from the target. Aim the water stream of the nozzle at the EUT, specially aim at the following point of analysis: • In between modules; try to cover front, back and top of the equipment. • At the door hinges and union between door and main cubicle. • At the head cabinet; aim at the “ON/OFF” switch, leds and the panel that cover the HMI (if applies). • Lateral side of the equipment. • At the air intake filter (aim with a stream of 20º from the horizontal). Once the total area of the EUT has been tested. Repeat the test with the cooling system switched off. Once the test has been concluded, remove water excess before opening the door in order to avoid misleading results.
	Acceptance criteria	Open the doors one by one and verify absence of water, take special attention to the door seals and screws used to joint cubicles. In case of water ingress take a picture and note it in the checklist table with comments regarding the failure.

5.3 FAT results

Some of the main results for the HFD -STATCOM+Supercaps+DCDC- during FAT are shown next:

- **Heating Test**

Following section 5.2.4 guidelines, the results were ok, considering that Delta temperature of the components was lower than 2ºC with Voltage and Currents within the ranges:

- AC voltage ±10% nominal value
- AC current ±10% nominal value

Next figures show some of the snapshot during the tests:

Figure 36. Power Stacks temperature

Figure 37. Control system temperature

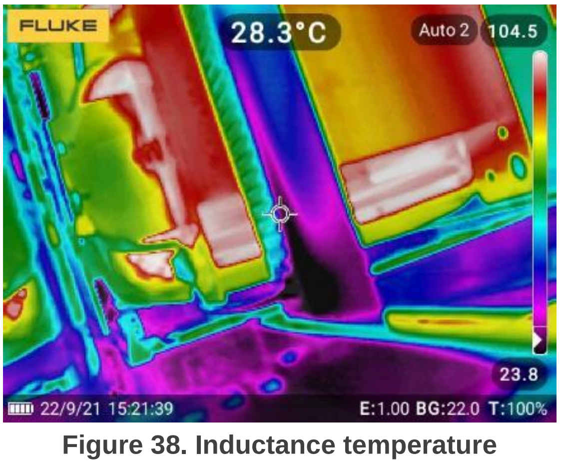


Figure 38. Inductance temperature

Additional results are shown in the *ANNEX. FAT Test* for the inductance and power stacks.

- **Losses Test**

Following section 5.2.3 guidelines, the losses result for the STATCOM + Supercapacitors, applying 700 kVAr, both capacitive and inductive, were the next:

Quadrant	kVAr Power	kW Power Consumption
100% Capacitive	700	60
100% Inductive	700	60

Table 2. Losses test for STATCOM + Supercapacitors

Regarding the DC-DC converter, the global efficiency was obtained, with the next efficiency results for 1150 V_{DC} input and 1350 V_{DC} output:

%	*KW Power*	*Efficiency value (%)*
100	1244	97,28
75	930	97,39
50	621	97,18
30	381	96,77
20	254	96,11
10	126	93,31
5	60	86,77

ηtotal_E (%)	96,48
ηtotal_CEC (%)	97,04

Table 3. Efficiency test for DC-DC converter

- **Dielectric Voltage Withstand Test**

In the frame of section 5.2.2, dielectric tests were performed on different components of the STATCOM-Supercapacitor's container to determine the effectiveness of its insulation. The results were satisfactory for the components tested:

Grounding plate
AC1 Door cabinet to ground
AC2 Door cabinet to ground
Double slice container door to ground
Ucap control frame to ground
STATCOM 1 Stack rail support to ground
STATCOM 2 Stack rail support to ground
STATCOM 1 reactor support to ground
STATCOM 2 reactor support to ground
Door Auxiliary cabinet 1 to ground
Door Auxiliary cabinet 2 to ground
Single container door to ground
HMI door cabinet to ground

Table 4. Component's tested for Dielectric Voltage Withstand

Additional results are shown in the *ANNEX. FAT Test* for the inductance and power stacks.

- **Enclosure IP test was ok, after a few modifications:**

Figure 39. Watering for IP test

IP tests are performed on all parts of the container and water ingress is detected in the HVAC absorption ducts.

Figure 40. First IP test failure

The next modifications were applied:

- In the HVAC impulsion holes, some plates are installed to prevent the entry of water through that area. In addition, a second inner rubber is placed, ensuring more tightness to the whole.
- Some protections are installed in the joints between ducts.
- Everything was sealed again

Before	After modifications

After the modifications, the water test was performed again, passing satisfactorily.

As a conclusion, following the test description of the section 5.2, all of them were successfully achieved. Therefore, HFD was ready for installation in CENER installations, as described in next section.

6 Installation of the HFD on CENER facilities

After manufacturing and validation in factory, the devices that constitutes the HFD were installed on LEA CENER facilities located in Sanguesa (Navarra). Details of the integrated solution, main components and installation works performed to implement the full demonstration are described in this section.

6.1 Installation layout

The layout of the physical devices that constitutes the HFD demonstrator is shown in Figure 41 and Figure 42. The demonstrator is connected to the 20kV substation in LEA facilities, to the low voltage installation in LEA for auxiliary power supply and to the existing ATENEA microgrid

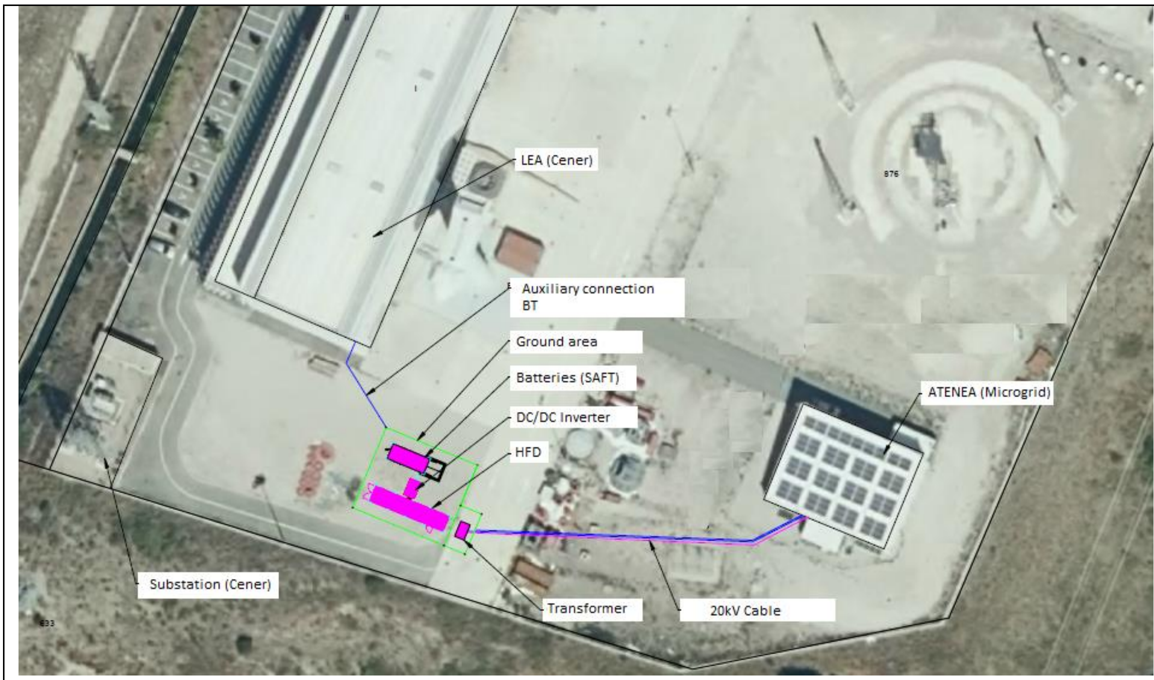


Figure 41. Layout of WP4 demonstrator (top-view)

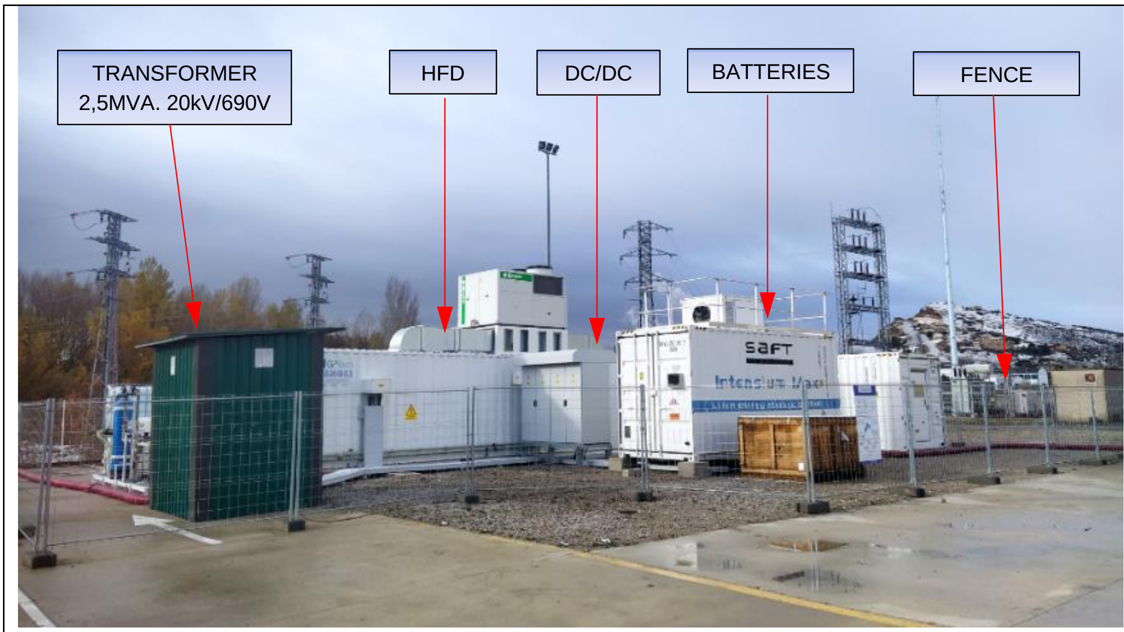


Figure 42. Layout of the WP4 demonstrator containers and devices

The associated electrical diagram of the of the installation is shown below, where the blue area represents the implemented demonstrator and the connection between the different components.

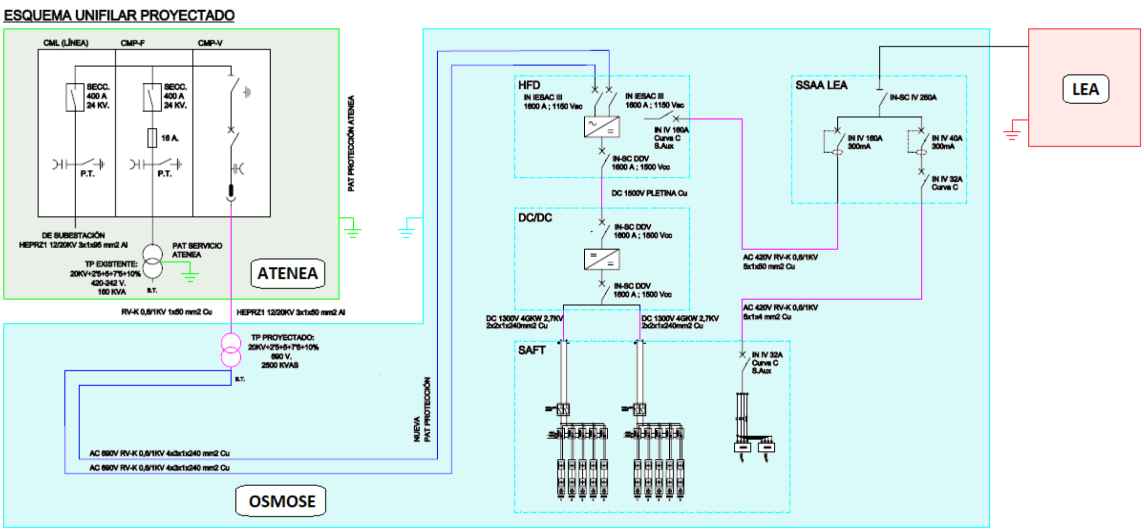


Figure 43. Electrical layout of the demonstrator

6.2 Civil works for the installation

For the placement of the containers and transformer, the ground is leveled with sand. Electrical equipment (HFD, Transformer, DC/DC and batteries) is placed on the ground using different systems, according to its design and the manufacture requirements.

6.2.1 STATCOM and supercapacitors container

Six steel gauges have been used on the ISO corners and on middle points of the HFD container in order to level and install it.

Figure 44. Steel Gauges under the HFD container

6.2.2 DC/DC Converter

Six adjustable supports have been used for the DC / DC converter, which have been designed and made ad-hoc for this kind of configuration. There are steel plates under these adjustable supports to stabilize the whole installation.

Figure 45. DC/DC Supports

6.2.3 Lithum-ion battery

The batteries container has been placed over six concrete pillars. Four of these concrete pillars are installed under the ISO corners, the other two blocks are placed in the middle of the container´s longest side.

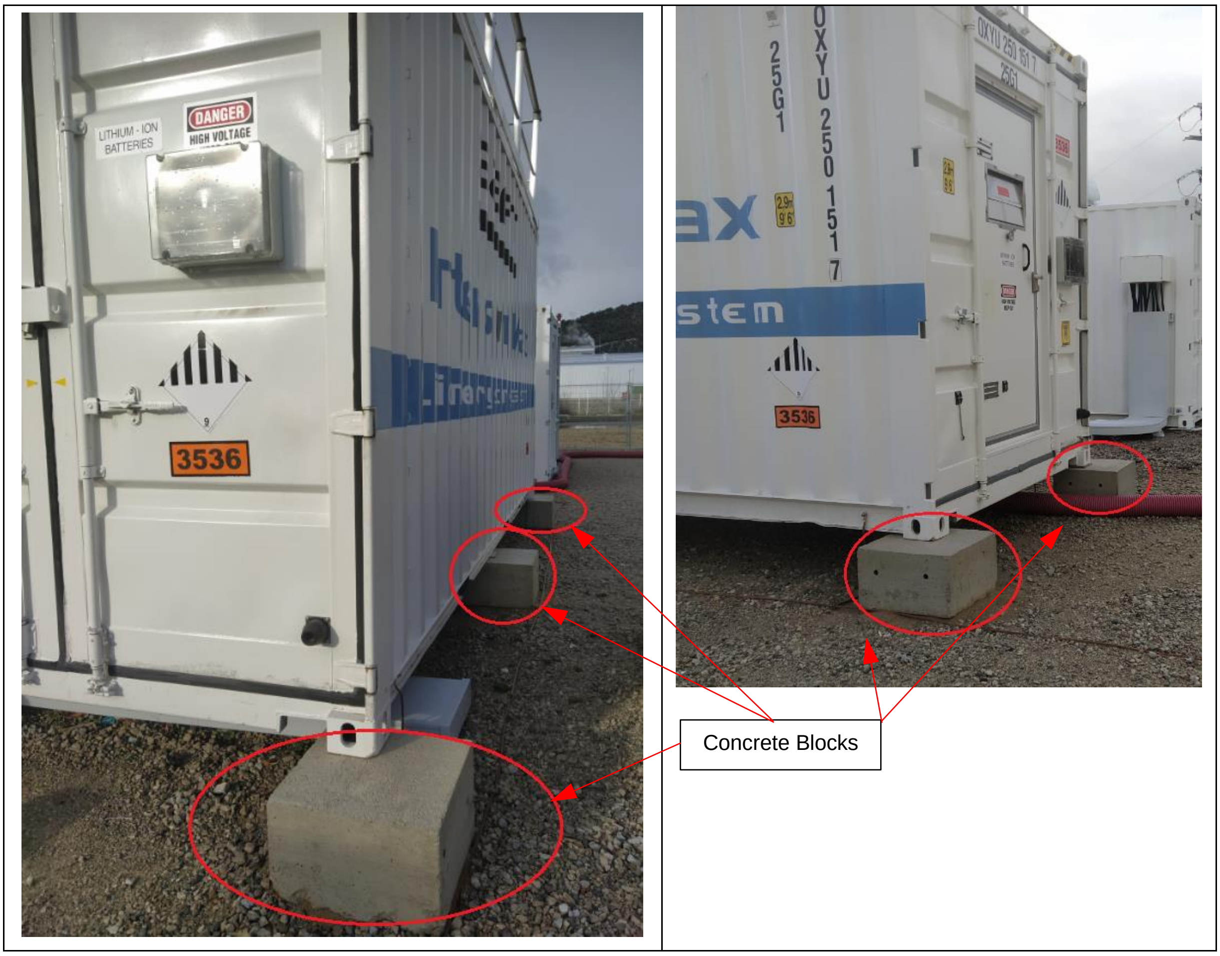


Figure 46. Concrete blocks of batteries container

6.2.4 Transformer

The HFD incorporates a 20kV / 690V power transformer, with 2.5MVA of power that connects the STATCOM (690V) with the substation in CENER (20 kV). The characteristics of the transformer are:

- Primary voltage: 20000+/-2,5+5+7,5+10% V
- Secondary voltage: 690/400 V
- Connection: Delta-Star
- Insulation: Dry
- Cooling: Natural
- Power: 2500kVA

Figure 47 shows an image of the cabin where the transformer is located. This cabin protects the transformer to be damaged by weather conditions, as it is an indoor transformer.

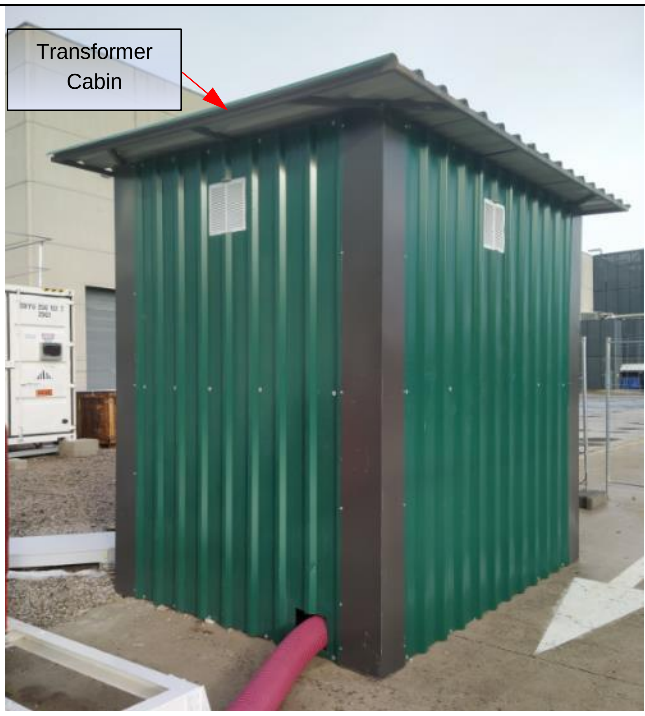


Figure 47. Cabin Transformer

6.3 Medium voltage installation

The power transformer is also connected to the circuit breaker of the Atenea microgrid by using a HEPR-Z1 12/20 kV. 3 x 1 x 50mm2 cable. The approximate length of this cable is 60m and it has a red ribbed protective pipe (160mm of diameter).

Figure 48. Input and output wiring of the transformer

The 20kV voltage reaches the transformation center of the microgrid from LEA substation and it is distributed to the 2,5MVA HFD transformer and the Atenea microgrid through the medium voltage cabinets. The characteristics of the cabinets are shown below.

Figure 49. Cabinets of the HFD and microgrid

The characteristics of the voltage and current transformers of the metering cabinet are as follows:

- Current transformer: 3 x 100A/5A CL 0,5
- Voltage transformers: 3x 22kV/110V CL 0,5

6.4 Low voltage installation

In the low voltage side, two parts can be differentiated: 690V of the secondary terminal of the 2.5MVA transformer (Figure 50) and 400V for the auxiliary supply.

HFD low voltage side (690V):

The cable used to connect the LV of the HFD with the transformer has the following properties: RV-K 0,6/1kV. 3 x 3 x 240mm2. It is placer in the following tray: Unex isolating tray for LV wiring distribution with isolation from ground 4 kV and peaks of 10 kV.

Figure 50. Tray from transformer cabin to HFD container

Figure 51.DC-DC Cabinet

Auxiliary power services cabinet (400V):

The auxiliary services cabinet is powered from the LEA with a 250A automatic switch break and through two protections of 160A (300mA) 4P and 32A (300mA) 4P (Figure 52), and in turn, it powers the equipment of the HFD (STATCOM and battey)

Figure 52. SSAA LEA cabinet

6.5 GROUNDING SYSTEM

In the surrounding area of experimental facility, a ring ground connection has been installed with 50 mm2 bare copper cable. This ring has copper rods at the vertices and at the midpoints.

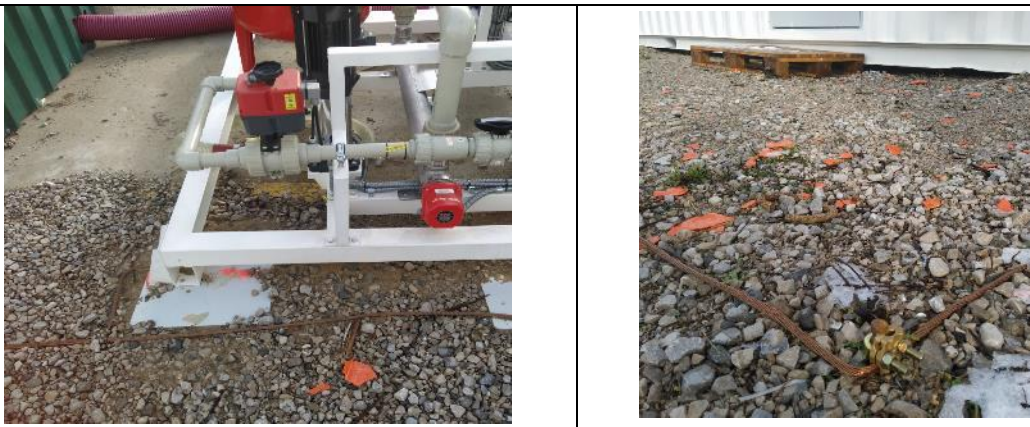


Figure 53. Ring ground of the experimental facility.

6.6 Communications

A dedicated IT infrastructure has been set up in order to allow for the communication between the different equipment in field. The figure 16 shows a general diagram of the connections (wired and wireless) that has been set.

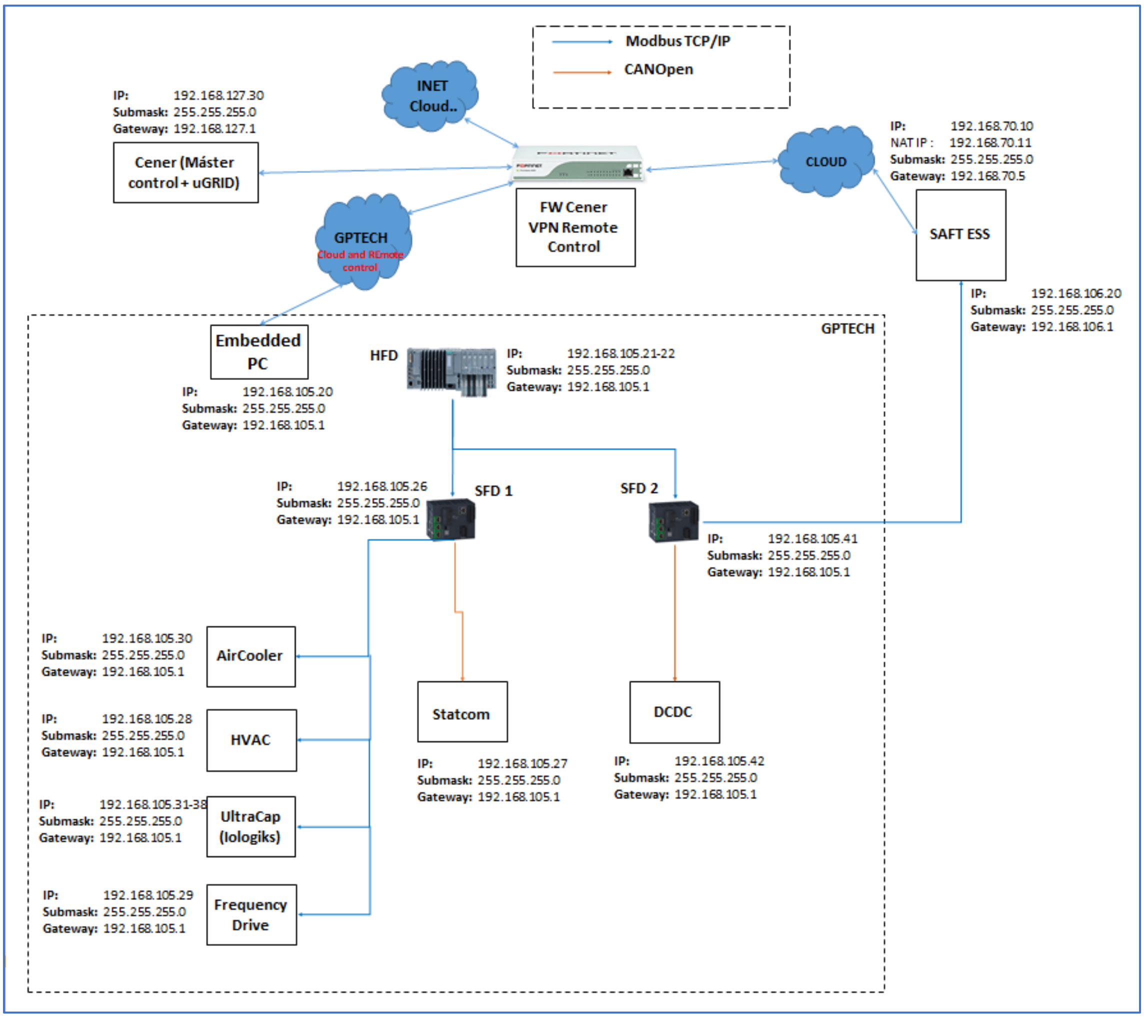


Figure 16: Communication Diagram for OSMOSE Installation

Figure 17 shows a detailed IP configuration for each of the devices involved into the project IT infrastructure.

HFD & SFD1						
Equipment	IP	Submask	Gateway	Local Port	Protocol	Remote Port
Embedded PC	192.168.105.20	255.255.255.0	192.168.105.1	502	TCP/IP	all
PLC Control Unit HFD Eth1	192.168.105.21	255.255.255.0	192.168.105.1	502	TCP/IP	-
PLC Control Unit HFD Eth2	192.168.105.22	255.255.255.0	192.168.105.1	502	TCP/IP	-
Switch EDS-408A UC1	192.168.105.23	255.255.255.0	192.168.105.1	502	TCP/IP	-
Switch EDS-408A UC2	192.168.105.24	255.255.255.0	192.168.105.1	502	TCP/IP	-
Switch EDS-408A PPC	192.168.105.25	255.255.255.0	192.168.105.1	502	TCP/IP	-
PLC Control Unit SFD1	192.168.105.26	255.255.255.0	192.168.105.1	502	TCP/IP	-
Service DCAC_01 SFD1	192.168.105.27	255.255.255.0	192.168.105.1	502	TCP/IP	-
HVAC Keyter	192.168.105.28	255.255.255.0	192.168.105.1	502	TCP/IP	-
Frequency Drive Schneider	192.168.105.29	255.255.255.0	192.168.105.1	502	TCP/IP	-
Air cooler Keyter	192.168.105.30	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1240 1 UC1	192.168.105.31	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1240 2 UC1	192.168.105.32	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1262 1 UC1	192.168.105.33	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1262 2 UC1	192.168.105.34	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1240 1 UC2	192.168.105.35	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1240 2 UC2	192.168.105.36	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1262 1 UC2	192.168.105.37	255.255.255.0	192.168.105.1	502	TCP/IP	-
Iologik 1262 2 UC2	192.168.105.38	255.255.255.0	192.168.105.1	502	TCP/IP	-

SFD 2						
Equipment	IP	Submask	Gateway	Local Port	Protocol	Remote Port
Switch EDS-408A DCDC	192.168.105.40	255.255.255.0	192.168.105.1	502	TCP/IP	-
PLC Control Unit SFD2	192.168.105.41	255.255.255.0	192.168.105.1	502	TCP/IP	-
Service DCDC_01	192.168.105.42	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.43	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.44	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.45	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.46	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.47	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.48	255.255.255.0	192.168.105.1	502	TCP/IP	-
Reserved	192.168.105.49	255.255.255.0	192.168.105.1	502	TCP/IP	-

SAFT BESS						
Equipment	IP	Submask	Gateway	Port	Protocol	Remote Port
Router FW SAFT port WAN	192.168.106.20	255.255.255.0	192.168.106.1	502	TCP	all
Routeur FW SAFT Port 2	192.168.70.10	255.255.255.0	192.168.70.5	all	TCP UDP	53, 443 53, 123
Routeur FW SAFT NAT	192.168.70.11	255.255.255.0	192.168.70.5	all	TCP	9080, 11022
Reserved						
Reserved						
Reserved						
Reserved						
Reserved						

Figure 17: IP addressing for the OSMOSE Installation

7 SCADA Development

A dedicated SCADA for the OSMOSE Project has been developed to allow for test monitoring and data recording. The data will be monitored in real time to ensure the tests are properly performed and the HFD and battery functioning under safe conditions.

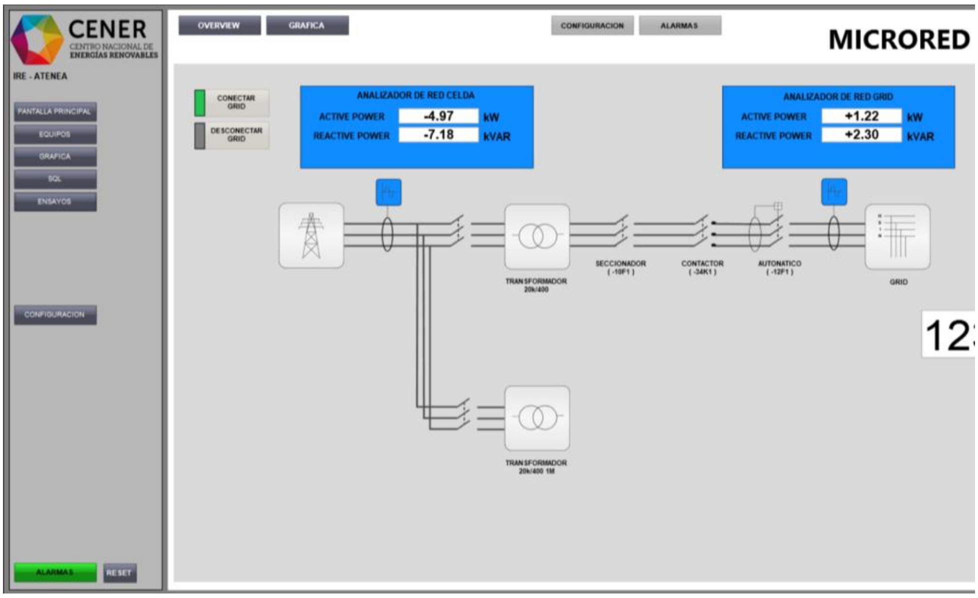


Figure 18: Electrical Test Bed Configuration

A dedicated user menu has been developed allowing the user to switch between different Windows. The windows allows the user to select:

- ATENEA microgrid storage devices
- HFD components
- SAFT Battery components
- Electrical protections and communications of the whole test bed

The Figure 18 shows the SCADA option for monitoring the different OSMOSE storage and power electronics devices. There is a general windows displaying the most representative values of each device and by clicking on each device, a detailed list of variables of every device is displayed. Every value is stored in a local SQL database every second.

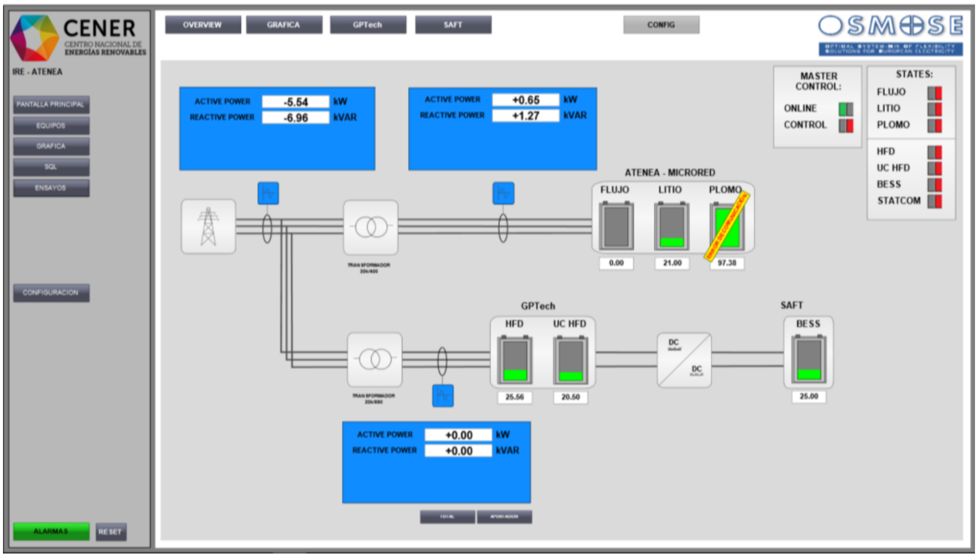


Figure 18: OSMOSE Storage and Power Electronics Monitoring Window

Real time data monitoring window allows the user to select a set of desired variables and displayed them in real time in a GRAPH. These data are being stored in the database, but can also be exported as a picture or exported to a spreadsheet.

This screen also provides the option to display historical data by selecting the variables of interest and the date's interval of interest. Figure 19 represents an example of this user option.

Figure 19: Real time data monitoring

A dedicated screen broth for SAFT and GPTECH has been developed that provides the user the indicators to monitor the most relevant parameters of its devices. Figure 20 represent a snapshot of the HFD main parameters while figure 21 and 22 represent SAFT BMS parameters as well as the first five SSU´s parameters.

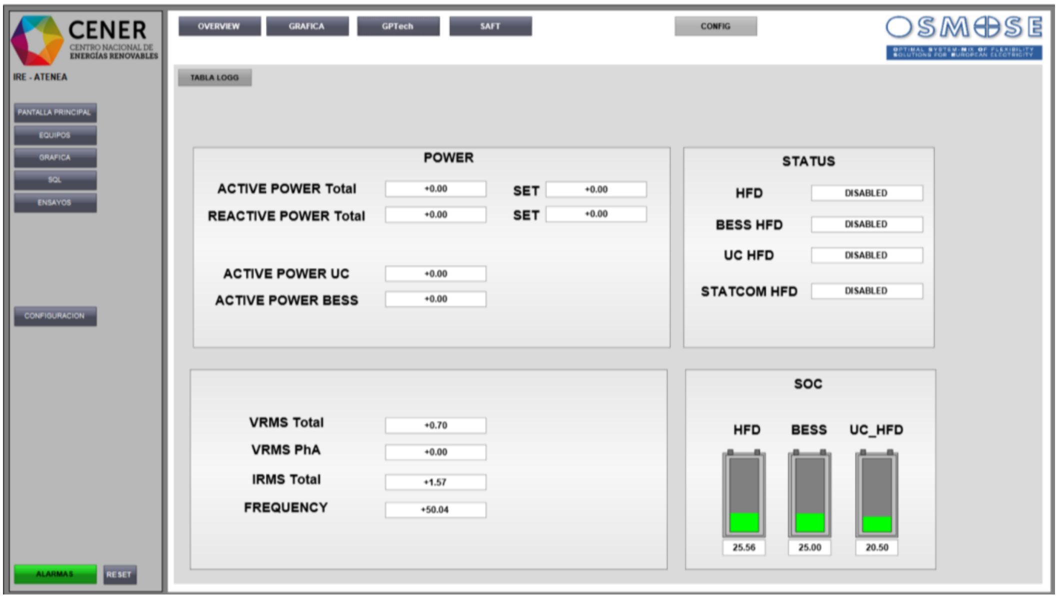


Figure 20: HFD Main Screen Parameters

Figure 21: SAFT BMS main Parameters

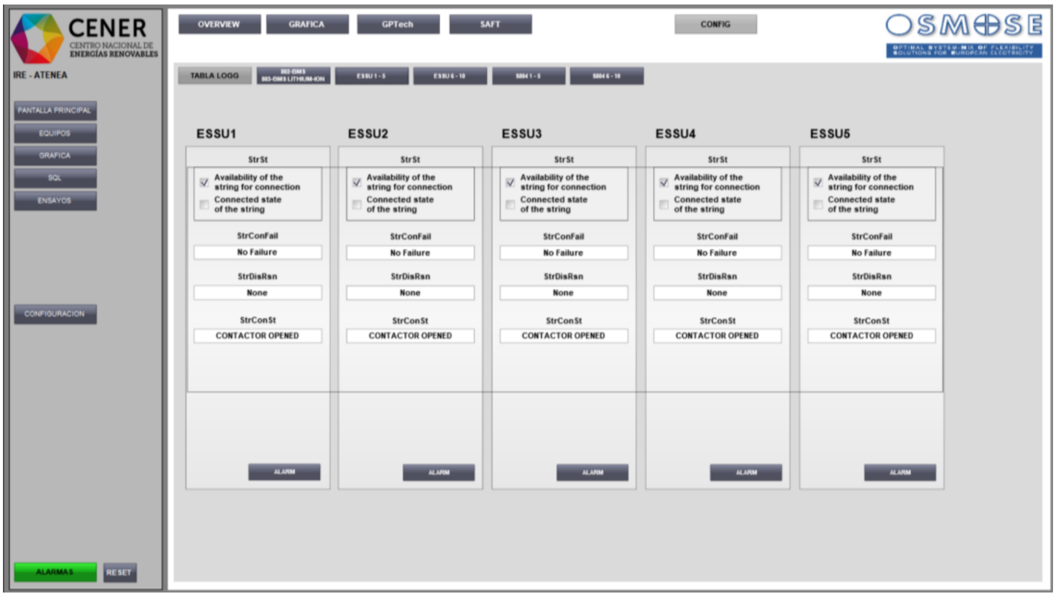


Figure 22: SAFT first five SSU´s parameters

Clicking on top of every parameter, will display a full list of variables as per the manufacturer Modbus list and variables developed, as shown in figure 23.

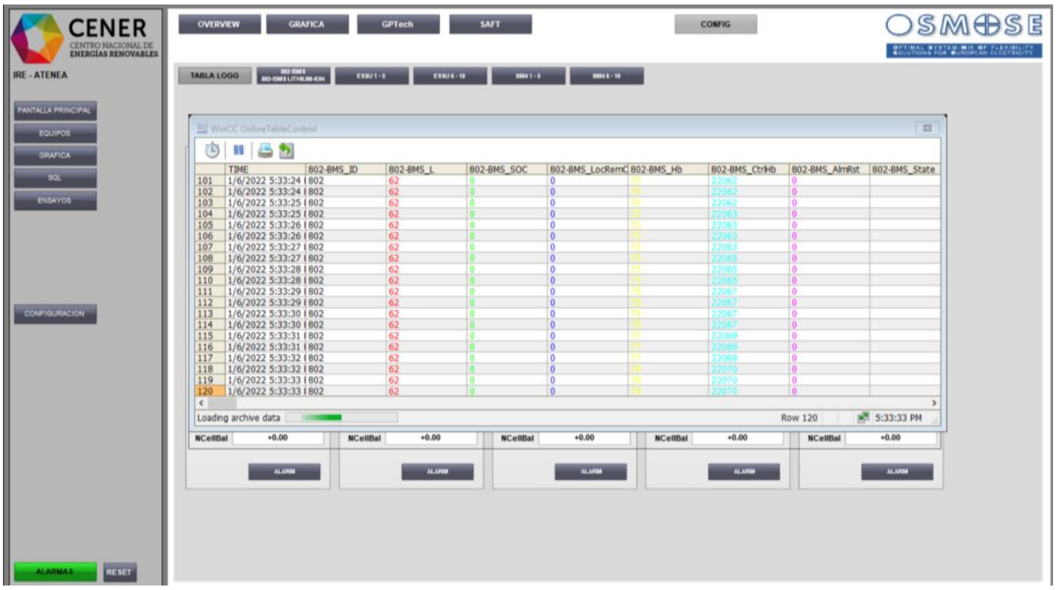


Figure 23: List of variables for every device

8 Master Control Integration

The Master Control is a software that coordinates the services and optimizes the operation of the equipment, based on the control strategies, depending on the objective to be achieved. It is installed in the CENER facilities in Sangüesa, in a Cincoze CV-W115C-R11/P2102-i5-R10 Industrial computer as can be seen in Figure 24.

Figure 24: Master Control Installed at OSMOSE Site

The Master Control communicates through an intermediate PLC and via ModBus TCP/IP protocol with the following OSMOSE devices:

- HFD
- Redox-Flow Battery
- Lead-Acid Battery
- Ion-Lithium Battery
- Photovoltaic inverter
- Network Analyzer in PCC

The main screen of the graphic interface of the Master Control shows all the equipment mentioned above giving information of the most representative readings of each of them and indicating if these are operational or not, as shown in figure 25.

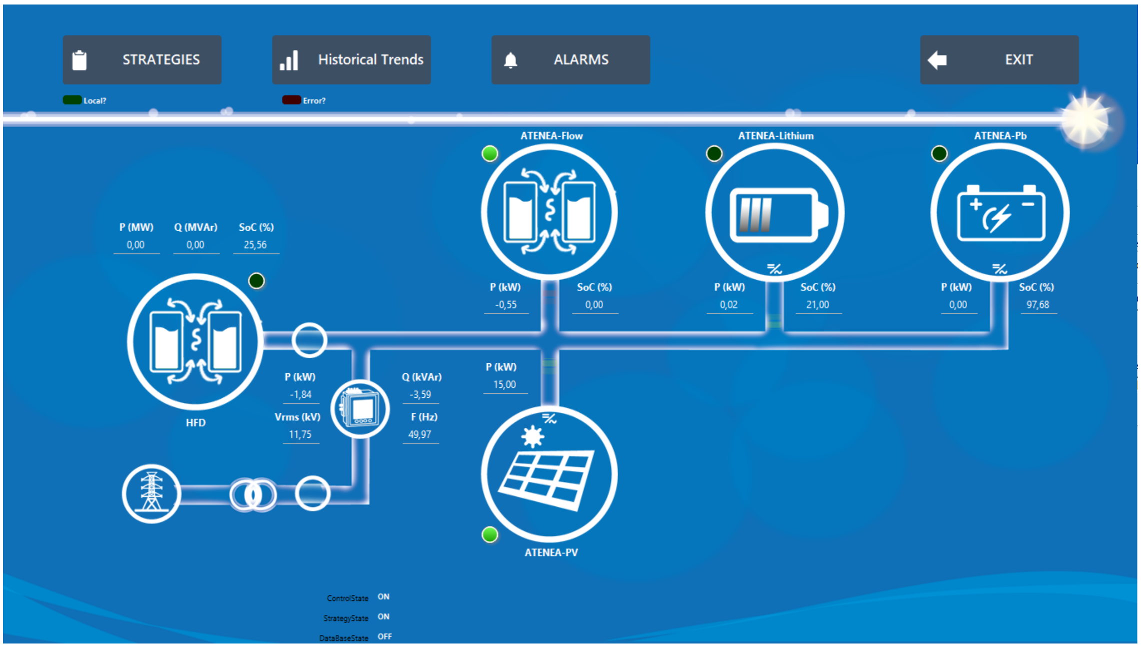


Figure 25: Master Control Main Screen

Each of these devices is associated with a communications port through which the MC accesses the different read and write Modbus registers. The values collected in these reading records can be consulted at any time by clicking on the corresponding equipment on the main screen of the Master Control graphical interface. Figure 26 shows an example of the HFD readings during its integration into the OSMOSE site.

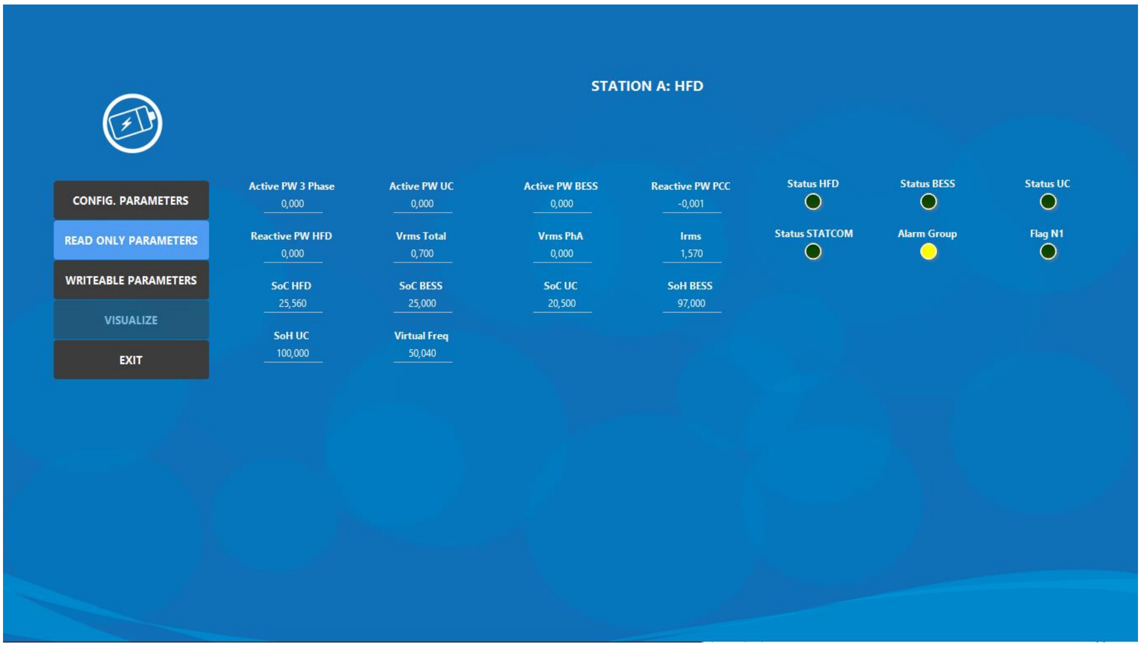


Figure 26: HFD real Time reading data value into the MC

Also there is an option of monitoring the configuration of the equipment during real time operation, as shown in figure 27.

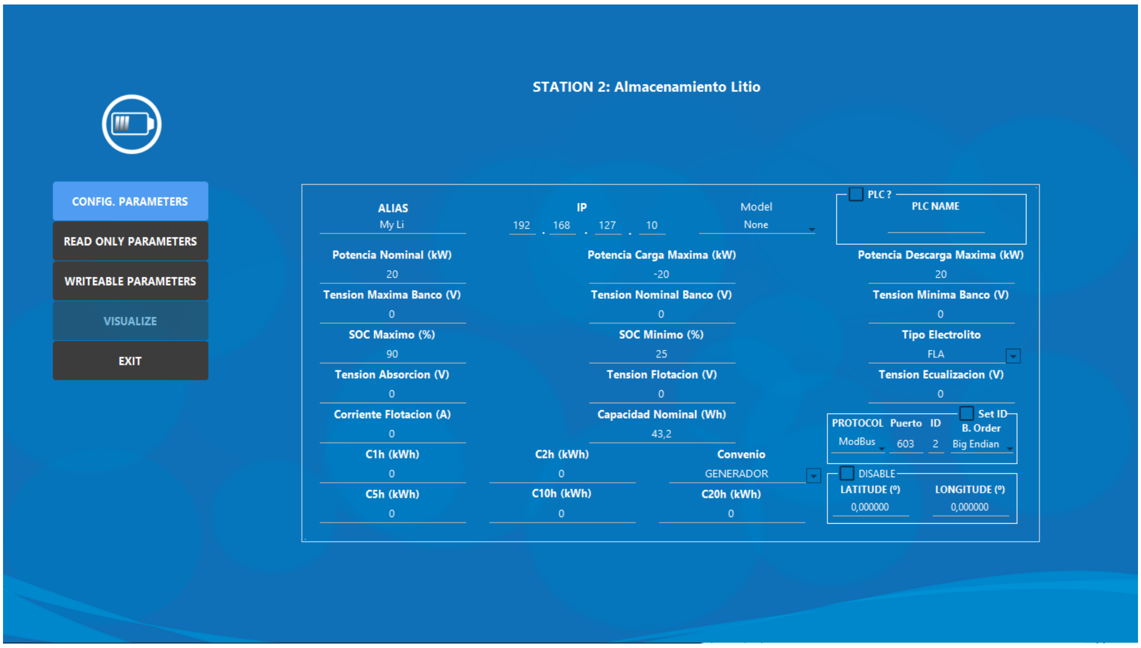


Figure 27: HFD Real Time Configuration Parameters

To perform a test, the user ,must click on the "Strategies" button, select the desired type of test to be performed and press "Set". The trial will start automatically with the selected configuration.

Figure 28: Test Launch Configuration into the MC

9 Conclusion

The HFD for provision of multiple flexibility services to the transmission grid has been successfully developed and installed in CENER facilities. This deliverable presents the main characteristics of the device and information related to its design, manufacture, and factory testing. Also, the works performed for the on-site installation and connection of the complete HFD – both single components and grid connection – is described and illustrated in the document.

The successful results obtained during the factory acceptance tests represents an important step forward the correct manufacturing of the components that constitutes the hybrid flexibility device. This represent an important achievement since, as it is common in R&D projects, complexities and difficulties appears in the design and manufacturing on new equipment. The information compiled in the report is useful for future development of such kind of technologies.

The deliverable also shows that the hybrid flexibility device has been installed on-field in CENER facilities and connected to the power grid, which represents one of the main achievements in the project. Layout, connections and communications and control infrastructure of the hybrid flexibility device installed represents also an additional resource for future implementation of this kind solutions.

Main future step is the real operation of the demonstrator in order to test and validate the performance of the HFD, its functionalities and its impact on the grid.

10 ANNEX. FAT Test

- **Heating Test for Inductance and Power Stacks**

Next figure shows the temperature variation in the main power part: Inductance and Power Stacks, during a 5 hours test.

HEATING TEST (PRUEBA DE CALENTAMIENTO)

HOT SPOTS (PUNTOS CALIENTES)	
Thermal picture	Value
Not detected, further information in folder "Thermal Pictures"	

	1000 Vdc, 700 kVar Q.at Test Ending										
Module 1	Inner Ambient Temperature(ºC) and Humidity(%)				Inductance (ºC)		Power Stacks (ºC)				
Time (h)	Container Temp (Stego)	Container Hmd (Stego)	Cabinet Temp (Stego)	Cabinet Hmd (Stego)	sFoto Tind Branch 1	sFoto Tind Branch 2	Sfoto (StackR_heatsink)	Sfoto (StackS_heatsink)	Sfoto (StackT_heatsink)	Warm water Temp (outlet)	Cold water Temp (inlet)
0.00	21.68	34.18	27.32	24.58	80.01	79.02	48.37	47.4	48.01	39.73	34.71
0.50	21.88	34.34	27.33	24.93	91.21	91.61	48.62	47.7	48.36	40.22	34.58
1.00	22.08	34.44	27.55	24.98	102.04	102.75	49.35	48.27	48.96	40.28	34.42
1.50	21.92	34.62	27.48	24.95	110.48	111.79	48.72	47.67	48.32	40.09	34.49
2.00	21.6	34.8	27.5	24.81	116.83	116.83	48.94	47.87	48.44	39.99	34.38
2.50	22.2	34.55	27.51	25.13	123.36	123.88	49.76	48.59	49.19	40.61	35.22
3.00	21.87	34.79	27.4	25.02	129.22	130.93	49.15	48.07	48.68	40.09	34.91
3.50	21.69	34.72	27.22	25.23	135.81	134.99	49.29	48.2	48.71	39.95	34.32
4.00	21.6	35.25	27.31	25.38	139.03	140.18	49.74	48.59	49.17	40.2	34.75
4.50	22.19	34.63	27.1	25.72	140.57	143.19	49.2	48.08	48.65	39.73	33.99
5.00	22.04	35.07	27.13	25.65	144.12	145.28	49.73	48.53	49.07	40.46	34.5
T. limit [ºC]	35	85	40	85	155	155	70	70	70	70	70

Figure 54. Heating test results for STATCOM+Supercaps

HEATING TEST (PRUEBA DE CALENTAMIENTO)		
Thermal picture	Value	Limit
Ambient temp.	25.2	35
Ir_17_AC_Plate_60x10_item1	N/A	50
Ir_18_AC_Plate_60x10_item2	N/A	50
Ir_19_AC_Plate_60x10_item3	N/A	50
Ir_20_Ancillary_Power_Supplies_Head_Cabinet	26.5	50
Ir_21_Ancillary_Supply_Transformer_Fe	N/A	60
Ir_22_Ancillary_Supply_Transformer_Cu	N/A	60
Ir_23_AC_Circuit_Breaker_Case_Power_Module_2	26	50
Ir_24_PLC	26	50

HOT SPOTS (PUNTOS CALIENTES)	
Thermal picture	Value
OK	
OK	
OK	
OK	

Table 5. Heating test to the DC-DC head cabinet, at 1350 Vdc and Power 1100 kW

HEATING TEST (PRUEBA DE CALENTAMIENTO M2)		
Thermal picture	Max temperature of the image	Limit
Ambient temp. Troom1	23.9	35
Ir_1_Reactor_L1_Cu	39.7	77
Ir_2_Reactor_L2_Cu	40.7	77
Ir_2_Reactor_L3_Cu	38.3	77
Ir_4_Reactor_L1_Fe	58.3	64
Ir_5_Reactor_L2_Fe	61.7	64
Ir_5_Reactor_L3_Fe	55.4	64
Ir_DC_Capacitor_Case	33.4	45
Ir_7_Driver_Phase_S	41.7	55
Ir_9_Clamp	28.7	43
Ir_10_Flexible_Plate_5x80x1	36.9	62
Ir_15_Ancillary_Power_Supplies_Power_Module	25.8	54
Ir_17_DC_BREAKER_1	29.3	45
Ir_18_DC_BREAKER_2	29	45
Ir_DC capacitor filter	26.9	55
Ir_18_DC ground capacitor	24.4	55
Ir_R grounding	30.2	55
Ir_BRD19001	33.8	55
Discharge resistor of power stack	63.1	100

Table 6. Heating test to the DC-DC power modules

- Dielectric Voltage Withstand Test

DIELECTRIC VOLTAGE WITHSTAND TEST (PRUEBA DE AISLAMIENTO DIELECTRICO)							
Test Voltage ≥ Limit Voltage (Y/N)	Time (s) IEC / UL	V [ac]			Circuit Location	Current (mA)	Current < 150mA?
		Test Voltage (V)	Limit Voltage IEC (Vac rms)	Limit Voltage UL (Vac rms)			Pass [Y][N]
Y	5 / 30 : 6 / 90	3200	2200	3200	Between AC output contactor (R, S and T), AC input contactor (R, S and T), DC output contactor (positive and ngative pole), DC intput contactor (positive and ngative pole) short-circuited and dead-metal parts.	39.40	Y
Y	5 / 30 : 6 / 90	N/A	2200	3200	Between primary of auxiliary transformer and dead-metal parts.	N/A	N

ISOLATION RESISTANCE TEST (PRUEBA DE RESISTENCIA DE AISLAMIENTO)					
Time (s)	Limit Test Voltage (Vdc)	Test Voltage (Vdc)	Circuit Location	Isolation Resistance (Mohms)	Absorption Index (60/30)
0	1000	1000	Between AC output contactor (R, S and T), AC input contactor (R, S and T), DC output contactor (positive and ngative pole), DC intput contactor (positive and ngative pole) short-circuited and dead-metal parts.	100	1.369863014
10	1000	1000		120	
20	1000	1000		135	
30	1000	1000		146	
40	1000	1000		160	
50	1000	1000		180	
60	1000	1000		200	
0	1000	N/A	Between primary of auxiliary transformer and dead-metal parts.	N/A	#¡VALOR!
10	1000	N/A		N/A	
20	1000	N/A		N/A	
30	1000	N/A		N/A	
40	1000	N/A		N/A	
50	1000	N/A		N/A	
60	1000	N/A		N/A	

Grounding Impedance (Resistencia de puesta a tierra)				
Measurement Points	Voltage Drop (mV)	Calculated Resistance (ohms)	Limit resistance (ohms)	Compliance (Y/N)
A	0.02	0.002	0.1	Y
B	0.03	0.002	0.1	Y
C	0.02	0.002	0.1	Y

Figure 55. Dielectric Voltage Withstand Test results for DCDC

DIELECTRIC VOLTAGE WITHSTAND TEST (PRUEBA DE AISLAMIENTO DIELECTRICO)							
Test Voltage ≥ Limit Voltage (Y/N)	Time (s) IEC / UL	V [ac]			Circuit Location	Current (mA)	Current < 150mA?
		Test Voltage (V)	Limit Voltage IEC (Vac rms)	Limit Voltage UL (Vac rms)			Pass [Y][N]
Y	5 / 30 : 6 / 90	4000	4000	4400	Between AC output contactor (R, S and T), AC input contactor (R, S and T), DC output contactor (positive and ngative pole), DC intput contactor (positive and ngative pole) short-circuited and dead-metal parts.	74.00	Y

Grounding Impedance (Resistencia de puesta a tierra)				
Measurement Points	Voltage Drop (mV)	Calculated Resistance (ohms)	Limit resistance (ohms)	Compliance (Y/N)
Grounding plate	40	0.003	0.1	Y
AC 1 Door cabinet to ground	50	0.004	0.1	Y
AC 2 Door cabinet to ground	30	0.002	0.1	Y
Double slice container door to ground	80	0.006	0.1	Y
Ucap control frame to ground	40	0.003	0.1	Y
Statcom 1 Stack rail support to ground	40	0.003	0.1	Y
Statcom 2 Stack rail support to ground	40	0.003	0.1	Y
Statcom 1 reactor support to ground	50	0.003	0.1	Y
Statcom 2 reactor support to ground	30	0.002	0.1	Y
Door auxilary cabinet 1 to ground	20	0.002	0.1	Y
Door auxilary cabinet 2 to ground	50	0.004	0.1	Y
Single container door to ground	330	0.026	0.1	Y
HMI door cabinet to ground	130	0.009	0.1	Y

Figure 56. Dielectric Voltage Withstand Test results for STATCOM+Supercapacitors' container

- Dielectric Voltage Withstand Test in the container

DIELECTRIC VOLTAGE WITHSTAND TEST (PRUEBA DE AISLAMIENTO DIELECTRICO)							
		V [ac]					Current < 150mA?
Test Voltage ≥ Limit Voltage (Y/N)	Time (s) IEC / UL	Test Voltage (V)	Limit Voltage IEC (Vac rms)	Limit Voltage UL (Vac rms)	Circuit Location	Current (mA)	Pass [Y][N]
Y	5 / 30 : 6 / 90	4000	4000	4400	Between AC output contactor (R, S and T), AC input contactor (R, S and T), DC output contactor (positive and ngative pole), DC intput contactor (positive and ngative pole) short-circuited and dead-metal parts.	74.00	Y

Grounding Impedance (Resistencia de puesta a tierra)				
Measurement Points	Voltage Drop (mV)	Calculated Resistance (ohms)	Limit resistance (ohms)	Compliance (Y/N)
Grounding plate	40	0.003	0.1	Y
AC 1 Door cabinet to ground	50	0.004	0.1	Y
AC 2 Door cabinet to ground	30	0.002	0.1	Y
Double slice container door to ground	80	0.006	0.1	Y
Ucap control frame to ground	40	0.003	0.1	Y
Statcom 1 Stack rail support to ground	40	0.003	0.1	Y
Statcom 2 Stack rail support to ground	40	0.003	0.1	Y
Statcom 1 reactor support to ground	50	0.003	0.1	Y
Statcom 2 reactor support to ground	30	0.002	0.1	Y
Door auxilary cabinet 1 to ground	20	0.002	0.1	Y
Door auxilary cabinet 2 to ground	50	0.004	0.1	Y
Single container door to ground	330	0.026	0.1	Y
HMI door cabinet to ground	130	0.009	0.1	Y

Figure 57. Dielectric Voltage Withstand Test results