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System Integration

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Figures

List of abbreviations

Abbreviation	Definition
EV	Electric Vehicle
PV	Photovoltaics
IoT	Internet of Things
MV	Medium voltage
LV	Low voltage
DC	Direct current
V2G	Vehicle to grid
AC	Alternative current
OCPP	Open charge point protocol

PCS	Power conversion system
SoC	State of Charge
EMS	Energy management system
CPMS	Charge point management system
AMR	Automatic meter reading
DSO	Distribution system operator
API	Application programming interface
P2P	Peer to peer
WSS	Web socket secure
QR	Quick response
RFID	Radio frequency identification
BESS	Battery energy storage system
EVSE	Electric vehicle supply equipment
NFC	Near field communication
BMS	Battery management platform
GTE	Energy management platform
GTB	Building management platform
GTR	CO2 network installations management platform
GTBatt	Batteries management platform

Contents

Abstract

This report describes the preparation and integration works which have been completed before the actual demonstration activities in OEDAS and HES-SO pilot sites.

In the report, general information is provided about both the installation of the infrastructure to be used within the scope of demo activities and the system integration studies carried out. Within this scope, devices which are installed during the project and also other existing devices on each pilot sites have been presented with the information of its measurement systems and also communication architectures have been defined and presented in Turkish (OEDAS Eskisehir) and Swiss pilot sites (HES Campus). In addition, energy management platforms where the devices will be controlled in the pilot regions have also been presented for both pilot sites.

System integration

According to DoA, the successful procedure toward the integration of the required functionalities in each test-site will be described in D8.2. More specifically, functionalities of EV management platform and mobile application as in the Turkish test-site will be presented. Furthermore, the successful development of the power-to-gas facility functionalities and the building management system of the Swiss demo-site will be explained. Finally, the adequate integration of the IoT platform in these demo-sites will be validated.

1. Introduction

This report includes activities under Task 8.2 System Integration, a sub-task of the FlexiGrid project WP8 (Demonstration of flexibility measures and electricity grid services provided by local energy storage and EVs). The main content of the report basically consists of the details of preparational work and system integration activities that were carried out in Turkish and Swiss pilots before the demo activities.

Controllable flexible assets that will be used in demonstration activities of Turkey and Switzerland pilot sites are presented in the "Measurement system and Controllable devices" section, which is the second section after the introduction. The measurement data that can be collected about the assets are presented separately. In this direction, general information is given about the collectable data of the battery storage system, electric vehicle charging stations, PVs and transformer, which are the main assets to be used in demonstration activities of the Turkish pilot. Likewise, similar information is presented for flexible assets such as PVs, heat pumps and batteries in the Swiss campus.

In the third section (Communication Architecture) of the report, general information about the communication protocols which are used to provide a connection between flexible assets and energy management tools and IoT platform is presented. Accordingly, a general communication architecture was shared for both pilot regions and information on IoT platform integration was also presented.

In the fourth section (Energy management platforms) of the report, different tools that will be used in demo activities are presented. Accordingly, EV management platform, mobile application and battery management system were presented for the Turkish demo, while the Energy Management Platform (GTE), Building Management platform (GTB), CO2 network installations management platform (GTR), Batteries management platform (GTBatt) and Power-to-Gas management platform were presented for the Swiss demo.

In the conclusion section, which is the last part of the report, general evaluations are given.

2. Measurement system and Controllable devices

This section describes measurement systems, data signals and the different controllable devices in Turkish (OEDAS) and Swiss (HES-SO) pilot sites.

2.1 OEDAS pilot site

OEDAS demonstration activities will take place in a local municipal area in Eskisehir, as shown in Figure 1. Most of the houses have rooftop solar PV panels and connected to the main distribution grid of OEDAS. The area is powered by one 34.5kV/0.4kV MV/LV transformer which has an active power rating of 400kVA. During the sunny hours, buildings are capable to meet their electricity needs from PV panels and when there is excess production, surplus energy is sent back to the OEDAS grid. These PV panels are owned and operated by the property owner (local municipality). OEDAS is not authorized to send signals to control the PVs. OEDAS measures bi-directionally the house energy consumption or production. OEDAS automated meter reading system located at the grid connection point of PVs, measures surplus energy (the energy value which is sent back to the grid)

Figure 1 View of OEDAS pilot region

The demonstration activities of OEDAS, which will be carried out in Task 8.3, mainly focus on the optimal management of EV charging stations and battery storage system using with EV management platform and smart charging algorithms. In order to perform the Electrical vehicle charging management/integration part in the Demo case, one DC 50 kW fast charger and one DC 10 kW (V2G compatible) charger, as well as 32kWh battery storage system were installed in the selected pilot area. (The area surrounded by a rectangle in Figure 1 shows the exact location where the installations were made). Also single line diagram of pilot network can be seen in Figure 2.

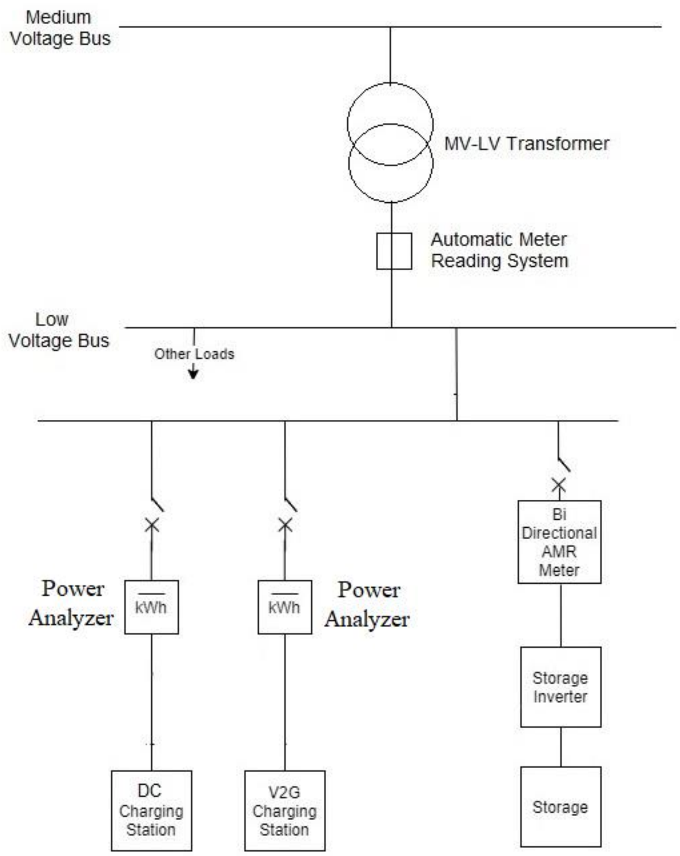


Figure 2 Basic single line diagram of pilot network

As shown in the above diagram, two separate power analysers were installed to get power quality measurements from each electric vehicle charger. For the demo case mainly, energy (consumption) data of the chargers will be used as an input for smart charging algorithms and this data will be collected directly from the AC meters inside chargers via open charge point protocol, OCPP 1.6 (it is an application protocol for communication between Electric vehicle (EV) charging stations and a central management platform)[1]. The operational information (measurement, performance) from the battery storage system, will be collected either from the battery itself or from the battery inverter via the battery management system. Additionally, one bi-directional electricity meter (not a smart meter) was also installed for billing and monitoring purposes. Images of the charging stations and battery storage container are presented in Figure 3 and Figure 4.

[1] https://www.openchargealliance.org/

1

Figure 3 V2G (left) and DC fast (right) charging stations

Figure 4 Battery Storage System

the existing infrastructure in OEDAS allows to collect data from each of these systems via the installed devices and platforms and subsequentially to push/send these collected data to the Flexi Grid IoT platform in different time resolutions. Signal lists, data and measurements that will be collected from Demo cases infrastructure is be presented in the next sections.

2.1.1 Battery storage system

The battery storage system consists of 9 battery packages, each with a capacity of 3,552 kWh. The total energy capacity of battery packages is nearly around 32 kWh. The output voltage of the battery system is 48 V DC. Basic parameters of battery packages can be seen in Table 1.

Table 1 Basic specification of battery module

Basic Parameters	
Nominal Voltage (V)	48
Nominal Capacity (Wh)	3552
Usable Capacity (Wh)	3374
Communication Port	RS485,CAN
Working Temperature Charge	0~50
Working Temperature Discharge	-10~50

The system includes a 3x15 kVA AC/DC inverter and the total capacity of the battery inverter is 45 kVA. Overall layout plan of the battery storage container and an image of battery packages and inverter can be seen in Figure 5 and Figure 6.

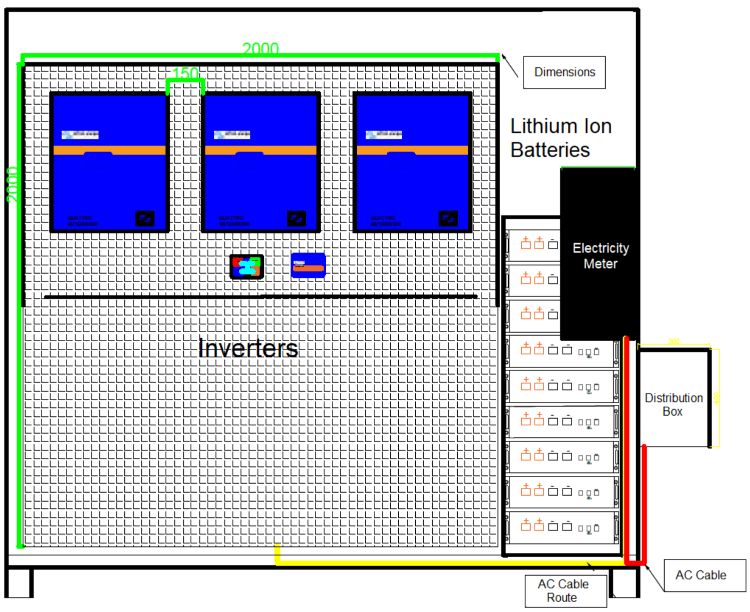


Figure 5 Battery storage system container layout plan

Figure 6 Battery packages (right) and battery inverter (left)

It is possible to collect various data measurements from the battery itself and also from the inverter. And real time control of batteries is also possible via the battery management system. In the table below the measurement data and control signals are available from the EV charging station battery are listed and specified Table 2 and Table 3.

Table 2 Measurement data of battery storage system

Measurement Data					
No	**Device Name**	**Data**	**R/W**	**Unit**	**Tag Name**
1	Battery Inverter	Total AC active power	R	W	p
2		Total Charged Energy	R	Wh	totalch
3		Total Discharged Energy	R	Wh	totaldisch
4		AC line voltage L1 to N	R	V	Van
5		AC line voltage L2 to N	R	V	Vbn
6		AC line voltage L3 to N	R	V	Vcn
7		AC L1 current	R	V	Ia
8		AC L2 current	R	V	Ib
9		AC L3 current	R	V	Ic
10		AC frequency	R	Hz	freq
11		General Alarm	R	-	Alarm
19		Manual Active Power Control Mode Read	R	-	MPContRead
20		Load Support Control Mode Read	R	-	LoadSupRead
21		Min SoC percentage assigned by the user Read	R	-	SoCminRead
22		Max SoC percentage assigned by the user Read	R	-	SoCmaxRead
23		Charging power when no load is active Read	R	-	PsetloadRead
24		Psetman1 Read	R	-	Psetman1Read
25		PCS Alarm	R	-	PCSAlarm
26		BMS Alarm	R	-	BMSAlarm
27		Power Factor	R	-	pf
28		Reactive Power	R	VAr	q
29	Battery	BMS_BAT_U	R	V	vdc1
30		BMS_BAT_I	R	A	idc1
31		BMS_BAT_SoC	R	-	soc
32		BMS_BAT_SoH	R	-	soh
33		BMS_DC_Power	R	W	Pdc
34		BMS_Status	R	-	status
35		BMS_BAT_Temp	R	C	temperature

Table 3 Control data of battery storage system

Control Data					
No	**Device Name**	**Data**	**R/W**	**Data Type**	**Tag Name**
1	**Battery Inverter**	PCS Reset	RW	Analog	PCSReset
2		Min SoC percentage assigned by the user	RW	Analog	SoCmin
3		Max SoC percentage assigned by the user	RW	Analog	SoCmax
4		Charging power when no load is active	RW	Analog	Psetload
5		Manual Active Power Control Mode	W	Single Point	MPCont
6		Load Support Control Mode	W	Single Point	LoadSup
7		Psetman1 (Manual Power Setting)	W	Analog	Psetman1

2.1.2 Electric Vehicle Chargers (DC and V2G compatible charger)

In the demo case pilot, there are 2 chargers installed 1) first chargers is a DC fast charger compatible with CCS and CHAdeMO charging, with a maximum DC charging power of 50 kW 2) second charger is also a DC 10 kW bi-directional charger compatible with Vehicle to Grid (V2G) technology. The second charger allow when using the V2G compatible vehicle, energy transfer from the vehicle to the local distribution grid via discharging. V2G charger has only one CHAdeMO socket.

According to the current structure of OEDAS, charging point management is managed with the CPMS (charging point management system) and communication & data collection processes are provided with OCPP connection. Besides data collection, remote control of charging points and real time management of charging sessions are also possible with OCPP protocol. Below you can see the basic data list of EV chargers that can be collected from CPMS.

Charging station information;

- **id:** cp_id identifying charging station
- **charge_box_id:** charge box id for charging station
- **connector_id:** id identifying charging station connector
- **power:** maximum available power per phase (in kW)
- **phases:** maximum available phases
- **voltage:** maximum available voltage (in Volt)
- **current:** current type (AC|DC)
- **charger_type:** charger type (V1G|V2G)

Charging station meter data

- **ec_meter_index**: energy consumed meter index
- **ep_meter_index**: (if applicable) energy produced meter index
- **timestamp**: timestamp of meter reading
- **additional_information**: (optional) key/value pairs with additional information about the meter reading such as soc, session_id and connected vehicle’s battery capacity in kWh

Charging station real time energy data

- **ec**: energy consumed (Wh)
- **ep**: (applicable for V2G case) energy produced (discharged) (Wh)
- **duration**: actual time duration for which energy reading data is available (in seconds)
- **sessions_cnt**: number of charging sessions recorded for the given time period

To collect the power quality measurements from the chargers, two separate power analyzers are installed. The main purpose of installing these analysers is to monitor the measurement values collected from charging stations via the battery management system. The list of collectible data can be seen in Table 4.

Table 4 Measurement data of EV chargers

DC Fast Charger Analyzer				
No	**Data**	**R/W (Read/Write)**	**Unit**	**Tag Name**
1	PF_H1_ANALYZER	R	-	pf
2	F_H1_ANALYZER	R	Hz	freq
3	S_H1_ANALYZER	R	VA	s
4	Q_H1_ANALYZER	R	Var	q
5	P_H1_ANALYZER	R	W	p
6	VAN_H1_ANALYZER	R	V	Van
7	VBN_H1_ANALYZER	R	V	Vbn
8	VCN_H1_ANALYZER	R	V	Vcn
9	VAB_H1_ANALYZER	R	V	Vab
10	VBC_H1_ANALYZER	R	V	Vbc
11	VCA_H1_ANALYZER	R	V	Vca
12	IA_H1_ANALYZER	R	A	Ia
13	IB_H1_ANALYZER	R	A	Ib
14	IC_H1_ANALYZER	R	A	Ic
15	WQNEG_H1_ANALYZER (discharging reactive)	R	VAr	expreactive
16	WQPOS_H1_ANALYZER (charging reactive)	R	VAr	impreactive
17	WPNEG_H1_ANALYZER (discharging active)	R	W	expactive
18	WPPOS_H1_ANALYZER (charging active)	R	W	impactive

2.1.3 Photovoltaic Panels

PVs are located on the roofs of each residential building and during the daytime, it is possible to meet the energy consumption of buildings with production. The operation of the panels is under the responsibility of the local municipality who owns the infrastructure. Therefore, OEDAS has no authority to control and/or operation of the panels.

OEDAS has energy meter installed on the grid connection point of the solar box. When there is excessive power generation during the sunny days, surplus energy is sent back to the grid and OEDAS is able to measure this excess power data with the automatic meter reading system (AMR). In addition, the total generation of PV panels are collected from solar inverter via API. An image of PVs and measurements data parameters can be found in Figure 7 and Table 5. Also real power data measurement can be seen in Figure 8.

Figure 7 PV panels installed on the roofs

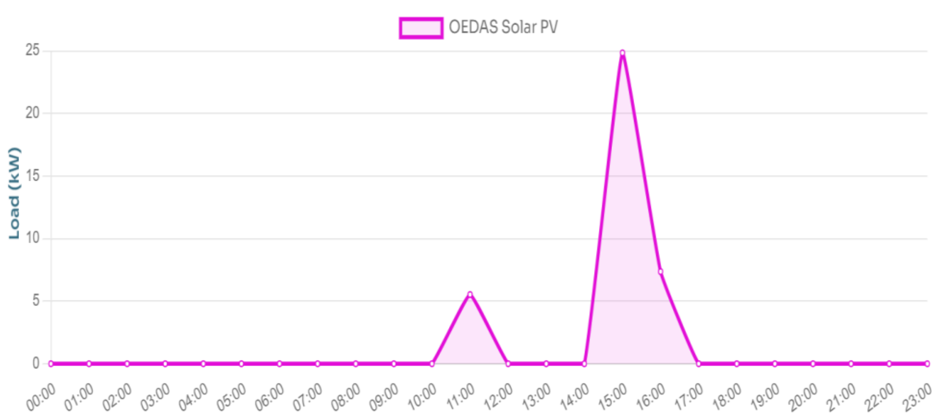


Figure 8 Surplus PV production profile in a day in March

Table 5 Measurement data of PVs

PV Measurement Data				
No	**Data**	**R/W**	**Unit**	**Tag Name**
1	P (Active power production)	R	W	ActiveProduction
2	VAN	R	V	Voltage1
3	VBN	R	V	Voltage2
4	VCN	R	V	Voltage3
5	IA	R	A	Current1
6	IB	R	A	Current2
7	IC	R	A	Current3

2.1.4 MV/LV transformer

The transformer which is feeding the area has 400 kVA power rating. The medium voltage substation where the transformer is located is connected to the OEDAS SCADA system. The expected average loading rate of the transformer is not high (peak load is around %60) but there are loading peaks during the peak hours. Consumption, voltage and current measurement can be read with the meter installed on the low voltage side of the transformer. Details about the available data can be found in Table 6. Also load profile of local transformer which was created with the real consumption measurements can be found in Figure 9.

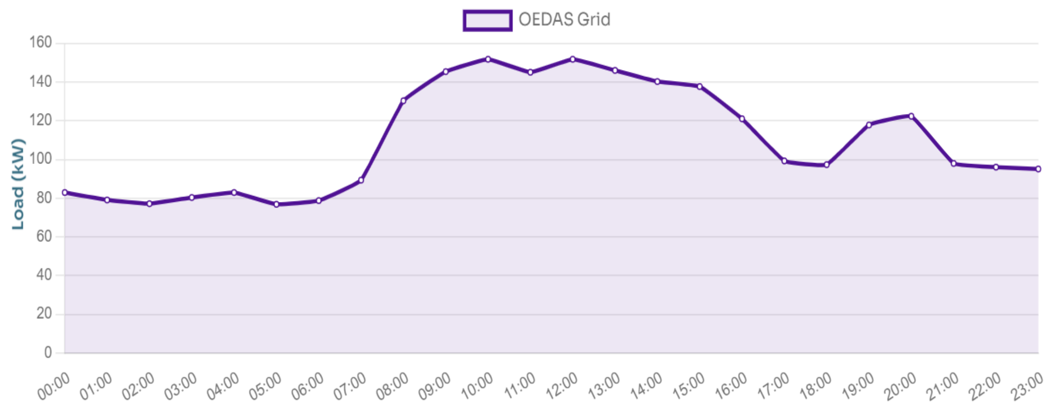


Figure 9 Load profile of transformer in a typical day

Table 6 Measurement data of PVs

MV/LV Transformer Measurement Data				
No	**Data**	**R/W**	**Unit**	**Tag Name**
1	P (Active power consumption)	R	W	ActiveConsumption
2	VAN	R	V	Voltage1
3	VBN	R	V	Voltage2
4	VCN	R	V	Voltage3
5	IA	R	A	Current1
6	IB	R	A	Current2
7	IC	R	A	Current3

2.2 HES campus

This work package also integrates the demonstrations performed at the HES Campus, which is located in Sion, Switzerland. It is composed of three buildings (buildings 19, 21 and 23, see Figure 10). All buildings contain classrooms and offices, while buildings 19 and 23 also include laboratories. Building 21 also integrates a fully equipped kitchen / canteen. The buildings are heated via the district heating network owned by OIKEN, the local DSO. Three heat pumps (one per building) connected to a CO2 network will also be used in this project to heat the buildings and to provide flexibility. The heat is distributed in the buildings by concrete active slabs and ventilation units, which are controlled by the building management platform (GTB). In addition to this, solar pannels are installed on the roofs of buildings 19 and 23. Finally, batteries will be installed in the basement of building 23 during next months.

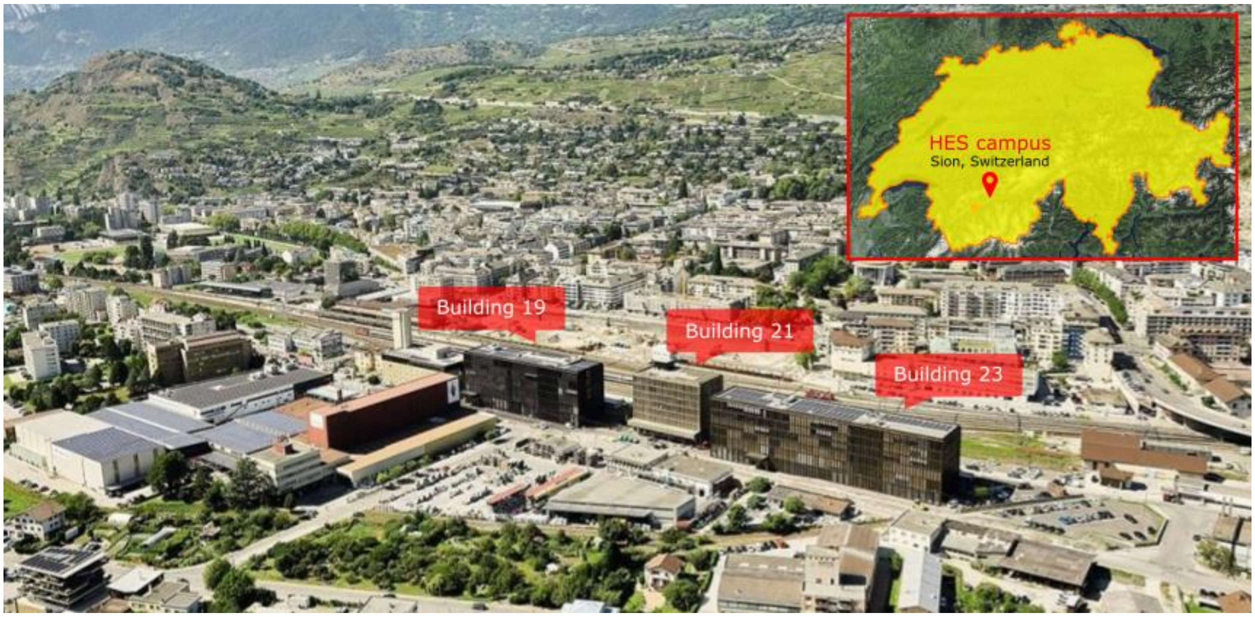


Figure 10 : HES campus and its three buildings

2.2.1 PVs

PV panels are installed on the roofs of buildings 19 and 23, for a total peak power of about 260 kWp. Part of the PV panels can be observed on Figure 13. Production measurements are performed by OIKEN, the local DSO. Measurements are available via a web-application (SolarEdge) and can easily be downloaded with a resolution of 15 minutes. The list of available measurements collected from the inverters is presented in Table 7. The web-application allows HES to detect errors as well as to visualize the logical configuration of the solar panels as well as the measured variables (see Figure 11 and Figure 12). These measurements will notably be used to maximise and estimate the self-consumption of the buildings.

Table 7: Measurement data of PVs for the Swiss pilot site

Data	R/W	Unit
Power AC	R	W
Reactive power	R	VAR
Current AC – L1	R	A
Current AC – L2	R	A
Current AC – L3	R	A
Voltage AC – L1	R	V
Voltage AC – L2	R	V
Voltage AC – L3	R	V

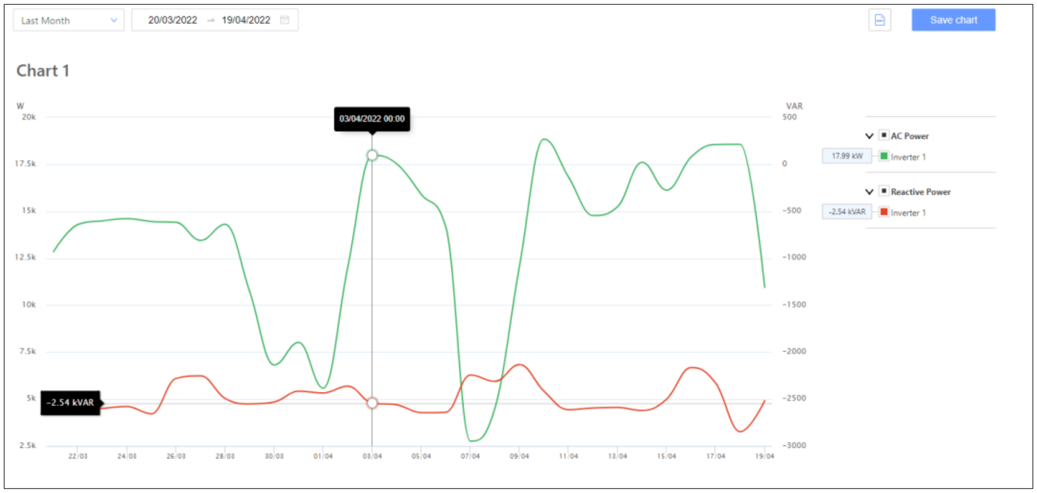


Figure 11:Example of production measurement, here active and reactive powers

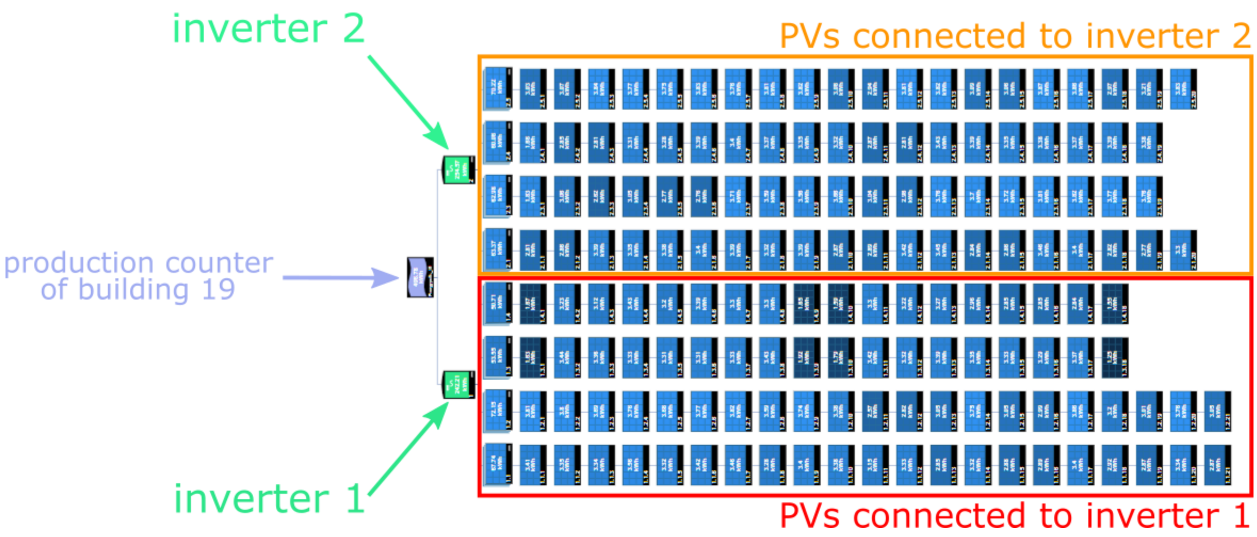


Figure 12: Logical representation of the PV panels of building 19. The system is constituted of a general counter and 2 inverters. Each inverter includes 4 lines of PVs

A direct access to the measurement device is also being considered. This would allow HES via the energy management platform (GTE, see the section concerning the management platforms) for a faster and automated recovery of the data.

Figure 13: PV panels on the roof of building 23

2.2.2 Heat Pump

Energypolis campus is supplied by district heating and cooling networks. In addition, a CO2-based energy network coupled to heat pumps is being installed. This system is redundant and the associated heat pumps will be used for the demonstration activities within the Flexigrid project. Order and delivery of the heat pumps took a couple of months. As of now, heat pumps were received and are currently still being connected to the actual heating system (see Figure 14). Concretely, one heat pump per building is being installed, for a total of three heat pumps (1x 140 kW_{th} in building 19, 1x 100 kW_{th} in building 21 and 1x 100 kW_{th} in building 23).

Connection of the heat pumps to the existing heating system involves large piping work. Even if heat pumps are not running yet, communication specifications have however already been established. Two main modes have been defined: a “local” mode and an “external” mode. The “local” mode is the standard mode of the heat pump. Basically, setpoints are defined using a heat curve, whose slope and offset are parametrizable. This mode is adopted most of the time for sake of simplicity. The “external” mode, as its name suggests, is a mode allowing the heat pump to receive external setpoints. This is the mode which will be used in the framework of this project.

Most of the time, only simple temperature setpoints can be sent to a standard heat pump. However, this results in real difficulties when providing flexibility services as the heat pump’s behavior differs from what was expected, eg. the heat pump does not turn on/off. In an attempt to tackle this issue, the installed heat pumps have been designed in a way such that three variables can be controlled: supply temperature (temperature of the water leaving the heat pump and flowing either to the concrete slab or to the batteries of the ventilation units, most of the time between 30°C – for the concrete slabs and 50°C – for the ventilation), thermal power and electrical power consumed. This results in 5 possible inputs combining these control variables:

1. Electrical power consumed and supply temperature
2. Thermal power and supply temperature
3. Electrical power consumed
4. Thermal power consumed
5. Supply temperature

This configuration should result in a more reliable supply of flexibility, and this will be tested in this project.

Figure 14: Heat pump of building 19 and some piping work in building 21

2.2.3 Batteries

Batteries were received but are unfortunately not installed yet, as of the time of this report. However, communication specifications have already been established. The general configuration is presented in Figure 15. First of all, a simple predictive control algorithm has been developed in Python. The latter uses production forecasts as well as information concerning the current state of the system. The setpoints resulting from the control optimization are posted on cloud.IO, the rest API developed by HES in the framework of another project. This API allows to communicate data and is associated to a timeseries database to be able to store the data.

Then, data is transferred to an OPAL-RT. This device presents the following advantages:

- It allows to perform hardware-in-the-loop for development purposes
- It can include a communication layer and is thus able to communicate via MQTT for example.
- It can integrate security layers

Once data are received by the OPAL-RT, setpoints are sent to the battery storage system. The list of exchanged data is presented in Table 8. Concretely, only power setpoints are sent from the control algorithm to the OPAL-RT. These setpoints can either be relative to the actual power (power_shaving) or absolute (power_setpoint) The communication of these setpoints is triggered by the user. On the other hand, status information such as the state of charge, the accepted power, the total capacity, default, etc. are returned. Depending on the quantity, the trigger of this status feedback can either be made by a timer (eg. send data every 5 minutes) or a modification of the attribute. As these batteries will also be used in other projects, general setpoints / status information have been defined to cover a broad range of applications and additional setpoints which could be potentially used in the future have ben planed. In the framework of the FlexiGrid project, two main status feedback will be used : the state of charge of the batteries (soc) and the real power profile followed by the batteries (power_real).

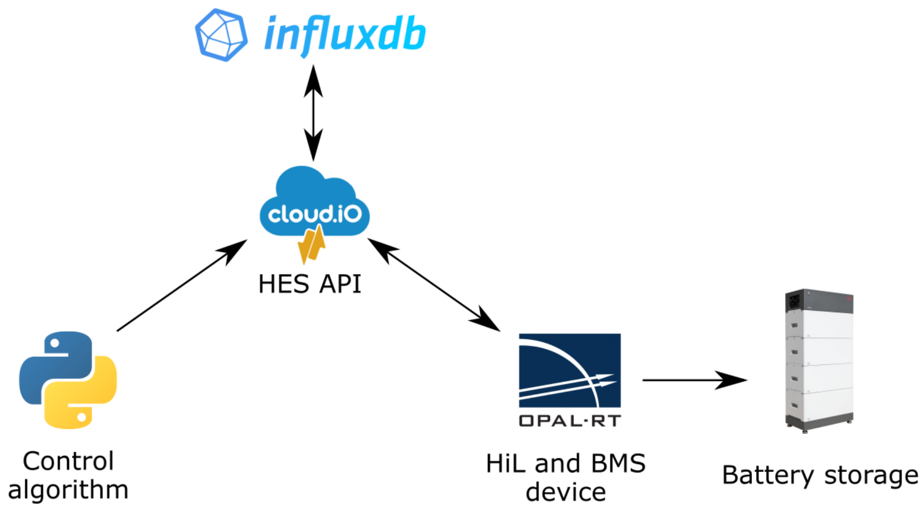


Figure 15: General configuration / setup used for the control of the electrical battery system

Table 8: Information exchanged via cloud.IO for the control of the battery storage system

CloudIO - tags							
Direction	**Trigger**	**Endpoint**	**Node**	**Attribute**	**Units**	**+/-**	**Description / comments**
Setpoint	Triggered by the user	PE	SSE	power_shaving	kW	Positive/negative	Relative to power already consumed
Setpoint	Triggered by the user	PE	SSE	power_setpoint	kW	Positive/negative	Absolute power setpoint
Setpoint	Triggered by the user	PE	SSE	additional_setpoint_1	tbd	tbd	Additional setpoint
Setpoint	Triggered by the user	PE	SSE	additional_setpoint_2	tbd	tbd	Additional setpoint
Setpoint	Triggered by the user	PE	SSE	additional_setpoint_3	tbd	tbd	Additional setpoint
Status feedback	Timer	PE	SSE	power_shaving_accepted	kW	Positive/negative	
Status feedback	Timer	PE	SSE	power_setpoint_accepted	kW	Positive/negative	
Status feedback	Timer	PE	SSE	power_real	kW	Positive/negative	Real power profile
Status feedback	Modification of the attribute	PE	SSE	power_charge_min	kW	Positive	Minimum possible charging power
Status feedback	Modification of the attribute	PE	SSE	power_charge_max	kW	Positive	Maximum possible charging power
Status feedback	Modification of the attribute	PE	SSE	power_discharge_min	kW	Negative	Minimum possible discharging power
Status feedback	Modification of the attribute	PE	SSE	power_discharge_max	kW	Negative	Maximum possible charging power
Status feedback	Timer	PE	SSE	soc	-	Positive	State of charge, between 0 and 1
Status feedback	Modification of the attribute	PE	SSE	soc_min	-	Positive	Minimum authorized state of charge
Status feedback	Modification of the attribute	PE	SSE	soc_max	-	Positive	Maximum authorized state of charge
Status feedback	Modification of the attribute	PE	SSE	on_off	-	0/1	
Status feedback	Modification of the attribute	PE	SSE	Total_capacity	kWh	Positive	Total actual capacity of the battery
Status feedback	Modification of the attribute	PE	SSE	soh	-	Positive	State of health, between 0 and 1
Status feedback	Modification of the attribute	PE	SSE	default	-	0/1	
Status feedback	Timer	PE	SSE	additional_status_1	tbd	tbd	Additional status feedback
Status feedback	Timer	PE	SSE	additional_status_2	tbd	tbd	Additional status feedback
Status feedback	Timer	PE	SSE	additional_status_3	tbd	Tbd	Additional status feedback

3. Communication architecture

This section mainly consists of communication architecture of each pilot site, definition of communication platforms between different assets and IoT platform integration details.

3.1 OEDAS pilot site

3.1.1 Main architecture

The devices and systems in the demo area of OEDAS communicate with the central energy management systems through different communication protocols. In general, MODBUS TCP protocol is used for the communication of the battery storage system and power analysers with the battery management system. The communication of the battery management system with SCADA is provided by the 104 protocol.

OCPP 1.6 protocol is used for communication and control of charging stations. Charging point management system (CPMS), the sub-module of the EV management platform, undertakes the integration process of charging stations through OCPP 1.6. Websocketsecure (WSS) connection is preferred for charging point connection and with the IP restriction, the system is closed to any external IP for security. In addition, since the charging and discharging processes of the battery storage system will be controlled by the algorithms on the backend side of the EV management platform, Modbus TCP protocol is used to provide an integration between two platforms. Hereby, control signals can be sent from the EV management platform to battery management system by using Modbus TCP. Also, electricity meter (including bi-directional meters) data are collected in the AMR system with the help of GSM modem and serial communication protocol. Main communication architecture can be found in Figure 16.

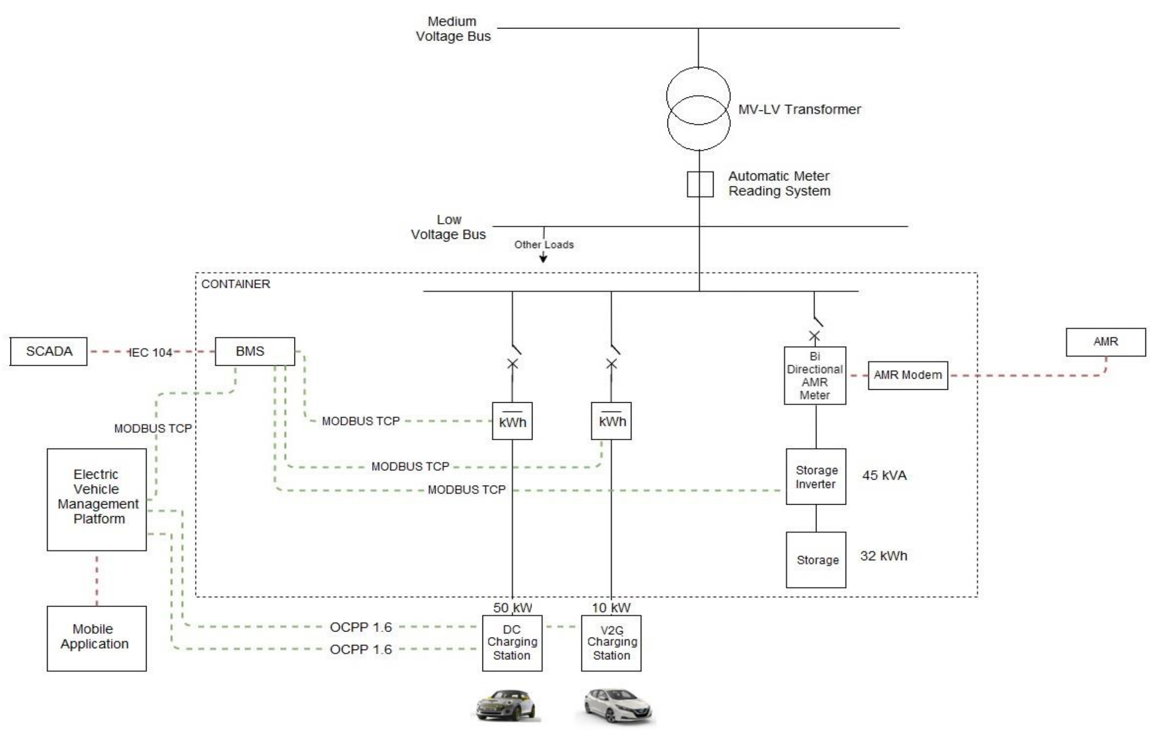


Figure 16 Communication architecture of OEDAS pilot site

3.1.2 IoT platform integration

All devices in the pilot area are able to provide measurement data to the IoT platform. For data integration of systems to the IoT platform, data transfer is provided from different systems with various APIs. At this point, different API documentation has been prepared for integration.

A service gateway has been created to transfer data from the existing transformer of OEDAS and the electricity meter of PVs in the region. In this service gateway, data filtering and anonymization are performed. Anonymized data is transferred from the service gateway to the IoT platform via RESTAPI.

For the battery storage system and EV management platform, relevant data to be monitored is provided by separate APIs from each system. The basic structure of the data transferring process can be seen in Figure 17.

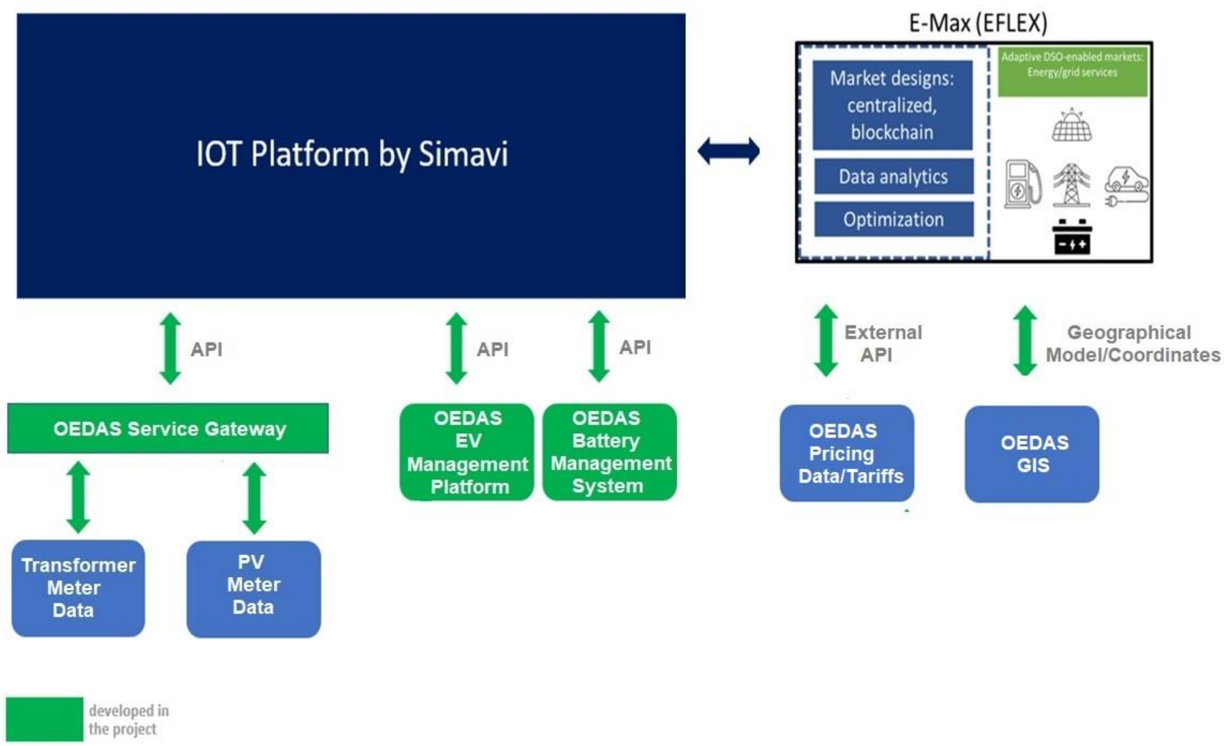


Figure 17 IoT platform integration of OEDAS systems

Apart from the measurement data, a Modbus list of control signals is also provided to the IoT platform with the static IP of the system and port information. With that signal list, commands such as charging/discharging or on/off can be sent manually from the IoT platform to the battery storage system. Modbus map can be found in Table 9.

Table 9 Modbus signal list of battery storage system

SIGNAL LIST						
No	**Data**	**R/W**	**Data Type**	**Tag Name**	**Modbus Function**	**Unit**
1	Battery State Of Charge	R	UINT	BMS_SOC	FC3	%
2	P Set Manual	R/W	INT	PSetman1	FC16	kW
3	MPCont (Manuel Power Control Mode)	R/W	BOOL	MPCont	FC1/FC15	kW
4	Battery Fault	R	BOOL	BMS_Fault	FC1	-
5	PCS (Power Conversion System) Fault	R	BOOL	PCS_Fault	FC1	-
6	PCS Close (Command)	R/W	BOOL	PCS_Close	FC1/FC15	-
7	TOTAL CHARGE	R	UINT	TOTCH	FC3	kW
8	TOTAL DISCHARGE	R	UINT	TOTCDISCH	FC3	kW

3.2 HES campus

3.2.1 Main architecture

Communication between devices and especially communication between devices connected to different networks reveals to be challenging due to safety reasons. Indeed, HES's network needs to be protected from any external entity. In order to ensure this, devices and management platforms will be able to communicate via two different methods: if they are connected to HES's network, they will be able to communicate directly; if not, Cloud.IO will be used to transfer data (Cloud.IO is used here in the sole objective of communicating data; it does not control the assets by itself).

3.2.2 IoT platform integration

The integration to the IoT platform was tested during the past months. Even if the IoT platform will not be used to control directly the assets in Swiss pilot, it will serve monitoring and validation purposes. As already mentioned, real data were not ready on time for the test of the communication with the IoT platform. To address this issue, the communication was first tested with dummy data and then with simulated data. A simulation model of the three buildings was developed in Matlab Simulink to provide data realistic enough. The model developed for building 21 is presented in Figure 18.

Basically, each building includes with a certain number of zones (depending on its geometrical and thermal configuration) with specific temperatures (temperature of the air inside the zone and temperature of the active slab inside the zone).

Solar gains and heat losses are considered. A heat production and distribution component allow the computation of the different mass flows and transfer heat to the zone either via the slab models or via a ventilation unit component.

The model is detailed enough to include small components such as three-way valves or local controllers (e.g., PI controller for the ventilation units). It also considers the thermal inertia of the slabs, walls, air, etc. The inputs and outputs of the model have been defined in a way to coincide with the real data that will be send to the IoT platform. The list of provided data is presented in Figure 19. The data was posted on HES's API, and a user was created for the IoT platform, allowing it to retrieve the data whenever needed. A variety of data was posted as the tests were performed for 4 weeks with a data resolution of 1 minute. As a result, a dashboard presenting the assets of HES campus and the evolution of their attributes was integrated in the IoT platform.

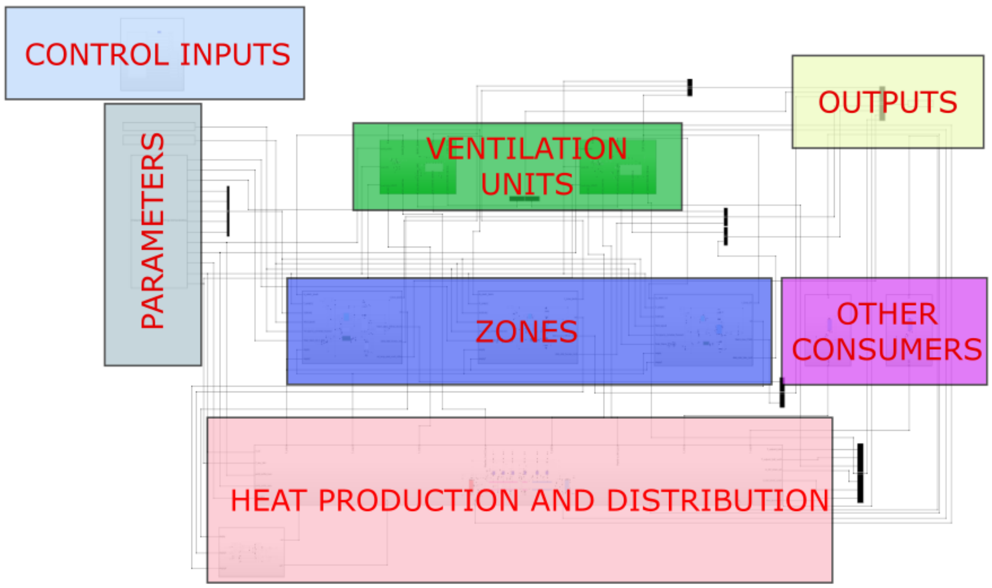


Figure 18: Simulation model of building 21

Data information					Expected availability of the data		
Node	Object	Name	Description	Unit	Dummy	Simulated	Real
building_19	BUILD_Lab_N	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-07-01	2022-02-28
building_19	BUILD_Lab_S	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-07-01	2022-02-28
building_19	BUILD_Off_N	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-07-01	2022-02-28
building_19	BUILD_Off_S	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-07-01	2022-02-28
building_19	HP_1	T_sup	Supply temperature of the heat pump	[Celsius]	2021-05-14	2021-07-01	TBD
building_19	HP_1	T_ret	Return temperature of the heat pump	[Celsius]	2021-05-14	2021-07-01	TBD
building_19	HP_1	P_el	Electric power consumed by the heat pump	[kW]	2021-05-14	2021-07-01	TBD
building_19	PV_1	P_el	Electric power produced by the solar panels	[kW]	2021-05-14	2021-07-01	TBD
building_19	PV_1	Irr	Global Tilted Irradiance	[W/m2]	2021-05-14	2021-07-01	TBD
building_19	WeatherStation	T_ext	External temperature measured at the weather station	[Celsius]	2021-05-14	2021-07-01	2022-02-28
building_21	BUILD_Lab_N	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-08-01	2021-07-15
building_21	BUILD_Lab_S	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-08-01	2021-07-15
building_21	BUILD_Off_N	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-08-01	2021-07-15
building_21	BUILD_Off_S	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-08-01	2021-07-15
building_21	HP_1	T_sup	Supply temperature of the heat pump	[Celsius]	2021-05-14	2021-08-01	TBD
building_21	HP_1	T_ret	Return temperature of the heat pump	[Celsius]	2021-05-14	2021-08-01	TBD
building_21	HP_1	P_el	Electric power consumed by the heat pump	[kW]	2021-05-14	2021-08-01	TBD
building_21	WeatherStation	T_ext	External temperature measured at the weather station	[Celsius]	2021-05-14	2021-08-01	2022-02-28
building_23	BAT_1	SoC	State of charge of the batteries	[-]	2021-05-14	2021-09-01	TBD
building_23	BAT_1	P_ch	Charging power of the batteries	[kW]	2021-05-14	2021-09-01	TBD
building_23	BAT_1	P_disch	Discharging power of the batteries	[kW]	2021-05-14	2021-09-01	TBD
building_23	BUILD_Lab_N	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-09-01	2021-07-15
building_23	BUILD_Lab_S	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-09-01	2021-07-15
building_23	BUILD_Off_N	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-09-01	2021-07-15
building_23	BUILD_Off_S	T_z	Temperature of the air inside the zone	[Celsius]	2021-05-14	2021-09-01	2021-07-15
building_23	HP_1	T_sup	Supply temperature of the heat pump	[Celsius]	2021-05-14	2021-09-01	TBD
building_23	HP_1	T_ret	Return temperature of the heat pump	[Celsius]	2021-05-14	2021-09-01	TBD
building_23	HP_1	P_el	Electric power consumed by the heat pump	[kW]	2021-05-14	2021-09-01	TBD
building_23	PV_1	P_el	Electric power produced by the solar panels	[kW]	2021-05-14	2021-09-01	TBD
building_23	PV_1	Irr	Global Tilted Irradiance	[W/m2]	2021-05-14	2021-09-01	TBD
building_23	WeatherStation	T_ext	External temperature measured at the weather station	[Celsius]	2021-05-14	2021-09-01	2022-02-28

Figure 19: List of data communicated to the IoT platform

4. Energy management platforms

In this section, details about the tools and the platforms which will be used for energy management, control and optimization are provided.

Energy management platforms will mainly be used for monitoring and control of assets available in both pilot sites. Here, processes for manual/automatic control will be carried out in order to demonstrate the use cases in the project. All assets will be controlled through local management systems. The main role of the IoT platform will be data monitoring, visualization and verification. The measurement data collected from the assets will be pushed to the IoT platform and the data will be monitored on the IoT platform at specified time intervals. Apart from the control strategies that will be managed by energy management platforms, also manual control of the batteries will be possible via IoT platform for Turkish pilot.

4.1 OEDAS pilot site

Since OEDAS demo activities will mainly consist of electric vehicle charging stations and battery storage system, EV management platform and battery storage system will be used for the management of these assets.

4.1.1 EV management platform and its functionalities

Electric vehicle management platform will be used to manage the charging sessions and to perform the charging sessions with the smart charging algorithm. In general, a charging process is started via the mobile application (QR code or RFID) and the management & optimization processes will be carried out on the backend of the EV management platform. The main aim of using this platform is balancing the load of the local transformer with optimum charging/discharging slots.

Some of the fundamental functionalities of EV management platform back-office are;

- Integration with charging stations
- Remote management of the charging station using Energy management dashboard
- Charging point control and management (switch on / off, status, etc.).
- Management, monitoring and triggering of electric vehicle chargers.
- Management and identification of users
- Smart charging/Discharging of charging stations
- Real time energy transaction by the charger (charge or discharge).
- Historical load curve by equipment.

Platform includes various sub-modules, mainly EMS and CPMS. Basically, EMS forms the main part of the platform and EMS is the section where smart charging and flexibility operations are managed. The local EMS is linked to all other submodules and also to a mobile application. It takes into account the data it receives from sub-modules and network equipment such as transformer, BESS, PV when calculating the peak/off peak slots and when defining smart charging sessions. EMS is also directly connected with the demand response module externally. If the flexibility requirement for a certain time is sent manually from this module, EMS directly bases on this information and defines the charging sessions with this information.

The module where the communication and management of charging stations are carried out is the charging point management system (CPMS). This module directly undertakes the task of communicating with charging stations via OCPP. The main task of this module is to communicate directly with the charging stations via OCPP. Also Smart Agents are available to provide communication with DSO/BESS/SOLAR/EMS meters using Modbus/REST protocols and creating the energy transactions accordingly.

The following depicts the infrastructure architecture of the system considering the integration with OEDAS components. EMS application will be built on microservice architecture and consists of the following.

- Distributed Microservices (Smart Charging, Flexibility Services, User Management, etc.)
- API Gateway
- Scheduler Service

The structure of the EV management platform can be seen in Figure 20.

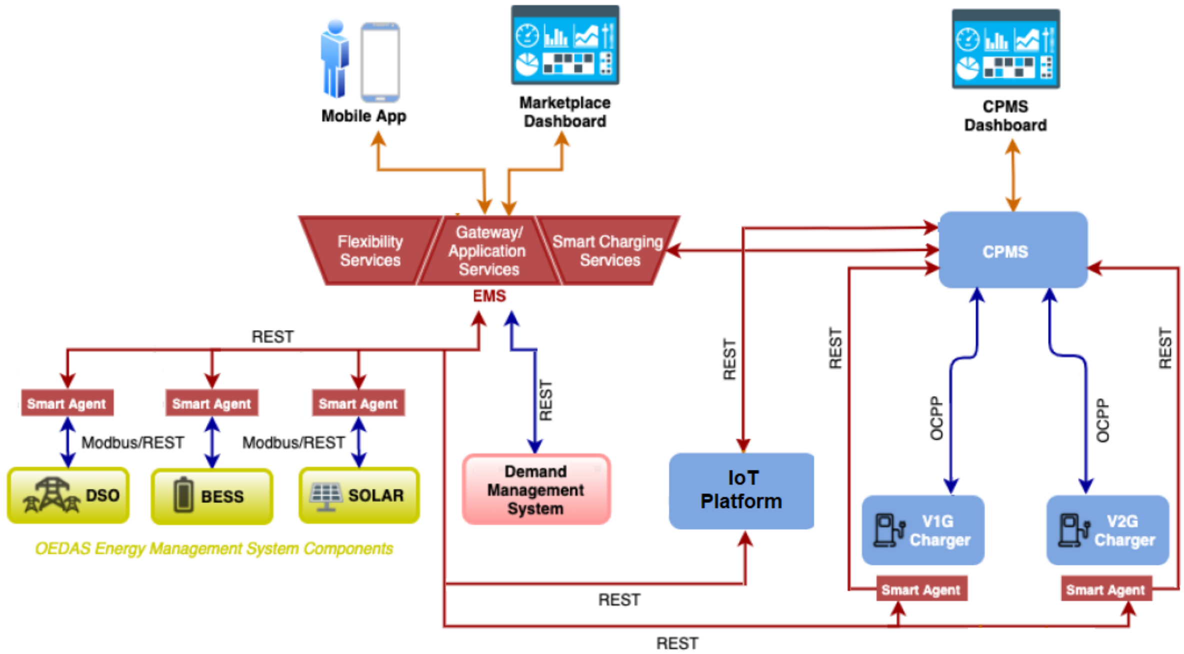


Figure 20 Architecture of EV management platform

4.1.1.1 Information exchange between EMS and other components

As can be seen from the main architecture diagram above, the EV management platform basically consists of a central EMS and sub-modules. EMS communicates with the submodules and in line with the information received from other modules, EMS defines the optimum charging slots and manages all the charging session operations, including smart charging. Details of the information exchange between EMS and other components are presented below.

Information exchange between EMS and grid assets (transformer, battery, PV)

- Unidirectional
- From grid assets to EMS
  - Energy consumption data of transformer with 15 minutes resolution
  - Total energy production of PVs with 15 minutes resolution
  - Charging/discharging values and SoC of batteries
- From CPMS
  - Meter readings on the electric vehicle supply equipment (EVSE) meters for active EV sessions.

Information exchange between EMS and Demand Management System

- Bidirectional
- From OEDAS
  - Flexibility request
  - Activation signal
- To OEDAS

    - Flexibility bids

Information exchange between EMS and CPMS

- Bidirectional
- From CPMS
    - Meter readings on the EVSE meters for active EV sessions.
    - Data regarding EV driver (id tag) when a vehicle is connected/disconnected using RFID/NFC tags locally at the charging station
    - Availability of charge points to be communicated to EV driver
    - State of charge of EV vehicles if available
    - Any exception scenarios like Charge point unavailable/failure etc. that need to be communicated to the EV driver. For e.g.:
        - The charger↔connector communication has failed
        - The transaction was aborted due to an error
- To CPMS
    - Smart charging profiles based on the activation signals, EV charging preferences, Renewable energy data etc.
    - IdTag data of EV drivers registered in EMS
    - EVSE charge point Ids registered in EMS

Information exchange between EMS and EV Driver (Mobile App)

- Bidirectional
- From EV Driver
    - Id tag used for authenticating to the charging station using NFC/RFID
    - Charging capacity of the vehicle (Could provide a model of the vehicle using which the charging capacity can be identified from EV master data)
    - Charging Requirements while connecting a vehicle
        - Desired State of Charge
        - Current State of Charge
        - Parking duration
        - Confirmation on participation for flexibility and smart charging
- To EV Driver
    - Charging session details (State of Charge, Energy charged/discharged, Energy Cost plus incentives)
    - Notifications on the expected desired state of charge towards departure time, flexibility signal details. EV drivers can opt in for participating in flexibility signals which can impact their desired state of charge, but can be incentivized.
    - Historical sessions
    - Impact to the environment (CO2 saved)

Information exchange between CPMS and EVSE

- Bidirectional
- Remote management of EVSE using OCPP 1.6 along with customization for V2G including

- o Bidirectional meter readings. Meter reading data can include information on import/export current, import/export power (Active & Reactive), import/export energy (Active & Reactive), frequency, voltage, temperature, SoC, RPM etc.
- o State of Charging Data for DC Charging
- o Smart charging profiles received from EMS

4.1.1.2 Energy management dashboard

With the energy management platform dashboard (can be seen in Figure 21 and Figure 22), it is possible to see information such as the total consumption (charge and discharge) of the charging sessions, grid and renewable consumption during EV charging and the number of connected electric vehicles. Platform is mainly capable to do:

- charging points Adding / deleting users and charging points
- Managing user groups
- Viewing charging sessions

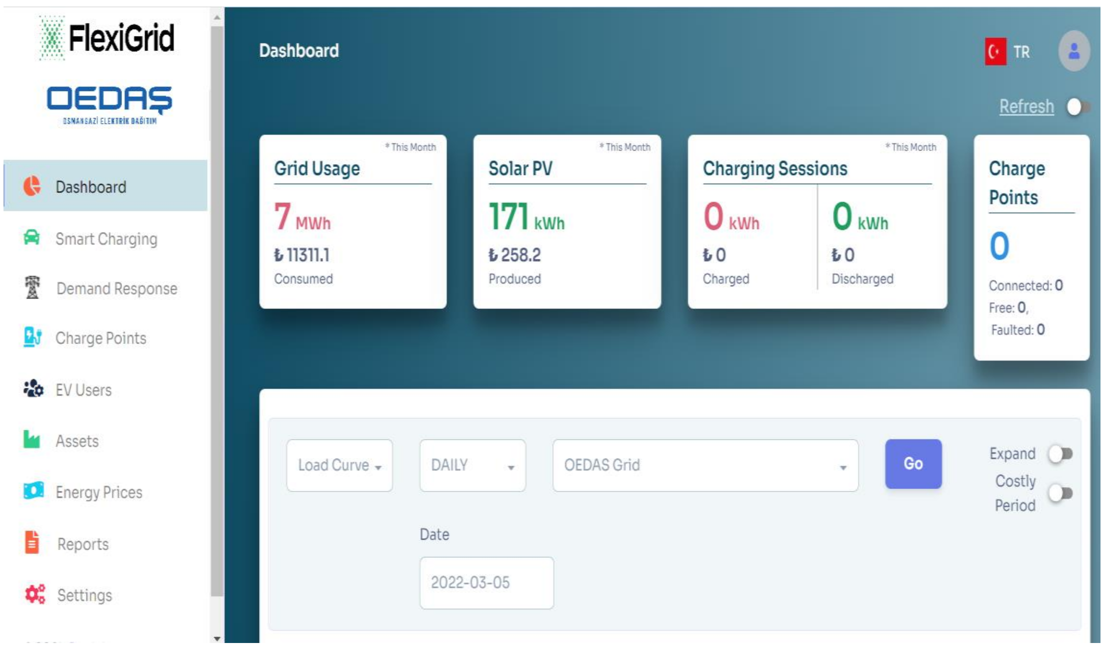


Figure 21 EV management platform dashboard

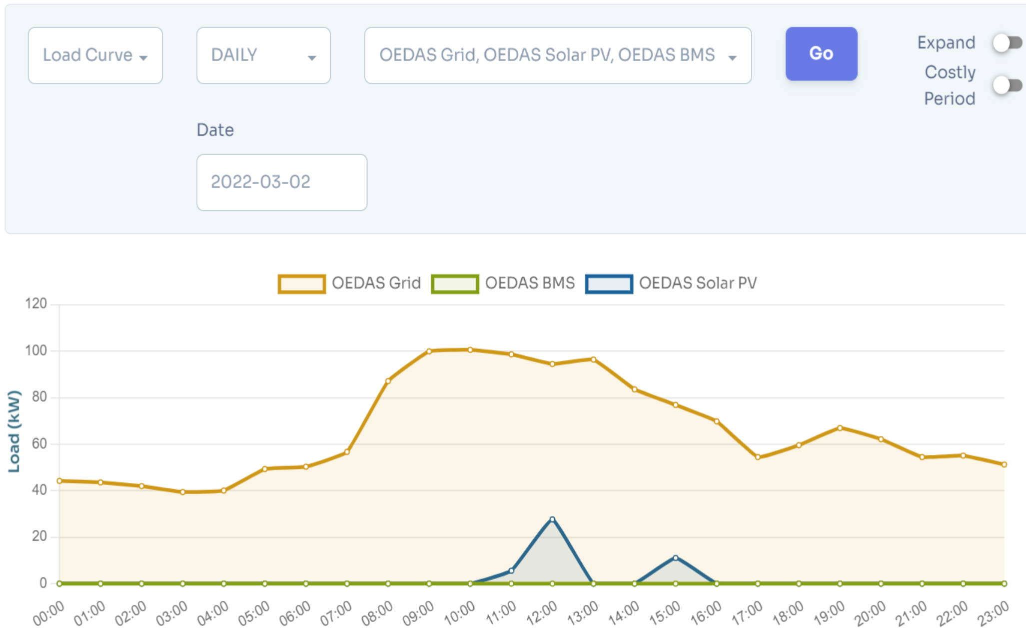


Figure 22 EV management platform dashboard-2

4.1.1.3 Smart charging

The EV management platform is also compatible with smart charging option. Smart charging process of EVs mainly considers the grid condition (consumption), the status of assets such as renewable energy source/battery storage system and energy prices. Interface of the smart charging tab of EV management platform can be seen in Figure 23.

An algorithm which runs on the backend uses this information to calculate optimum charging sessions for electric vehicles. Following are the sequence of operations performed in the charging process.

1. User connects the vehicle to the EV charger and authorizes using RFID/NFC tag.
2. Upon successful authorization, CPMS communicates with EMS on the information about the connected charger and ID tag of the driver.
3. EMS sends a notification to EV driver's mobile app asking to engage in the smart charging programme by entering details such as SOC, Departure time etc.

Upon receiving a request from an EV driver, EMS calculates the smart charging profile considering the input parameters and other relevant data and starts the charging process. The smart charging profile is communicated with CPMS every minute and the entire profile will be recalculated on the following events:

- Vehicle connecting/disconnecting
- EV driver updates SOC/Departure time in mobile app
- Updating of profiles in every 15 minutes based on the grid load conditions.

Key parameters for smart charging are;

- Energy retail price/ distribution time of use rates

- Energy peak demand (customer level)
- Onsite solar generation
- Arrival and departure time
- EV battery state of charge
- Type of charger (available capacity)
- DSO signal (flexibility need)
- Peak demand management
- Maximize solar self-consumption
- User engagement

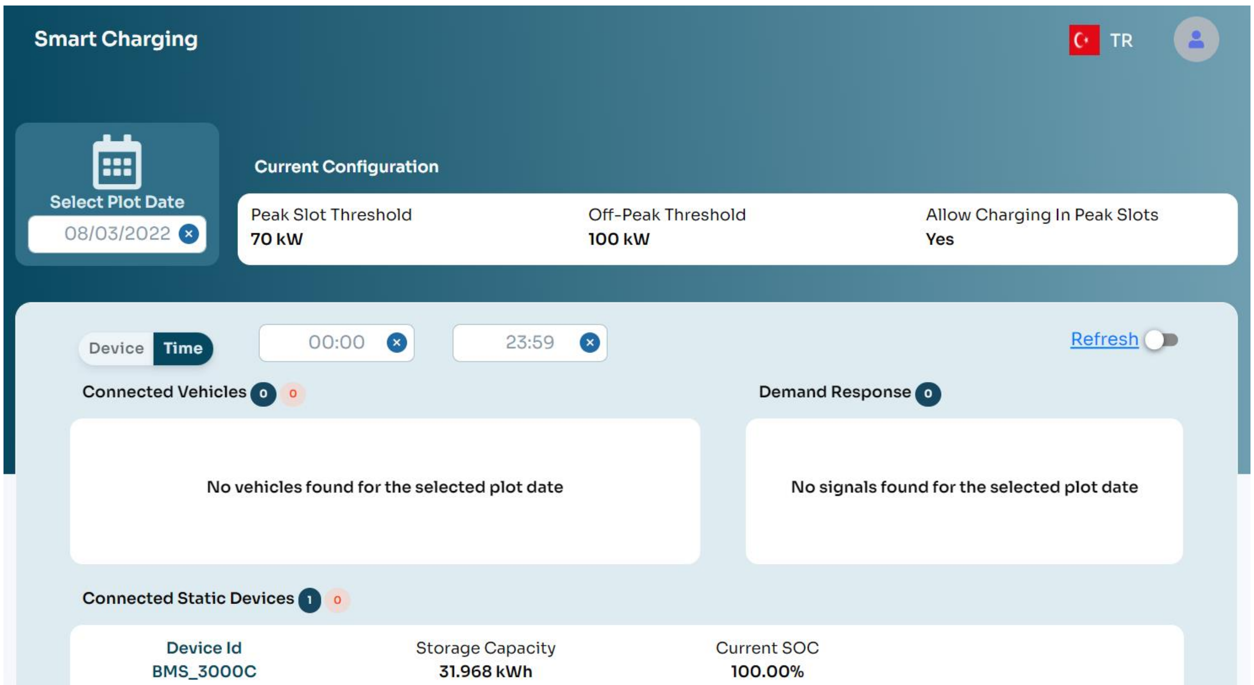


Figure 23 Smart charging dashboard

4.1.2 Mobile application

Through a mobile application, potential end users will be able to book the charging stations and as mentioned in Section 4.1.1, an energy management dashboard is available to manage these charge points remotely in terms of the load condition and pricing. The mobile app contains a variety of features, such as:

- EV charging station availability and remote booking
- Starting of a charging session
- Real-time notifications: state of the charging process, rate of renewable energies used, cost of the charge and amount of incentives received

The interfaces and main features of the mobile application are listed below.

- **Login and sign up**

Users can register with their e-mail addresses and login into the application using their registered email id and password. Registration and sign up processes can be seen in Figure 24.

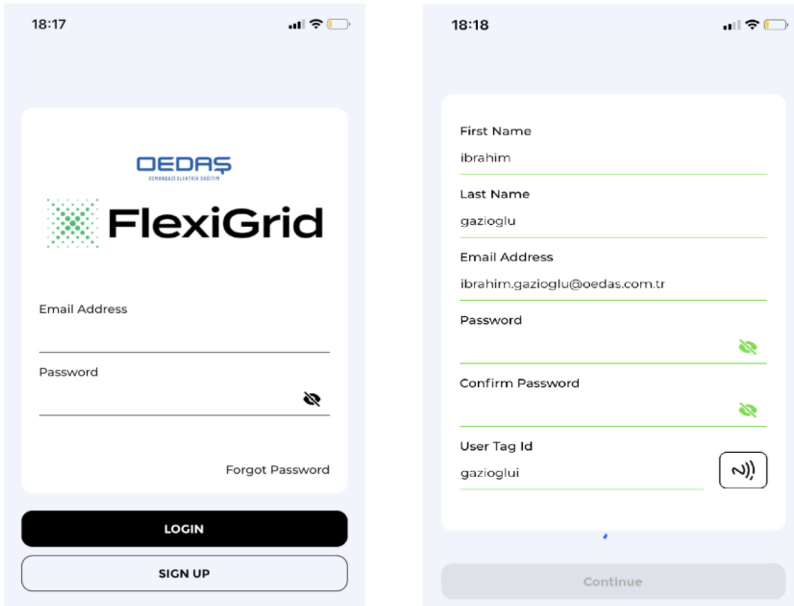


Figure 24 Login/Sign up process of mobile application

- **Home screen**

As can be found in Figure 25, home screen shows an overview of the charge, discharge, cost of charging, rewards, CO2 avoided, balance available to the user for daily, weekly, monthly or yearly.

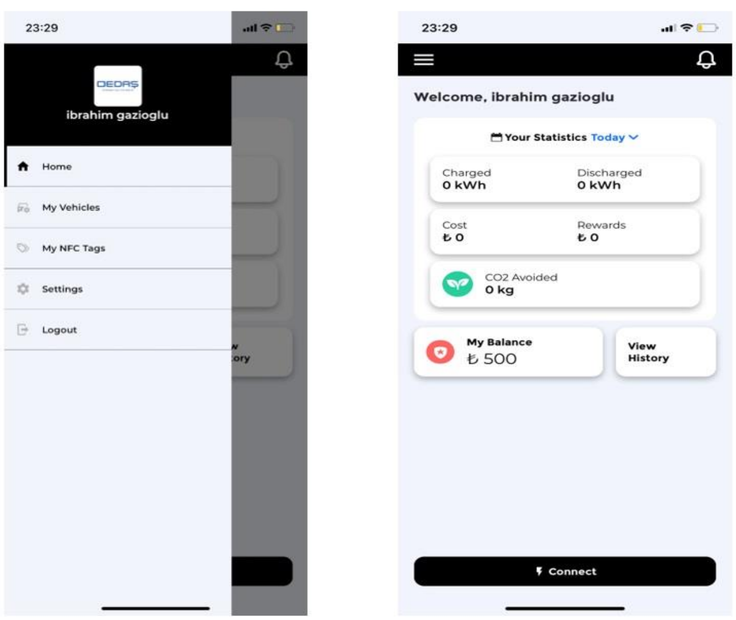


Figure 25 Home screen of mobile application

- **User menu**

Users can access the following functionalities from the application menu.

- Home – Dashboard view.
- My Vehicles – To view and add new vehicles.
- My NFC Tags – To add or view NFC tags added by the User.
- Settings – Edit user profile and change password.
- Logout

- **Vehicle connection**

The driver will have the option of using the mobile application or an authorized RFID card to activate the charge. If the driver uses an RFID card, he/she will receive a message on his/her mobile phone requesting additional information like state of charge, parking time. This information will allow the management platform to optimize load profiles. Following the steps involved in connecting a vehicle;

1. When the user reaches a charging station infrastructure, the user plugs in the charging socket to the vehicle and authorizes the session using his RFID card or mobile applications NFC feature or scanning the QR code.
2. User receives a notification on the mobile saying the vehicle has been connected. Alternatively, the user can also connect using the 'Connect' button on the mobile application home screen.
3. Clicking on the notification takes the user is shown the configuration screens for connecting the vehicle which captures the following details:

   a. Current state of charge (in percentage) of the vehicle
   b. Desired state of charge
   c. Departure time
   d. Participate in V2G flexibility or not

4. On submit, the EV charging session is created and the smart charging algorithm is triggered which computes unique charging profiles for the session, the user also receives a notification stating the same.
5. After connecting, the user returns to the screen and it shows the energy charged/discharged (includes green energy), and incentives.

In parallel with the explanations above, a diagram which shows the general process and an image of the interface where the user provides input is presented in Figure 26 and Figure 27.

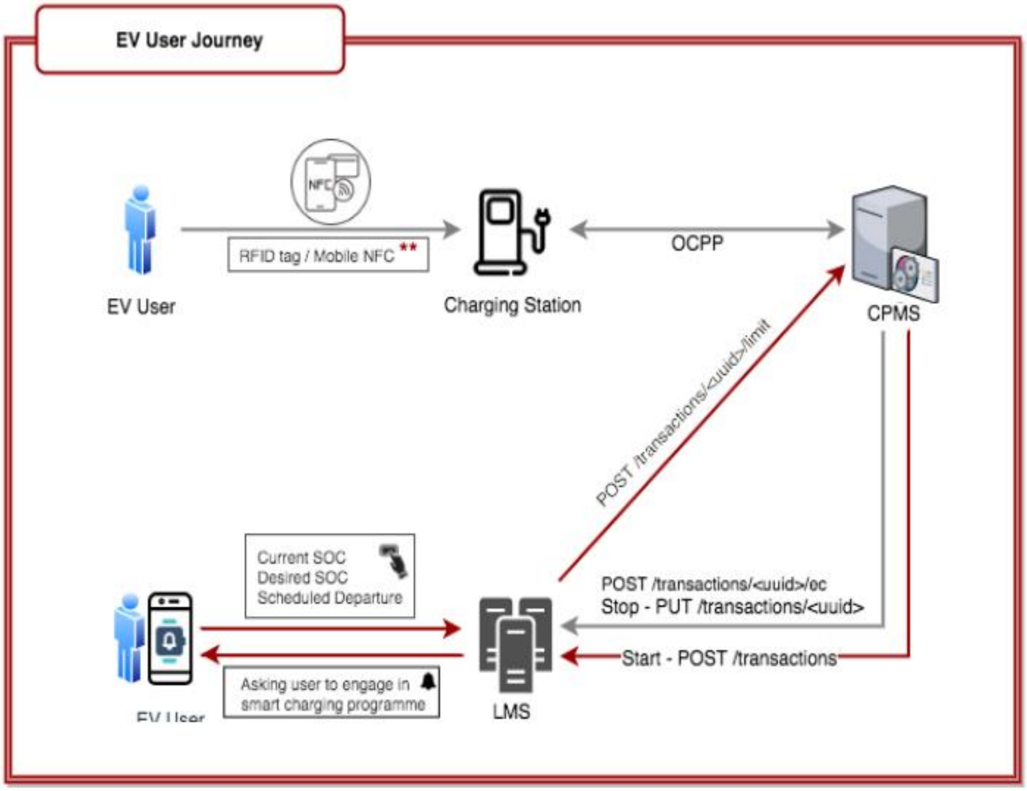
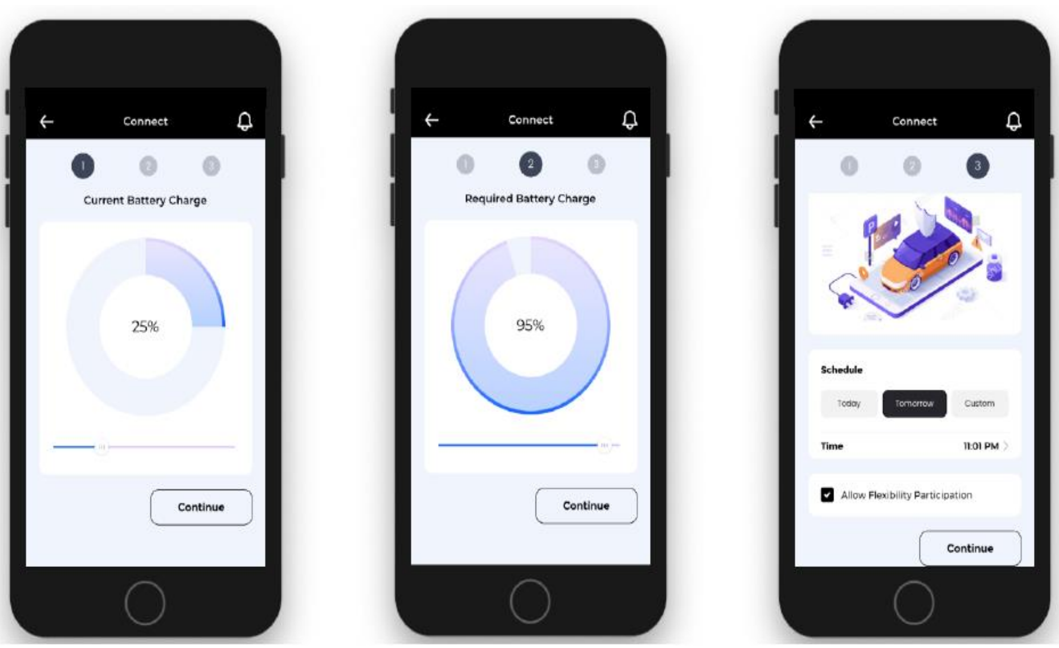


Figure 26 EV user journey



State of Charge | Charge Desired | Parking time

Figure 27 User input via mobile app

- **Vehicle disconnection**

Following the steps involved in disconnecting a vehicle

1. When the user reaches a charging station infrastructure, the user unplugs the vehicle from the charging station.
2. User receives a notification on the mobile app stating that the vehicle has been disconnected.
3. The settlement happens in a few minutes' time which accounts for all the energy transferred and the tokens.

4.1.3 Battery management system

The battery management system allows to control of the charging and discharging activities of batteries in real time. With BMS, it is possible to monitor, control and report critical parameters for the battery storage system. An image of the web interface of the battery management system can be found in Figure 28.

Figure 28 Web Interface of the battery management system

Real-time control of the battery storage system is possible from the Control tab. In this tab, there are two separate control modes. With the manual active power control mode, it is possible to manually charge and discharge the battery storage system at desired levels. The second mode is the Load Support mode. With the critical load support mode, in case of charging stations that is present at the system architecture is active, the battery discharges with an equal amount of the total load of these charging stations (limited with battery inverter power).

If no load exists from these charging stations, the battery will charge until its fully charged with a power determined by the user. Critical load in this case is determined as the total load of the charging stations. If the V2G charging station provides energy from the electric vehicle to the grid, the storage system will not be charged. In this way, the V2G charging station can be used to avoid grid congestion. An image of the control panel can be seen in Figure 29.

As mentioned in Chapter 3 (Communication architecture), there is integration between the battery management system and the EV management platform, and it is possible to control the batteries from the EV management platform via the Modbus connection. In the current scenario, the optimum charging and discharging sessions of the batteries will be carried out with the smart charging algorithm available in the EV management platform so the ”Critical Load Support” mode of BMS will stay as an alternative control mode.

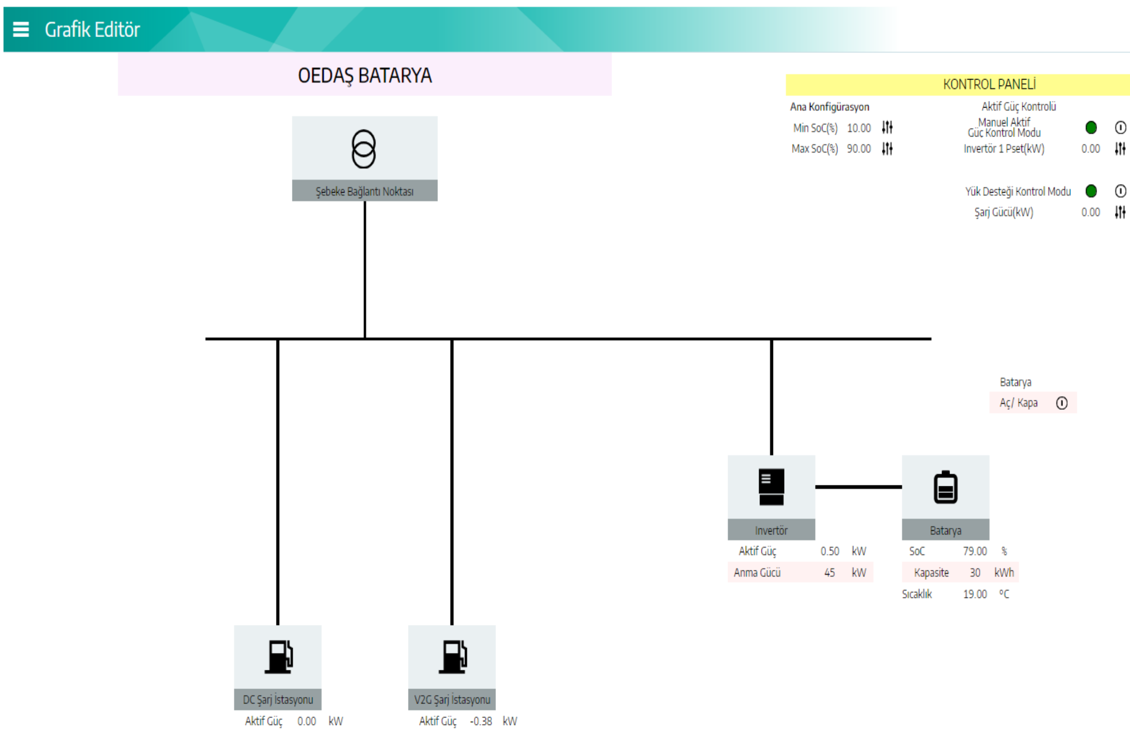


Figure 29 Control tab of the battery management system

4.2 HES campus

On the Swiss pilot site, different energy management platforms collaborate: the energy management platform (GTE), the building management platform (GTB), the CO2 network installations management platform (GTR) and the battery management platform (GTbatt). A scheme of the general configuration is presented in Figure 30. Concretely, GTE is a central unit communicating with the other management platforms.

A fifth management platform, the power-to-gas management platform (GTP2G), is also presented in the scheme even if represented with a dashed line. Indeed, the power-to-gas facility is immensely delayed and will not be operational before the end of the FlexiGrid project. Nevertheless, it was proposed to replace the power-to-gas technology with a “simulation twin” and to potentially provide a proof of concept with a small one-directional fuel cell. For this reason, a management platform of this installation is represented here.

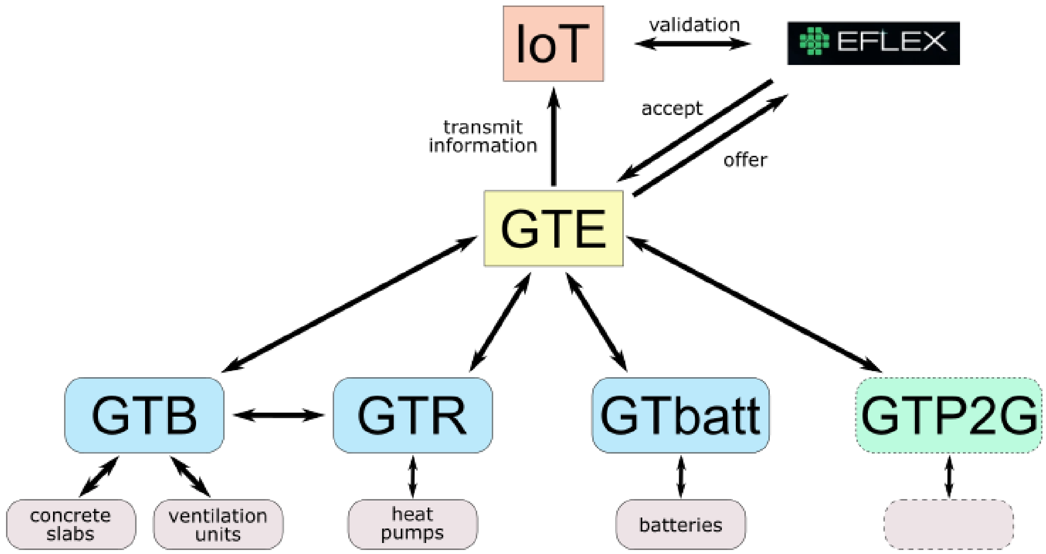


Figure 30: Relationships between the different energy management platforms. The assets controlled by each platform are also illustrated.

4.2.1. Energy Management Platform (GTE)

The energy management platform (GTE) gathers all data from the other platforms (PV production, temperature of the rooms, state of charge of the batteries, etc.). Then, it embeds predictive algorithms which are used to dispatch electricity loads on the different assets optimally. Concretely, the algorithms minimize an objective function which was preliminarily defined. The final goal could be to maximize the self-consumption for example. The objective could also be to provide flexibility. In such a case, if HES and OIKEN have agreed on a power profile to follow, the objective function would then be to minimize the difference between the power consumed and the chosen trace. If no trace was preliminary chosen, the objective could be to maximize or minimize the consumption during a certain period. Finally, the role of the GTE is also to send the measured data resulting from the control of the installation to HES's API to share it with the IoT.

As installations are not available yet, simple predictive control algorithms were developed and tested on simulation models. The goal is to simply replace the Simulink model by the real installation once it will be ready. The general configuration of the controller is presented in Figure 31. Concretely, a python framework was set up, allowing to:

1) Specify control and prediction horizons
2) Integrate models of the installations (e.g., PV production, batteries, heat pumps, etc.),
3) Formulate an optimization problem and solve it for a specific horizon,
4) Send the computed setpoints to a Matlab Simulink model (replacing the real system)
5) Retrieve the values given by the Simulink model
6) Integrate these real values and repeat the steps 3) to 6) for multiple control horizons.

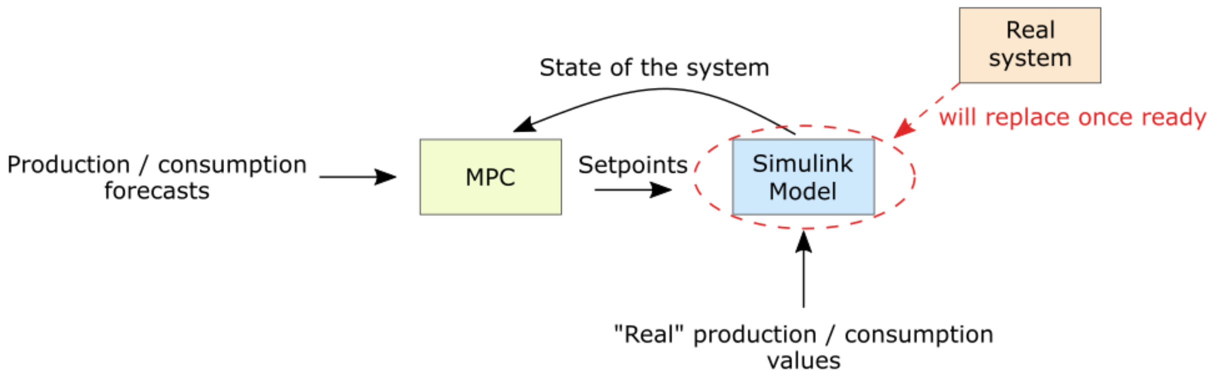


Figure 31: General configuration for the control of the installations

The model predictive control algorithms were implemented during different steps and under various forms during the project. These are presented in detail in the following section.

Electrical MPC

Electrical MPC is the model predictive control framework which was setup for the management of the batteries. Concretely, it was developed along the project through different steps:

Step 1 - Electrical: Testing of the MPC algorithm on a Simulink Model for optimization of the self-consumption

Step 2 - Electrical: Testing of the MPC on a Python model (required for the communication tests in 3.)

Step 3 - Electrical: Adaptation of the MPC to perform in real time and application to the Python model developed in step 2., using the communication protocol used for the control of the real batteries

Step 1 – Electrical

The main goal of this step is to test the MPC algorithm by verifying if the interaction with another model is working properly and by checking if the prediction and control horizons are correct. In this step, the MPC algorithm interacted with the Simulink model using a functional mock-up interface (see https://fmi-standard.org/). Indeed, Simulink allows one to export a model under the .fmu format, with which Python can interact using specific libraries (in this case the library fmipp was used, see https://pypi.org/project/fmipp/). Additional specific requirements are needed by Simulink to do so (such as a fixed-step simulation time step for example) but these will not be presented in the framework of this report.
The considered test case consists of batteries, consumption of the buildings and PV production. The MPC algorithm aims at optimizing the self-consumption by controlling the different electrical fluxes taking place inside the buildings, based on consumption and production forecasts. The setpoints controlled by the MPC and the data points available in the Simulink model are presented in Table 10.

Table 10: Summary of the MPC setpoints / parameters and Simulink model data points

	Value	Unit
MPC setpoints	PV production sent to the grid	kW
	PV production sent to the consumers of the buildings	kW
	PV production sent to the battery	kW
	Grid power sent to the consumers	kW
	Battery power sent to / received by the grid	kW
	Battery power sent to the consumers	kW
MPC parameters	PV production forecasts	kW
	Consumption forecast	kW
Simulink model data points	Real PV production	kW
	Real consumption	kW
	Effective PV production sent to the grid	kW
	Effective PV production sent to the consumers of the buildings	kW
	Effective PV production sent to the battery	kW
	Effective grid power sent to the consumers	kW
	Effective battery power sent to / received by the grid	kW
	Effective battery power sent to the consumers	kW
	Battery state of charge	-

An example of the actual values vs. the forecasts is presented in and the associated control setpoints and model answers are presented in Figure 32 and Figure 33.

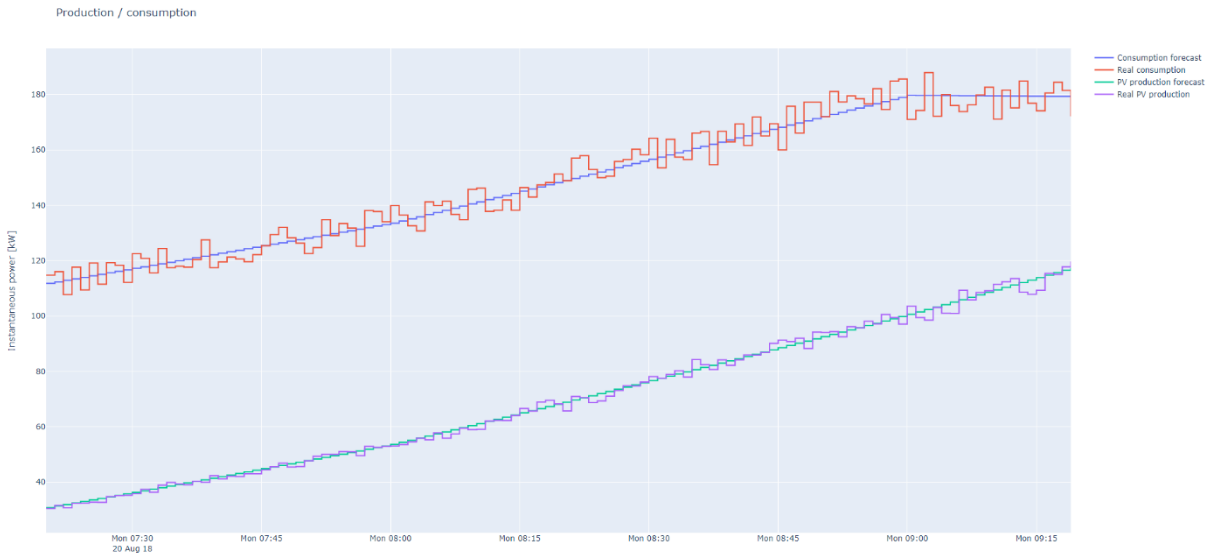


Figure 32 : Example of forecasted consumption / production vs actual value

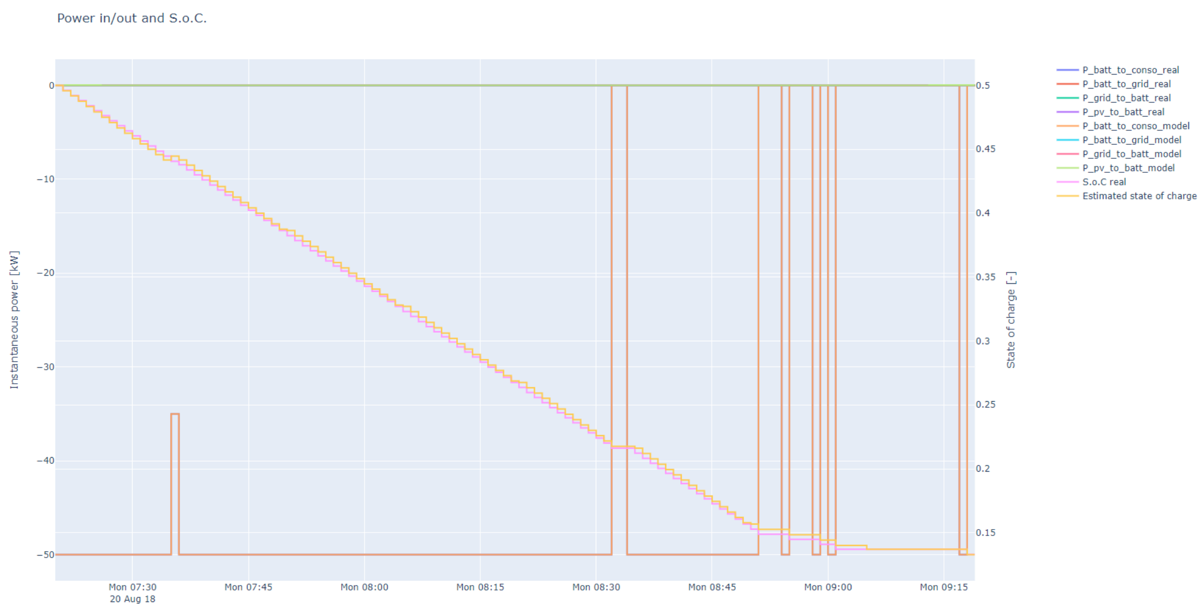


Figure 33 : Example of result values

Step 2 - Electrical

In this step, the main goal is to prepare the MPC for the control of a real battery. To do so, a Python model of the battery is elaborated (simple state-of-charge equation, similar to the Simulink model) but this time with input and state variables corresponding to the real ones presented in the batteries' description earlier in this report. These parameters are not presented here again for sake of conciseness.

Step 3 - Electrical

The battery model and MPC are updated to perform in real time and using the actual communication protocol that was presented in the batteries' description section. To do so, on one hand, the Python model of the battery was adapted to run permanently, waiting for inputs, and returning its state every x seconds. On the other hand, the MPC algorithm was adapted to update its inputs based on values received in real time. Also, a communication function allowing it to send .HTML PUT requests was developed to allow it to communicate with the battery model. The HES API (Cloud.iO) used for this communication procedure is associated to an InfluxDB database and allows one to easily visualize the results in tools such as Grafana. The MPC setpoints and the battery's data points are the same than previously presented in Step 2.

Thermal MPC

Thermal MPC is the model predictive control framework which was setup for the management of the heat pumps of the buildings. Initially, it was planned to use the complex Simulink building model which was developed earlier in the project to 1) generate accurate simulation data and share it to the IoT platform, consisting in a mitigation strategy for the delay in the devices installation, 2) to directly test the MPC algorithm on it. However, it appeared that the building control system is too complex to be easily incorporated in the MPC. For this reason, easier models were developed in multiple steps:

Step 1 - Thermal: MPC algorithm testing performed on a simple 2 nodes Simulink building model

Step 2 - Thermal: MPC algorithm applied to a simple 2 nodes Simulink building model combined to a heat pump

Step 3 - Thermal (Ongoing): MPC algorithm applied to a real-time building model using the communication protocol used for the control of the real heat pumps

The interaction between the MPC and the Simulink model is performed using a .fmu file, similar to what was presented for the electrical MPC.

Step 1 - Thermal

This step consists primarily in a testing of the MPC algorithm, more precisely regarding specific constraints and / or cost functions. Concretely, the building is represented as one air battery (whose state of charge represents the temperature in the rooms) and one concrete battery (whose state of charge represents the temperature in the concrete slab of the building). Real values from the building have been considered, such as the mass of concrete and the volume of air. The control setpoints of the MPC are thus the following:

- Q_{ventil}: the heating / cooling power provided by the ventilation units directly to the air battery
- Q_{slab}: the heating / cooling power sent by the heat pumps directly to the concrete battery

Different configurations which are tested:

- Air battery model without losses and concrete slab model dissociated (no exchange between them)
- Air battery model without losses and concrete slab model linked (exchange between them)
- Air battery model with losses (the overall U value of the building was used) and concrete slab model linked (exchange between them)

The final model which was used in this step is presented hereunder (Figure 34).

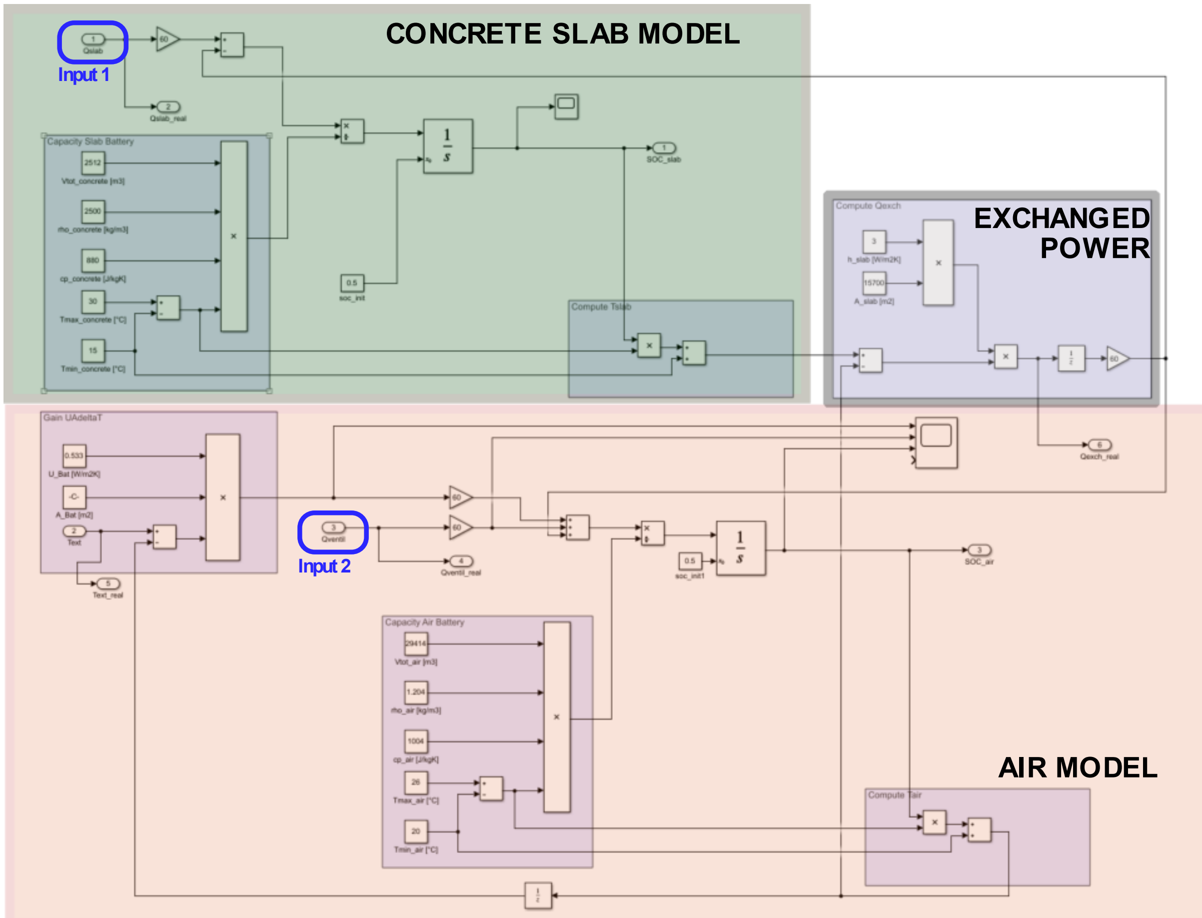


Figure 34: Simulink model developed during step 1 of the thermal MPC

In parallel with the development of this model, different constraints and objective functions are tested, such as:

- Constraints: cyclic constraints, costs associated for power setpoint changes, limitations on the maximum state of charge,
- Objective functions: Minimization of the operational costs, including electricity cost (fixed or variable), introduction of thermal comfort costs,

The data points given by the model are the state of charge of the air battery and the state of charge of the concrete slab battery

Step 2 - Thermal

In this step, a simple data driven heat pump model is included to consider the change of the COP of the heat pump with the source and the sink temperatures. More specifically, a heat curve is determined for the heat pump, linking the supply temperature of the heat pump to the external temperature. Associated to that, manufacturer data for the COP are processed (linear regression and extrapolation) and a table is obtained, and the COP is obtained for different operation points (see Figure 35).

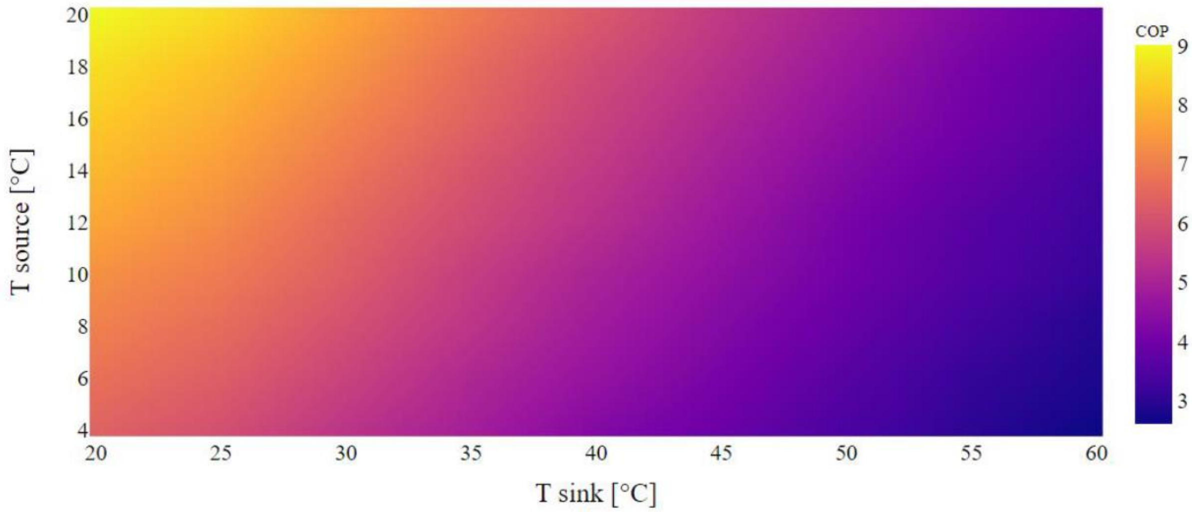


Figure 35: COP of the heat pump model as a function of the source and sink temperatures

In this model, the heat pump supplies the concrete slab while the ventilation units are alimented via the district heating. Thus, the control setpoints generated by the MPC are now the electrical power of the heat pump and the heating / cooling power of the ventilation units, while the data points returned by the model are the states of charge of the air battery and of the concrete slab battery, as well as the COP of the heat pump. For this step, an objective function aiming at reducing the difference between the electricity consumption and a given load profile is tested. An example of results is presented in Figure 36.

Figure 36: Example of thermal MPC controlling the heat pump electrical power and the power provided by the ventilation units

Step 3 - Thermal (Ongoing)

Work has been carried out to adapt the thermal MPC so that it fits as close as possible to the real demonstration configuration. To do so, the models previously presented were adapted to Python in order to: 1) perform in real time, 2) use the communication protocol which will be used to communicate with the heat pumps (modbus TCP/IP). This later step of communication is still ongoing.

A table summarizing the different MPC control setpoints and model data points for all steps of the thermal and electrical MPC is provided in Appendix.

4.2.2. Building management platform (GTB)

The building management platform was set up during the construction of the campus. This platform allows to manage everything related to the operation of the three buildings, from lights and blinds up to heating and cooling. It gathers multiple functionalities:

- Monitoring: All devices and sensors in the buildings are connected to the GTB and send the required information to it. Moreover, the GTB is connected to a server hosing a PostgreSQL database in order to store data. As of now, about 4'500 different measurements are stored on the server. Data have been stored for about 6 months now. The acquisition frequency is different for each measurement. It might even vary for one measurement as some measurements send data only when the observed quantity changes.
- Visualization: On its homepage, the building management platform allows the user to have an overview of the campus (see Figure 32). The user can then select the desired location / installation and visualize its status in real time. An example for a ventilation unit is given in Figure 33. In addition to this, a Grafana dashboard was developed for the visualization of the data stored in the PostgreSQL database (see Figure 34).
- Security: The building management platform is used for security purposes. Any alarm from the different systems is returned to the GTB. The latter will then take actions (if possible) to protect the integrity of the system and will alert the manager of the buildings.

- Control: The different set points can be changed directly in the building management platform. Also, calendars can be setup to specify the operation time of the devices or to define special shifts (e.g., special setpoints during holidays, etc.)

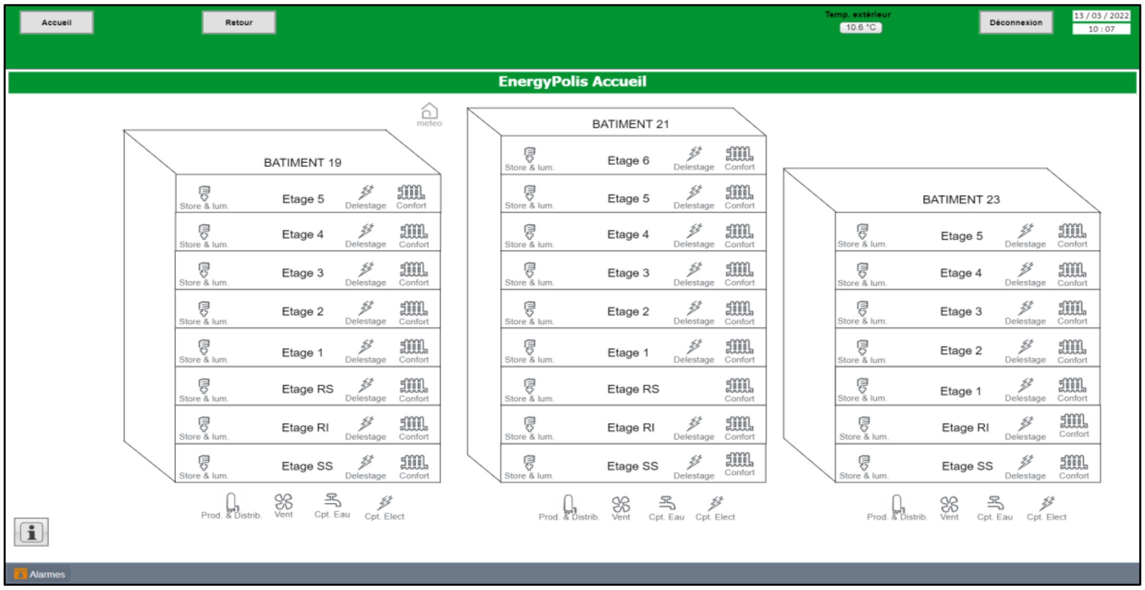


Figure 37 : Overview of the campus as presented by the building management platform

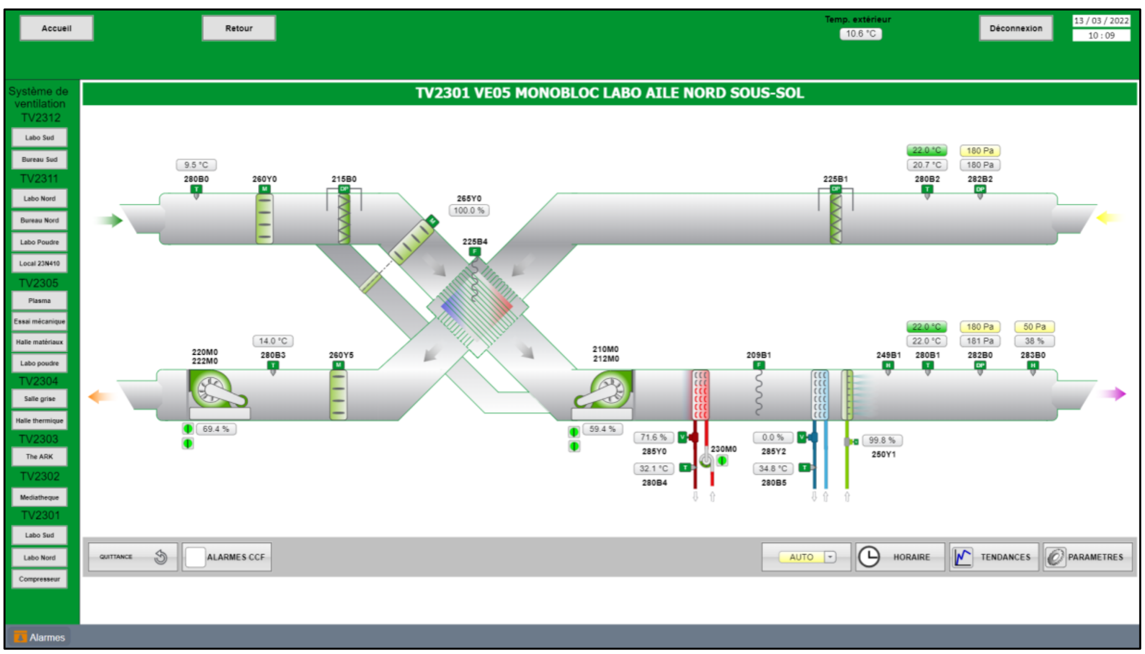


Figure 38: Visualization of the status of a ventilation unit in building 23

4.2.3. CO2 network installations management platform (GTR)

The CO2 network installations management platform is still in development in the framework of another project. Eventually, it will contain everything needed for a proper functioning of the CO2 network (standard regulation). In addition to that, it will communicate with the GTB to ensure that the heat

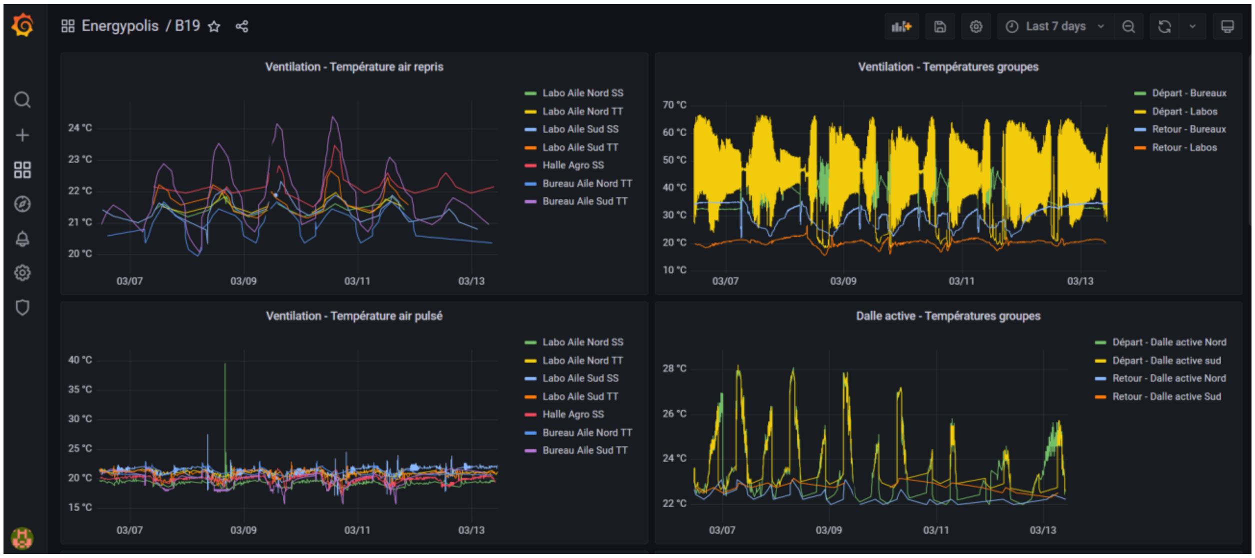


Figure 39: Visualization of the historical data gathered by the GTB

produced by the heat pumps can actually be consumed by the buildings. This exchange of information integrates signals like heat demands or functioning authorizations, but also control signals like valves' openings, etc. Finally, it will be designed to be able to receive signals from the GTE and transmit required setpoints to the heat pumps for example.

4.2.4. Batteries management platform (GTBatt)

As mentioned in section "*2.2.3 Batteries*", data and set points concerning the batteries will transit by an OPAL-RT. This device will also integrate a management layer, which will cover for everything related to security aspects, life cycle, temperature, available capacity, etc. With this configuration, the GTE is then agnostic about the specific control of the batteries: it does not need to control current and voltage or to manage the different cells for example. Only charging/discharging power setpoints are communicated.

As the batteries are not available yet, the OPAL-RT will also allow to test the communication and the control algorithm beforehand. Indeed, it can integrate a simulation model of the storage. The plan regarding this integration is to test the control with a simulation model embedded in the OPAL-RT in a first time, to test it with a reduced battery stack in a second step and to finally perform the demonstration with the integral capacity.

4.2.5. Power-to-gas management platform (GTP2G)

The power-to-gas management is slightly different from the others as it will link in a first time the simulated power-to-gas installation to the GTE. Concretely, the algorithms contained within the GTE will simply run the simulation model for specified conditions. The management platform of an eventual small one-directional P2G installation still needs to be determined.

5. Conclusions

As a result of the studies presented in the report, the process within the scope of the preparatory work before the demo activities of both Turkish and Swiss pilot sites was summarized. In this context, details were given about the equipment and system integrations and also the monitoring and management platforms used.

In line with the demo activities within the scope of T8.3, smart charging of EVs will be carried out based on different tariff structures with two electric vehicles, two charging stations and a battery storage system in the Turkish pilot site. The main purpose here is to balance the daily load profile of the local transformer and to provide flexibility to the distribution network by performing the charge-discharge processes in an optimum way. The installations of devices and system integration studies for the demo activities have been completed. Demonstration activities which were presented in D8.1 will start shortly after the completion/submission of this report.

Demonstrate the use of innovative battery technologies to minimise energy losses (AC/DC conversion) while charging Evs" objective will not be run for Turkish pilot. Within the scope of this case, it was aimed to supply electricity to AV charging stations directly with DC voltage at the battery output and to eliminate the losses that will occur in AC / DC - DC / AC conversions. However, in order to realize this case, a battery storage system with high DC output is needed. In addition, charging stations must be compatible with DC input. Such solutions are generally feasible for charging station hubs with many charging stations, and the installation of a system within the scope of the project caused problems in terms of cost and also delivery within the scope of the project. More importantly, according to the market research, there is no commercialized V2G charging station with DC input in the market. As a summary, instead of focusing on losses, only cases of supporting electric vehicle charging with batteries and providing flexibility to the grid will be studied.

Energypolis campus, where demonstration activities will be carried out within the scope of Swiss pilot, is about to be ready for testing and most of the installation and system integration works have been completed as in the Turkish demo. Installation process of batteries and heat pumps are still in progress and these installations will be completed in a short time. Since the power to gas facility is immensely delayed, and will not be operational before the end of the FlexiGrid project, demonstration of power-to-gas technologies will be replaced with a "simulation twin" of such technologies. The models of the technologies and their controllers can be calibrated on real technologies. Unfortunately It is also proposed to use a small fuel cell which will provide a proof of concept of the power to gas technology, although this will be a one-directional technology and not bi-directional.

6. Appendix

Table 11 : Summary of the MPC control setpoints and Simulink models data points for the Swiss demo

		Value	Unit
Step 1 - Electrical	MPC setpoints	PV production sent to the grid	kW
		PV production sent to the consumers of the buildings	kW
		PV production sent to the battery	kW
		Grid power sent to the consumers	kW
		Battery power sent to / received by the grid	kW
		Battery power sent to the consumers	kW
	Simulink model data points	Real PV production	kW
		Real consumption	kW
		Effective PV production sent to the grid	kW
		Effective PV production sent to the consumers of the buildings	kW
		Effective PV production sent to the battery	kW
		Effective grid power sent to the consumers	kW
		Effective battery power sent to / received by the grid	kW
		Effective battery power sent to the consumers	kW
		Battery state of charge	-
Step 2 - Electrical & Step 3 - Electrical	MPC setpoints	Power setpoint	kW
	Simulink model data points	Power setpoint accepted	kW
		Power real	kW
		Power charge min / max	kW
		Power discharge min / max	kW
		State of charge	-
		State of charge min/max	-
		On/off	-
		Total capacity	kWh
Step 1 - Thermal	MPC setpoints	Heating / cooling power provided by the ventilation units	kW
		Heating / cooling power provided to the slab	kW
	Simulink model datapoints	State of charge of the air battery	-
		State of charge of the concrete slab battery	-
Step 2 - Thermal & Step 3 - Thermal	MPC setpoints	Heating / cooling power provided by the ventilation units	kW
		Electrical power of the heat pump	kW
	Simulink model datapoints	State of charge of the air battery	-
		State of charge of the concrete slab battery	-
		COP of the heat pump	-