ebalanceplus

Specification of smart storage interfaces

Deliverable D3.1

Date: 2/2/2022

Author(s): Jose Manuel Torrelo Ponce, Samuel Sánchez Baeza, Diego Artés García, Óscar Gutierrez Martinez, Úrsula Pérez Ramirez

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Technical References

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

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Summary

1.1. Summary of Deliverable

The objective of Ampere Energy is to design and develop innovative three-phase smart-storage systems able to provide flexibility services to the grid. The system capacity for flexibility services, being externally managed by the ebalance-plus platform through a defined and developed API (Application Protocol Interface). The design has been based in a viable economic model that may allow a promising payback time.

The Smart-storage systems have been designed considering the inputs for the future installation in the Pilots defined for the University of Málaga and University of Calabria, to support the balancing and resilience services, for both non-residential and residential buildings. The energy consumption patterns of the buildings participating in the pilots have been analysed, with the objective to determine (and define) a methodology for properly sizing energy storage systems for buildings with high rates of power and energy demand.

The following graphs show the integration of the Smart Storage systems into the ebalance-plus architecture:

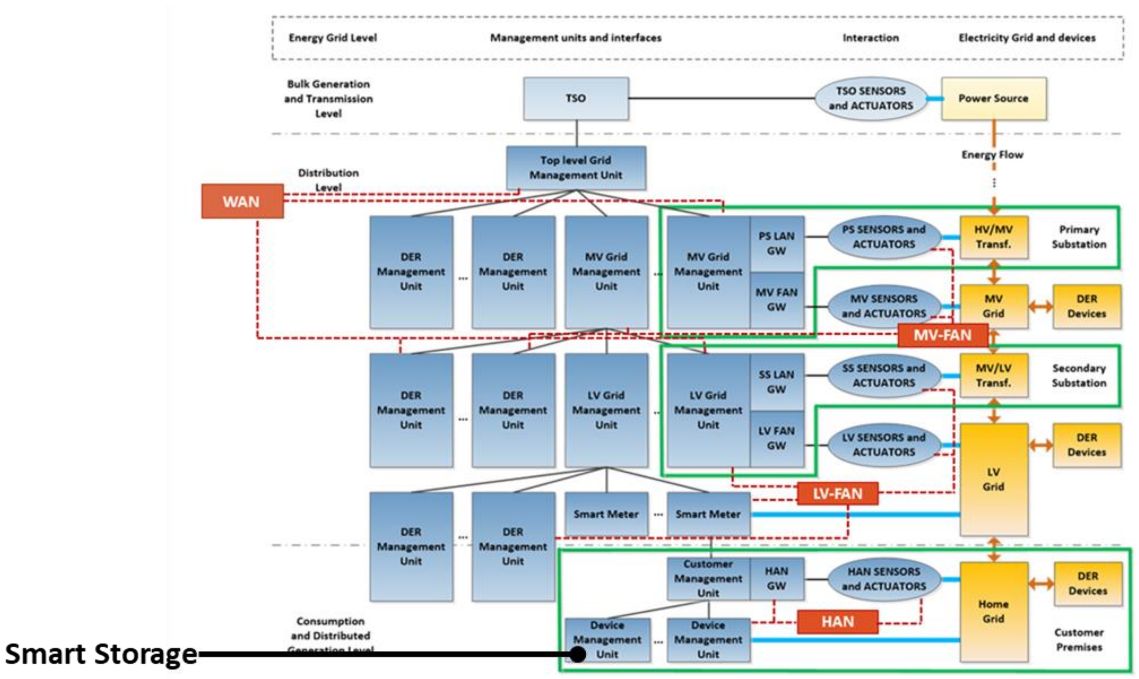

Figure 1. Smart-Storage systems into the ebalance-plus architecture

The following graphs show the layers and relationship between the Smart-Storage systems and the different actors and solutions developed into the ebalance-plus architecture:

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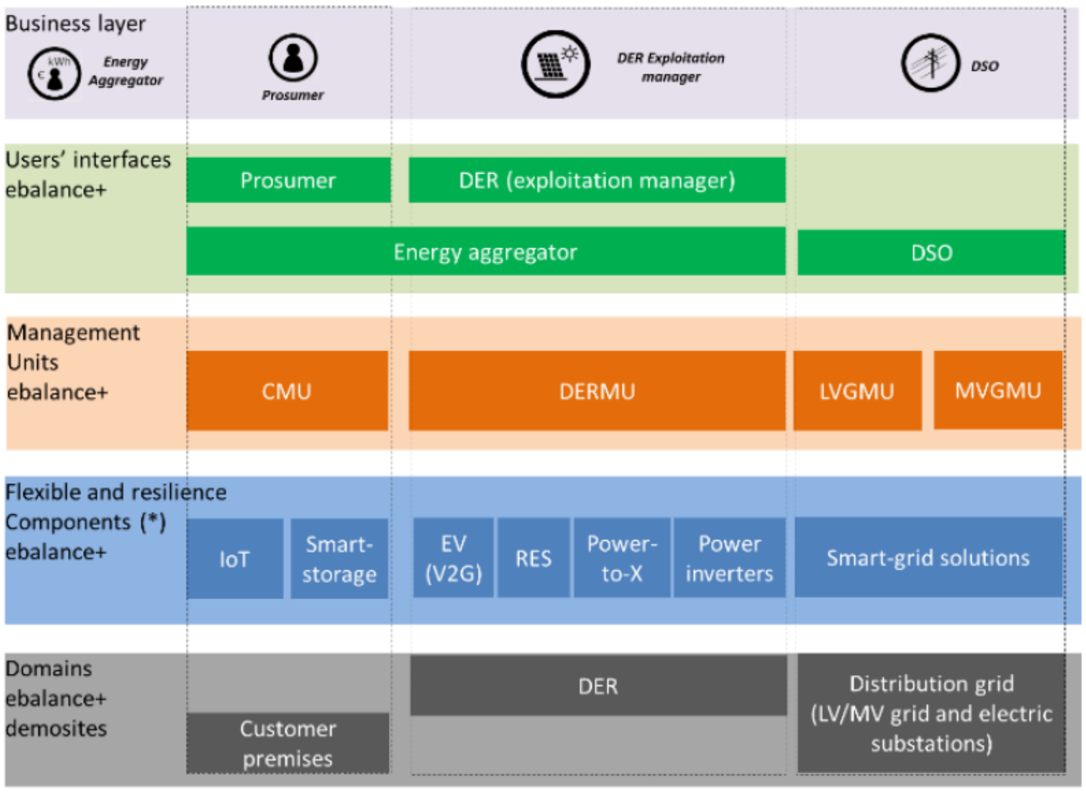
Business layer
Energy Aggregator
Prosumer
DER Exploitation manager
DSO
Users' interfaces ebalance+
Prosumer
DER (exploitation manager)
Energy aggregator
DSO
Management Units ebalance+
CMU
DERMU
LVGMU
MVGMU
Flexible and resilience Components (*) ebalance+
IoT
Smart-storage
EV (V2G)
RES
Power-to-X
Power inverters
Smart-grid solutions
Domains ebalance+ demosites
Customer premises
DER
Distribution grid (LV/MV grid and electric substations)

Figure 2. Different layers in the Smart-storage system

Disclaimer

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1 Work and developments done by AMP

The work done by AMP during the project have been focused on the following developments:

- **Development of a 3-phase smart storage system for small-residential use, called "T-PRO". These systems will be installed in the University of Calabria Pilot.**
- **Development of a 3-phase smart storage system for large installations use, called "SEMS BUFFER". These systems will be installed in the University of Málaga Pilot.**
- **Development of a Smart Energy Management device that will be integrated inside each of the previous Smart Storage Systems, providing the functionality and connectivity required, called "SEMS ONE".**

For each of these developments it will be explained the technical objectives, selected main components/providers/solutions, design and development in hardware/firmware, prototypes manufacturing and initial prototypes tests results.

Additionally, the API developed for managing the smart-storage systems and integrate them in the ebalance-plus platform for this project will be explained.

1.1. Development of a 3-phase smart storage system for small-residential use, called "T-Pro"

The main parts of the T-PRO development are broken down below.

1.1.1. Technical objectives

The main objective is to develop a 3-phase smart solution able to improve the grid flexibility and resilience for residential use and, in pursuit of this aim it has been designed an all-in-one solution equipped with a high efficiency power inverter, lithium-ion batteries and a SEMS ONE EMS inside.

1.1.2. Selected main components

1.1.2.1. EMS

The EMS is a Printed Circuit Board designed by AMPERE ENERGY and it provides communications, power and I/O interfaces to the system. The main specifications are:

Communications:

- **RS485_1**
- **RS485_2**
- **CAN**
- **Gigabit ethernet**
- **USB Host**

Digital outputs:

- **4x GND outputs by relay NO 250V 5A**
- **4x Dry contact NO 250V 5A**
- **2x Dry contact NO/NC 250V 10A**

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- **1x Relay DPDT 12V 2A**
- **1x Relay NO 250V 5A**

Digital inputs:
- **Input power 1 monitor (12V)**
- **Input power 2 monitor (230V)**
- **Main switch state monitor**
- **2x analog input**

Storage:
- **Micro SD card**

Power:
- **Input power 1 12V 30W**
- **Input power 1 12V 30W**

1.1.2.2. **Inverter**

The selected inverter for the installation will be the Imeon 9.12 model, a three-phase hybrid (battery and photovoltaic) inverter with the following specifications:

Properties	Value
AC output power (W)	9000
AC voltage (V)	3/N/PE; 230/400 (+-15%)
Frequency (Hz)	50-60
AC Output nominal current (A)	13 / phase
Maximum input current (A)	17.5 / phase
PV maximum power (W)	Up to 12000
Number of MPPT / Strings for MPPT	2 / 2
MPPT Voltage range (V)	380 – 750
Maximum PV voltage (Voc max) (V)	850
MPPT Maximum current (A)	2 x 18 (Isc max. = 20A)

Table 1. T-Pro Inverter specifications

1.1.2.3. **Battery**

AMPERE T-Pro gives the possibility of modular useful capacity from 12 kWh to 36 kWh depending on the number of batteries mounted. The batteries are from LG Chem and have the following specifications:

Properties	Value
Battery chemistry	Li-on
Useful capacity (kWh)	6
Useful capacity (Ah)	116
Max. charge/discharge current (A)	63
Max. Depth of Discharge (DoD) (%)	95
Nominal voltage (V)	51.8
Operating voltage (V)	42 – 58.8
Life cycle (95% DoD, 25ºC)	>6000

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Table 2. T-Pro Battery specifications

1.1.3. Main components integration

AMPERE T-Pro has the different components indicated above inside. They are strategically placed inside the device to reduce space and consequently save money in the manufacturing process, reduce electromagnetic emissions and allow all connections with the external components of the installation easily.

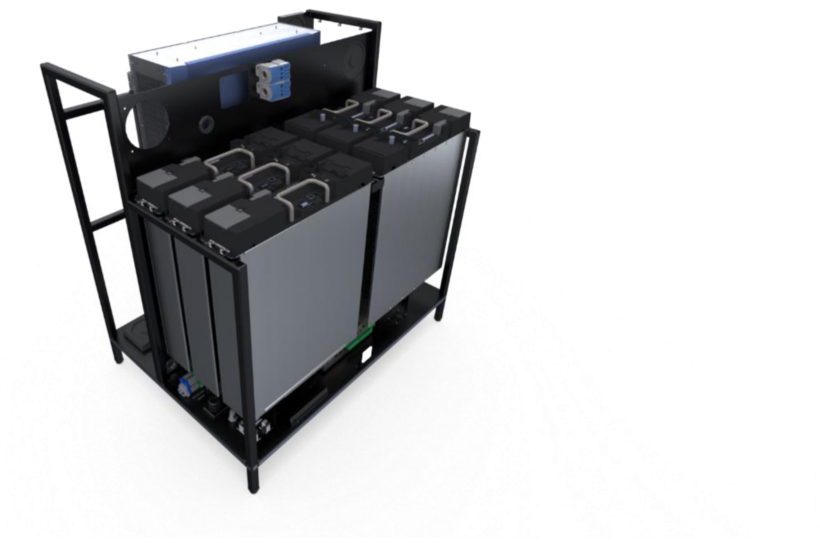

Figure 3. AMPERE T-Pro internal components integration

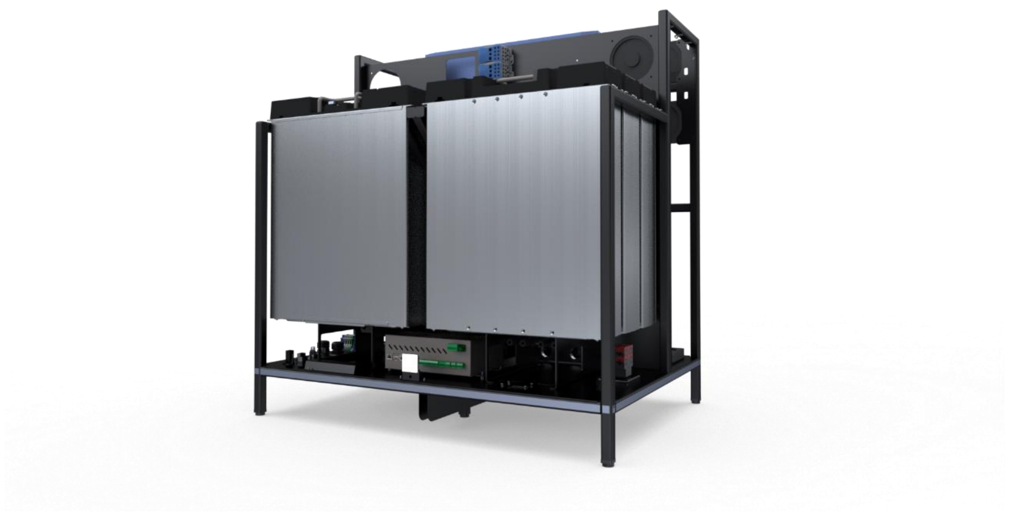

Figure 4. AMPERE T-Pro internal components integration

1.1.3.1. Enclosure design

Once the internal components had been selected and distributed, the enclosure was designed. The figure below shows the designed enclosure:

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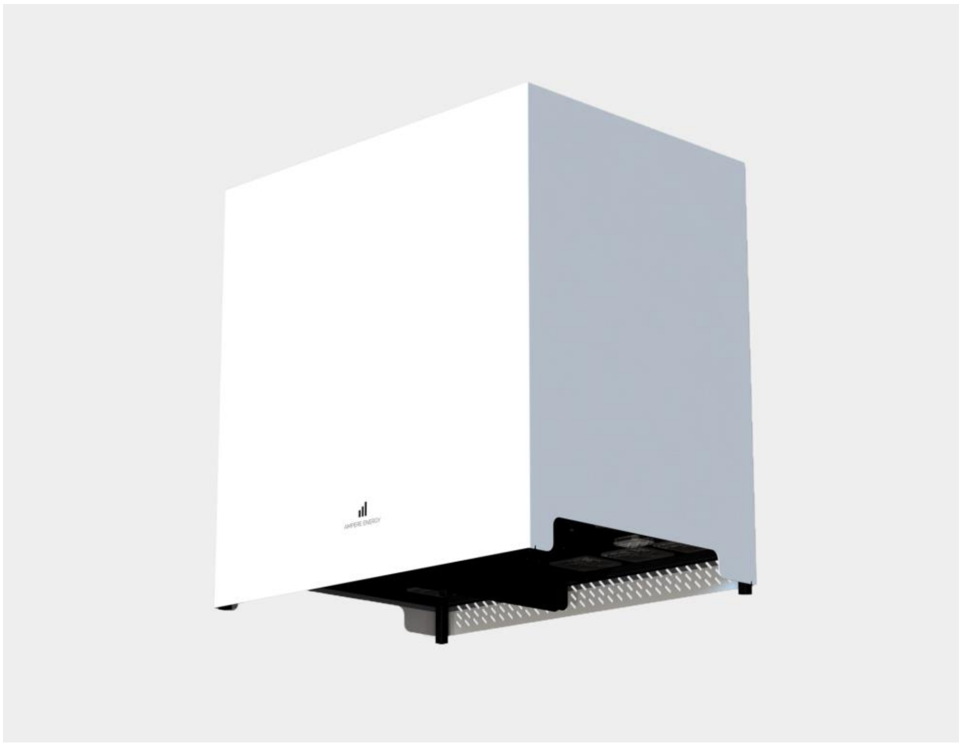

Figure 5. T-PRO Enclosure design

The dimensions for the AMPERE T-Pro have enough space to introduce all the necessary elements inside and it is W x H x D = 141 x 121 x 108 cm as shows *Figure 6*.

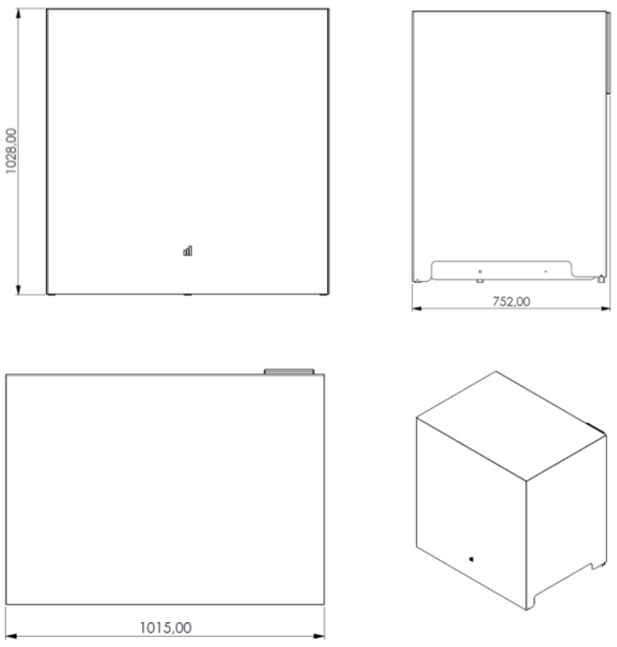

Figure 6. T-PRO dimensions

The weight depends on the selected capacity, i.e. the number of batteries in the box. The following table shows the different weights:

Device	Device without batteries	+2 Batteries	+3 Batteries	+4 Batteries	+5 Batteries	+6 Batteries	Complete device
T-PRO	96 kg	184 kg	228 kg	272 kg	316 kg	360 kg	400 kg

Table 3. T-Pro Weights

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1.1.3.2. Electrical protections and user interactions

To maintain a safe installation, the AMPERE T-Pro has electrical protections to shut down the system if necessary. In this way, it has 2 circuit breakers, one for the battery and another one for the PV installation. Thus, the critical components of the installation are protected ensuring that if there is any electrical risk or any other dangerous risk for the user, the circuit breaker will cut the power flow and then, once the risk is solved, it will be easily rearmed by the user following the instructions given by AMPERE ENERGY in the user manual.

In addition to the physical protections, the firmware of the EMS is monitoring all time if there is any error or warning with the different components of the installation. If there is an error or a slight chance of risk to the user, the AMPERE T-Pro will stop that process and will enter in a safe mode to avoid any problem. In case the problem occurred is not important and does not affect the normal operation mode, the user will be informed through the frontal LED, blinking a specified number of times for each warning that might be occurring (e.g. loss of internet communication will not be a dangerous problem because the device can work without internet connection, but might be necessary to solve it to ensure a normal operation with all functions available).

In addition, the user could opt for manual system shutdown, which would give him the possibility to decide when to switch his equipment on or off. This manual action will be done via the Standby button and after pressing the Standby button to turn off the system, the battery will stop detecting communication and will automatically shut down after 10 minutes, tripping the battery circuit breaker.

1.1.3.3. EMS

The EMS of the AMPERE T-Pro is the brain of the system and consists of several subsystems that enable all the necessary processes and functions to be carried out in the system, such as energy management, power control, machine learning, performance optimisation, user's interaction, data monitoring and representation, etc.

All of that will be possible thanks to the firmware programmed inside the EMS that gives the device a complete and complex intelligence to complete every process in the EMS. Moreover, each of the EMS processes has been implemented as a state machine, running in parallel in the controller and the exchange of information between the different processes is done using FIFO (First Input First Output) queues and CVT (Current Value Table) tables.

The ensemble of all subsystems acting simultaneously results in a complete EMS algorithm, in which each part of the software machinery developed works in coordination with the others, ensuring optimal, reliable and robust system behaviour and guaranteeing a great user experience.

The control process is the core of the energy management carried out by the EMS. It controls the flow of energy from the batteries to ensure optimisation of system operation for maximum possible cost-effectiveness, based on daily estimation and forecast data. It encompasses the following sub-processes:

- **Data recompilation: estimations, forecasts and real-time operation**
- **Data analysis**
- **Peak Shaving**
- **Battery charge control at low price**
- **Calculation of battery discharge limits based on state of charge and estimated optimum state of charge**
- **Battery discharge control according to price and estimated optimum state of charge**

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1.1.3.4. **Communications**

As mentioned above, the energy flow produced in the AMPERE T-Pro is managed by the internal EMS component and to achieve that goal, the EMS communicates with external and internal components with several communication ways.

<u>Communications between internal components</u>
The communications between the EMS and the internal components will be the following ones:

- **EMS - Batteries: CAN communication**
- **EMS – Inverter: MODBUS RS485 communication**

The communications protocol of each component is integrated into the EMS firmware, thus enabling the EMS to communicate with both devices.

The information shared between internal components is very important because the EMS sets the charge and discharge power setpoint of the batteries in accordance with the data received from inverter, battery and external information received from the internet such as the weather prediction or energy prices.

<u>Communications with external components</u>
The communication between the EMS and the external components will be the following ones:

- **EMS – Energy Meter: the energy meter measures all energy consumed and generated in the installation. It is connected through a RJ45 cable in the port labelled as "ENERGY METER"**
- **EMS – Internet: connecting the system to the Internet is essential for the proper operation and monitoring of the device. This connection is necessary to:**
  - **Optimise the system's performance: access to weather forecasts and variable energy prices**
  - **Keep the equipment's warranty**
  - **Receive firmware updates**
  - **View data in the App and in the WEB platform**
  - **Remote maintenance**

This connection can be made via an ethernet cable using the RJ45 port placed labelled as "ETHERNET" or wirelessly thanks to a USB-WiFi device provided with the AMPERE T-PRO and placed in the port labelled as "USB".

1.2. Development of a 3-phase smart storage system for large installations use, called "SEMS Buffer"

The main parts of the SEMS Buffer development are broken down below.

1.2.1. Technical objectives

AMPERE SEMS Buffer is a three-phase storage system formed by a 120 kWh battery, a 100kW inverter and an AMPERE SEMS (Smart Energy Management System). AMPERE SEMS is the brain of the system and consists of several subsystems that enable all the necessary processes and functions to be carried out in the system, such as energy management, power control, machine learning, performance optimisation, user's interaction, data monitoring and representation, etc.

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The device is connected to the Internet and provides information about the installation that will be sent to the AMPERE Cloud for monitoring and representation. All the information sent to the AMPERE Cloud after will be represented via AMPERE App / Web.

1.2.2. Selected main components

1.2.2.1. EMS

The AMPERE SEMS is a device that provides the user with great energy flexibility, allowing him to efficiently manage the energy flow in his installation. In addition, the device will have an internet connection that will allow to make charging schedules for the batteries externally. The main technical specifications are:

General Specifications	Ampere SEMS ONE
Nominal Voltage AC (Vac)	115 - 230
Maximum Current AC (A)	0,25
Nominal Frequency AC (Hz)	50-60
Dimensions (mm)	243x148x66
Weight (kg)	1,2
Communication ports	Ethernet, USB, WiFi , BT, CAN y RS-485 MODBUS (x2)
Type of grid connection	Monofásico L-N-PE
Degree of Protection IP	IP31
Working temperature (ºC)	0 to 40
Relative humidity (%)	20 - 85 (non-condensing)

Table 4. SEMS Buffer EMS specifications

1.2.2.2. 100kW Inverter

The selected inverter for the installation will be the Ingeteam 100TL version, a three-phase battery inverter without transformer and with maximum power density. The main features of the inverter are detailed below:

Properties	Value
DC Operating voltage range (V)	570 - 850
DC Maximum voltage (V)	1100
DC Maximum charge / discharge current (A)	111/185
DC Short-circuit current (A)	240
Communications	CAN Bus 2.0 / Ethernet BMS
AC Rated power (kW)	100
AC Maximum current (A)	145
AC Rated voltage (V)	400
AC Rated frequency (Hz)	50/60
Power factor	1

Table 5. SEMS Buffer inverter specifications

1.2.2.3. 120kWh Battery

To achieve a battery system of 120kWh 2 racks of Ketter manufacturer was selected. The Ketter Power Charge 60 KWh is a battery for a high-power lithium-ion phosphate system with intelligent control technology for use with an external device. The main technical specifications of the inverter are detailed below:

Properties	Value

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Battery chemistry	LiFePO4
Useful capacity (kWh)	60
Useful capacity (Ah)	828
Operating voltage range (V)	600 - 780
Nominal voltage (V)	691
Minimum discharge voltage (V)	600
Maximum charging voltage (V)	780
Maximum load current (A)	111
Maximum discharge current (A)	185
Efficiency (%)	>98
Communication ports	RS485, CAN
Dimensions LxWxH (mm)	800 x 600 x 2055
Net weight (kg)	712
Working temperature (ºC)	-20 ºC a + 55ºC
Storage temperature (ºC)	-20 ºC a + 55ºC
Humidity (%)	<90
Altitude (mm)	<2500
Life cycle	>6000, 25 C

Table 6. SEMS Buffer battery specifications

1.2.3. Main components integration

As mentioned above, the AMPERE SEMS Buffer is mainly formed by a 120kWh battery, a 100kW inverter and an AMPERE SEMS (Smart Energy Management System) that will be installed inside of a control box that will contain all the electrical protections too.

An example of the assembled installation mounted in a wall is shown below:

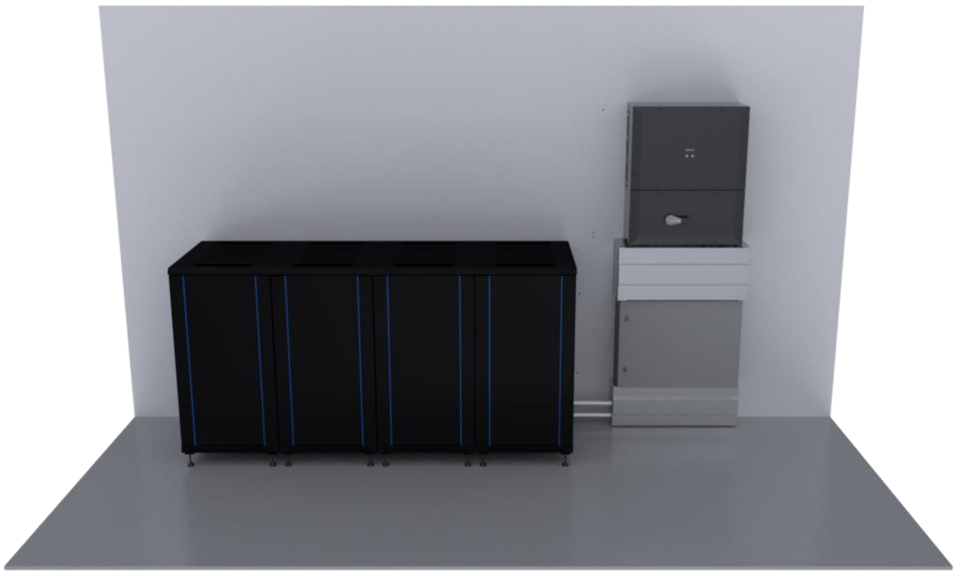

Figure 7. Component distribution in AMPERE SEMS Buffer

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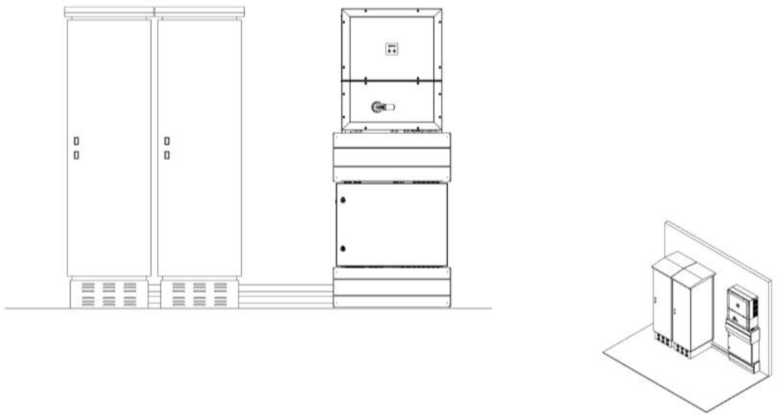

Figure 8. AMPERE SEMS Buffer drawing

The weight to be supported by the wall for installation and by the floor where the installation is carried out shall be as follows:

	Components installed	Weight
Wall	Control box and inverter	200kg
Floor	Battery racks	1500kg

Table 7. SEMS Buffer weights

1.3. Development of a Smart Energy Management system, called “SEMS ONE”

The Smart Energy Management System described below will be integrated inside each of the previous Smart Storage Systems, providing the funcionatilty and connectivity required, called “SEMS ONE”.

1.3.1. Technical objectives

There are several points of view of the development that we are facing with this project, regarding each point of view we plan different technical objectives, but first we separate each necessity in order to figure out what would be the best option to achieve each target and, in the end, optimize the different provided solutions in order to create reasonable and reachable objectives.

Use of open-source environment (Linux/Python)

The currently provided solution for the Ampere EMS is based on National Instruments sbRIO platform which implies the use of privative tools and licenses to develop the solution and the usage of the LabVIEW code forces to the use of the NI hardware solution. In order to have an energy management software with a low hardware dependency we plan the objective of using Linux as the operative system running over a general-purpose microcontroller platform. With this target we make sure that there are many hardware platforms which will guarantee the execution of the intelligence while managing the energy regardless of the hardware support.

Portable design

Taking into account that there are in the market several inverters solutions, meters and batteries, and what is more important the amount of architectures that can be designed to satisfy each location is huge. We plan to create a portable device (meaning "portable", a device which can be installed easily because of the external finishes, low weight and ease of

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connection) which may satisfy the connectivity between the main energy actors in a location (inverters solutions, meters and batteries) in order to make the construction of heterogeneous energy solutions easier.

Prepare for the future integration with ML platforms
Taking GNU/Linux as the base OS where the intelligence will be working, we plan to use Python as the programming language of the application which will be in charge of managing the functional operations of the SEMS. There are several reasons to determine this technical objective: Python is a widespread language which means that for the company it is easier to get more people involved in the development even coming from different areas. Python is an open-source language and has a huge community behind, who is working on a vast list of support libraries which will help us to speed up the development. And finally, nowadays Python is the base language used for Machine Learning, this is because the most relevant ML libraries used nowadays are based on Python (keras, tensorflow, pytorch, …). This means that using the same language as the algorithms and research teams will create a powerful synergy.

1.3.2. Selected main components

The device under consideration has three main parts which require a preliminary analysis before going further with the design. At electronic level we decided to go with a SOM based system in order to avoid risks with the platform design but also speed up the development time, this implies that a carrier board was needed to provide periphery connectivity and power to the SOM. The third main component in the device is the mechanical enclosure. In the next paragraphs we are going to talk about them.

1.3.2.1. System On Module selection

In order to start the research for the new platform we started from an initial requirement taking into account the system solution based on National Instruments.

- **Processor: Xilinx Zynq-7020 667 MHz / Dual-Core ARM Cortex-A9 / Artix-7 FPGA Fabric**
- **Size: 50.8 mm x 78.2 mm (2 in. x 3 in.)**
- **Power Typical: 3W to 5 W | Max: 10W**
- **Dedicated Processor I/O: Gigabit Ethernet, USB 2.0 Host, USB 2.0 Host/Device, SDHC, RS232 TX/RX**
- **Memory Nonvolatile: 512 MB / DRAM: 512 MB**
- **Operating Temperature: -40 ˚C to 85 ˚C Local Ambient**
- **FPGA I/O 160 Digital I/O Channels**
    - **16 Single-Ended 3.3V**
    - **144 Single-Ended / 72 Differential (3 banks with user-supplied voltage)**
    - **Configurable Peripherals**
    - **Gigabit Ethernet, RS232 x3, RS485 x2, CAN x2**

Connections summary:

- **ETHERNET**
- **CAN_0**
- **USB_0**
- **USB_1**
- **RS485_0**
- **RS485_1**
- **SD**
- **RELAYS DRIVER GPO**

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- **RELAYS DRIVER**
- **PS**
- **LEDS**
- **PWR OUTPUT**
- **PWRxternal connections or features**
- **Wifi/BT module**
- **SD card**

Our main research topics to measure and help us to select the best solution for us were:

- **Provide a system which satisfies the technical solution**
- **Cost**
- **The availability of a wiki page with an open community working with the provided platform**
- **Good documentation for the hardware and firmware adoption**
- **Offers the possibility of having direct support from the SOM manufacturer**
- **Offers the possibility of getting specific help for some design parts if there was a lack of expertise in some design topic**

Taking these indicators into account we performed research for SOM manufacturers. The following list shows the manufacturers included into the research and the main reason for the digest these list and conclusions:

- **Variscite: current adopted solution, best cost, support and it is used by some partners**
- **EmCraft: discarded. Client support in the USA only**
- **PHYTEC: discarded. No external WiFi/BT transceiver is provided in the solution**
- **SOMLabs: discarded. Early adopters have only 5 products in their portfolio**
- **Emtrion: discarded. Don't have what we are looking for in terms of communication interfaces**
- **Compulab: discarded. Software out-of-date. SW releases are old compared to the rest of imx6 SOMs**
- **Venco: discarded. Based on Kontron and Digi, lack of detailed information**
- **Digi: discarded. Product specifications are not clear, FW support has no versioning repository**
- **Ka-Ro: discarded. No external WiFi/BT transceiver**
- **Toradex: selected as second supplier if the main selection has problems in the future**
- **Embedded Artists: discarded. Long term availability 2022-2025 (we were looking for >= 2030)**
- **iWave: discarded. Poor documentation**
- **ENGICAM: discarded. No external WiFi/BT transceiver**
- **KAMAMI: discarded. Sells SOMLabs products (discarded original solution)**

Regarding the Carrier board, taking into account that the carrier board design has a mandatory dependency regarding the selected SOM, once the SOM manufacturer is selected, we start the design. By using the provided information from the SOM manufacturer and also the information from the prototyping phase we designed 1 version for the first iteration of hardware development which we called EVT (Engineering Validation Test). After that, including the product specific requirements and improvements from EVT detected issues, we designed the

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DVT (Design Validation Test) where we could say that we had a close prototype to the final development stage.

The main tasks performed to do the SEMS ONE design and development are:

This project needs the cooperation from different expertise fields. In order to classify the main related tasks we can split the design in terms of the tasks from the Hardware, Firmware and Software point of view. In general, there is cooperation with the “concept” team in order to make sure that all the different areas have the same image about the project objectives but also helping to define those characteristics that could not be completely designed or which need a new target solution.

1.3.2.2. Hardware design:

- **Schematics, layout, manufacturing and test for EVT**
- **Schematics, layout, manufacturing and test for DVT**
- **Design, test and validate manufacturing Standard Of Production steps**
- **Create and check mechanical prototypes**
- **Create, build and check DVT external casing**
- **Create, build and check device packaging**
- **Design documentation creation**

1.3.2.3. Firmware design (Firmware + software onboard):

- **Proof of concept with the prototype based on the demo board**
- **Provide the Board Support Package to the designed system (device tree and carrier support)**
- **Include all the support for the OS for device drivers**
- **Include OS OTA support**
- **Create main application architecture**
- **Implement and test all the main application modules**
    - **Local communications (Ethernet, RS485, CAN, USB, Wi-Fi, BT)**
    - **Cloud communications (HTTPS API communication, WebSocket)**
    - **Support for meter communication (Modbus RTU over RS485)**
    - **Support for inverter communication (Modbus TCP)**
    - **Calculations module (for data processing)**
    - **User Interface modules (led/button)**
    - **Application OTA support to include new functionalities**
    - **Create, test and validate manufacturing tool:**
        - **Device creation tool**
        - **Manufacturing test and report tool**
    - **Design documentation creation**

1.3.2.4. Software design

- **Data model support and structure**
- **Data model database implementation**
- **Give device support in the back-office operational system**

1.3.3. Main components integration

We have split the design of this device into phases where the target is to release an expectation in terms of items to satisfy and then check and validate the proposed solution. Taking this into account, we have started the development by researching about the selected platform in order

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to confirm if the selected solution can satisfy the final requirements. For that purpose, we acquired the demo board of the platform to perform our prototyping tests. After that we designed our own carrier board (EVT).

After that we have performed an interaction where we have corrected the found issues in the electronic field, matched with the mechanical prototypes and finally built new PCB interactions with the first iteration of mechanical design (DVT). Little adjustments were required to achieve the production optimization (PVT) and get the final solution which can be improved once the market feedback is recovered.

1.3.3.1. **PROTO**

For the proto phase we ordered 2 Concerto boards. These boards are the demo boards for the platform which help us with the familiarization with the platform. In the following image we can see a preliminary setup for the testing board.

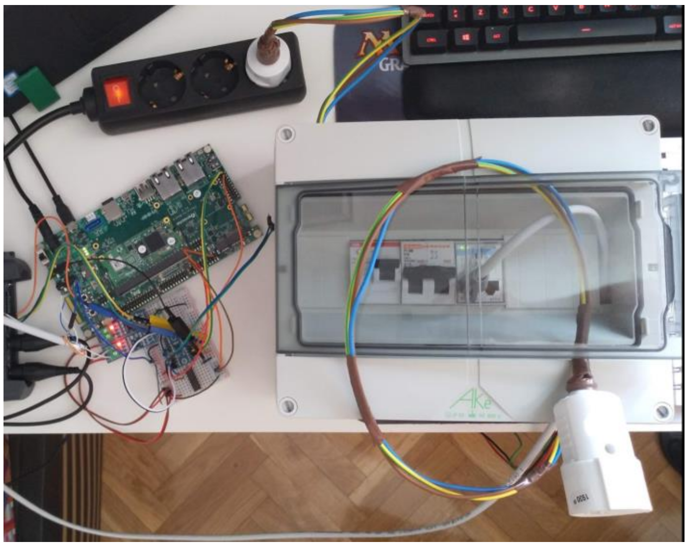

Figure 9. SEMS ONE Proto

1.3.3.2. **EVT (Engineering Validation Test)**

In this phase a carrier board using our knowledge from the previous platform and periphery necessity has been designed and also applying our knowledge from the demo board. For this validation phase, we ordered 3 pieces.

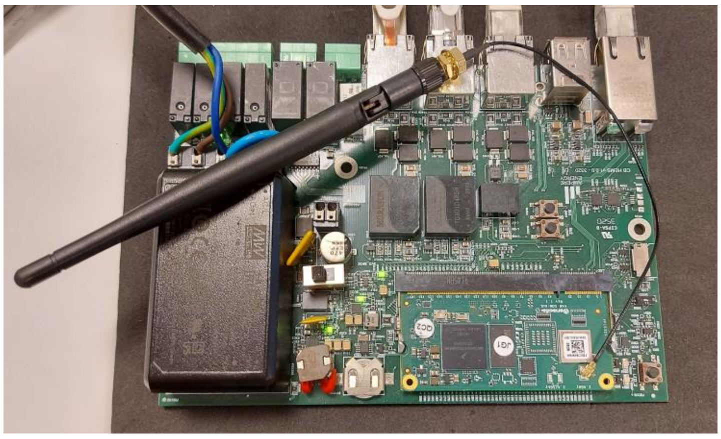

Figure 10. SEMS ONE EVT

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1.3.3.3. **DVT (Design Validation Test)**

In DVT phase we changed some requirements (power supply, debugging options, led/button inclusion, reduce relays, …) in order to optimize the design and develop what would be the desired solution for the project. For this validation phase, we ordered 3 electrical parts (SOM+Carrier) and 5 mechanical pieces.

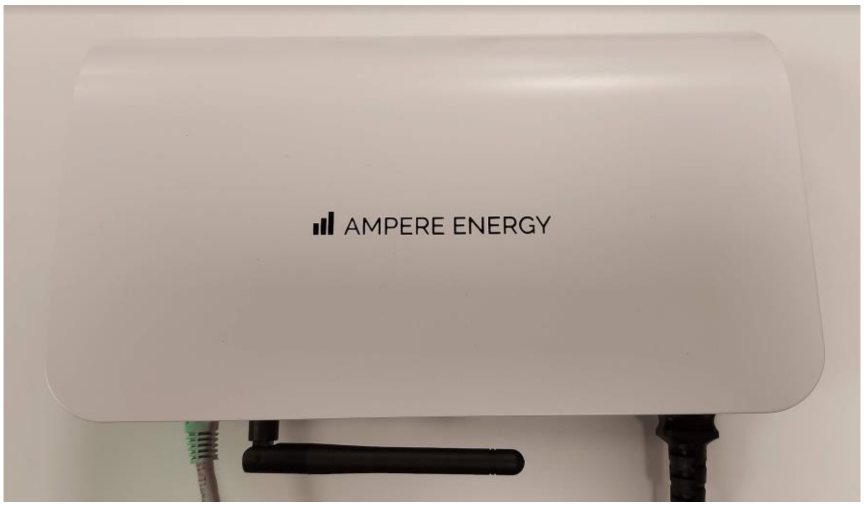

Figure 11. SEMS ONE DVT

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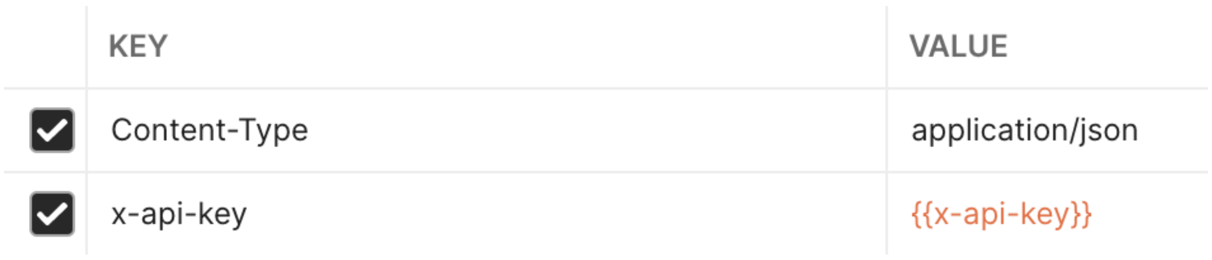
1.4. Development of the API to manage the smart-storage system

To get the data from the devices, we have created a secure API. This API is programmed in NodeJs with a Mysql database to save all the data obtained from the device, all of which is hosted on AWS with continuous integration. Analyzing the needs of the requirements, we saw the need to send commands to the device, in order to do so we created a websocket server to be able to send commands from the cloud to the different devices.

Some examples about how to get some parameters from the API are shown below.

1.4.1. Get user Token

To use the API, we will always have to send the following headers in all requests:

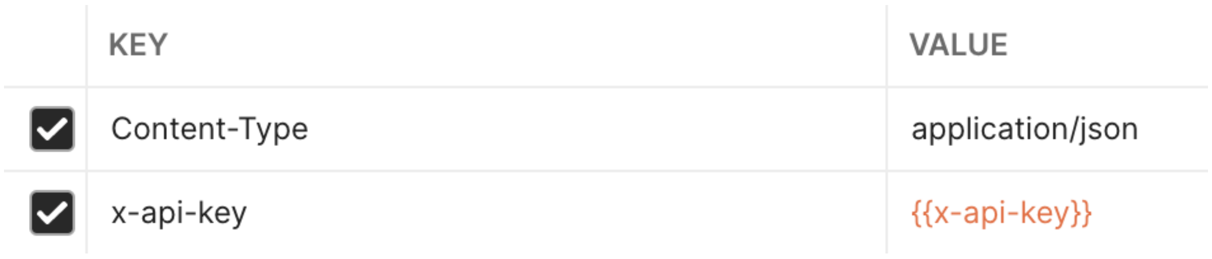


	KEY	VALUE
✓	Content-Type	application/json
✓	x-api-key	{{x-api-key}}

Figure 12. User Token

First of all, we must obtain the token to operate with the others endpoints.

The request will be the following, with your username and password:
POST: https://api-partners.ampere-energy.cloud/login
Headers:



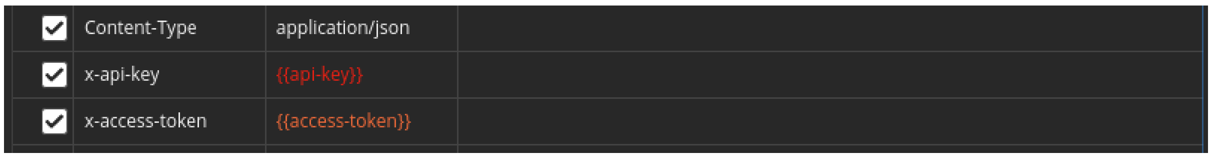
	KEY	VALUE
✓	Content-Type	application/json
✓	x-api-key	{{x-api-key}}

Figure 13 User Token

Body:

```
{
  "userName": "XXX",
  "password": "your password"
}
```

Once the token has been obtained, it will be used to make the subsequent requests. As a header with the key: x-access-token and value obtained in the previous requests.
`access-token = response.token`



✓	Content-Type	application/json
✓	x-api-key	{{api-key}}
✓	x-access-token	{{access-token}}

Figure 14. User Token Request

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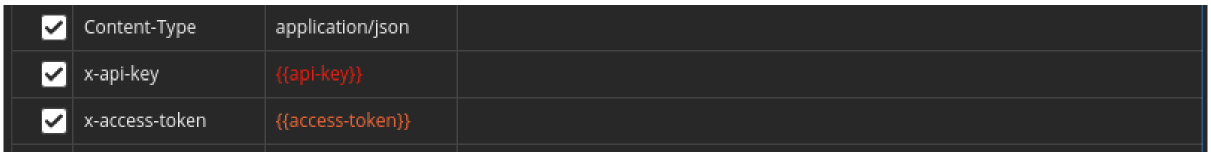
1.4.2. Get User Profile.

To obtain the user profile, you must do the following requests:

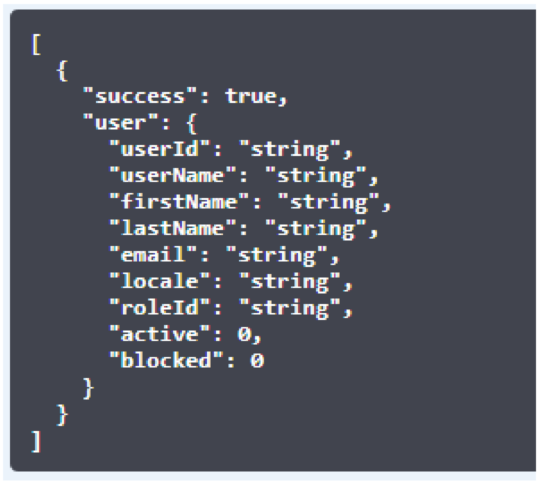
GET */users/profile*
Headers: *x-api-key, x-access-token*
Body: *<empty>*



✓	Content-Type	application/json
✓	x-api-key	{{api-key}}
✓	x-access-token	{{access-token}}

Figure 15. User Profile Request

Response:



```
[
  {
    "success": true,
    "user": {
      "userId": "string",
      "userName": "string",
      "firstName": "string",
      "lastName": "string",
      "email": "string",
      "locale": "string",
      "roleId": "string",
      "active": 0,
      "blocked": 0
    }
  }
]
```

Figure 16. User Profile Response

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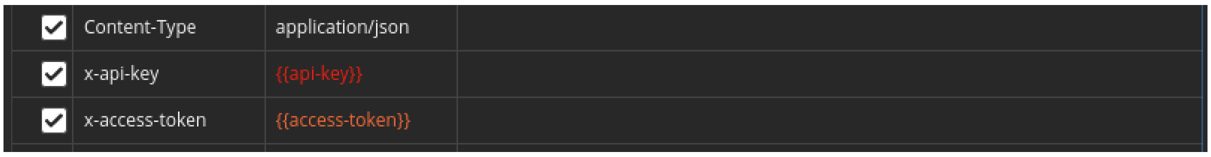
1.4.3. Get user locations

To continue the flow in the following requests you must know the locations assigned by the user.

To do this, you have to call the following end-point:
GET */users/{userId}/locations*
Params: *userId*
Headers: *x-api-key, x-access-token*
Body: <*empty*>



✓	Content-Type	application/json
✓	x-api-key	{{api-key}}
✓	x-access-token	{{access-token}}

Figure 17. User locations endpoint

Response:

```
[
  {
    "success": true,
    "user": {
      "userId": "string",
      "userName": "string",
      "addressId": "string",
      "firstName": "string",
      "lastName": "string",
      "email": "string",
      "roleId": 0,
      "locale": "string",
      "active": "string",
      "blocked": "string",
      "locations": [
        {
          "locationId": "string",
          "locationName": "string",
          "parentId": "string",
          "addressId": "string",
          "rateId": "string",
          "currencyId": "string",
          "typeId": "string",
          "pvPowerContract": 0,
          "pvSolar": 0,
          "activateCompensation": 0,
          "compensationRateId": "string",
```

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```
          "devices": [
            {
              "deviceId": "string",
              "deviceName": "string",
              "description": "string",
              "firmware": "string",
              "osVersion": "string",
              "typeId": "string",
              "countryId": "string",
              "latitude": "string",
              "longitude": "string"
            }
          ],
          "address": {
            "addressId": "string",
            "countryId": "string",
            "city": "string",
            "address": "string",
            "zipCode": "string",
            "latitude": "string",
            "longitude": "string"
          },
          "rate": {
            "rateId": "string",
            "rateName": "string",
            "countryId": "string",
            "currencyId": "string",
            "supplierId": "string",
            "typeId": 0,
            "freeMarket": 0,
            "discrimination": 0,
            "compensation": 0,
            "maxTimeSlots": 0,
            "description": "string"
          }
        }
      ]
    }
  }
]
```

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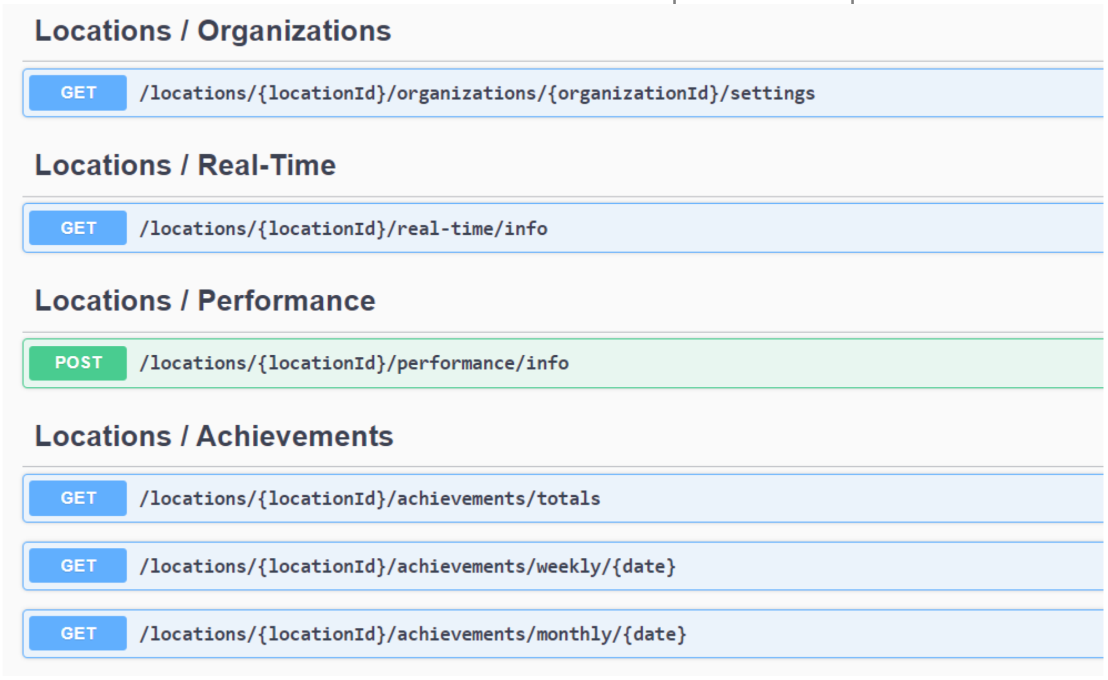
1.4.4. **Locations**

From here, to invoke the location-related endpoints, we need to include the specific organizationId in one of them:

- **organizationId: GCut9dd030eh1KndCKRajQ**

And the identifier of the location that we obtained in the previous end-point.



Locations / Organizations

GET /locations/{locationId}/organizations/{organizationId}/settings

Locations / Real-Time

GET /locations/{locationId}/real-time/info

Locations / Performance

POST /locations/{locationId}/performance/info

Locations / Achievements

GET /locations/{locationId}/achievements/totals

GET /locations/{locationId}/achievements/weekly/{date}

GET /locations/{locationId}/achievements/monthly/{date}

Figure 18. Locations end-point

1.4.4.1. **Get location configuration.**

For this we will call the following end-point:
GET */locations/{locationId}/organizations/{organizationId}/settings*
Params: *locationId, organizationId*
Headers: *x-api-key, x-access-token*
Body: *<empty>*

Response:

```
{
  "success": true,
  "location": {
    "locationId": "string",
    "locationName": "string",
    "parentId": "string",
    "addressId": "string",
    "rateId": "string",
    "currencyId": "string",
    "typeId": "string",
    "pvPowerContract": 0,
    "pvSolar": 0,
    "activateCompensation": 0,
    "compensationRateId": "string",
```

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```
    "devices": [
      {
        "deviceId": "string",
        "deviceName": "string",
        "description": "string",
        "firmware": "string",
        "osVersion": "string",
        "typeId": "string",
        "countryId": "string",
        "latitude": "string",
        "longitude": "string"
      }
    ],
    "address": [
      {
        "addressId": "string",
        "countryId": "string",
        "city": "string",
        "address": "string",
        "zipCode": "string",
        "latitude": "string",
        "longitude": "string"
      }
    ],
    "absortion_prices": [
      {
        "date": "string",
        "initHour": "string",
        "endHour": "string",
        "price": "string",
        "currencyId": 0
      }
    ],
    "injection_prices": [
      {
        "date": "string",
        "initHour": "string",
        "endHour": "string",
        "price": "string",
        "currencyId": 0
      }
    ]
  }
}
```

1.4.4.2. **Get location information**

For this we will call the following end-point:
GET `/locations/{locationId}/real-time/info`
Params: `locationId`
Headers: `x-api-key, x-access-token`
Body: `<empty>`

Response:

```
{
```

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```
    "success": true,
    "location_info": {
      "soc": 0,
      "batteryPower": 0,
      "batteryVoltage": 0,
      "inverterPower": 0,
      "acLoadsPower": 0,
      "meterVoltage": 0,
      "meterPower": 0,
      "pvPower": 0,
      "pvVoltage": 0,
      "energyPrice": 0,
      "acLoadsEnergy": 0,
      "meterEnergy": 0,
      "totalPVEnergy": 0,
      "internalPVEnergy": 0,
      "newTariffTotalCost": 0,
      "standardTotalCost": 0,
      "realTotalCost": 0,
      "pvBatteryEnergy": 0,
      "gridBatteryEnergy": 0,
      "gridInjectionEnergy": 0,
      "internalPVPower": 0,
      "externalPVPower": 0,
      "loadEnergy": 0,
      "loadPower": 0,
      "consumo": 0,
      "ahorro": 0,
      "online": true,
      "aggregatedEnergyMonth": 0,
      "totalCostMonth": 0,
      "pvPanels": true,
      "battery": true,
      "charger": true,
      "master": true,
      "slave": true,
      "nuDevices": 0,
      "gridBatFlow": true,
      "batGridFlow": true,
      "sunBatFlow": true,
      "batHomeFlow": true,
      "sunHomeFlow": true,
      "gridHomeFlow": true,
      "batteryPowerFlow": true,
      "vehicleChargerFlow": true,
      "chargerVehicleFlow": true,
      "grid_bat": 0,
      "bat_grid": 0,
      "bat_home": 0,
      "sun_bat": 0,
      "sun_home": 0,
      "grid_home": 0
    }
  }
```

1.4.4.3. **Get historic information of the location.**

For this we will call the following end-point:
POST *`/locations/{locationId}/performance/info`*
Params: *`locationId`*
Headers: *`x-api-key, x-access-token`*

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Body:

```
{
    "dateIni": "2021-06-08",
    "dateFin": "2021-06-08"
}
```

Response:

```
[
  {
    "success": true,
    "location_performance": [
      {
        "datetime": "string",
        "loadEnergy": "string",
        "meterEnergy": "string",
        "soc": "string",
        "totalPVEnergy": "string",
        "batteryEnergy": "string",
        "gridInjectionEnergy": "string"
      }
    ]
  }
]
```

1.4.4.4. **Get total achievements for the location.**

For this we will call the following end-point:
GET */locations/{locationId}/achievements/totals*
Params: *locationId*
Headers: *x-api-key, x-access-token*
Body: *<empty>*

Response:

```
{
    "success": true,
    "location_performance": {
      "timestamp": 0,
      "energy_independence": 0,
      "battery_independence": 0,
      "solar_independence": 0,
      "co2_kg": 0,
      "car_km": 0,
      "planted_trees": 0,
      "savings": 0,
      "compensation_savings": 0,
      "nuDevices": 0,
      "battery": 0
    }
  }
```

1.4.4.5. **Get filtered by month achievements for the location**

For this we will call the following end-point:
GET */locations/{locationId}/achievements/monthly/{date}*

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Params: *locationId, date (YYYY-MM-DD)*
Headers: *x-api-key, x-access-token*
Body: *<empty>*

Response:
```
{
    "success": true,
    "location_performance": {
      "timestamp": 0,
      "energy_independence": 0,
      "battery_independence": 0,
      "solar_independence": 0,
      "co2_kg": 0,
      "car_km": 0,
      "planted_trees": 0,
      "savings": 0,
      "compensation_savings": 0,
      "nuDevices": 0,
      "battery": 0
    }
  }
```

1.4.4.6. Get filtered by weeks achievements for the location

For this we will call the following end-point:
GET */locations/{locationId}/achievements/weekly/{date}*
Params: *locationId, date (YYYY-MM-DD)*
Headers: *x-api-key, x-access-token*
Body: *<empty>*

Response:
```
{
    "success": true,
    "location_performance": {
      "timestamp": 0,
      "energy_independence": 0,
      "battery_independence": 0,
      "solar_independence": 0,
      "co2_kg": 0,
      "car_km": 0,
      "planted_trees": 0,
      "savings": 0,
      "compensation_savings": 0,
      "nuDevices": 0,
      "battery": 0
    }
  }
```

1.4.5. Devices

From here to invoke the end-points related to the devices of a location we need to include the specific organizationId in all of them:

- **organizationId: GCut9dd030eh1KndCKRajQ**

And the device identifier that we got from the device list when asking for location settings.

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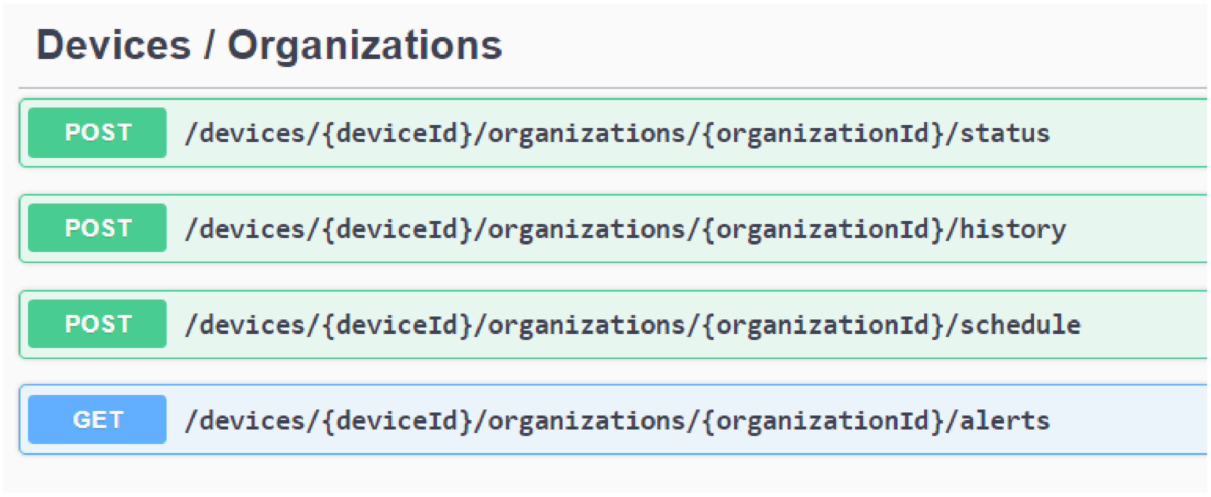
Devices / Organizations

POST /devices/{deviceId}/organizations/{organizationId}/status

POST /devices/{deviceId}/organizations/{organizationId}/history

POST /devices/{deviceId}/organizations/{organizationId}/schedule

GET /devices/{deviceId}/organizations/{organizationId}/alerts

Figure 19. Devices end-points

1.4.5.1. **Get devices status.**

For this we will call the following end-point:
POST */devices/{deviceId}/organizations/{organizationId}/status*
Params: *deviceId, organizationId*
Headers: *x-api-key, x-access-token*
Body (opcional):

```
{
      variables: [
            "batterySoc",
             "batteryPower",
             "batteryTemperature",
             "inverterActivePowerPh1",
             "inverterActivePowerPh2",
             "inverterActivePowerPh3",
             "meterActivePowerPh1",
             "meterActivePowerPh2",
             "meterActivePowerPh3"
       ]
}
```

Response:

```
{
  "success": true,
  "systemStatus": {
    "meterActivePowerPh1": 0,
    "meterActivePowerPh2": 0,
    "meterActivePowerPh3": 0,
    "inverterActivePowerPh1": 0,
    "inverterActivePowerPh2": 0,
    "inverterActivePowerPh3": 0,
    "batterySoc": 0,
    "batteryPower": 0,
    "batteryTemperature": 0
  }
}
```

1.4.5.2. **Get historic devices status**

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For this we will call the following end-point:
POST `/devices/{deviceId}/organizations/{organizationId}/history`
Params: `deviceId, organizationId`
Headers: `x-api-key, x-access-token`
Body:
```
{
      "initTime": "YYYY-MM-DDTHH:00:00Z",
      "endTime": "YYYY-MM-DDTHH:00:00Z"
}
```

Response:
```
{
  "success": true,
  "systemHistory": {
    "meterActivePowerPh1": 0,
    "meterActivePowerPh2": 0,
    "meterActivePowerPh3": 0,
    "inverterActivePowerPh1": 0,
    "inverterActivePowerPh2": 0,
    "inverterActivePowerPh3": 0,
    "batterySoc": 0,
    "batteryPower": 0,
    "timestamp": 0,
    "datetimehours": "string"
  }
}
```

1.4.5.3. **Send energy schedule to the device.**

For this we will call the following end-point:
POST *`/devices/{deviceId}/organizations/{organizationId}/schedule`*
Params: *`deviceId, organizationId`*
Headers: *`x-api-key, x-access-token`*
Body:
```
{
      "schedule": [
          {
              "initTime": "YYYY-MM-DDTHH:00:00Z",
              "endTime": "YYYY-MM-DDTHH:00:00Z",
              "power": 0
          }
      ]
}
```

Response:
```
{
  "success": true,
  "message": "string"
}
```

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2. Test results

In this section will be shown the different results obtained for the different components of the system.

2.1. T-PRO validation test

To validate if the AMPERE T-Pro prototypes comply with the requirements fixed for a normal operation in standalone mode, several test results were made.

A normal operation is showed in the figure below. The battery SOC - State of Charge % (red colour) is charging whit PV power (green colour) while the AC Loads (purple colour) are compensated with the photovoltaic energy surplus. Around 17:00 pm the PV power starts to be very low, and the AC loads power consumption are compensated by the energy stored in the battery instead of the AC grid due to the energy price (orange colour), reason why the percentage of SOC starts to reduce gradually. Thanks to that behaviour the user will have some savings because in the expensive period of the day, the energy from the AC grid is avoided and all the energy needed to maintain the AC loads is given by the battery, battery that was previously charged from the PV energy surplus.

Thanks to this behaviour, the user will have some economic savings, since in the most expensive period of the day the AC grid power is avoided and all the energy needed to maintain the AC loads is provided by the battery, a battery that was previously charged with the surplus PV energy, increasing the savings obtained.

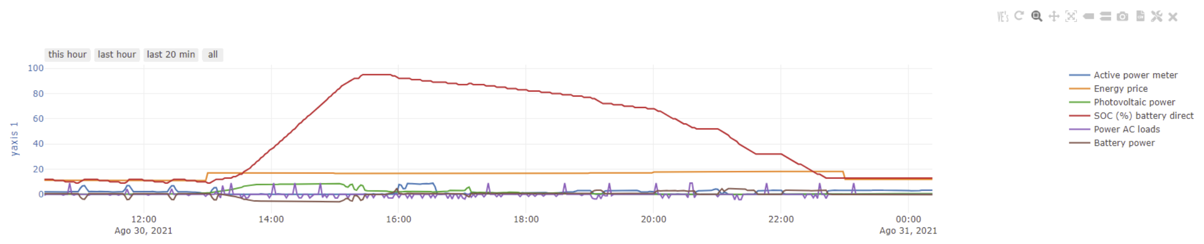
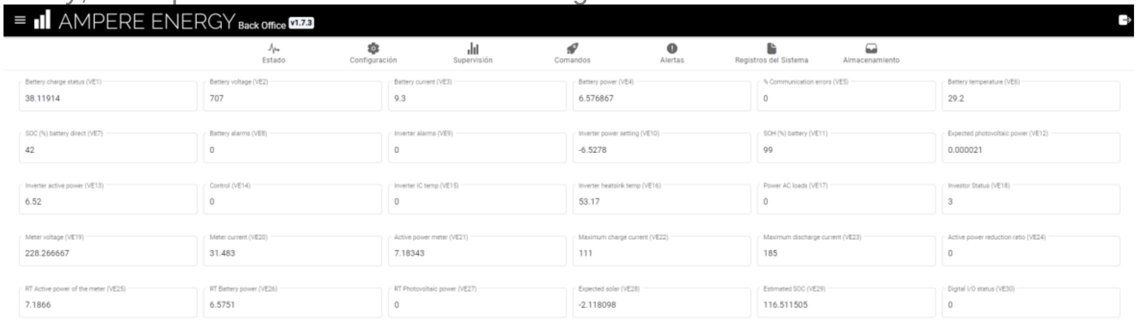


Figure 20. AMPERE T-Pro normal operation

2.2. SEMS Buffer validation test

The AMPERE SEMS Buffer communicates correctly with the AMPERE's Cloud and thanks to that, it will be possible to monitoring and easily represent the data of the device as shows the below figures where it can be seen first the data monitored from the device in real time and secondly, the representation of some interesting variables over time.



Battery charge status (VE1) 38.11914	Battery voltage (VE2) 707	Battery current (VE3) 9.3	Battery power (VE4) 6.576867	% Communication errors (VE5) 0	Battery temperature (VE6) 29.2
SOC (%) battery direct (VE7) 42	Battery alarms (VE8) 0	Inverter alarms (VE9) 0	Inverter power setting (VE10) -6.5278	SOH (%) battery (VE11) 99	Expected photovoltaic power (VE12) 0.000021
Inverter active power (VE13) 6.52	Control (VE14) 0	Inverter IC temp (VE15) 0	Inverter heatsink temp (VE16) 53.17	Power AC loads (VE17) 0	Investor Status (VE18) 3
Meter voltage (VE19) 228.266667	Meter current (VE20) 31.483	Active power meter (VE21) 7.18343	Maximum charge current (VE22) 111	Maximum discharge current (VE23) 185	Active power reduction ratio (VE24) 0
RT Active power of the meter (VE25) 7.1866	RT Battery power (VE26) 6.5751	RT Photovoltaic power (VE27) 0	Expected solar (VE28) -2.118098	Estimated SOC (VE29) 116.511505	Digital I/O status (VE30) 0

Figure 21. Data monitoring

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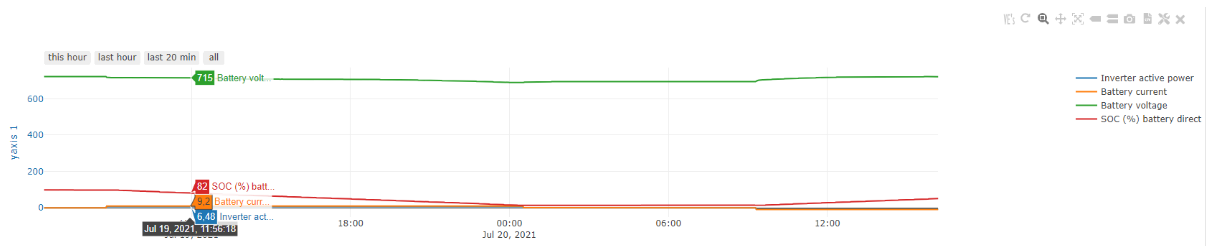

Figure 22. Data representation

To validate the correct behaviour a peak shaving feature has been tested with the following scenario.

- **Contracted power: 8kW**
- **Load Power: 15kW**

In the test the first step was to configure the contracted limit power to 8kW, simulating it as the limit of a real installation. After that, a charge process was set in accordance with the schedule obtained from the cloud, the orange line shows the different charge processes started. In the last one, a 15Kw load was activated too and it can be seen that the total consumption (blue line) was 15kW giving all the demanded energy by the system, but never overcoming the limit of the contracted power (8kW). Therefore, what the equipment did was to perform peak shaving in order not to exceed the contracted power and to provide all the necessary energy to the system.

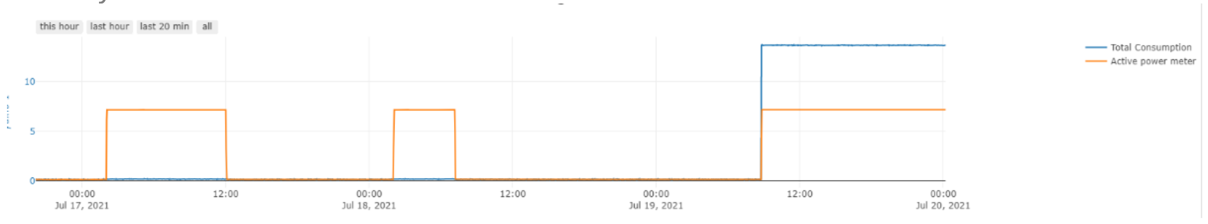

Figure 23. PEAK Shaving demonstration

2.3. SEMS validation test

In order to ensure correct assembly of the prototypes but also the product itself when mass manufacturing it is necessary to establish a list of tests/checks to validate the assembly of the device. Taking into account that the functionalities were implemented during the prototypes design and verification, the tests for the EVT and DVT prototypes at electrical level were carried out with laboratory instruments (oscilloscope, DC loads, AC/DC power supply, power meters, …) after that we worked on designing a way to test the prototypes and devices functionalities in a more efficient way.

2.3.1. Visual inspection

This implies taking a look at the connectors in the carrier board and big PCB elements assembly looking for detached components and some external damage. On the other hand, mechanical parts are measured to check the main measuring points to validate the correct delivery of the pieces.

2.3.2. Electrical tests

Power supply stability check. There are different power supplies in the system so we make sure that the nominal voltage and also the ripple of each power rail is correct by checking with an oscilloscope. All the power checks from the 4 main power supplies were satisfied (VCC_12V, VCC_5V, VCC_3V3, VCC_SOM).

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2.3.3. Functional tests

Taking into account the basic and main functionalities at hardware level it is necessary to ensure that the communication interfaces works correctly and all the expected support from the hardware point of view is satisfied. In order to guarantee the testing over all the produced devices, a factory testing system has been implemented. The test manufacturing tool has different "tests" which are completed by different "test items". The main tests areas are:

Item to test	Test description	Results
Relays	Check that each relay is closed/open and works as expected	Pass
RGB LED	Check that the RGB led can display all the colours	Pass
User Button	The operator is required to check single press and long press, the tool detects automatically the required push events sequence	Pass
CAN port	A "master" board with an all-time working server is attending the CAN port in order to answer when the correct communication sequence is detected and the test tool verifies the read information	Pass
RS485 ports	The same as for CAN BUS port, but this time by using one Modbus RTU server for each RS485 ports	Pass
USB	In order to check the USB, 2 USB pen drives are used to write and read operations. The tool compares the written information and read information and validate the operation with the USB ports	Pass
Temperature and humidity	The tool measures the temperature and humidity from the ambient and asks the operator about the external reference in the manufacturing table, the tool compares the provided information against the internal read one	Pass
RTC	Communicate with the RTC module and write the date, verify the time after a few seconds	Pass
EEPROM	Check to write data to the EEPROM in the carrier board and then check the read data, compare the written against the read and verify	Pass
WiFi	Check the signal strength from a known wireless network in the factory, if the signal strength is not over the threshold the test fails	Pass

Table 8. SEMS validation test

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Example of the output from the factory tool for the RS485 test:

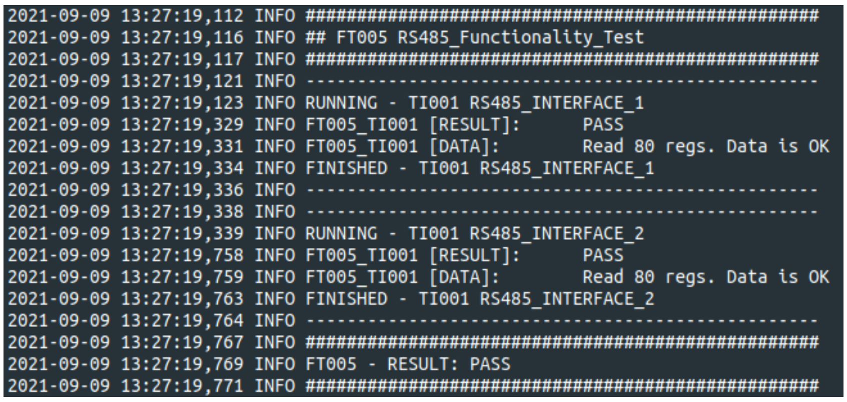
```
2021-09-09 13:27:19,112 INFO ##################################################
2021-09-09 13:27:19,116 INFO ## FT005 RS485_Functionality_Test
2021-09-09 13:27:19,117 INFO ##################################################
2021-09-09 13:27:19,121 INFO --------------------------------------------------
2021-09-09 13:27:19,123 INFO RUNNING - TI001 RS485_INTERFACE_1
2021-09-09 13:27:19,329 INFO FT005_TI001 [RESULT]:      PASS
2021-09-09 13:27:19,331 INFO FT005_TI001 [DATA]:        Read 80 regs. Data is OK
2021-09-09 13:27:19,334 INFO FINISHED - TI001 RS485_INTERFACE_1
2021-09-09 13:27:19,336 INFO --------------------------------------------------
2021-09-09 13:27:19,338 INFO --------------------------------------------------
2021-09-09 13:27:19,339 INFO RUNNING - TI001 RS485_INTERFACE_2
2021-09-09 13:27:19,758 INFO FT005_TI001 [RESULT]:      PASS
2021-09-09 13:27:19,759 INFO FT005_TI001 [DATA]:        Read 80 regs. Data is OK
2021-09-09 13:27:19,763 INFO FINISHED - TI001 RS485_INTERFACE_2
2021-09-09 13:27:19,764 INFO --------------------------------------------------
2021-09-09 13:27:19,767 INFO ##################################################
2021-09-09 13:27:19,769 INFO FT005 - RESULT: PASS
2021-09-09 13:27:19,771 INFO ##################################################
```

Figure 24. Results of the RS485 tests

2.4. API validation test

To verify that the API works correctly, the following tests have been carried out:

Item to test	Test description	Results
User login	Check whether login can be conducted quickly and seamlessly	Pass
Get organization locating settings	Should be as specified in the concept. Response time should be less than 1 minute.	Pass
Get organization device	The operator is required to check single press and long press, the tool detects automatically the required push events sequence	Pass
Alert status	A “master” board with an all-time working server is attending the CAN port in order to answer when the correct communication sequence is detected, and the test tool verifies the read information	Pass
Get organization device history	The same as for CAN BUS port, but this time by using one Modbus RTU server for each RS485 ports	Pass
Set organization device schedule	In order to check the USB, 2 USB pen drives are used to write and read operations. The tool compares the written information and read information and validate the operation with the USB ports	Pass
Get organization device status	The tool measures the temperature and humidity from the ambient and asks the operator about the external reference in the manufacturing table, the tool compares the provided information against the internal read one	Pass

Table 9. API validation test

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