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Demonstration of flexibility measures and electricity grid services provided by local energy storage and EVs

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List of abbreviations

Abbreviation	Definition
AC	Alternative current
AMR	Automatic meter reading
API	Application programming interface
BESS	Battery energy storage system
BMS	Battery management platform
CO2	Carbondioxide
CPMS	Charge point management system
CPO	Charge point operator
DC	Direct current
DER	Distributed energy resource
DSO	Distribution system operator
DSoC	Desired State of Charge
EMS	Energy management system
EPA	Environmental Protection Agency
EV	Electric Vehicle
EVSE	Electric vehicle supply equipment
GTE	Energy management platform
GTB	Building management platform
GTR	CO2 network installations management platform
GTBatt	Batteries management platform
HTML	HyperText Markup Language
HV	High voltage
IoT	Internet of Things
LV	Low voltage
MV	Medium voltage
OCPP	Open charge point protocol
P2P	Peer to peer
PID	Proportional integral derivative controller
PV	Photovoltaics
QR	Quick response
RES	Renewable energy system
RFID	Radio frequency identification

SoC	State of Charge
SOEC	Solid oxide electrolyzer cell
SOFC	Solid oxide fuel cell
V1G	Uni-directional smart charging
V2G	Vehicle to grid

Contents

Abstract

The increasing of distributed generation resources, along with the electrification of the heating and transportation sectors, is causing a change in the existing structure of distribution networks. With this new configuration of the electricity distribution grids, the traditional one-way energy flow can be two-way in some certain locations and "grid flexibility" will be an opportunity that DSOs need to consider. Especially with the emergence of new business models, DSOs will have new roles and interact with end user more actively. Activities of the WP8 of FlexiGrid project mainly focus on this expectation and within this scope studies have been carried out to provide grid flexibility with different flexible assets and business models in pilot regions in Switzerland and Turkey. Demo activities have been presented in the direction of the test cases proposed in D8.1 and the installation and system integration work presented in D8.2.

The demo work carried out in OEDAS pilot site was designed to demonstrate the potential flexibility that electric vehicles and battery storage systems can provide to the distribution grid to mitigate the negative effects of potential congestion problems that may occur in LV grid. In this context, business models based on demand side management and simulating the process with end-user participation were demonstrated with real assets and systems. (Due to the regulatory and technological barriers presented in the demonstration activities section of the report, it was not possible to work with real users.)

The studies that were carried out in the report have shown that electric vehicles and battery storage systems can be dynamically managed in coordination with DSOs due to their ability to respond quickly to setpoints. With the implemented scenarios, it has been demonstrated that the discharge feature of battery storage systems and V2G chargers can be actively used in load management, and the distribution transformer does not exceed the defined thresholds at certain times of the day. When considered from the end-user perspective, price-based optimization is expected to be important for users to gain profits in the future, and it has been shown that charging/discharge operations based on tariffs determined by DSOs according to the grid load will be important for load management.

Standard electric vehicles (which are compatible with uni-directional charging), which will have much higher number than V2G-capable vehicles, also have a significant flexibility potential for grids. By managing the charging process of these vehicles in a smart way, DSOs can use them for load management and to limit congestion problems. The studies in the report demonstrates the management of the charging process by extending the user's charging time to an acceptable level and reducing the charging power. The results show that V1G smart charging can provide significant benefits to DSOs in reducing peaks during the day. However, incentivizing users is critical to making the process sustainable in real scenarios.

The report has also highligted the importance of technological infrastructure and systems for dynamically implementation of all of these scenarios in a way that meets the needs of both end-users and DSOs. The test cases conducted have shown that it is essential to have platforms and algorithms that are compatible with smart charging processes in order to dynamically manage relevant assets.

At the Swiss pilot site, test cases previously established in deliverable 8.1 (can be seen in Figure 2) were performed and are presented in this deliverable. In a first step, proper monitoring and control of the installations are validated, despite the few limitations observed on the control of heat pumps, especially

in terms of restrictions on consecutive activations. Then, a strategy developed for the estimation of the flexibility potential, based on typical power profiles, is presented. Finally, flexibility for balancing purposes was provided to OIKEN using the different assets of the campus. The reliability of heat pumps and batteries is studied and compared with each other and then tests are presented for both positive and negative flexibility services. When the asset behaves as planned baseline, batteries appear to accurately deliver 100% of the flex offer volume, due to their high reactivity. For the performed tests, results show that heat pumps are rather reliable, showing delivery rates situated between 94.7% and 109.2% of the promised volume, in the case of constant baselines. The P2G installations being unavailable for the timeline of the project, a simulation model was used and combined to the other assets to generate flexibility offers with the whole system. A test combining HP19, batteries and the P2G simulation model resulted in delivery rates between 98.75% and 101.1%.

1. Introduction

The concept of flexibility is becoming increasingly significant, particularly with the growing deployment of distributed production sources, electric vehicles, and electric heating systems. These systems are crucial in achieving the goal of electrification, which is a critical step towards decarbonization objectives. However, if these systems are not properly designed, their proliferation can lead to congestion problems for distribution network operators at local or larger scales. Nevertheless, well-designed business models and intelligent management platforms can reduce these negative effects and even leverage this disadvantage in some cases.

In this context, this report presents the details of the work, results, and evaluations obtained in the development and execution of demo activities with different flexible resources in two different demo areas. The first part of the report discusses the basic objectives and goals. In the second part, demo areas in Turkey and Switzerland are reintroduced with their final states, and information is provided about measurement systems and controllable devices. In this section, the platforms used during demo activities are also analyzed, and information is provided about the final integration process. The same section provides brief information about the purposes of using the platforms during demo activities, and more detailed information is presented about the EV management platform and smart charging methodology for OEDAS. In the third chapter, demo studies and results carried out within the scope of previously determined test cases in Turkey and Switzerland are given. The report was completed with the 4th chapter, the summary and conclusion part.

Scope and Objectives

The main purpose of the report is to demonstrate flexibility in the electricity distribution network through the systems and architectures designed in Turkey and Switzerland with different use cases. In this context, the main objectives of the report, in parallel with the objectives defined in the Grant Agreement, are:

- Demonstration of the flexibility measures and electricity grid services provided by battery storage, electric vehicles, vehicle-to-grid (V2G), heat pumps and power-to-gas solutions (digital twins and small-scale fuel cell).
- Performing of the real time control of integrated equipments to enhance renewable energy integration.
- Performing of the integrated platforms within the scope of flexibility provisioning.
- Definition/validation of the roles of DSO and FSP on the energy/flexibility trading platform, EFLEX
- Demonstration of the basic demand side management use case with electric vehicles and EV management platform.

2. Description of demo sites and platform integration for demonstrations

This section presents the final configuration of the architecture of the OEDAS and HES-SO pilots where demo activities were carried out in Turkey and Switzerland.

2.1 OEDAS pilot site

The general configuration of OEDAS campus was already presented in the previous deliverables D8.1 and D8.2. Some details regarding eventual modifications are given in the next sections.

2.1.1 OEDAS assets / platforms description and integration

As mentioned in previous deliverables (D8.1 and D8.2), the OEDAS demo will demonstrate the provision of flexibility to the distribution grid through the smart charging process of electric vehicles and battery storage systems. To this end, the DC fast (50 kW) electric vehicle charging station, V2G bi-directional electric vehicle charging station, and battery storage system (can be seen in Figure 1) were installed and integrated with the local energy management system called the EV Management platform. On the other end, the EV Management platform was integrated with the FlexiGrid platforms (SIMAVI's IoT and EMAX's EFLEX platforms), and the use cases were demonstrated using the relevant platforms.

Figure 1 Battery Storage System (left), V2G and DC fast charging stations

The final diagram obtained from the installation and system integration works carried out in the OEDAS pilot area is shown in Figure 2. It can be seen that all assets are integrated with the EV Management platform with different communication protocols.

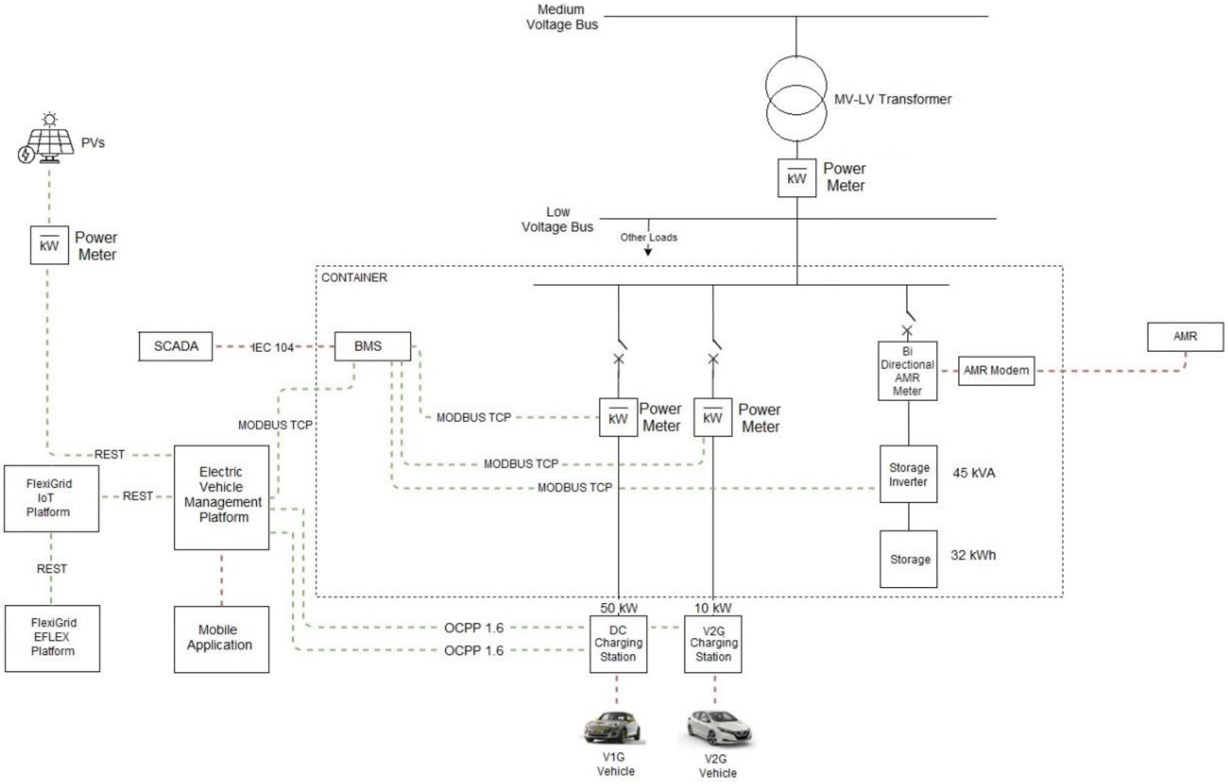


Figure 2 General scheme of OEDAS pilot site

During the test case demonstration activities carried out by OEDAS, the electric vehicle management platform (EV management platform), FlexiGrid IoT platform, and EFLEX trading platform were mainly used. The EV management platform, where all control processes were performed, was the main platform for the demo activities. FlexiGrid platforms were integrated into the EV management platform according to the use case scenarios. General information and usage details of the platforms can be found in the following sections.

2.1.2 EV management platform description and integration

The electric vehicle management platform is designed to manage and optimize the charging sessions of electric vehicles using a smart charging algorithm. Typically, a charging session is initiated through a mobile application, which can use QR codes or RFID to communicate with the platform. The optimization and management processes take place on the back-end of the EV management platform, with the main goal of balancing the load on the local transformer by calculating and scheduling the optimum charging and discharging slots for both EV chargers and battery storage systems. The platform's intelligent scheduling algorithms can help to reduce peak demand, optimize energy consumption, and minimize the impact of EV charging on the local grid.

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.

During the demo activities, the control of the devices installed in the OEDAS pilot area (EV chargers and batteries) will be directly performed through the EV management platform, utilizing its smart charging algorithms. More detailed information about the functions of the platform can be found in the D8.2 document. The key objectives for the smart charging are:

- Minimizing the impact of the EVSE infrastructure on customers' internal distribution system with focus on:
    - Reducing power peaks with smart charging application
    - Maximizing the use of internal energy sources
- Allowing clients to supply grid services (balancing services) (e.g. identify power and energy flexibility, typical response time, etc…)

As mentioned before, the platform is integrated with the devices in the field and with DSO assets, and there is bi-directional communication with the devices. The general architecture of the platform can be seen in Figure 3.

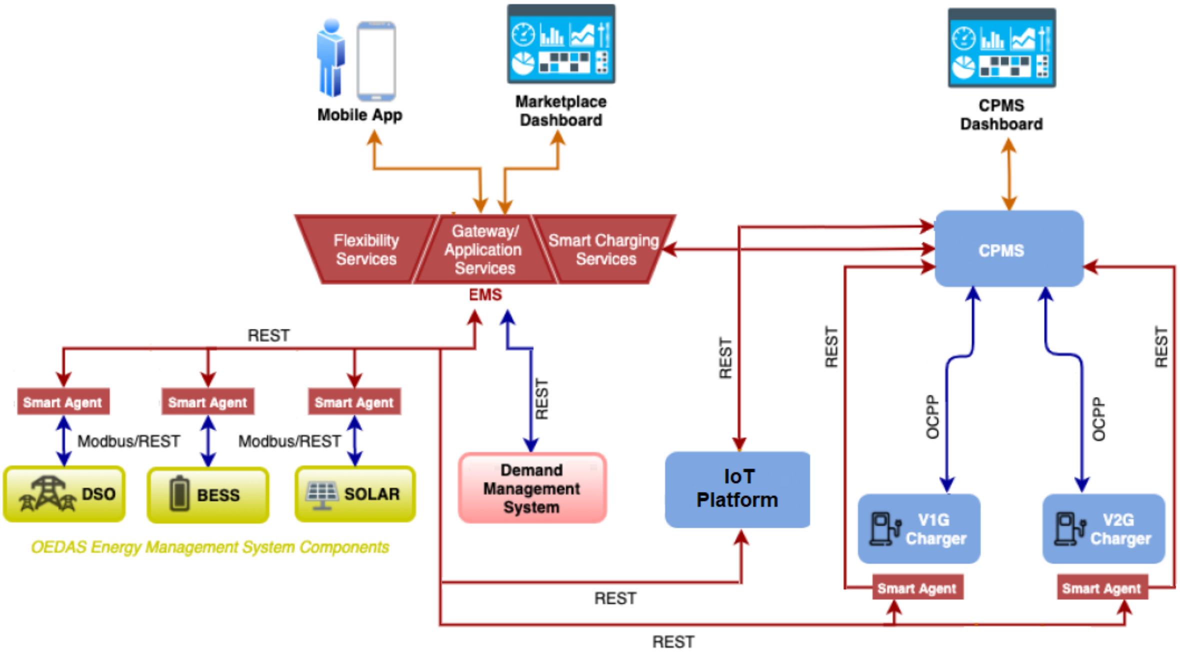


Figure 3 Final architecture of EV management platform

The smart charging module in the Central EMS evaluates the charging and discharging profiles based on inputs received from relevant devices and users. The determined profile slots can be adjusted through the platform, and in general, it is decided that 15-minute intervals are appropriate for the slots. Within this scope, the platform calculates the appropriate flexibility potential every 15 minutes in a 24-hour period. The basic criteria for this calculation are listed below.

- Solar and other renewable generation forecasting - based on historical data;
- Peak and off-peak load and its pattern is predicted using historical load by checking on the average consumption over a period of one month for every 15 mins slots;
- Parking utilization - based on analysis of number of vehicles connected to the charging stations over a period of time.

For each vehicle, the following user input is derived:

- Departure time (duration of vehicle being connected);
- Desired state of charge at departure time (DSOC) normally 100%;
- Current state of charge (SOC);
- Max capacity of the vehicle - calculated empirically.

So, when vehicle is connected for the first time, algorithm uses the predicted information and the given user details to calculate the 15 mins slots for charging and discharging (in case of V2G). The charging/discharging sessions for a vehicle will be represented using “blocks” where each block represents the respective kW for the 15-minute interval. Here, the capacity can range from a slow charging (usually 1-2 kW) to fast charging (10 kW, 22 kW, etc.) as supported by the respective charger.

For each of the connected vehicles, the following are derived using the users input:

- For V2G compliant vehicles offering flexibility, the energy required to achieve the desired state of charge (DSOC).
    - If DSOC is less than 100%, then the difference between DSOC to Full charge is treated as flexibility.
    - If DSOC is 100%, then a pre-configured percentage (20%) of the vehicle’s maximum capacity would be considered as flexibility.

The utilization of the flexibility has to consider the departure time of the vehicle and will be different in each slot based on grid conditions. The goal here is to charge the vehicle up to DSOC based on the disconnect time interval while utilising the flexibility offered until then.

Users can nevertheless opt-out from providing flexibility via the mobile app also.

- For V1G vehicles or V2G (opt-out option selected)
    - Calculate the respective energy required to achieve DSOC and assign blocks considering the departure time of the vehicle

The goal here is to charge the vehicle at a minimum rate possible in order to achieve the DSOC based on the departure time. For such vehicles, the entire charging process would be balanced across the available time intervals whereas, in case of V2G vehicles with flexibility, there would be spikes in charging and discharging capacity in order to utilize flexibility as well as to refill.

Once the charging and discharging blocks have been calculated, it looks at the predictability of factors such as load, solar generation & parking utilization and determines which slots should be used.

The load balancing-based profile calculation is mainly based on the peak and off-peak thresholds determined by the DSO through the platform. The peak threshold indicates the threshold value that the transformer load should not exceed during peak times, while the off-peak threshold indicates the consumption value taken into account outside of peak times. Information on how the algorithm performs calculations during peak and off-peak times can be found below.

During the **Peak slot**:

- The e-vehicle would never be charged unless the load is below a configurable peak threshold in which case, they would be slow charged.
- In case of V2G e-vehicle would discharge at a maximum rate for every 15 mins slot (if the charging station is 10 kW capacity it would be discharge at the maximum: 10 kW);
- No cars leaving at the current peak period would be discharged.

During the **Off-Peak slot**:

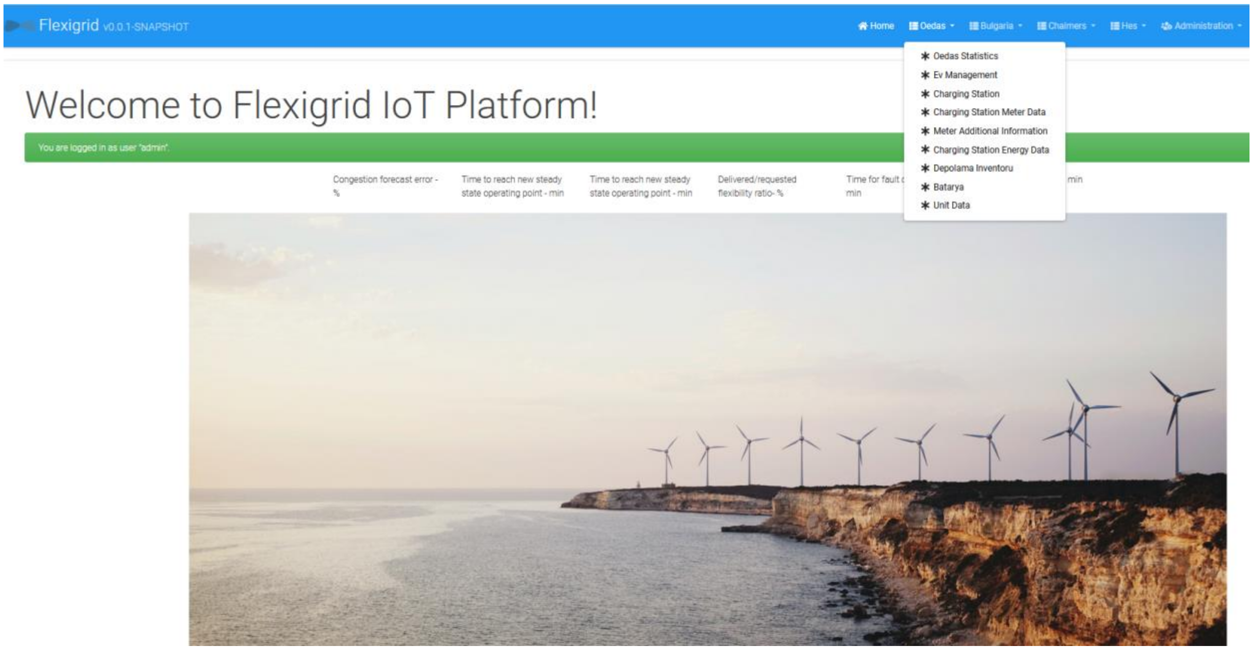
- There is a configurable off-peak threshold the charging algorithm always uses to determine the number of cars charged during 15 mins;
- If for some reason the real time consumption goes above the threshold, then V2G would trigger discharging;
- All V2G car would be charged up-to threshold until it gets to 100%;
- All V1G car would be charged at slow or fast rate depending on the departure of the car, so if the car is leaving the day after, by instance, then it will only be charge at a slow rate (1kW for AC and 5 kW for DC charging);
- For V2G, any discharge during the peak would be re-charged at off-peak to the same level so the car is always ready for flexibility at the next peak.

These profiles, calculated automatically based on the specified inputs, are recalculated under certain conditions. Events that lead to recalculating charging profile are:

- If actual SOC is different to the estimated SOC obviously due to the losses, etc
- If a new car arrives or departs earlier than the recorded departure;
- If a Grid event occurs.

2.1.3 FlexiGrid IoT platform description and integration

All assets in the demo area (including transformers and PVs), have been integrated with the FlexiGrid IoT platform through an API prepared by OEDAS. Thus, real-time or 1-minute resolution data monitoring is possible through the IoT platform. **The main purpose of the data monitoring can be stated as the verification of flexibility delivery and equipment control**. The IoT platform dashboard prepared for OEDAS and visuals of the data transferred and visualized by OEDAS can be seen in Figure 4 and Figure 5.



Welcome to Flexigrid IoT Platform!

You are logged in as user "admin".

Figure 4 IoT platform dashboard for OEDAS

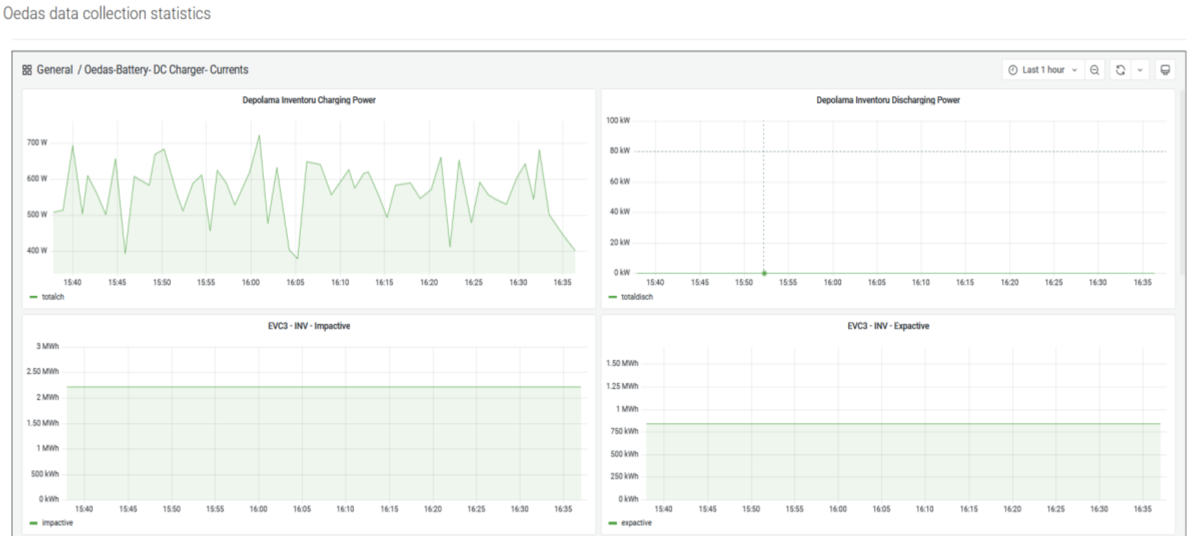


Figure 5 Visualization of OEDAS data

In addition to the API prepared for data monitoring and validation purposes, a second API has been provided by OEDAS to the IoT platform. **The main purpose of this API is to provide the IoT platform user with the opportunity for setting and equipment control**. This API allows IoT platform user to make adjustments and trigger changes to the smart charging process of EV management platform. The basic functionalities provided by the API are listed below:

- Enabling/disabling of smart charging (POST)
- Peak/Off-peak threshold setting (POST)
- Peak slot creation (POST)
- Base price setting (POST)

- Pricing setting (intraday-day ahead or Time of Use rates) (POST)
- Creation of Demand response event for direct equipment controlling (POST)
- Smart charging profiles (including transformer load and PV production forecasts) (GET)

The integration resulted in the possibility of performing these operations and the dashboard prepared for OEDAS on the IoT platform can be seen in Figure 6. During the demonstration activities, the IoT platform works in integration with the EV management platform. General settings are made on IoT platform and are automatically activated/ triggered (via API) on EV management platform that executes the set changes.

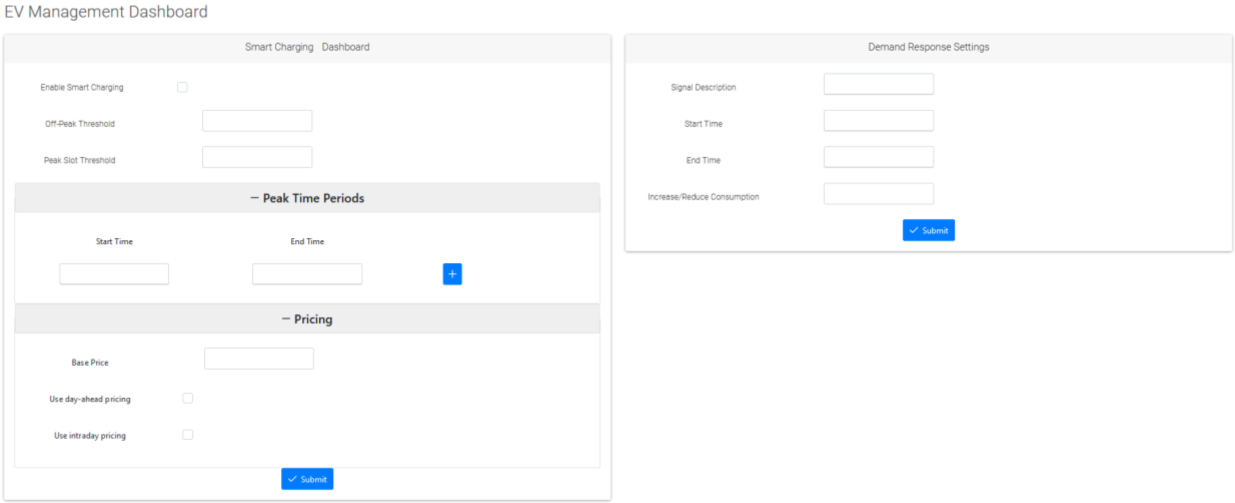


Figure 6 EV management dashboard of IoT platform

2.1.4 FlexiGrid P2P Trading description and platform integration

The EFLEX platform (developed by EMAX) serves as the marketplace for energy/flexibility trading between the DSO and the FSPs. Through the platform interface, the necessary steps for completing trading transactions can be carried out seamlessly. The only integration requirement here is to ensure the verification of the flexibility delivery, which necessitates the provision of measurement data from the relevant assets. To this end, it has been decided that there will be no direct integration between OEDAS and EFLEX for transferring of measurement data that will be used for flexibility trade validation, and that the required data will be transferred from the SIMAVI IoT platform to the EFLEX platform via API.

In addition to the aforementioned process, after the offer and request transactions are matched on the EFLEX platform, OEDAS has prepared an API to directly send the final flexibility command to OEDAS assets (through the EV management platform). Through this API, the consumption reduction or increase command can be sent by the EFLEX platform and trigger the OEDAS asset, initiating the flexibility provisioning process. Further details on this process can be found in ***Section 3.1.2.1 TC.8.8***.

2.2 HES campus

The general configuration of HES campus was already presented in the previous deliverables D8.1 and D8.2. Some details regarding eventual modifications are given in the next sections.

2.2.1 HES assets / platforms description and integration

The final devices available on Energypolis Campus are the following:

- 1 x Heat pump 140 kWth
- 2 x Heat pump 100 kWth
- 1 x Batteries 250 kWh
- 1 x (simulated) solid oxide electrolyser cell (SOEC) 20 kW
- 1 x (simulated) solid oxide fuel cell (SOFC) 6 kW

The assets are operational and match the specifications that were already communicated. These assets are controllable through different platforms, that were already described in details in D8.2. The final structure is exactly the same as the one which was already presented. A summary of the platforms is again given in Figure 7.

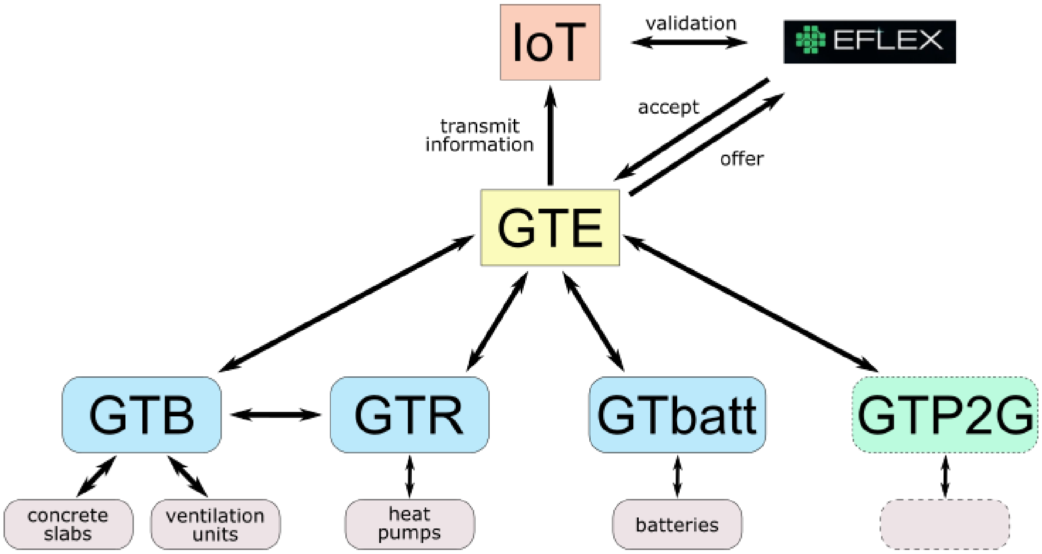


Figure 7: Platforms available at HES for assets management and flexibility services procurement

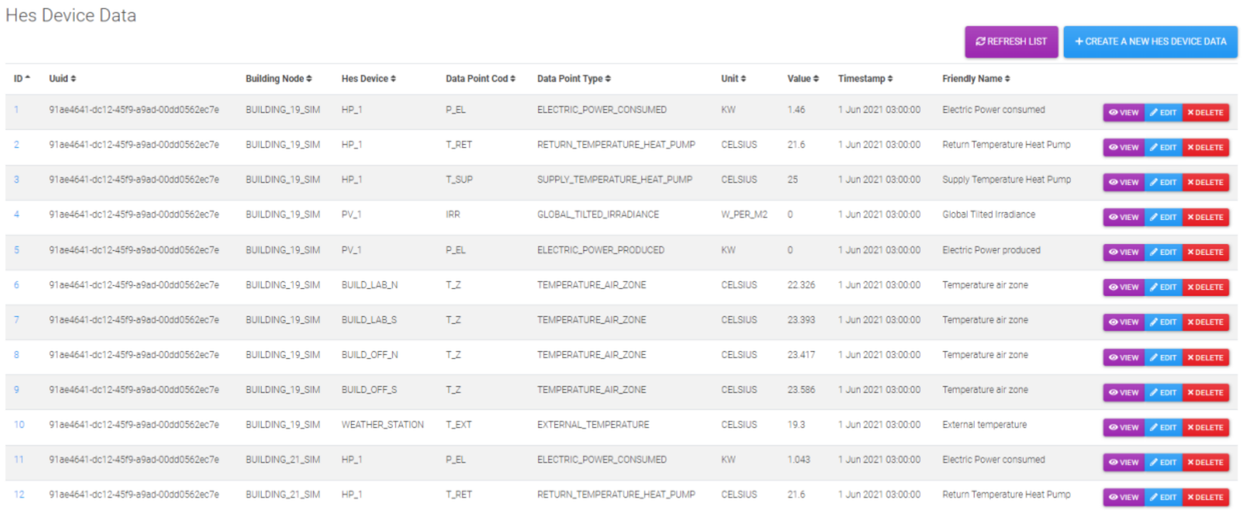
2.2.2 FlexiGrid IoT platform description and integration

In the case of the Swiss demo site, the Flexigrid IoT platform is used for two purposes:

1) To provide a visualization tool for the data measured onsite.
2) To gather measurement data to validate the actual delivery of flexibility services.

Developments have been made and data for the buildings, heat pumps, photovoltaic modules (PV) and batteries are shared to the platform at a 1 minute resolution. Raw data can be easily accessed on the IoT platform under a table format (see Figure 8). In addition, a graphical visualization is also available on the

IoT platform. An example is provided in Figure 9. This data is gathered on the HES side and shared via the HES API. The IoT platform then gets the data using simple HTML requests. Finally, the visualization tool available on the IoT platform allows one to access historical data.



Hes Device Data

ID	Uuid	Building Node	Hes Device	Data Point Cod	Data Point Type	Unit	Value	Timestamp	Friendly Name
1	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	HP_1	P_EL	ELECTRIC_POWER_CONSUMED	KW	1.46	1 Jun 2021 03:00:00	Electric Power consumed
2	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	HP_1	T_RET	RETURN_TEMPERATURE_HEAT_PUMP	CELSIUS	21.6	1 Jun 2021 03:00:00	Return Temperature Heat Pump
3	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	HP_1	T_SUP	SUPPLY_TEMPERATURE_HEAT_PUMP	CELSIUS	25	1 Jun 2021 03:00:00	Supply Temperature Heat Pump
4	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	PV_1	IRR	GLOBAL_TILTED_IRRADIANCE	W_PER_M2	0	1 Jun 2021 03:00:00	Global Tilted Irradiance
5	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	PV_1	P_EL	ELECTRIC_POWER_PRODUCED	KW	0	1 Jun 2021 03:00:00	Electric Power produced
6	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	BUILD_LAB_N	T_Z	TEMPERATURE_AIR_ZONE	CELSIUS	22.326	1 Jun 2021 03:00:00	Temperature air zone
7	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	BUILD_LAB_S	T_Z	TEMPERATURE_AIR_ZONE	CELSIUS	23.393	1 Jun 2021 03:00:00	Temperature air zone
8	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	BUILD_OFF_N	T_Z	TEMPERATURE_AIR_ZONE	CELSIUS	23.417	1 Jun 2021 03:00:00	Temperature air zone
9	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	BUILD_OFF_S	T_Z	TEMPERATURE_AIR_ZONE	CELSIUS	23.586	1 Jun 2021 03:00:00	Temperature air zone
10	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_19_SIM	WEATHER_STATION	T_EXT	EXTERNAL_TEMPERATURE	CELSIUS	19.3	1 Jun 2021 03:00:00	External temperature
11	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_21_SIM	HP_1	P_EL	ELECTRIC_POWER_CONSUMED	KW	1.043	1 Jun 2021 03:00:00	Electric Power consumed
12	91ae4641-dc12-45f9-a9ad-00dd0562ec7e	BUILDING_21_SIM	HP_1	T_RET	RETURN_TEMPERATURE_HEAT_PUMP	CELSIUS	21.6	1 Jun 2021 03:00:00	Return Temperature Heat Pump

Figure 8: Example of raw data available on the IoT platform

Figure 9: Snapshot of the IoT platform visualization tool for the Swiss demo site

Concretely, plots are available for each individual asset and gather the most important state variable of the assets. For the heat pumps (Figure 10), the electrical consumption of each individual heat pump (19, 21,23) is monitored, allowing to use each asset separately for the supply of flexibility. For the batteries (Figure 11), both charging (positive) and discharging (negative) powers can be visualized, as well as the state of charge. Charing and discharging cannot be non-zero at the same time, and both are taken into account during the flexibility validation period.

Figure 10: Heat pump monitoring available on the IoT platform

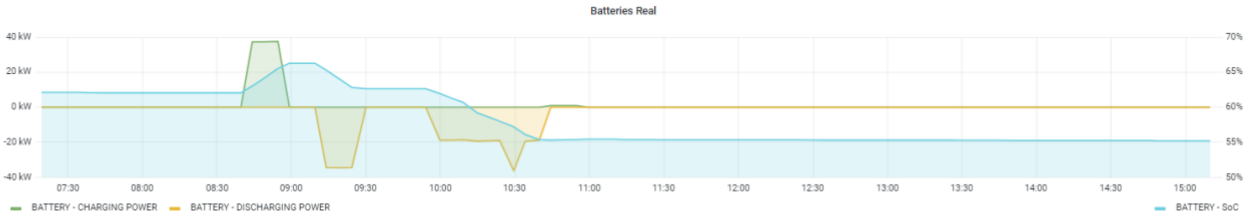


Figure 11 : Batteries monitoring available on the IoT platform

2.2.3 FlexiGrid P2P Trading description and platform integration

The interaction of HES and OIKEN with the EFLEX platform (P2P trading platform) is limited to the following aspects :

- Posting of flex offers by HES or flex requests by OIKEN
- Matching of the offers
- Notification of flex offer acceptance by email
- Validation by OIKEN using the measurement data provided by HES

For the three first points, a general procedure was established, with offers being exchanged every hour for the next hour in an automated process, as described below:

xx:00-xx:04:	Computation of flexibility needs performed by OIKEN
xx:05:	Publication of a flexibility request by OIKEN on the API of the HES
xx:05-xx:30:	Computation of flexibility offers by HES
xx:30:	Publication of the flexibility offer(s) by HES on the API of the HES
xx:30 -xx:34:	Matching of the requests/offers by EFLEX platform
xx:35:	Publication of the offers to be accepted by EFLEX on HES's API
xx:45:	Offers acceptance posted by EFLEX / OIKEN on HES's API
xx+1:00-xx+2:00	Active performance by HES for the supply of flexibility

This automated process could unfortunately not be integrated into the EFLEX platform due to limitations related to blockchain technology; flex offers and requests are then posted manually. Except for that, the presented procedure is the same. A detailed description of the procedure is given in section TC 8.2 Communication with OIKEN. HES reacts and triggers its assets as soon as it receives a notification of flex offer acceptance by email, but no direct control setpoint is sent from EFLEX to HES assets.

Regarding validation, HES shares measurement data to the IoT platform as described in the previous section. Then, EFLEX retrieves data according to its needs, in order to be able to validate the flexibility service procurement.

3. Demonstration Activities

This section presents information on the demonstration studies carried out within the scope of the test cases defined for both the Turkey and Switzerland demos.

3.1 OEDAS pilot site

3.1.1 Introduction

This section presents the different test cases which were implemented at the demo site in Turkey. All test cases along with their objectives are listed in Table 1 and were already presented in deliverable 8.1. With these test cases, the whole flexibility delivery process is demonstrated, and various assets are tested.

Table 1 Test cases of Turkish pilot site

Number	Name	Main Objective
8.8	Definition of roles and validation of processes for flexibility trading with EFLEX Platform	During this test case, main roles of DSO and FSP will be defined and communication processes with the EFLEX platform of WP-7 will be tested and validated.
8.9	Provision of flexibility by Battery Storage System and V1G compatible DC charger	This test case will demonstrate flexibility measures and electricity grid services provided by battery storage system and fast DC EV charger. Within this scope, load and price based optimization studies will be demonstrated.
8.10	Provision of flexibility by EV-V2G platform	This test case will demonstrate flexibility measures and electricity grid services provided by V2G compatible EV charger and vehicle. Smart charging of V2G compatible EV will be tested with load based scenarios and different tariff schemes for provisioning the flexibility.
8.11	Provision of flexibility by Demand Side Management/Demand Response	This test case has not been demonstrated. Detailed explanation can be found in relevant section (3.1.2.4)
8.12	Provision of flexibility services with the whole system	This test case will demonstrate the flexibility delivery with whole system together. Battery storage system and electric vehicles will be run in the same scenario to demonstrate the flexibility provisioning to balance the load of local transformer

Also, potential barriers that currently impede the demo study have been presented from the perspective of the DSO.

- **Demonstration barriers**

Since the general barriers related to all of the market participants, more detailed analysing has to be done for specifying demonstration barriers from only DSO perspective. First of all, today there is not any regulation enacted in Turkey to define the roles of market participants for flexibility services. Thus, it is not possible to foresee the responsibilities of a DSO in flexibility service applications. This uncertainty causes a barrier for DSOs to being prepared and making right investments for applying flexibility services not only today, but also in the future.

Demand side response is also very important to applying flexibility services. According to the SHURA, the current regulations related to the demand response in Turkey are mainly focusing on power plants. Contrary to this, consumers and aggregators needs to be defined as market participants in regulations. By this way, demand side can reach to the electricity market. Today there is not any aggregator role defined in regulations of electricity market in Turkey. Thus, without aggregator it is hard to integrate distribution grid connected consumers to the electricity market.

Despite it is a fact that electric vehicles will be provide large scale opportunity for flexibility services, from DSO perspective using EVs for these services are very restricted in the current regulations. The Charging Services Regulation was enacted for the first time in Turkey in 2022. With this regulation, a framework covering many issues related to charging stations such as installation and operating of charging stations, developing charging network, licensing charging operators and arranging their activities and etc. has been created [20]. Unfortunately, in this current regulation, a DSO does not have a right to applying for a charging station operator license. A direct relationship has not yet been defined between the CPO and DSO under the potential flexibility market mechanism. Thus, using EVs for flexibility services is not an applicable solution for DSOs in Turkey. This is one of the key barriers of DSOs for flexibility services.

However, there is another important issue when the topic is analysed in a more specific perspective as OEDAS. The number of electrical vehicles in Turkey is 14.552 in 2022. When it is compared with the total vehicle number such as about 14 million, the ratio of EVs is at very low level in current situation. This rate is even lower in the OEDAŞ distribution region where demo activities are carried out.

In addition to that, for V2G applications in flexibility services, there is not a V2G compatible vehicle on sale today in Turkey. For the first time, a V2G compatible vehicle was brought to Turkey from abroad with a special permission granted within the scope of the FlexiGrid R&D project. Thus, the Nissan Leaf is the first “officially imported” V2G vehicle in Turkey. Also, the FlexiGrid project is the first project in Turkey that include real test environment for V2G studies. Unfortunately, this situation creates a critical barrier. Because even if regulations allow V2G services, there is no other vehicle or charger to implement relevant use cases. Still, FlexiGrid project is a very important step for developing flexibility services and their applications in Turkey.

Another important barrier can be categorized as the technological inadequacy. For implementation of flexibility services, electricity demand has to be monitoring instantaneously. The conventional electricity meters cannot provide this. For real time monitoring of the demand, smart meters are a must for electricity grid. Unfortunately, today only a few customers have smart meters on their system and this is one of the most critical barrier on the purpose of implementation of flexibility services. In the Turkey Smart Grids 2023 Vision and Strategy Determination Project report of ELDER (Electricity Distribution Services Association of Turkey), the Smart Grid Roadmap of Turkey has been summarized. According to that, it is aiming to establish of advanced metering infrastructures covering at least 80% of the distributed energy until 2025 and at least 80% of the number of customers by 2035 [1]. On this purpose, the MASS (National Smart Meter Systems) R&D project are being held with participation all of the DSOs in Turkey. With this project, it is aimed to develop smart meter systems domestically. Thus, their cost will be lower and the demonstration activities also will be easier.

Also, it is mentioned before there is not an existing comprehensive regulation about the flexibility services in Turkey. This situation cause uncertainty for pricing of flexibility services. To implement these services ideally, the responsibilities of all market participants should be defined clearly via regulations. Additionally, pricing mechanisms and applying methods of these mechanisms also defined with all of the details.

Nevertheless, all these technical, regulatory and social barriers can be overcome with the right policies, incentives and educations. Here, it is critical for decision makers in Turkey to create and audit the necessary action plans for the dissemination of flexibility practices.

3.1.2 Test case implementation

3.1.2.1 TC 8.8 Definition of roles and validation of processes for flexibility trading with EFLEX Platform

- **Description of the test case**

Within the scope of this test case, the general processes and roles of participants have been defined for tests to be conducted using the EFLEX platform. This platform, developed for WP7, facilitates the implementation of electricity/flexibility trading between DSOs and FSPs. The basic output offered by the platform is the ability for DSOs and FSPs to indicate their flexibility needs through the platform and manage the energy trading process between them.

During the OEDAS demo studies, battery storage systems and electric vehicles are ready as flexible assets. FSPs possessing these flexible resources can offer flexibility options through the platform, which enables energy trading. Similarly, DSOs with flexibility needs can create flexibility requests through the platform and view the offers published by FSPs.

The primary goal of TC8.8 is to define the relationship and basic process between the EFLEX platform, the FlexiGrid IoT platform, and the OEDAS EV management platform to effectively manage this process. The test case commences with the presentation of the definition and particulars of the study, planned to be conducted within the confines of the test case, aligning with the intended objective. Thereafter, the specifics of the test case scenario are expounded upon. The "outcomes" section showcases instances of flexibility trading, which are carried out in accordance with the pre-established scenario, and the essential results obtained. Ultimately, the final section entails a comprehensive discussion on the overarching process.

Scenario-based test cases performed on the platform are not presented in this report, as they are shown in D7.3. In line with the content of the test case, this report only presents the determination of relationships related to the relevant process, integration processes, and an example of a transaction.In the context of this demo study, since OEDAS performs the installation and operation of the relevant flexible assets, it will play a role as both DSO and FSP in the demo and will test the system with real devices and systems in a real environment.

During the demo study, the platforms presented in Table 2 will primarily take part. Details regarding the roles of these platforms in the process can be found in the "proposed scenarios for implementation" section.

Table 2 Platform roles in TC.8.8

Platform Name	Platform Owner	Platform Role
EFLEX	EMAX	Trading, Billing & Settlement
IoT Platform	SIMAVI	Monitoring and Flexibility Validation
EV Management Platform	OEDAS	Equipment Control and Flexibility Provisioning

From the perspective of FSP, the process will be carried out by submitting offers to the platform in daily periods based on the flexibility potential of the assets (battery storage system and V2G-DC charging stations) available in the demo region, depending on their availability. When these offers are submitted, the SoC lower limit is assumed to be 20% for the stationary battery storage system. For values above this limit, the battery storage system can offer flexibility within the specified period with full capacity (+-10 kW) by giving an offer. For electric vehicles, offers can be made when the vehicle is connected, so an offer will be created through the platform at least 1 hour before any vehicle is connected. The electrical availability details during the offer creation process for the V2G charging station are similar to the structure of the battery storage system. The only difference is that the minimum SoC limit for the electric vehicle is 30%. Discharge up to a maximum of 10 kW can be performed from the vehicle battery at SoC values of 30% or higher, and this value can be offered to the platform as flexibility offer. As the charging process is one-way for the 50 kW DC fast-charging system, flexibility potential can only be achieved through consumption shifting. The offer for the relevant charging station can be presented as "Reducing consumption by X kW" for a certain period of time. During the presentation of flexibility, this information will be communicated to the EV management platform, and the platform's smart charging algorithm will perform power distribution in a way that will reduce consumption by X kW in the DC charging process at specified time intervals.

From DSO's perspective, the process is managed by identifying the flexibility requirement and posting the relevant amount as a request on the platform. In the pilot study, the transformer load in the region where the demo study is conducted is taken as the base load, and this load is monitored in real-time. There is no load or congestion problem in the transformer in reality. At the same time, since OEDAS does not use any flexibility/congestion forecasting tool, the flexibilityrequirement determination process will be performed manually based on transformer load thresholds.

At the end of the process, the matching of requests and offers will be carried out through the EFLEX platform, and the most suitable offer will be matched with the most appropriate request and then verified. An IoT platform will be used to verify the flexibility delivery process. Following the verification process, invoicing will be carried out depending on whether the flexibility trade has taken place as expected or not, and the process will be finalized for all parties involved. More detailed information about these processes can be found in D7.3.

- **Proposed scenarios for implementation and outcomes**

As previously mentioned, the process is designed to be initiated through the EFLEX platform, controlled via the EV management platform, monitored and verified through the IoT platform, and ultimately finalized via transactions that will be made through the EFLEX platform. Within this framework, the structure established between the platforms and the envisioned scenario are presented in Figure 12.

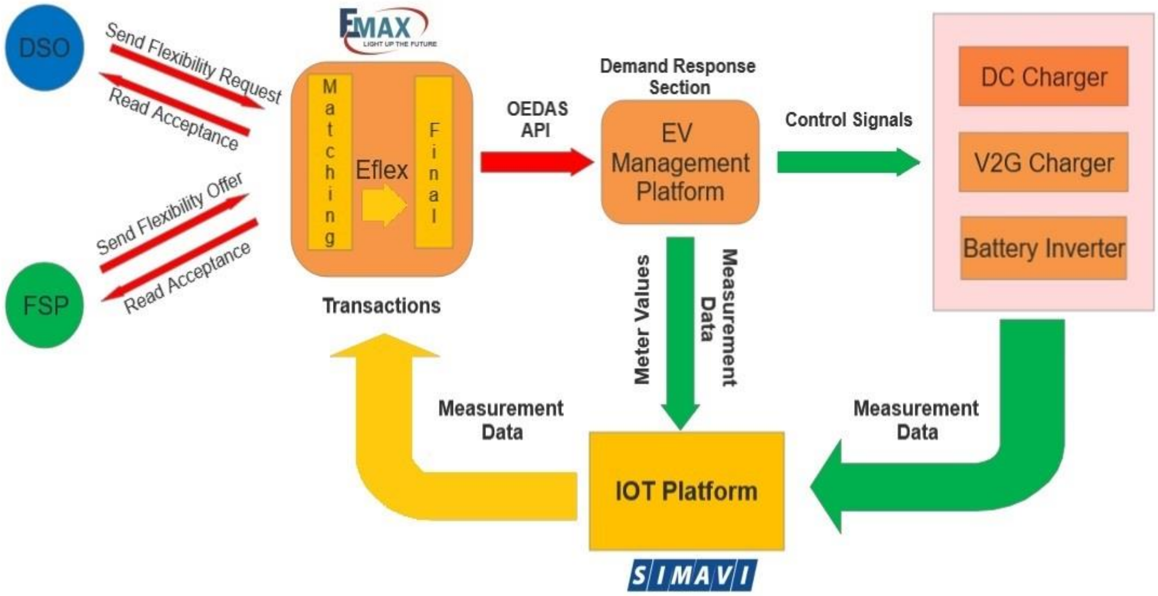
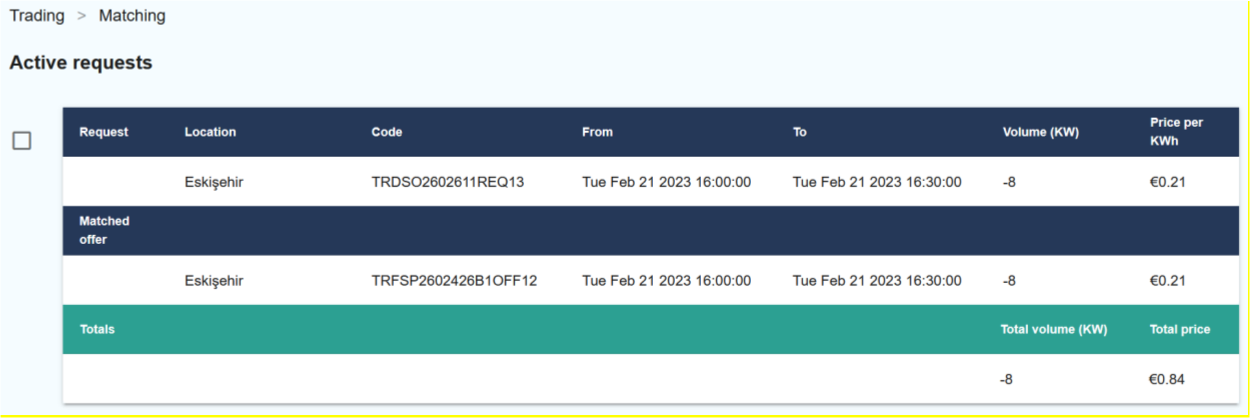


Figure 12 Trading process with FlexiGrid platform

As mentioned, requests and offers are created through the EFLEX platform and the process is monitored through the same platform. Details on asset definition and offer/request creation can be found in D7.2 and D7.3. Afterwards, the matching process is completed and the final matching is published on the platform. Following the final matching, the FSP is notified via email that their offer has been accepted. An example process and email notification for a matching process conducted for a flexibility requirement of -8 kW between 04.00 pm – 04.30 pm is presented in Figure 13 and 14.


Trading > Matching

Active requests

☐ Request	Location	Code	From	To	Volume (KW)	Price per KWh
	Eskişehir	TRDSO2602611REQ13	Tue Feb 21 2023 16:00:00	Tue Feb 21 2023 16:30:00	-8	€0.21
Matched offer						
	Eskişehir	TRFSP2602426B1OFF12	Tue Feb 21 2023 16:00:00	Tue Feb 21 2023 16:30:00	-8	€0.21
Totals					Total volume (KW)	Total price
					-8	€0.84

Figure 13 Matching of offer and request via EFLEX platform

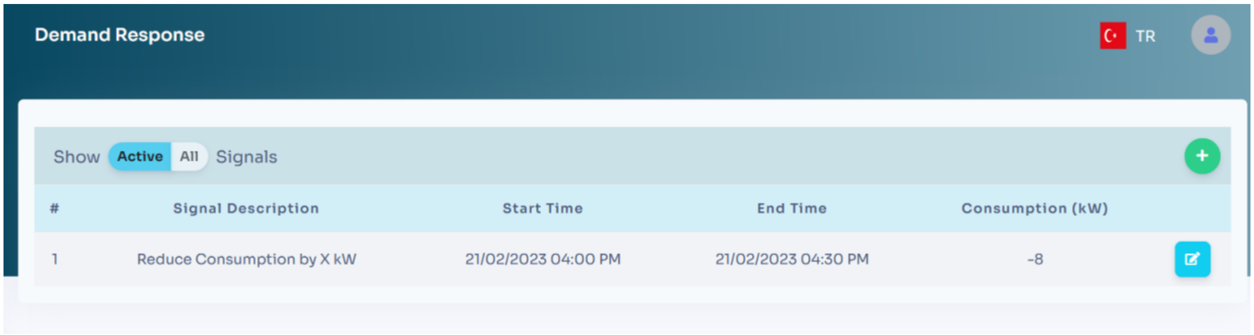
Dear,

Your request has been sent to FSP.

Request code:	TRDSO2602611REQ13
From date:	2023-02-21
To date:	2023-02-21
From time:	16:00
To time:	16:30
Day type:	weekdays
Price:	21
Volume:	-8 KW

Figure 14 Notification email that is sent to FSP

After the final matching process, the same information is sent from the EFLEX platform to the EV management platform through a post request using the API prepared by OEDAS. The parameters in the email are accepted as input by the Demand Response section of the EV management platform, and control signals are generated for the available equipment (this can be selected by DSO, for below case it is battery storage system). The input received by the EV management platform is sent to the selected device during the offer creation process, and the flexibility is triggered. For example, after the final flexibility amount resulting from the matching process described above is communicated to the EV management platform, the flexibility signal generated on the platform interface can be seen in Figure 15.



#	Signal Description	Start Time	End Time	Consumption (kW)
1	Reduce Consumption by X kW	21/02/2023 04:00 PM	21/02/2023 04:30 PM	-8

Figure 15 Creation of the DR signal in the EV management platform after matching

After receiving the flexibility signal, the EV management platform sends this signal to the battery storage system, which is the asset offered in the matching process, and a discharge operation is performed at the specified kW value between 04:00 pm and 04:30 pm. The performed discharge operation can be monitored through the IoT platform, as shown in Figure 16, and the energy (kWh) value obtained during the discharge operation is calculated and sent from the IoT platform to the EFLEX platform.

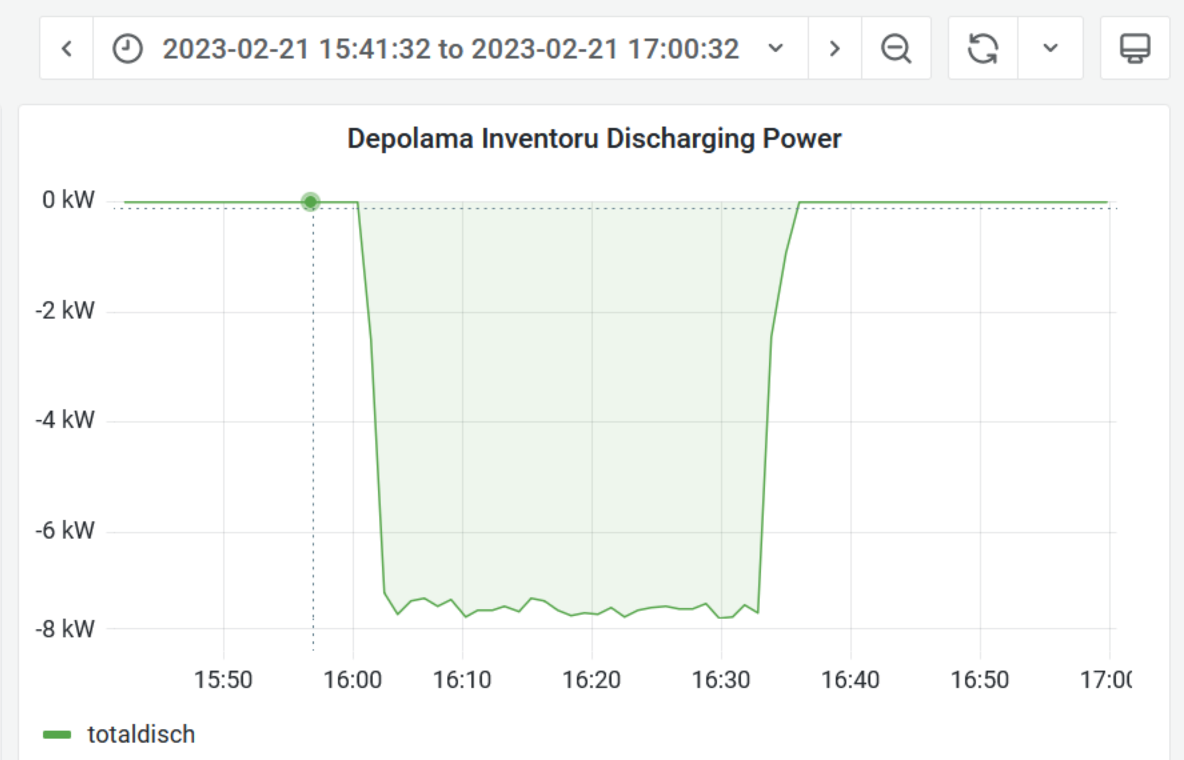
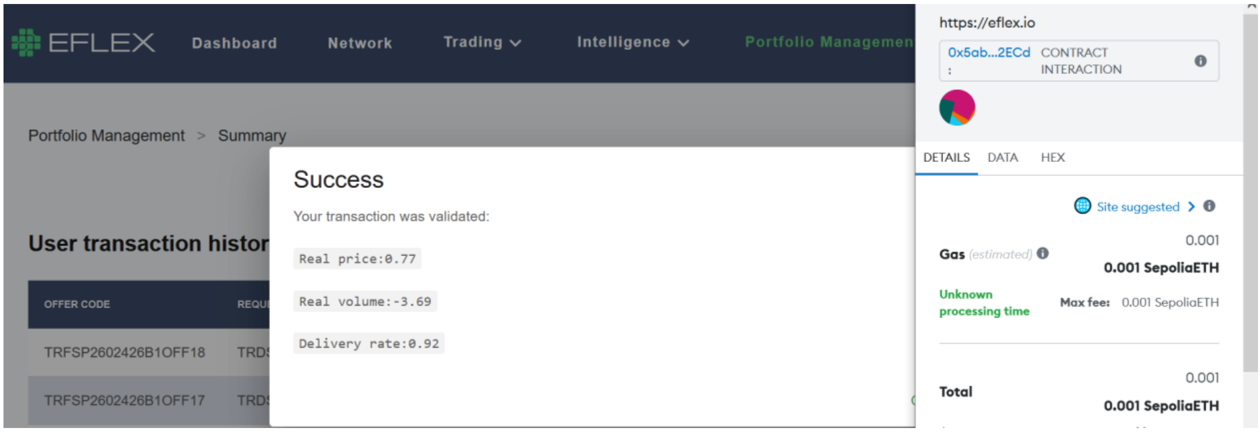


Figure 16 Monitoring the discharge process in the battery from the IoT platform

EFLEX platform uses the energy (kWh) values provided by the IoT platform to determine the extent to which the committed flexibility trade has been realized. Based on the energy price, EFLEX platform manages the settlement and billing process as indicated in Figure 17 to complete the process. Test scenarios related to this process are documented in D7.3.



Success

Your transaction was validated:

```
Real price:0.77
Real volume:-3.69
Delivery rate:0.92
```

Gas (estimated) 0.001 **0.001 SepoliaETH**

Unknown processing time — Max fee: 0.001 SepoliaETH

Total 0.001 **0.001 SepoliaETH**

Figure 17 Validation process via EFLEX platform

The validation process in Figure 17 shows that the delivery rate (the rate at which flexible trading is realized) was around 92%. This number was obtained by dividing the potential energy that could be delivered by a volume of 8 kW for 30 minutes (-4 kWh) by the actual energy transfer (-3.69 kWh). Upon examination, After conducting an examination, it was determined that the ratio was calculated in this way due to the following factors:

- The actual discharge level of the battery was 7.83 kW on average, which caused an approximately 4% discrepancy in the calculation.
- There was a 3% difference between the value calculated by the FlexiGrid IoT platform and the value transmitted to the EFLEX platform for calculation and validation.

Within this test case, a cross-platform process that will be primarily used has been designed and information has been provided regarding platform roles. Additionally, a sample trading transaction has been conducted to verify the process. Demo cases related to the relevant P2P trading platform can be found in ***Section 2.2 Turkey demo site (OEDAS) of D7.3.***

- **Discussion**

This test case describes the necessary platforms, partners, and general process details for P2P trading on the EFLEX platform. The setup has been verified with real equipment and systems in a real environment, and the ability to trade flexibility at the agreed power/energy value between a potential FSP and DSO at a specified date and time has been confirmed. In Turkey, regulations and relatively technological infrastructure are not yet fully prepared for such a process. However, with an increase in such assets and the help of similar systems established between FSPs and DSOs, it will be possible to solve instant congestion problems on the grid. The widespread use of such systems and their large-scale implementation will provide a dynamic market structure for FSPs with flexible assets to earn profits while allowing DSOs to manage their loads and potentially defer investments in certain areas.

3.1.2.2 TC 8.9 Provision of flexibility by Battery storage system and V1G compatible DC EV charger

- **Description of the test case**

This test case mainly involves setting the charging/discharging profiles of a 32 kWh battery storage system and 50 kW DC charger installed in the demo site using the smart charging algorithm in the EV management platform, both based on spot market prices and transformer load. Although the battery storage system has a total capacity of 32 kWh, the maximum charging/discharging power can reach up to 10-11 kW when the predicted charging/discharging currents of the batteries are taken into account. The studies were conducted based on this limitation.

The battery storage system is essentially designed to support fast DC electric vehicle charging station during charging operations. Optimum charging/discharging profiles for the electric vehicle charging station and battery storage system will be determined based on grid constraints through smart charging algorithms. Studies have also been conducted within the scope of the test case to provide flexibility to the grid, independent of the charging session. Both price-based and grid constraint-based scenarios have been considered for batteries.

In order to perform manual control operations for the battery storage system, a Battery Management System (BMS) is available. This system enables the control of the batteries through the IEC 104 protocol. It is also used for emergency control and command purposes. The BMS is integrated with the EV management platform and the work to be carried out to provide flexibility to the grid within the scope of the test case will be carried out through the EV management platform. In addition, with the integration carried out between the EV management platform and the FlexiGrid IoT platform, smart charging processes and necessary settings can be controlled on the IoT platform, and the smart charging algorithm can be triggered.

- **Proposed scenarios for implementation and outcomes**

In the conducted works, initially, the DC charger and battery storage system were considered as separate assets, and demo works were performed accordingly. This method was preferred to demonstrate both the equipment-based profile determination method of the smart charging algorithm based on grid load and to reveal the flexibility potentials of the assets. Subsequently, scenarios were run by operating the DC electric vehicle charging station and battery storage system together. Finally, the optimization of charge/discharge profiles of the battery storage system based on both spot market prices was demonstrated. The basic scenarios demonstrated are listed below:

Equipment based optimizations based on grid load:

- **Flexibility delivery through battery storage system based on grid constraints.**

In this scenario, the flexibility provisioning was demonstrated by determining the optimal charging/discharging profiles of the battery storage system based on consumption threshold data determined by the DSO using the consumption data of the MV/LV transformer. As part of this info, optimization studies were conducted with a 32kWh battery storage system installed on the OEDAS grid. According to the basic scenario of the study conducted based on the transformer consumption data, DSO determines threshold levels for certain time intervals by monitoring the consumption data of the existing transformer. These threshold levels are entered into the system via the "EV Management Dashboard" interface created on the FlexiGrid IoT platform shown in Figure 18.

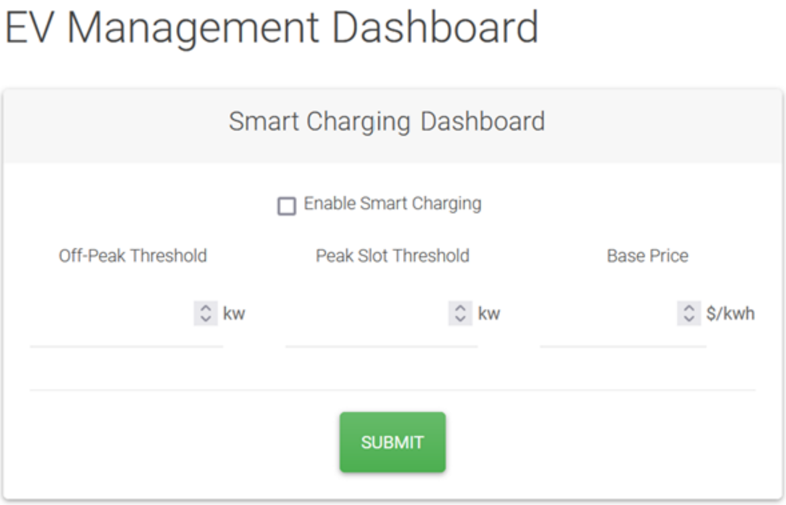


Figure 18 EV management dashboard of FlexiGrid IoT platform

The information is transmitted to the OEDAS EV management platform via the API provided by OEDAS. The smart charging algorithm in the backend of the EV management platform evaluates these threshold levels, the SoC data of the battery storage system, and the transformer consumption data to determine the charge/discharge profiles for the battery every 15 minutes based on the threshold levels. Due to limitations in the battery storage system, maximum limits of +-10 kW can be set for the charging and discharging processes.

In the scope of the study, threshold levels were updated at certain intervals according to the hourly consumption prediction data of the transformer. Afterwards, setpoints to be sent to the battery every 15 minutes were determined based on the 15-minute consumption data predictions of the transformer. Table 3 presents the thresholds and the corresponding setpoints calculated accordingly, along with the numerical data on the battery response and the final transformer load.

Table 3: Calculated setpoints for batteries during smart charging.

Time	Transformer Load Value (kW)	Threshold	Battery Setpoints	Battery Charging/Discharging Power(Avrg - kW)	Final Transformer Value (kW)
07:15-07:30	110.38	120	9.60	9.19	119.57
07:30-07:45	119.67		0.00	0.19	119.86
07:45-08:00	122.34		-2.30	-1.90	120.44
08:00-08:15	143.9	152	8.10	6.54	150.44
08:15-08:30	149.05		2.90	3.33	152.38
08:30-08:45	149.69		2.30	2.09	151.78
08:45-09:00	167.31		-10.00	-9.98	157.33
09:00-09:15	185.59	165	-10.00	-9.96	175.63
09:15-09:30	151.76		10.00	9.30	161.06
09:30-09:45	164.86		0.00	0.17	165.03
09:45-10:00	159.72		5.30	4.84	164.56
10:00-10:15	169.55		-4.50	-4.93	164.62
10:15-10:30	156.17		10.00	9.99	166.16
10:30-10:45	163.03		2.00	2.08	165.11
10:45-11:00	171.31		-6.00	-5.95	165.36
11:00-11:15	182.17	170	-10.00	-9.98	172.19
11:15-11:30	161.27		8.50	8.38	169.65
11:30-11:45	167.59		2.50	2.07	169.66
11:45-12:00	167.45		2.60	3.02	170.47
12:00-12:15	184.03	165	-10.00	-10.02	174.01
12:15-12:30	148.99		10.00	9.31	158.30
12:30-12:45	167.07		-2.00	-2.30	164.77
12:45-13:00	155.21		10.00	9.27	164.48
13:00-13:15	195.31	175	-10.00	-9.98	185.33
13:15-13:30	164.26		10.00	9.34	173.60
13:30-13:45	177.52		-2.30	-2.02	175.50
13:45-14:00	160.53		10.00	9.27	169.80
14:00-14:15	190.03	162	-10.00	-10.04	179.99
14:15-14:30	151.9		10.00	9.35	161.25

As seen, setpoints are generally calculated to keep the total transformer consumption below the determined threshold. In most cases, the final transformer consumption is below the threshold level. There are also time intervals when the threshold is exceeded, but this is because the maximum limit of the battery storage system (10 kW) is not enough to reduce the total consumption. It can be seen that the full discharge command (-10 kW) is set as the setpoint during these time intervals.

The setpoints were calculated for the batteries for 15 minutes, but it is possible to see the power value instantly/hourly from the system. The power values given in Table 3 are the average power values for 15 minutes. As can be seen, the battery's response to some setpoints (battery charging/discharging power) is very close to the setpoint itself, while in some cases, there are differences. This has been observed, especially when the command is fractional (2.6 kW - 8.1 kW, etc.). There is no clear idea about the reason for this issue. Along with the load-based battery charging/discharging optimization process, the visual representation of the base and final load of the transformer with the thresholds can be seen in Figure 19, and the charging/discharging powers that monitored via FlexiGrid IoT platform can be seen in Figure 20.

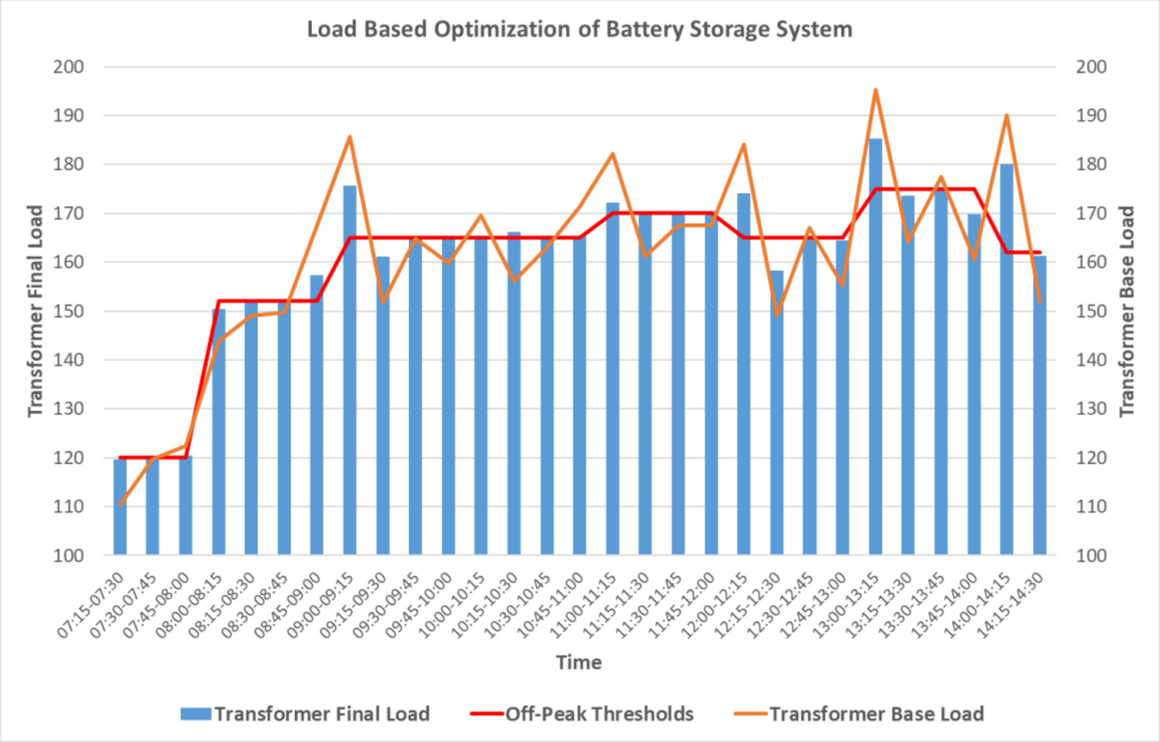


Figure 19 Load based optimization of battery storage system

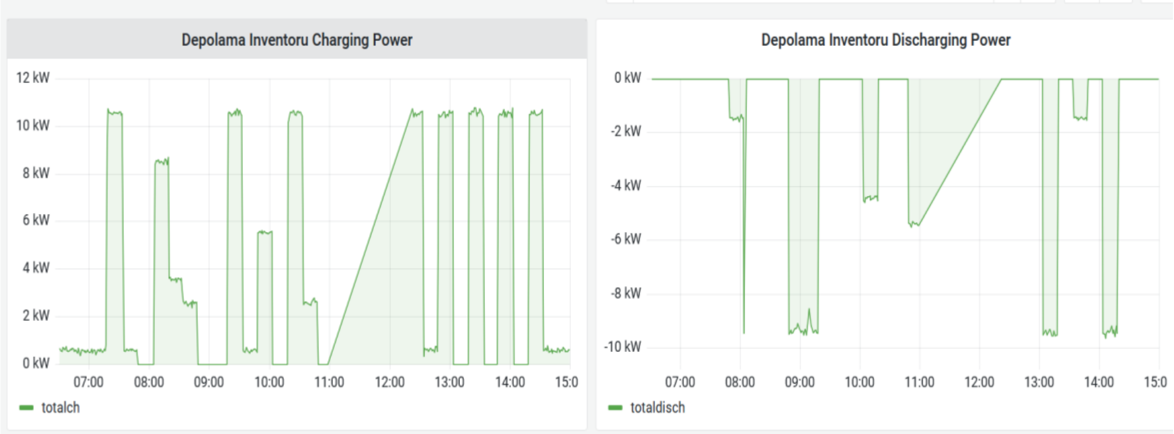


Figure 20 Charging/discharging powers of battery storage system in FlexiGrid IoT platform

During the process, there have been dynamic changes in the State of Charge value of the battery as a result of the charging/discharging operations performed on the battery. In this context, the SoC change for the battery storage system can be seen as shown in Figure 21.

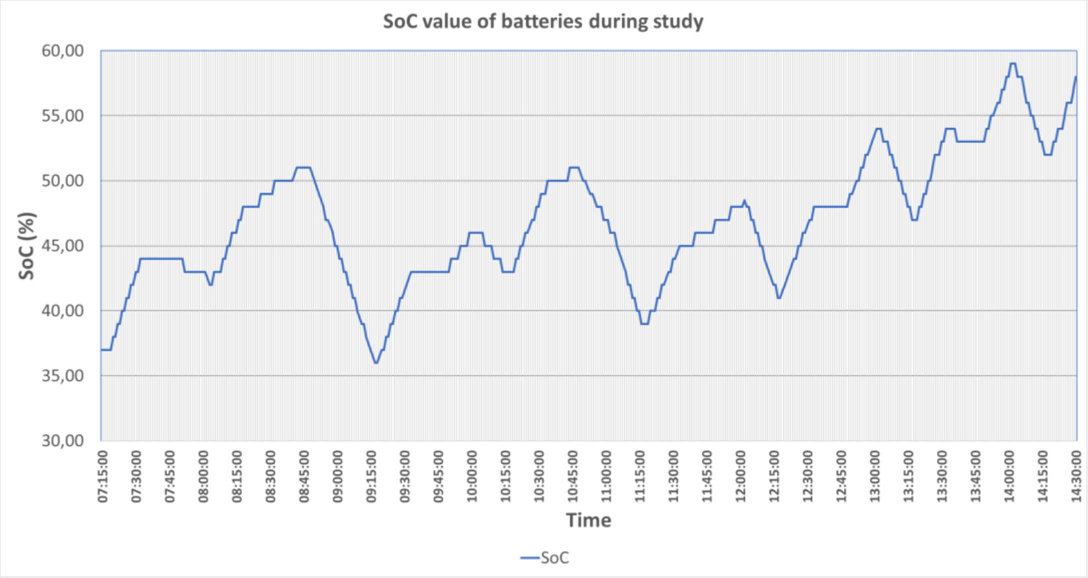


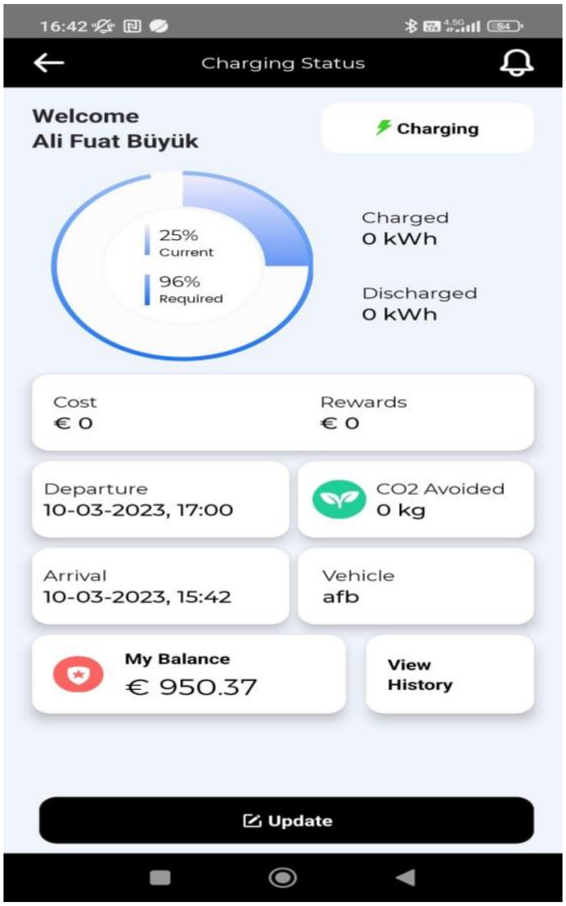
Figure 21 SoC value of battery storage system during study

❖ **Flexibility provided through a DC electric vehicle charging station based on grid constraints.**

In this scenario, the electric vehicle charging station considered is a 50 kW high-speed DC charging station. Unlike V2G, this station only allows one-way charging, and an example optimization is performed with a possible user and DSO within the scenario.

Due to the fact that a one-way DC charging station does not allow energy transfer to the grid, flexibility potential can only be achieved by shifting the load or reducing consumption at certain times. In this context, an optimization example was carried out with a one-way 50 kW high-speed DC charging station, where a potential user and DSO were included in the scenario. The main objective was to determine the charging profile based on the threshold value set by the distribution company at any given time of day, in such a way that the transformer consumption threshold established by the distribution company would not be exceeded during electric vehicle charging, whether during peak or non-peak hours. To achieve this, instead of the maximum power option, the potential user was asked to extend the charging process for a certain period of time according to their own limits and to charge at a lower power level than the maximum power level. Incentive schemes or persuasive methods such as discounts may be required to convince the user to cooperate in this process. In the scope of this study, the incentivization process could not be demonstrated in a real sense due to both the absence of an actual-real EV user and the regulatory barriers. However, the EV management platform and mobile application used in the studies are also able to provide the opportunity for incentivizing a potential user financially.

According to the scenario, the user arrives at the charging station and connects their vehicle to the charging station via the mobile application. After the authorization process, the charging station reports the relevant information to the charging station management platform via OCPP and the process of managing the charging operation by the charging operator and/or distribution company begins. At this stage, the user is asked to specify their charging request, the maximum time they can spend at the station, and the desired state of charge (SoC) they want to get at the end of the charging process. (As the station is a fast charging station, it is not very reasonable to exceed 1-1.5 hours of charging time.) In this context, a visual representation of the requests determined by the potential user through the mobile application is shown in Figure 22 for the sample demo study. As can be seen in the Figure 22, the user arrived at the station with a 25% charge, decided to spend 1 hour at the station, and requested to leave with a 96% charge level. This information is evaluated by the distribution company on the FlexiGrid IoT platform and the EV Management Platform Dashboard, and the consumption threshold level is determined. According to this, the consumption threshold level during the hours of operation was determined as 145 kW by the DSO, based on the local transformer load, the flexibility potential of the asset (DC charger), and the user's requests reported through the mobile application. This input can be entered into the FlexiGrid IoT platform and the information can be transmitted to the EV Management platform. The relevant interface of the IoT platform can be seen in Figure 23.



Welcome
Ali Fuat Büyük

25%
Current

96%
Required

Charged
0 kWh

Discharged
0 kWh

Cost
€ 0

Rewards
€ 0

Departure
10-03-2023, 17:00

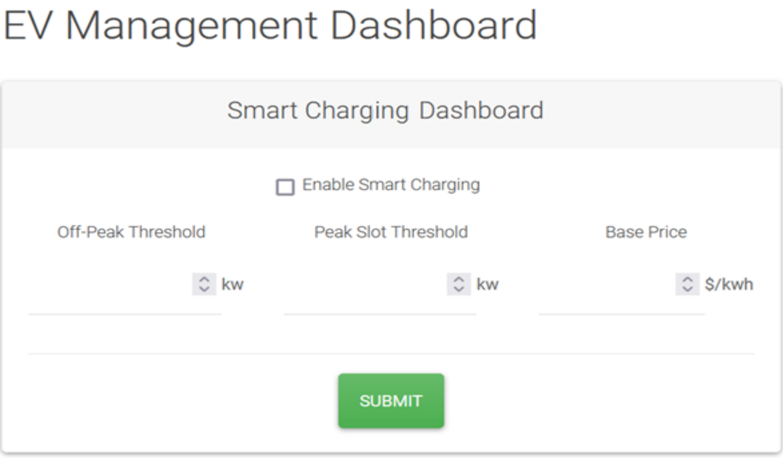
CO2 Avoided
0 kg

Arrival
10-03-2023, 15:42

Vehicle
afb

My Balance
€ 950.37

Figure 22 User inputs via mobile application



EV Management Dashboard

Smart Charging Dashboard

☐ Enable Smart Charging

Off-Peak Threshold kw

Peak Slot Threshold kw

Base Price $/kwh

SUBMIT

Figure 23 EV management dashboard of FlexiGrid platform

Based on this information, the charging process is initiated and managed with charging profiles determined at 15-minute intervals. The charging profiles, which are determined based on the threshold set by DSO and user requirements, are presented in visual Figure 24 and Table 4. When the power consumption for charging is combined with the transformer load, it can be seen that the total consumption does not exceed the set threshold.

64 15:45 - 15:59
1.65 ₺
95.56 kW
7.20 kW
0.13 kW
afb
veefil-130428-2
Charging 46.0 kW
SOC: 25.00% DSOC: 58.00%

65 16:00 - 16:14
2.447 ₺
133.08 kW
4.24 kW
0.03 kW
afb
veefil-130428-2
Charging 11.9 kW
SOC: 58.00% DSOC: 67.85%

66 16:15 - 16:29
2.447 ₺
129.91 kW
0.30 kW
0.15 kW
afb
veefil-130428-2
Charging 15.2 kW
SOC: 67.85% DSOC: 80.22%

67 16:30 - 16:44
2.447 ₺
124.55 kW
7.94 kW
0.08 kW
afb
veefil-130428-2
Charging 20.5 kW
DSOC: 96.99%

Figure 24 Calculated charging profiles by smart charging algorithm

Table 4: Calculated smart charging values for DC charger

Time	Transformer Base Load Value (kW)	Transformer Load Threshold (kW)	DC Charger Setpoints	Final Transformer Load Value (kW)
15:45-16:00	95.56	145	46.00	141.56
16:00-16:15	133.08	145	11.90	144.98
16:15-16:30	129.91	145	15.20	145.11
16:30-16:45	124.55	145	20.50	145.05

In order to show the flexibility potential of the charging process provided to the DSO, the same vehicle (Mini Cooper SE) was charged without smart charging, with the same initial charge and user requirements (desired SoC, departure time etc.). As can be seen in Figure 25, and Figure 26, when smart charging is not used (standard charging process), the vehicle is charged at levels close to maximum power (>40-45 kW), especially between 25% and 80% SoC levels of the charge curve. As a result of this charging process, it is observed that the same vehicle reaches 96% charge level from 25% charge level in about 37 minutes. The flexibility potential of the study conducted by taking into account the base load of the transformer is shown in Figure 27.

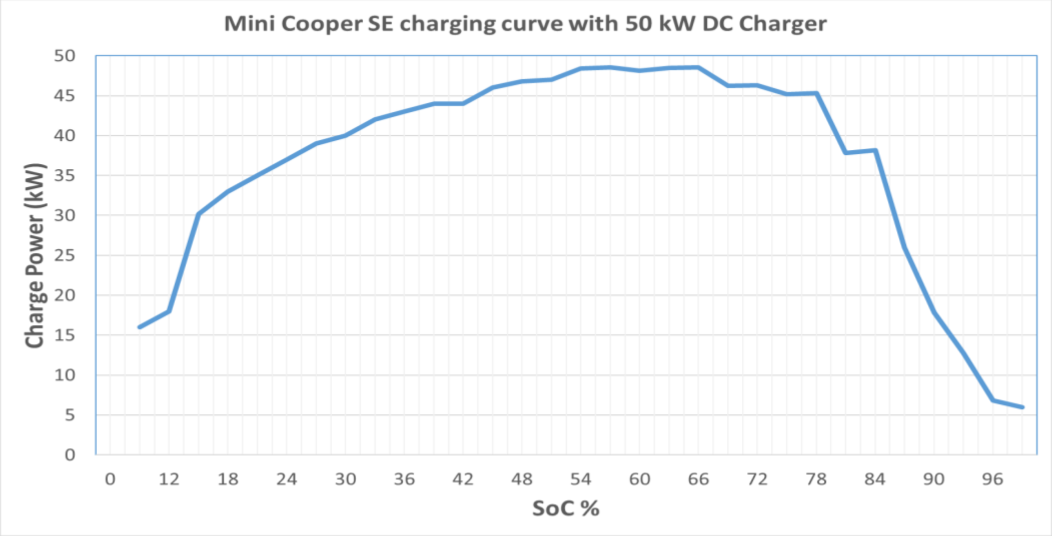


Figure 25 Standard charging power curve of Mini Cooper SE e-vehicle with 50 kW charger

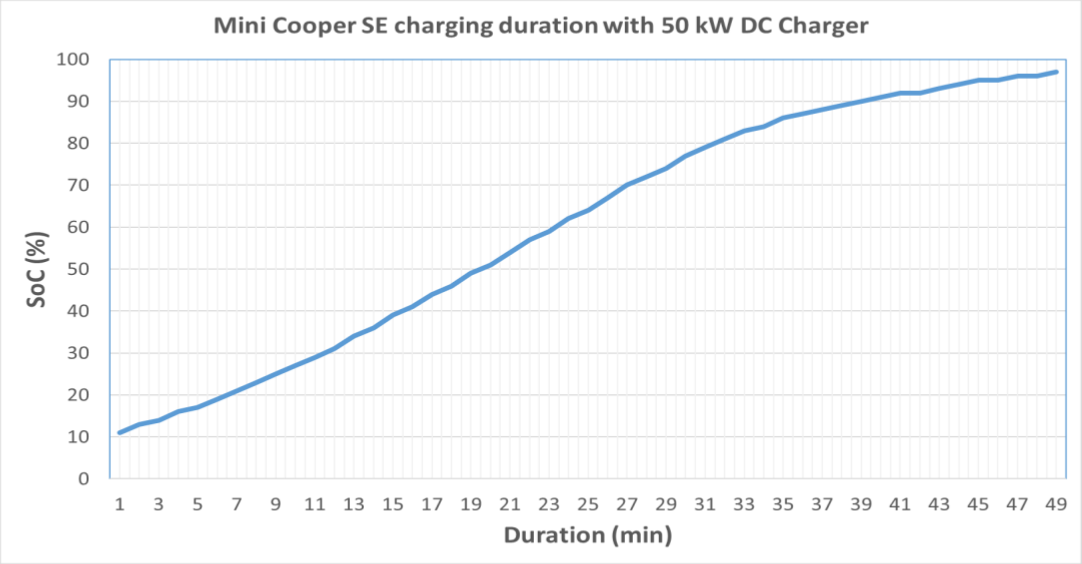


Figure 26 Standard charging duration curve of Mini Cooper SE e-vehicle with 50 kW charger

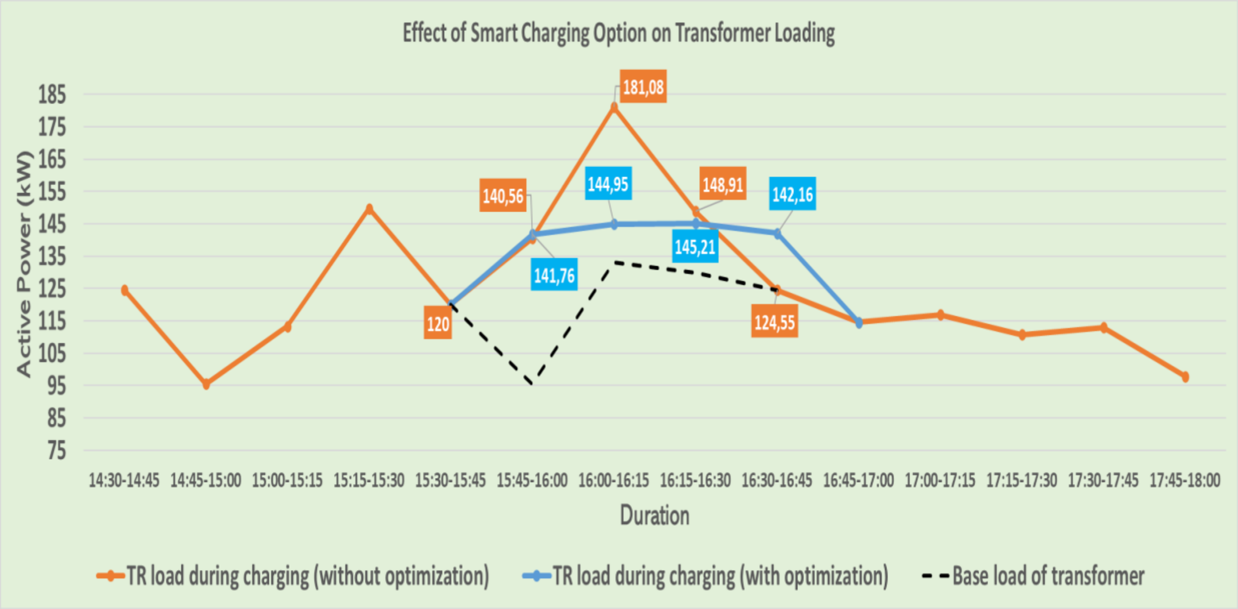


Figure 27 Flexibility potential of smart charging option (with DC charger) on transformer loading

As can be seen from Figure 27, the peak consumption that occurred in the transformer especially during the unoptimized charging process has been reduced below the threshold level determined by the DSO with the optimized option. The difference between the peak consumption of 181 kW and the value of 144.95 kW achieved during optimization can be referred to as flexibility in the simplest terms. The non-optimized charging process took approximately 37 minutes in total. In the smart charging process, the user has extended the charging time by up to 23 minutes compared to the standard charging process in coordination with the DSO, and can receive an incentive in return. As a result, the DSO has prevented the occurrence of peaks during the day.

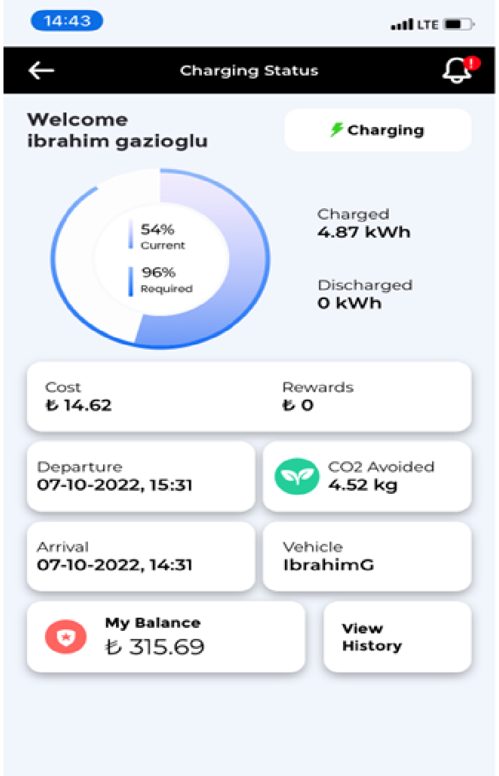
The average power data during the smart and standard charging processes can be seen in Table 4, which is presented in 15-minute intervals. Particularly in the last 15 minutes of the smart charging process, it can be observed that the charging process was not carried out at the exact specified charging power. Here, a charging command of 20.5 kW was sent, but the actual charging power started at 20.5 kW and decreased to around 14 kW, resulting in an average of 17 kW. The main reason for this is that the vehicle's own battery management system (BMS) limits the charging current for a healthy charging process, especially after the battery state of charge (SoC) reaches 80%. Table 5 is showing the values

Table 5: Calculated-Actual Charging powers during smart charging and standard charging

Time	Smart Charging		Standart Charging	
	Smart Charging Command (kW)	Actual Power (Average -kW)	Charging Command (kW)	Actual Power (Average -kW)
15:45-16:00	46	46.2	-	45.2
16:00-16:15	11.9	11.87	-	48.1
16:15-16:30	15.2	15.3	-	20.9
16:30-16:45	20.5	17.61	-	-

- **Flexibility provisioning through the scenario where battery storage system and DC electric vehicle charging station are used together.**

In this scenario, a demo study was conducted to use the existing battery storage system in the demo area as a flexibility asset during the EV charging process. Essentially, the steps followed in the previous scenario were also taken into account here. With the setting of the transformer load thresholds by DSO and requested charging time inputs based on user charging demands, charging/discharging profiles for both the electric vehicle charging station and battery were calculated by smart charging algorithm. As part of the scenario, the visual representation of the mobile application showing user preferences can be seen in Figure 28.



Welcome
ibrahim gazioglu

54% Current
96% Required

Charged
4.87 kWh

Discharged
0 kWh

Cost
₺ 14.62

Rewards
₺ 0

Departure
07-10-2022, 15:31

CO2 Avoided
4.52 kg

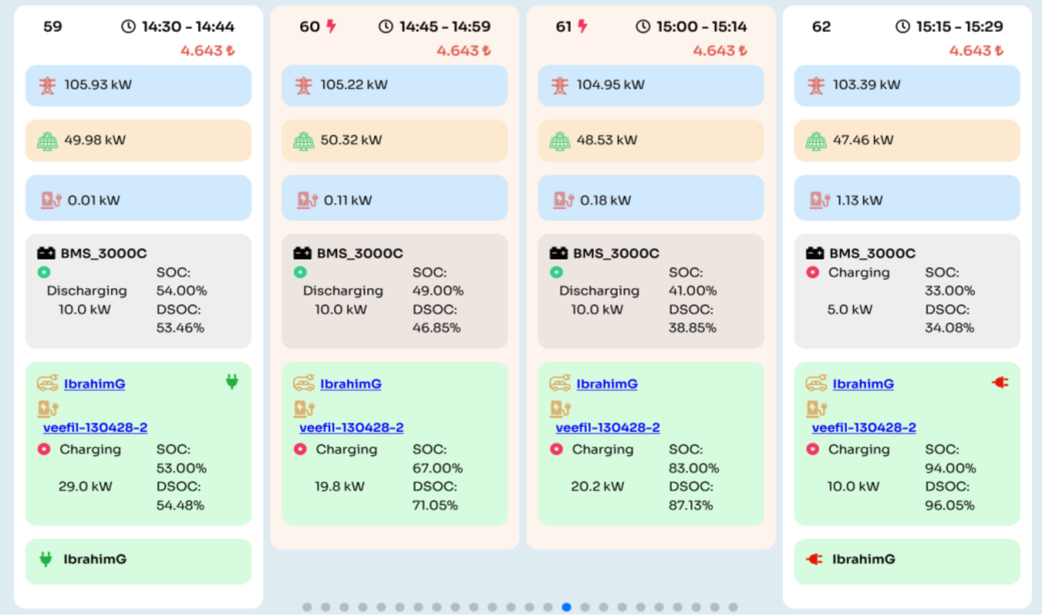
Arrival
07-10-2022, 14:31

Vehicle
IbrahimG

My Balance
₺ 315.69

Figure 28 Mobile application that shows the user charging preferences

According to the user's request, the charging process will start at 14:31 TR time and end at 15:31. The user arrived at the station with a charge level of 54% and requested to leave with a charge level of 96%. Here, the DSO has determined both peak and off-peak thresholds for the relevant one hour by evaluating the load of the existing transformer. The DSO has set the half-hour between 14:45 and 15:15 as the peak threshold (shown in red blocks in Figure 29) and requested that the power consumption of the transformer not exceed 115 kW during this time. The remaining two 15-minute slots have been designated as off-peak slots, and the DSO has set the threshold to 125 kW through the FlexiGrid IoT platform. As a result, smart charging profiles have been determined for the DC charging station and battery storage system every 15 minutes based on these thresholds, as shown in Figure 29 and Table 6.



59 14:30 - 14:44
4.643 ₺
105.93 kW
49.98 kW
0.01 kW
BMS_3000C
Discharging 10.0 kW
SOC: 54.00%
DSOC: 53.46%
IbrahimG
veefil-130428-2
Charging 29.0 kW
SOC: 53.00%
DSOC: 54.48%
IbrahimG

60 14:45 - 14:59
4.643 ₺
105.22 kW
50.32 kW
0.11 kW
BMS_3000C
Discharging 10.0 kW
SOC: 49.00%
DSOC: 46.85%
IbrahimG
veefil-130428-2
Charging 19.8 kW
SOC: 67.00%
DSOC: 71.05%

61 15:00 - 15:14
4.643 ₺
104.95 kW
48.53 kW
0.18 kW
BMS_3000C
Discharging 10.0 kW
SOC: 41.00%
DSOC: 38.85%
IbrahimG
veefil-130428-2
Charging 20.2 kW
SOC: 83.00%
DSOC: 87.13%

62 15:15 - 15:29
4.643 ₺
103.39 kW
47.46 kW
1.13 kW
BMS_3000C
Charging 5.0 kW
SOC: 33.00%
DSOC: 34.08%
IbrahimG
veefil-130428-2
Charging 10.0 kW
SOC: 94.00%
DSOC: 96.05%
IbrahimG

Figure 29 Calculated smart charging profiles for DC charger and battery storage system

Table 6: Calculated smart charging values for DC charger and battery storage system

Time	Transformer Base Load Value (kW)	Transformer Load Threshold (kW)	DC Charger Setpoints	Battery Storage System Setpoints	Final Transformer Load Value (kW)
14:30-14:45	105.94	125	29.00	-10.00	124.94
14:45-15:00	105.22	115	19.80	-10.00	115.02
15:00-15:15	104.95	115	20.20	-10.00	115.15
15:15-15:30	103.39	125	10.00	5.00	118.39

As can be seen from Figure 29 and Table 6, the smart charging algorithm has adopted the thresholds specified by the DSO as threshold values for the relevant slots (peak or off-peak), and has distributed the available power as a charging/discharge profile to the DC electric vehicle charging station and battery storage system in a way that will provide the electric vehicle user with the final SoC and total charging time requested. For example, if we look at Slot 1, a threshold value of 125 kW has been determined, and it can be seen that the total consumption value remains below 125 kW when the transformer consumption value (105.93 kW), DC EV charging power (29 kW), and battery storage discharge value (-10 kW) are added up. If we perform the same calculation for the 15-minute slots of peak slots 2 and 3, it can be seen that the total consumption value does not exceed the threshold value of 115 kW.

To demonstrate the flexibility potential in the results, the same charging process was repeated without smart charging optimization using the same criteria and input values as the current electric vehicle. In the optimized charging process, the user's intended charging duration of 1 hour was accomplished, whereas in the non-optimized standard case, the charging process took roughly 23 minutes. The graphical depiction of the total transformer consumption curve for both the smart charging-enabled and disabled scenarios is presented in Figure 30.

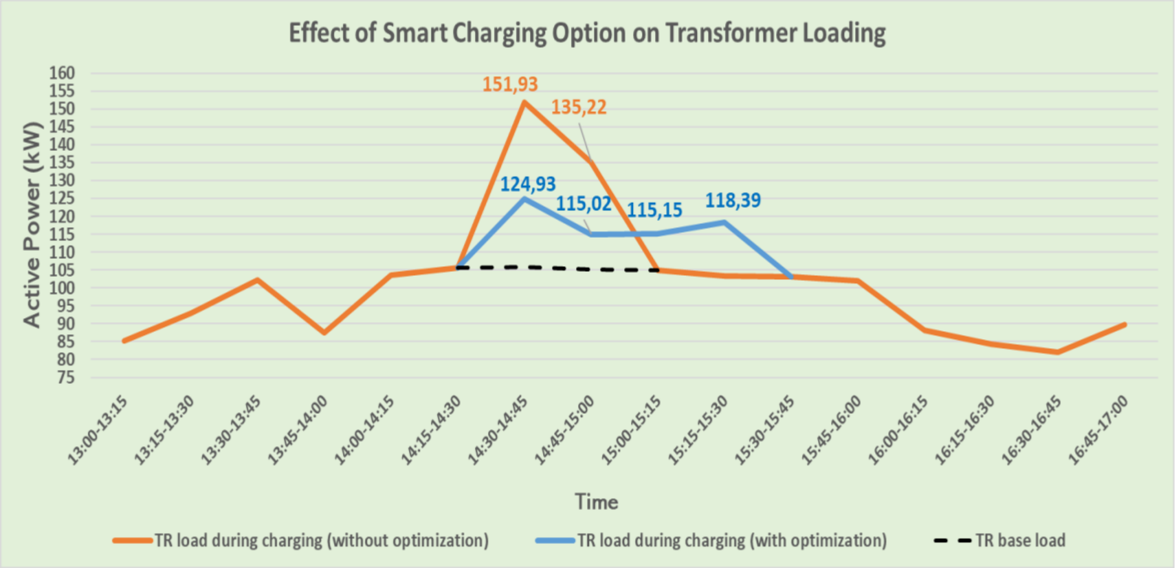


Figure 30 Flexibility potential of smart charging option (with DC charger and battery) on transformer loading

As can be seen from Figure 30, the charging time has been extended in coordination with the user through the smart charging function, but the peak value that will occur in the distribution transformer has been limited by the threshold value determined by the DSO. Simply put, the difference between the peak value (151.93 kW) that occurred in the uncoordinated case and the peak value (124.93 kW) that occurred with smart charging can be evaluated as the flexibility provided to the grid.

Equipment-based optimizations based on electricity market prices:

Integrating the electric vehicle charging station management platform with the current spot market prices has made it possible to determine the charge-discharge profiles of the battery storage system based on hourly market prices. The basic scenario here is to set a threshold value for the market price on the system side and to determine the battery profile through the charge-discharge algorithm according to this threshold value. According to the working principle of the algorithm, if the instantaneous market price is below the price value set as the basis, the battery will automatically charge itself at half power. Conversely, if the instantaneous market price is above the base price, the battery will discharge itself at full power. This scenario has been decided to be applied with hourly changing market prices. The same scenario can also be applied based on the DSO's time-of-use rates, providing optimization. The following section provides details about the optimization process based on spot market prices.

- **Optimizing charge/discharge of battery storage system based on spot market prices**

The spot market prices are published hourly on the EXIST (Energy Exchange Istanbul) transparency platform through regulations set by the Turkish national energy markets regulatory authority. Here, day ahead and intraday prices are presented on an hourly basis for the relevant day ahead or intra-day, and participants use these prices as a basis for their buying and selling transactions. In this section, the day ahead market clearing price (PTF in Turkish) presented hourly has been used as a basis for the optimization process. As an example, the market clearing price progression for the day on which the optimization demo was conducted can be seen in Figure 31.

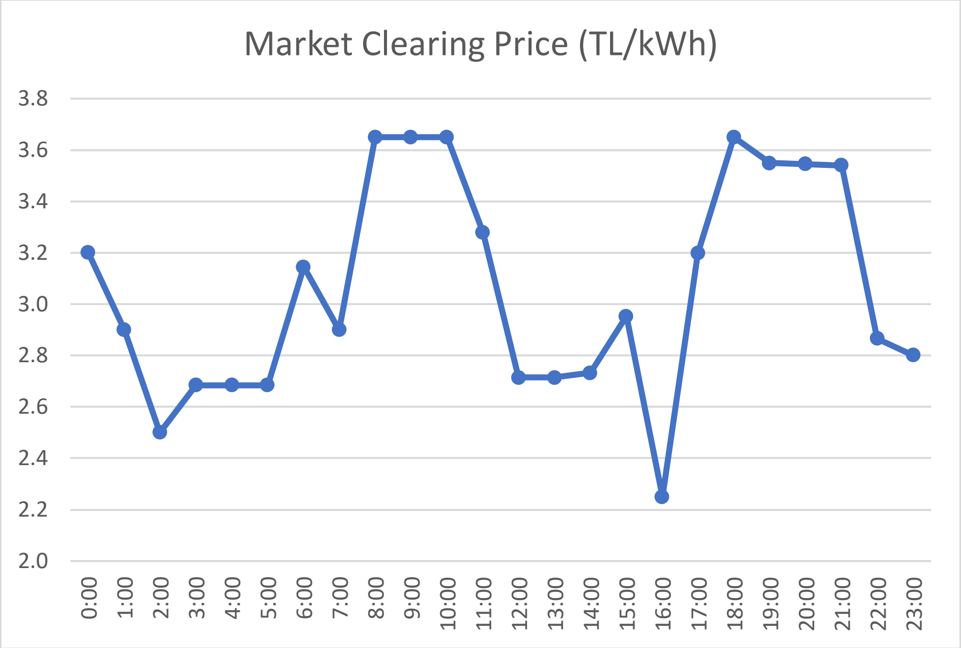


Figure 31 Published market clearing prices at 23rd of February

To enable the optimization process, the necessary settings are entered through the FlexiGrid IoT platform, and the market price (day-ahead or intraday) and the base price to be used are determined by the user of the IoT platform. The interfaces related to this process and the settings section of the IoT platform can be seen in Figures 32 and Figure 33.

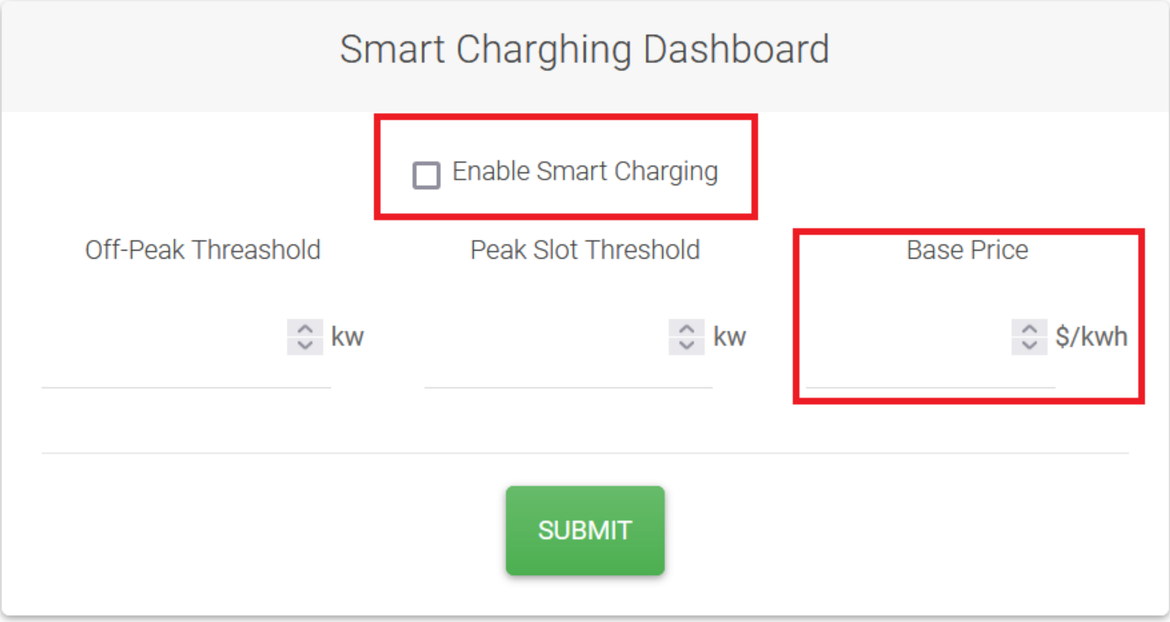
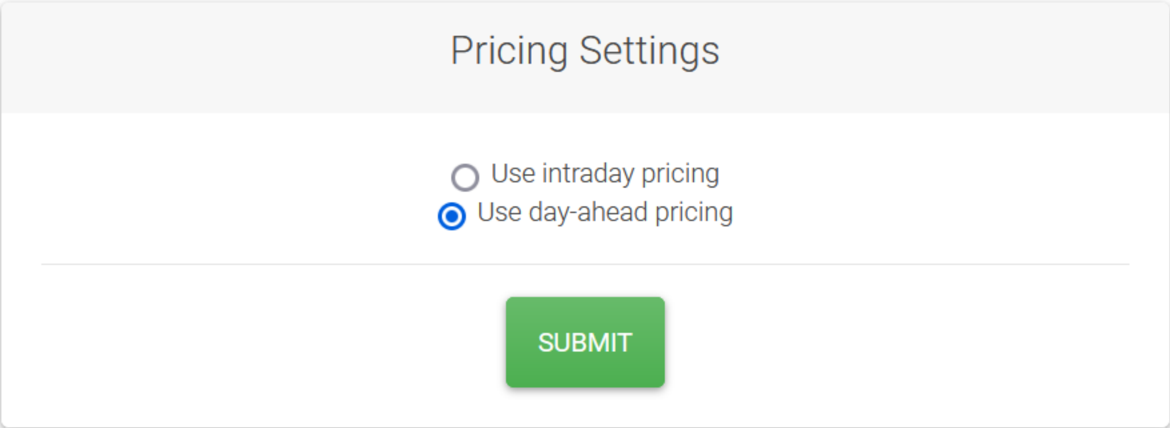


Figure 32 Smart charging and base price setting dashboard of IoT platform



Pricing Settings

○ Use intraday pricing
● Use day-ahead pricing

Figure 33 Pricing settings dashboard of IoT platform

These inputs trigger the smart charging algorithm in the background of the EV management platform through the prepared API, and the algorithm determines the charge-discharge profiles based on the base price. When evaluating the market clearing prices of the relevant day, it can be seen that the arithmetic average is at the level of 3 TL/kWh. Therefore, a base price of 3 TL/kWh has been accepted in the optimization process. The table containing the power values obtained by running the demo and the graphs showing the results can be accessed in Table 7, Figure 34, and Figure 35.

Table 7: Powers-SoC-Market Price values during optimization

Date&Time	Charging&Discharging Power (kW)	SoC (%)	Market Price (TL/kWh)
2023-02-23 10:30:00	-5.59	71.14	3.65
2023-02-23 11:00:00	-9.92	56.11	3.28
2023-02-23 12:00:00	4.91	27.00	2.71
2023-02-23 13:00:00	4.94	41.50	2.71
2023-02-23 14:00:00	4.94	56.20	2.73
2023-02-23 15:00:00	4.94	71.00	2.95
2023-02-23 16:00:00	4.94	85.50	2.25
2023-02-23 17:00:00	-9.96	97.10	3.20
2023-02-23 18:00:00	-9.84	67.62	3.65
2023-02-23 19:00:00	-9.93	36.50	3.55
2023-02-23 20:00:00	-0.01	22.00	3.55
2023-02-23 21:00:00	0.01	22.00	3.54
2023-02-23 22:00:00	6.33	23.00	2.87
2023-02-23 23:00:00	4.93	47.33	2.80
2023-02-24 00:00:00	4.95	61.52	2.80

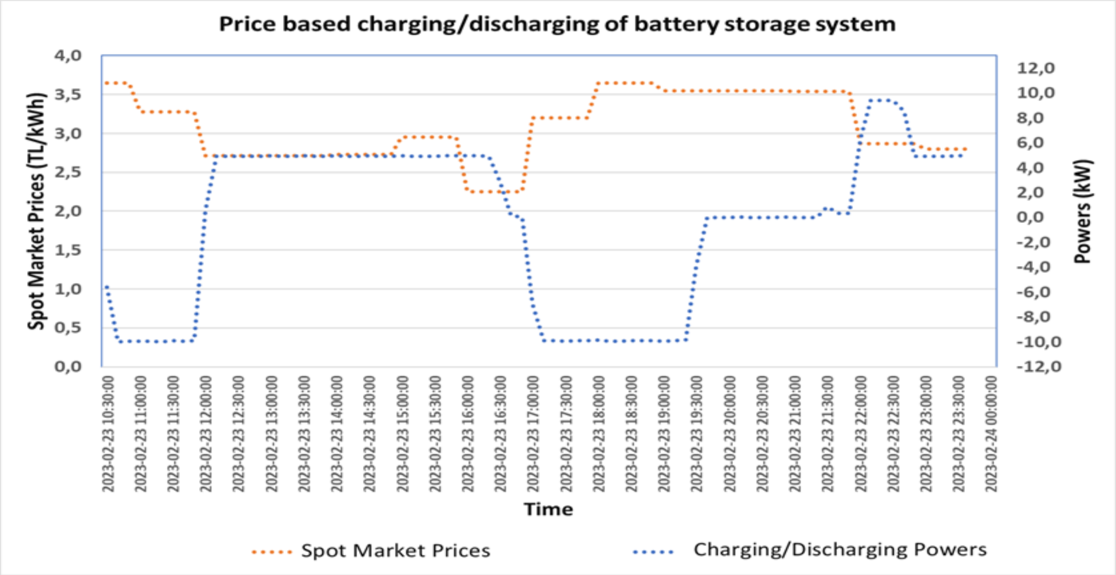


Figure 34 Spot market price – power relation during the charging/discharging of battery

As can be seen from Figure 34, when the market price is below the base price (3 TL/kWh), the battery charges itself, and when it exceeds the base price, it switches to discharge mode and provides power to grid at full capacity (10 kW in this case). The resulting SoC-Power curve during this process is also presented in Figure 35. The optimization process started at 10:30 am and the initial SoC was at around 70%. As expected, the SoC value increased during the charging process and decreased during the discharging process. The optimization was completed at 00:00 am at the end of the day, and the final SoC value was measured as 63%. When evaluated from the perspective of FSP, such optimization allows for the procurement of energy when market prices are low and the sale of energy when prices are high, thus enabling daily profits. When evaluated from the perspective of DSO, dynamic pricing can be used to balance the load by setting energy prices higher during peak hours and lower during off-peak hours.

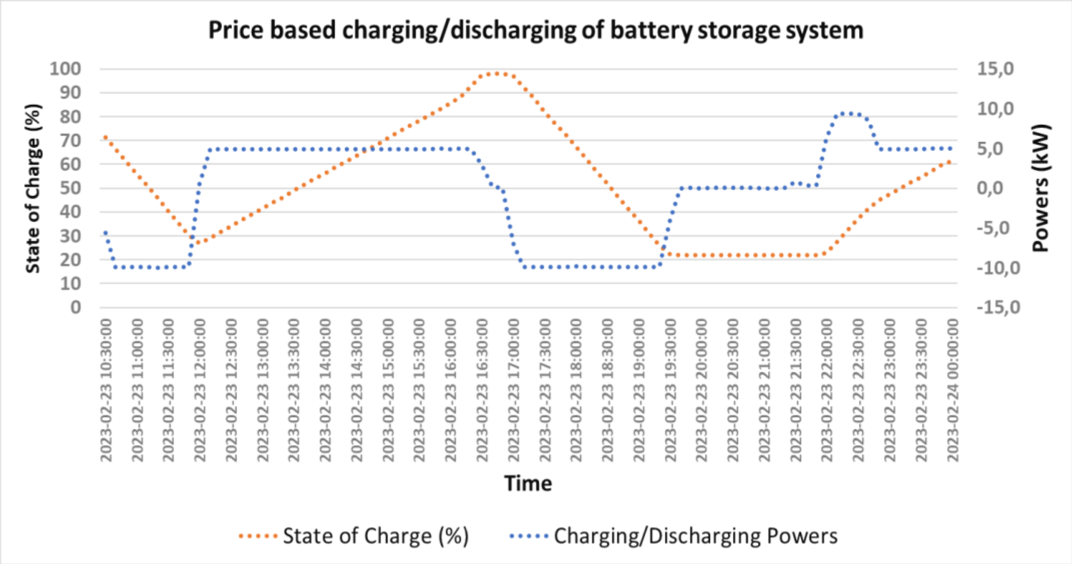


Figure 35 Battery state of charge – power relation during the charging/discharging of battery

Upon validation of the charging and discharging operations performed during the 12-hour period, it was observed that the total volume of kWh traded on the EFLEX platform was 78.16 kWh. Based on the transactions carried out, the FSP has generated profit in this simple process.

- **Discussion**

Mentioned scenarios were demonstrated on various days and times, taking into account both grid status and market prices, using the FlexiGrid IoT platform and the OEDAS EV management platform to provide flexibility separately and together with the battery storage system and DC high-speed electric vehicle charging station. The key findings of the study were as follows:

- The practicality of the flexibility trading to provide grid flexibility has been proven through examples of such trading processes between FSP and DSO in real-life systems and environments.
- It is believed that, with the removal of regulatory barriers, the introduction of supportive regulations, and with the establishment of supportive coordination between FSP and DSO, dynamic flexibility trading processes can become more widespread.
- It has been recognized that the participation of the demand-side is important in managing the grid load in the DSO network, and the huge potential in this area needs to be managed with smart systems and devices.
- It has been concluded that the establishment of necessary technological infrastructure requirements is critical for carrying out such a process.

3.1.2.3 TC 8.10 Provision of flexibility by EV-V2G management platform

During the scenarios carried out with V2G-enabled electric vehicles, demonstrations were conducted for both threshold-based charging/discharging profiles determined by the DSO and price-based charging/discharging profiles determined by setting a base price. In this context, charge requests were received via a mobile application from any electric vehicle user (real users could not be worked with due to regulatory restrictions), and with the help of the smart charging algorithm, charge/discharge setpoints were determined based on the DSO threshold data, DR signal sent by the DSO, or market & base price.

- **TC 8.10 Provision of flexibility by V2G compatible vehicle**
  - **Description of the test case**

In the context of D8.1, a test case was defined with minor modifications made to the contents of the applied scenarios while keeping the fundamental scenario unchanged. Scenario 1 aimed to determine the charging power that the user would receive during the charging session based on the transformer consumption threshold set by the DSO or triggered by an extra DR signal. In the second scenario, a price tariff related to the load was determined by the DSO, in addition to the spot market price, and flexibility was provided through price-based optimization with a base price set by the DSO. Proposed scenarios for implementation and outcomes

Scenario 1 – Load balancing with V2G charger according to the load threshold set by DSO :

In this scenario, the process will be approached from the perspectives of a potential electric vehicle user and the DSO. As a result, charging/discharging profiles for load balancing purposes will be determined for the V2G charging station.

For this test case, the electric vehicle (Nissan Leaf e+, can be seen in Figure 36) that is currently being used is compatible with V2G and has a battery capacity of around 62 kWh. The charging station used can charge and discharge with a maximum power of 10 kW. When the vehicle battery is charged from 20% to 90%, it is expected to take approximately 4.5 hours in total. Since the station provides slow power compared to a DC fast charging station, the scenario simulates the electric vehicle user leaving the car at the charging station for longer periods of time. (In real cases, this can be thought of as leaving the car connected to the charging station at office, train stations or airports, or at home until the user returns to the vehicle.)

Figure 36 A view of the V2G compatible vehicle during charging process

Within this scope, a potential user connects his vehicle to the charging station. The user's charging requests within the scenario can be seen as shown in Figure 37.

Welcome
ibrahim gazioglu

49% Current
75% Required

Charged: 0 kWh
Discharged: 0 kWh

Cost: ₺ 0
Revenue: ₺ 0
Rewards: ₺ 0

Departure: 21-03-2023, 17:00
CO2 Avoided: 0 kg
Arrival: 21-03-2023, 11:45
Vehicle: nleafIG
My Balance: ₺ 3394.2

Figure 37 V2G compatible vehicle - user charging preferences

As can be seen from Figure 37, the user has connected their vehicle to the station with a state of charge (SoC) level of 49%. The user has committed to spending 5 hours and 15 minutes at the station and has specified their desired SoC level upon return as 75%. Meanwhile, the Distribution System Operator (DSO) has determined the transformer consumption threshold levels for different hours during the charging period based on the current transformer load status (with 15-minute estimations) using the FlexiGrid IoT platform.

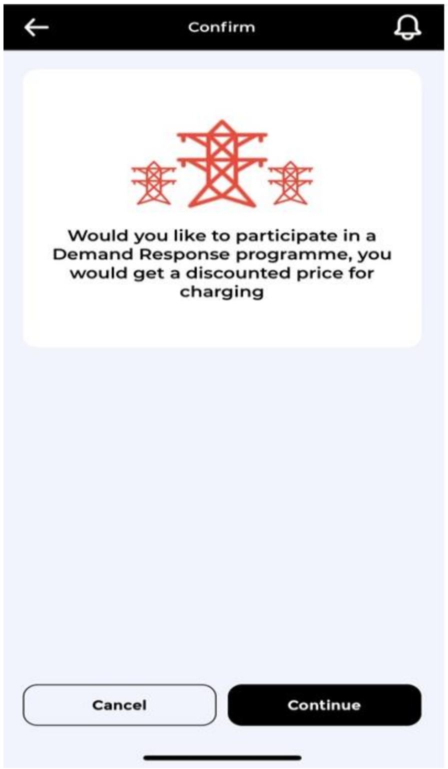
The information is transmitted to OEDAS' EV management platform through the API provided by OEDAS. The smart charging algorithm in the backend of the EV management platform evaluates these threshold levels, the SoC data of the V2G vehicle, and the current transformer consumption data to determine the charging/discharging profiles for the vehicle battery every 15 minutes. Based on these thresholds, the setpoints determined for the V2G charger and actual charging powers with SoC values can be seen in Table 8.

Table 8: Calculated setpoints for V2G charger during smart charging.

Slots	Time	Transformer Load Value (kW)	Load Threshold	V2G Charger Setpoints	V2G Vehicle SoC (%)	V2G Charging Discharging Power (Avrg - kW)	Final Transformer Value (kW)
Charging	11:45-12:00	165.49	175	9.50	50-55	9.60	175.09
Pause	12:00-12:15	174.39	175	0.00	55	0.00	174.39
Charging	12:15-12:30	161.55	175	10.00	55-59	9.90	171.45
Pause	12:30-12:45	178.76	175	0.00	59	0.00	178.76
Charging	12:45-13:00	165.36	175	10.00	59-64	9.90	175.36
Pause	13:00-13:15	174.41	175	0.00	64.00	0.00	174.41
Charging	13:15-13:30	168.14	175	6.50	64-67	6.70	174.84
Pause	13:30-13:45	180.83	175	0.00	67	0.00	180.83
Charging	13:45-14:00	168.41	175	6.50	67-71	6.80	175.21
Charging	14:00-14:15	166.91	175	8.00	71-75	8.00	174.91
DR	14:15-14:30	160.4	175	0.00	75	0.00	160.40
Discharging	14:30-14:45	178.76	150	-10.00	75-70	-9.92	188.68
Discharging	14:45-15:00	160.83	150	-10.00	70-65	-10.05	150.83
Discharging	15:00-15:15	154.4	150	-4.45	65-63	4.37	149.95
Discharging	15:15-15:30	155.03	150	-5.10	63-60	-5.10	149.93
Discharging	15:30-15:45	158.45	150	-8.50	60-57	-6.71	151.74
Pause	15:45-16:00	151.21	150	0.00	57.00	0.00	151.21
Charging	16:00-16:15	140.56	150	9.60	57-62	9.55	150.16
Charging	16:15-16:30	142.11	150	7.50	62-65	7.46	149.61
Charging	16:30-16:45	140.56	150	10.00	65-70	9.60	150.16
Charging	16:45-17:00	136.45	150	10.00	70-75	10.09	146.54

As indicated by Table 8, the DSO has established the transformer load threshold levels at 175 kW and 150 kW, respectively, during the periods of 11:45-14:30 pm and 14:30-17:00 pm, based on the transformer load conditions. The algorithm utilizes these threshold levels to determine the charging and discharging powers or to put the station in a pause state to halt consumption. Upon examining the final transformer powers in the last column, it is observed that the values are below the threshold level established by the DSO. However, in cases where the values do not fall below this level, it becomes apparent that the maximum discharge power of 10 kW is insufficient to reduce the total transformer consumption value below the threshold. As can be seen from the setpoints, although the transformer load is higher than the threshold, discharge does not occur in some slots and the charging station goes into pause state. According to the functionality of smart charging algorith, no discharging occurs unless the vehicle battery reaches the user's desired state of charge (DSOC). This is a command given by the algorithm in order to keep the vehicle's battery close to the levels requested by the user in case they want to arrive earlier than promised. So, the vehicle will be charged until it reaches the DSOC level first, and then discharge will occur according to the grid signal or threshold level. In these types of time slots where the threshold level is higher than the transformer consumption level, flexibility is provided to the distribution network by sending a command to stop consumption at the charging station instead of sending a discharge option. After 14:30 pm, since the vehicle reaches the desired SoC level, the discharge process is initiated according to the grid threshold level, and charging is continued to bring the vehicle back to the desired SoC level after the discharge process.

According to Table 8, in the red row (14:15-14:30), the DSO also sends a "Demand Response" signal to reduce/stop the consumption at that time. The smart charging algorithm, whose functions are specified in Section 2.1.3.1, sends a command to the electric vehicle charging station to discharge at full capacity/or regardless of the threshold level or stop consumption command to reduce consumption during that time.In this case, according to the SoC level, a signal to stop consumption has been sent to the charger. During this process, the electric vehicle user is notified about whether they will participate in the "Demand Response" activity (Figure 38), and when it is time for the user to confirm, the setpoint is sent to the V2G charging station.



Would you like to participate in a Demand Response programme, you would get a discounted price for charging

Figure 38 Notification that asks user about his/her participation on DR event

The commands given to the battery were set for a period of 15 minutes, however, it is possible to view the power values in real-time or by the minute from the system. The power values shown in Table 7 are the average power values that occurred over a 15-minute period. As can be seen, the battery's response to the setpoints (V2G charging/discharging power) is very similar to the main commands, unlike the situation experienced with some setpoints in the battery storage system. The visualization of the base and final loads of the transformer along with the thresholds through the load-based battery charging/discharging optimization process is presented in Figure 39.

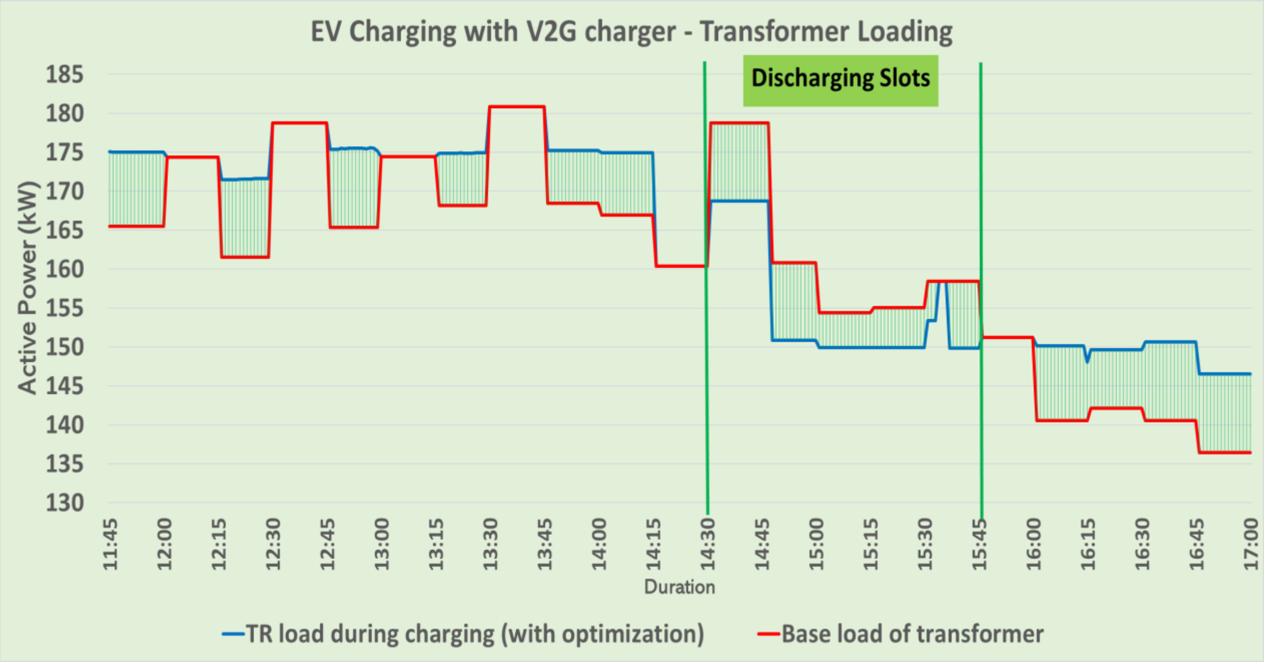


Figure 39 Load based optimization with V2G charger

It is possible to monitor the charging power of V2G vehicles through OCPP, but this process takes a considerable amount of time when carried out through logs on the interface. For data transfer to FlexiGrid platforms, it was possible to obtain energy values directly from the station meter data using an intermediate service and convert this value to a power value. However, due to meter reading errors caused by the charging station manufacturer, the data could not be directly provided from the station through API. (The data in the above graph is directly obtained from OCPP and represents the average of minute-level data. The API referred to here is the data transferred to other platforms outside of OCPP.) Therefore, an analyzer installed on the electrical panel of the V2G station was utilized for data transfer. The data from this analyzer was transmitted to the FlexiGrid platforms via API. However, due to an unidentifiable measurement error originating from the analyzer, there is a discrepancy of almost 8%-10% between the actual value and the measured value.

In this context, the charging/discharging powers obtained through the analyzer and transmitted to the IoT platform via API can be seen in Figure 40.

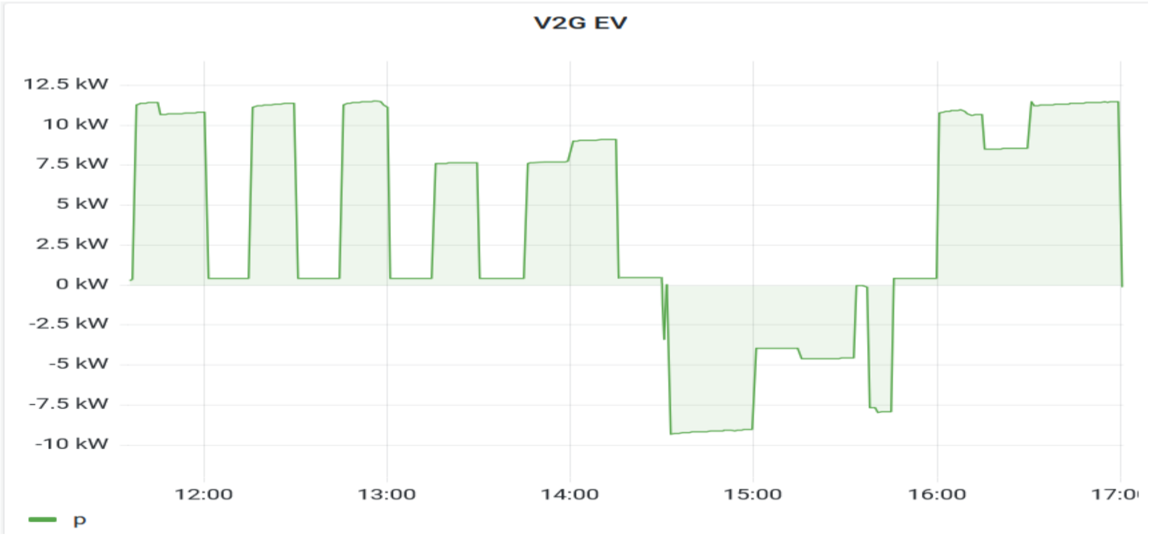


Figure 40 Charging/discharging powers of V2G charger in FlexiGrid IoT platform

Both Figure 39 and Figure 40 demonstrate that during the charging process in the time slot between 15:30-15:45, there was a momentary drop to zero discharge power. It is understood that the charging station operation was interrupted due to a brief electric flicker, most likely caused by voltage fluctuations. After this issue, the system was restarted to resume the charging process.

During the operation, there were dynamic changes in the State of Charge value along with the charging/discharging processes carried out in the vehicle. The change in SoC for the e-vehicle battery can be seen as shown in Figure 41.

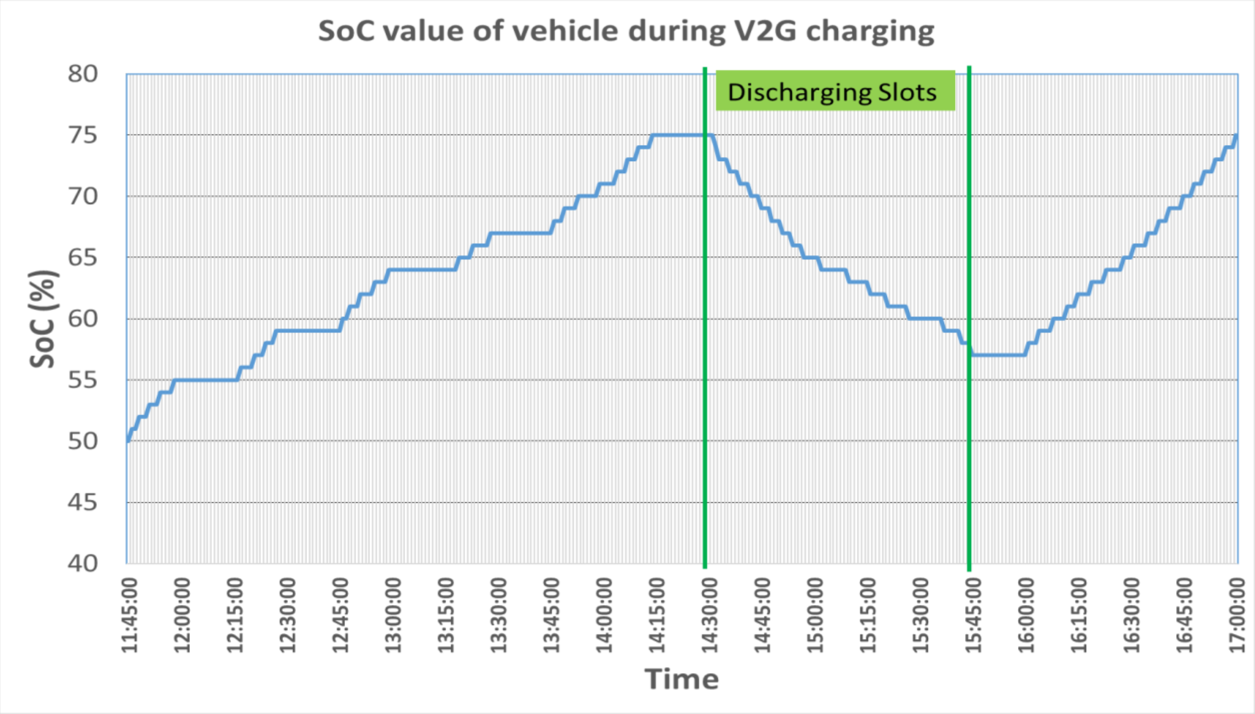


Figure 41 SoC value of the V2G compatible vehicle during study

Scenario 2 – Optimization with V2G charger according to the price scheme set by DSO :

In this scenario, the main premise is that a potential user of a V2G (Vehicle-to-Grid) compatible electric vehicle would be encouraged to charge their vehicle during periods when electricity prices are low, as determined by the DSO's pricing structure. Conversely, the user would be prompted to discharge their vehicle back to the grid during periods of high electricity prices. This scenario is designed to incentivize V2G users to consume electricity during off-peak hours and to help balance the grid by supplying power during peak hours.

According to the scenario, the DSO first develops a load-based electricity pricing scheme based on the current transformer load and hourly load estimates. This pricing scheme primarily encourages users to discharge their electric vehicles back to the grid during periods of high transformer load in order to avoid overloading the grid. Accordingly, the electricity price is set higher during periods of high load density and lower during periods of relatively low load density.

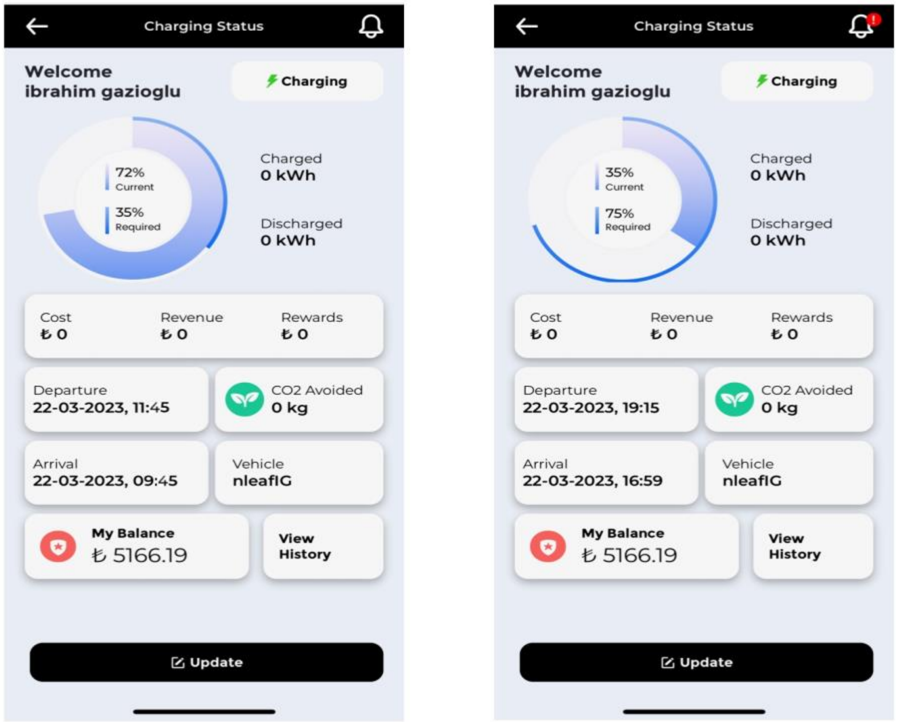
The proposed pricing scheme is designed to encourage electric vehicle owners to consume electricity during off-peak hours and to balance the grid by supplying power during periods of peak demand. The pricing scheme is based on a load-dependent tariff structure and aims to promote efficient use of the electricity network. The pricing scheme is presented in the following Table 9.

Table 9: DSO's tariff structure for demo study

Transformer Load Value (kW)	Transformer Loading (%)	Price (TL/kWh)
>180	>%90	3.8
180-160	%90-%80	3.5
160-140	%80-%70	2.9
140-120	%70-%60	2.5
<120	<%60	2.1

In formulating the tariff, the DSO has delineated various price coefficients contingent upon the transformer's load status. (In actuality, the transformer's load does not surpass 65-70% even during the annual peak times; yet, for the intents and purposes of this study, the transformer's power has been assumed as 200 kVA to simulate overloading situation on transformer.)

According to the scenario, an electric vehicle user who is informed about the tariff scheme participates in demand-response activity to both benefit from the process and indirectly assist the DSO (Distribution System Operator) for load balancing. Within this scope, the user connects their vehicle to the charging station and submits their charging requests (desired State of Charge (SoC) and departure time) through a mobile application. The visual representation of the user's charging requests for charging and discharging is shown in Figure 42.



Charging Status

Welcome
ibrahim gazioglu

Charging

72% Current
35% Required

Charged
0 kWh

Discharged
0 kWh

Cost	Revenue	Rewards
₺ 0	₺ 0	₺ 0

Departure
22-03-2023, 11:45

CO2 Avoided
0 kg

Arrival
22-03-2023, 09:45

Vehicle
nleafIG

My Balance
₺ 5166.19

Charging Status

Welcome
ibrahim gazioglu

Charging

35% Current
75% Required

Charged
0 kWh

Discharged
0 kWh

Cost	Revenue	Rewards
₺ 0	₺ 0	₺ 0

Departure
22-03-2023, 19:15

CO2 Avoided
0 kg

Arrival
22-03-2023, 16:59

Vehicle
nleafIG

My Balance
₺ 5166.19

Figure 42 V2G user charging preferences for price based optimization process

Within the scope of the study, a base price is determined via the FlexiGrid IoT platform (for this case it is 2.65 TL/kWh), based on the user's consent given at the beginning of the process, in order to automatically charge and discharge the user's vehicle in parallel. When the price exceeds the base price, energy is discharged from the vehicle battery with the maximum power (-10 kW), and the vehicle is charged with max power (10 kW) again for values below the base price. Thus, the user will be able to not only reach the desired SoC level at the requested charging time but also generate income, while the electricity distribution company can use the vehicle battery as a flexible asset to balance the load. In this context, the charging/discharging profiles calculated on an hourly basis by the smart charging algorithm, along with the base price determined, can be seen in Table 10.

Table 10: Calculated charge/discharge profiles for the study

Time	Transformer Load Value (kW)	Market Price	V2G Charger Setpoints	V2G Vehicle SoC (%)	V2G Charging Discharging Power (Avrg - kW)	Final Transformer Value (kW)
09:45-10:00	161.22	3.5	-10.00	72-67	-10.01	151.21
10:00-10:15	183.32	3.7	-10.00	67-62	-9.99	173.33
10:15-10:30	167.39	3.5	-10.00	62-57	-9.99	157.40
10:30-10:45	171.31	3.5	-10.00	57-54	-9.97	161.34
10:45-11:00	166.46	3.5	-10.00	54-49	-10.02	156.44
11:00-11:15	181.99	3.7	-10.00	49-44	-9.98	172.01
11:15-11:30	166	3.5	-10.00	44-39	-9.99	156.01
11:30-11:45	171.72	3.5	-10.00	39-35	-9.96	161.76
11:45-12:00	160.52	3.5	0.00	35	0.00	160.52
12:00-12:15	174.33	3.5	0.00	35	0.00	174.33
12:15-12:30	161.42	3.5	0.00	35	0.00	161.42
12:30-12:45	168.25	3.5	0.00	35	0.00	168.25
12:45-13:00	162.68	3.5	0.00	35	0.00	162.68
13:00-13:15	175.44	3.5	0.00	35	0.00	175.44
13:15-13:30	167.62	3.5	0.00	35	0.00	167.62
13:30-13:45	162.56	3.5	0.00	35	0.00	162.56
13:45-14:00	168.21	3.5	0.00	35	0.00	168.21
14:00-14:15	169.48	3.5	0.00	35	0.00	169.48
14:15-14:30	161.41	3.5	0.00	35	0.00	161.41
14:30-14:45	164.9	3.5	0.00	35	0.00	164.90
14:45-15:00	158.6	2.9	0.00	35	0.00	158.60
15:00-15:15	153.96	2.9	0.00	35	0.00	153.96
15:15-15:30	155.12	2.9	0.00	35	0.00	155.12
15:30-15:45	155.17	2.9	0.00	35	0.00	155.17
15:45-16:00	149.33	2.9	0.00	35	0.00	149.33
16:00-16:15	156.41	2.9	0.00	35	0.00	156.41
16:15-16:30	142.07	2.9	0.00	35	0.00	142.07
16:30-16:45	136.55	2.5	0.00	35	0.00	136.55
16:45-17:00	137.67	2.5	0.00	35	0.00	137.67
17:00-17:15	107.17	2.1	10.00	35-40	10.04	97.13
17:15-17:30	135.66	2.5	10.00	40-45	9.98	125.68
17:30-17:45	117.52	2.1	10.00	45-50	9.97	107.55
17:45-18:00	133.96	2.5	10.00	50-55	9.96	124.00
18:00-18:15	119.59	2.1	10.00	55-59	10.12	109.47
18:15-18:30	135.03	2.5	10.00	59-64	10.03	125.00
18:30-18:45	126.62	2.5	10.00	64-68	9.98	116.64
18:45-19:00	136.95	2.5	10.00	68-73	9.98	126.97
19:00-19:15	126.21	2.5	10.00	75	10.02	116.19

The flexibility potential and also impact on the transformer load of this process are illustrated in Figure 43. As can be seen, the process is designed based on the strategy of charging during non-peak hours and discharging during peak hours to achieve flexibility from the perspective of the DSO and when the market price is below the base price (2.65 TL/kWh), the battery charges itself, and when it exceeds the base price, it switches to discharge mode and provides power to grid at full capacity).

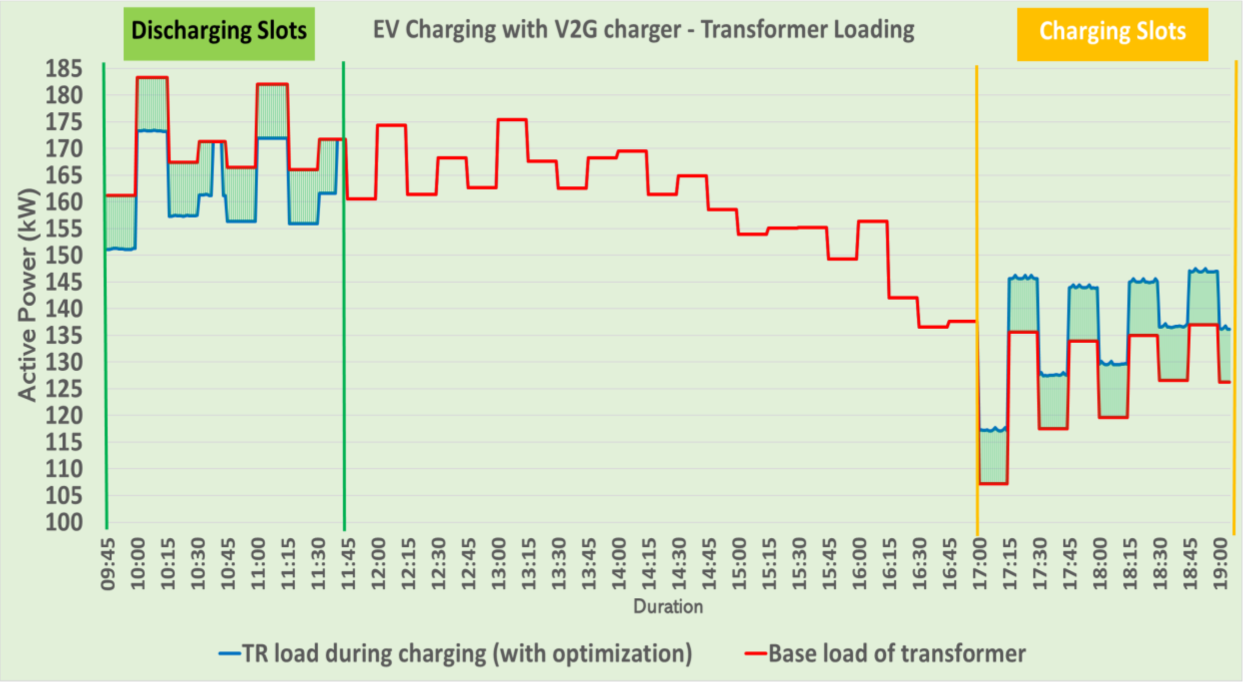


Figure 43 Transformer load value during the price based optimization with V2G compatible vehicle

The resulting SoC-price curve during this process is also presented in Figure 44. The optimization process started at 9:45 am and the initial SoC was at around %72. As expected, the SoC value increased during the charging process and decreased during the discharging process. The charging process was completed at 19:06 pm at the end of the day, and the final SoC value was measured as 75%. When evaluated from the perspective of FSP, such optimization allows for the procurement of energy when market prices are low and the sale of energy when prices are high, thus enabling daily profits. When evaluated from the perspective of DSO, dynamic pricing can be used to balance the load by setting energy prices higher during peak hours and lower during off-peak hours.

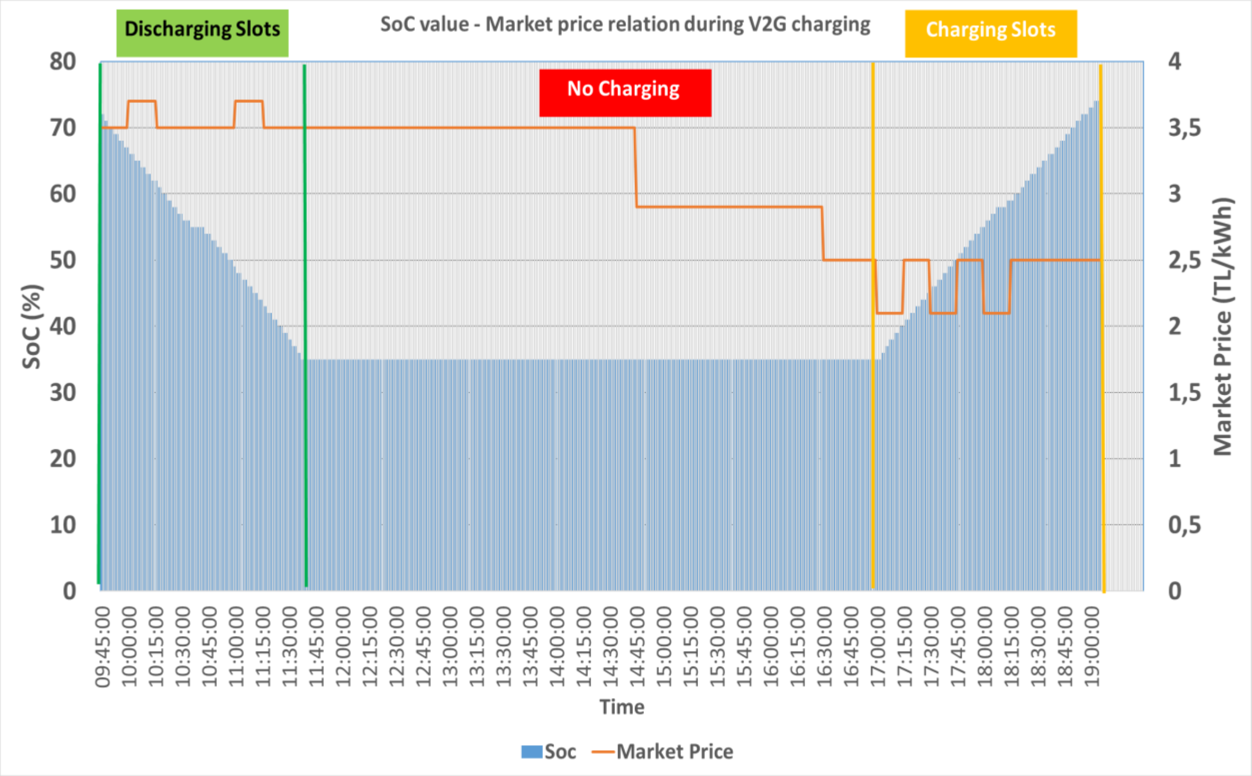


Figure 44 Spot market price – vehicle SoC relation during the charging/discharging of V2G compatible vehicle's battery

As seen in the graph, despite the high electricity prices after 11:45, no discharge occurred. The main reason for this is that discharging the battery below the recommended levels of 30-35% is not recommended.

- **Discussion**

Mentioned scenarios were demonstrated with V2G compatible vehicle and charging station, taking into account both grid status and market prices, using the FlexiGrid IoT platform and the OEDAS EV management platform to provide flexibility to local distribution grid. The key findings of the study were as follows:

- As the number of V2G compatible vehicles increases in the near future, there is a potential opportunity for distribution network operators to leverage vehicle batteries as a flexible asset (as virtual power plants), particularly during peak times, utilizing the bi-directional charging feature.
- As the demonstrated business model becomes more widespread, it can create a revenue model for electric vehicle users by allowing them to dynamically sell energy from their vehicle battery. If DSO can manage this process with load-based dynamic tariffs, it will be possible to reduce/postpone peak loads.
- The implementation of relevant technology with real users through demonstrated business models is hindered by regulatory barriers. Regulators must support regulations that remove these barriers and enable the adoption of such business models. In the context of this type of business model, it is crucial to define charging operatorship and the relationship between the companies responsible for this and the DSO. Doing so will facilitate the process of publishing regulations that

address key questions. Moreover, in the Turkey case, it will be important to define the flexibility market structure and rules, as well as the aggregator concept and relevant regulations.

- Finally, even if the relevant steps are completed, encouraging of the demand-side participation will be essential for the V2G concept to be implemented with such a business model, and steps that incentivize end-users must also be taken.

3.1.2.4 TC 8.11 Provision of flexibility by Demand Side Management/Demand Response

This test case was designed primarily at the beginning of the project with the possibility of a wider demo with more electric vehicles. For this reason, the priority was already set to "low."The main plan was to achieve a wider flexibility from the DSO's perspective by involving more charging stations in a larger area and with a higher number of electric vehicles. This plan aimed to direct the EV users to appropriate charging stations based on the varying load conditions of different transformers. Thus, the solution would cater to the needs of the users while optimizing the load distribution across the grid.

In summary, due to the lack of electric vehicles/charging stations in the region (in addition to the absence of additional budget for acquiring new stations and vehicles for a possible large-scale demo), the ownership and operation issues of existing stations (currently existing chargers are operated by the licensed CPO in the city without a regulatory connection to DSO), and the regulatory and technological barriers stated in report, it is not feasible for DSO to implement demand side participation with real users. However, it should be noted that the structure designed by OEDAS within the scope of the project and demonstrated with real assets and systems in the demo area can also be easily implemented as a Demand Response activity in a wide area with the participation of numerous vehicles and stations. With the increase in the number of EVs and charging stations in future projections and the clarification of regulatory issues, demand-side participation can be easily implemented as in the mentioned scenarios.

As evident from D8.1, the test case primarily includes the following details. Upon reviewing other test cases presented in previous sections, it is apparent that each test serves as an example of Demand Side Management. In other words, the participation of the demand side (battery or electric vehicle owner) is simulated in each scenario. Additionally, the dynamic pricing and load balancing case described below was utilized as an input in the optimization studies, especially in V2G-enabled scenarios. Hence, there was no need to perform an additional use case with the existing system.

3.1.2.5 TC 8.12 Provision of flexibility services with the whole system

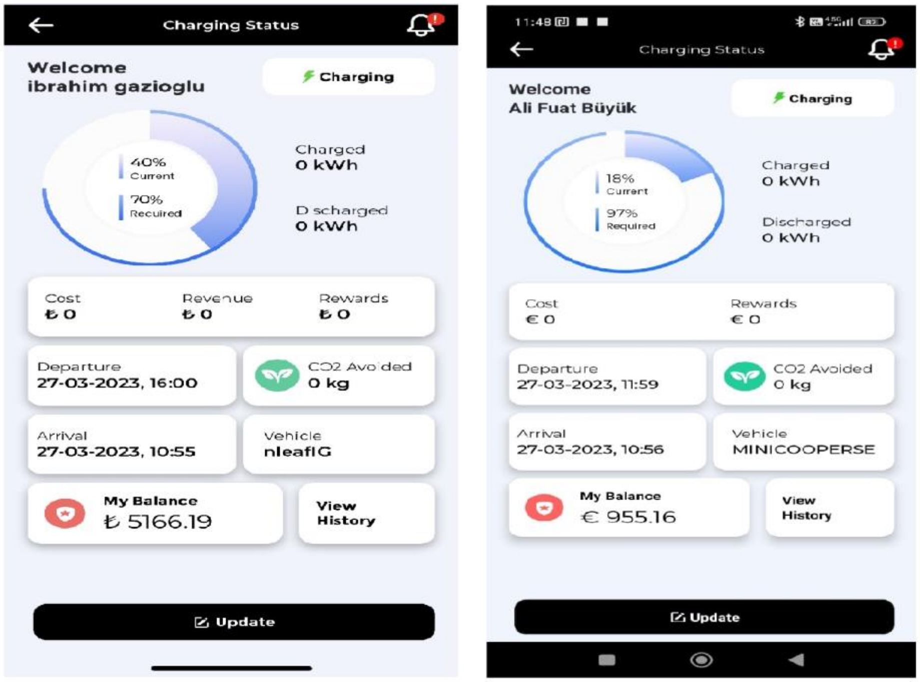
- **Description of the test case**

The equipment-based scenarios that were run in the previous scenarios were executed simultaneously for the entire system with this test case. In this scope, the smart charging function of the EV management platform was run for the entire system at the end of the process to balance the transformer load, and the results were presented.

- **Proposed scenarios for implementation and outcomes**

In this test, a sample study is conducted to demonstrate the potential flexibility of the entire system (EV chargers and battery storage system (see Figure 45) when operated simultaneously. According to the scenario, electric vehicle users come to the charging stations and initiate the charging process by entering their charging request through a mobile application (shown in Figure 46). As can be seen, the V2G user delivers their vehicle with a 40% state of charge (SoC) and commits to staying at the station for 5 hours, requesting to receive the vehicle with a 70% SoC. On the other hand, the V1G vehicle user delivers their vehicle with a 20% SoC and requests to receive it with a 97% SoC within 1 hour.

Figure 45 Simultaneous testing of V2G and V1G compatible vehicles



Welcome
ibrahim gazioglu

40% Current
70% Required

Charged
0 kWh

Discharged
0 kWh

Cost ₺ 0
Revenue ₺ 0
Rewards ₺ 0

Departure
27-03-2023, 16:00

CO2 Avoided
0 kg

Arrival
27-03-2023, 10:55

Vehicle
nleafIG

My Balance
₺ 5166.19

Welcome
Ali Fuat Büyük

18% Current
97% Required

Charged
0 kWh

Discharged
0 kWh

Cost € 0
Rewards € 0

Departure
27-03-2023, 11:59

CO2 Avoided
0 kg

Arrival
27-03-2023, 10:56

Vehicle
MINICOOPERSE

My Balance
€ 955.16

Figure 46 V2G (left) and V1G (right) user inputs

Within this context, the DSO determines the consumption threshold values for the transformer during the operational hours, based on the load curve of the current transformer. The smart charging algorithm then determines the charge and discharge profiles for the equipments (EV chargers and stationary battery), based on this threshold value. To this end, the DSO has established the transformer load threshold values for the relevant study, as illustrated in Table 11, and has incorporated these values into the system through the FlexiGrid IoT platform.

Table 11: Threshold values for transformer load during study

Time	TR Base Load (kW)	Threshold (kW)	Setpoints (kW) and SoC (%)						Final Load (kW)
			DC Charger	V1G EV SoC	Battery	Battery SoC	V2G Charger	V2G EV SoC	
11:00-11:15	155.74	185.00	24.50	21-41	-10.00	71-63	10.00	41-45	180.24
11:15-11:30	152.17	185.00	37.80	41-69	-10.00	63-55	5.00	45-48	184.97
11:30-11:45	144.25	175.00	35.70	69-93	-10.00	55-48	5.00	48-50	174.95
11:45-12:00	147.78	175.00	32.20	93-97	-10.00	48-47	5.00	50-54	174.98
12:00-12:15	148.5	165.00	-	-	6.50	47-52	10.00	54-58	165.00
12:15-12:30	164.2	165.00	-	-	-9.20	52-45	10.00	58-63	165.00
12:30-12:45	146.98	165.00	-	-	10.00	45-51	8.00	63-67	164.98
12:45-13:00	153.1	165.00	-	-	0.00	51	10.00	67-71	163.10
13:00-13:15	146.27	130.00	-	-	-10.00	51-44	-6.00	71-69	130.27
13:15-13:30	153.44	130.00	-	-	-10.00	44-36	-10.00	69-64	133.44
13:30-13:45	142.18	130.00	-	-	-10.00	36-28	-2.50	64-63	129.68
13:45-14:00	146.69	130.00	-	-	-10.00	28-20	-6.50	63-59	130.19
14:00-14:15	139.06	140.00	-	-	0.00	20	0.00	59	139.06
14:15-14:30*	146.27	DR	-	-	0.00	20	-10.00	59-54	136.27
14:30-14:45	130.18	140.00	-	-	5.00	20-24	5.00	54-57	140.18
14:45-15:00	132.21	140.00	-	-	4.00	24-27	4.00	57-59	140.21
15:00-15:15	134.52	140.00	-	-	0.00	27	6.00	59-61	140.52
15:15-15:30	145.92	140.00	-	-	-9.00	27-21	4.00	61-63	140.92
15:30-15:45	125.54	140.00	-	-	4.50	21-23	10.00	63-68	140.04
15:45-16:00	145.38	140.00	-	-	-10.00	23-20	4.50	68-70	139.88

As seen from Table 11, a V1G charging session for a DC electric vehicle was carried out with EV user between 11:00 and 12:00. During this time interval, the charging powers of the electric vehicles were determined by the algorithm in such a way that the thresholds set by the DSO (185 kW and 175 kW) were not exceeded. Finally, a profiling was defined to reach the desired charging level of the EV user. As explained in earlier sections, there is a decrease in actual charging power when the charge level of the electric vehicle, especially due to its own BMS, exceeds the 80% level. Although the power level is determined according to the threshold level, the power received by the vehicle during these charging intervals is different. This situation is shown in Table 12.

Table 12: Calculated and actual charging power during DC EV charging process

Time	Smart Charging - DC	
	Smart Charging Command (kW)	Actual Power (Average -kW)
11:00-11:15	24.5	24.07
11:15-11:30	37.8	37.19
11:30-11:45	35.7	27.49
11:45-12:00	32.2	13.57

Again, as seen in Table 11, when the DC electric vehicle charging process started, the V2G vehicle also began its charging session. At the same time, the stationary battery storage system is also in operation. According to the user's departure time data, the algorithm gives priority to the DC charging station for the threshold level, but the V2G vehicle has also started charging. (According to the algorithm design, the discharge process is not started before the V2G vehicle reaches the desired SoC value set by the user.) Therefore, to prevent the threshold level from being exceeded during the relevant interval, the battery storage system is discharging itself at full power (10 kW). At 12:00 pm, with the completion of the charging process at the DC charging station, the V2G vehicle's charging process continued. The V2G vehicle was charged with the maximum power possible according to the threshold level, and the user reached the DSOC input level of 70% at 13:00. During this process, the battery was charged or discharged according to the setpoint determined for the battery threshold level. As the threshold level determined by the DSO was relatively low between 13:00 and 14:30, as can be seen from the table, both the V2G vehicle and the stationary battery storage system were discharged. Here, priority was given to discharging the stationary battery at full power, considering the possibility of the user possibly ending the session early. According to the table, a "demand response" signal was sent by the DSO between 14:15 and 14:30. The DSO requested 10 kW of flexibility to the grid. During this time, discharging was carried out from the V2G vehicle instead of the battery storage system, since the stationary battery had reached its minimum SoC level of 20%. After 14:30, the charging process continued with battery support in order to reach the desired SOC level of the vehicle, and the process was completed around 16:00 to achieve the user's desired 70% vehicle charging level. The graph in Figure 47 shows the changes in transformer consumption data throughout the process.

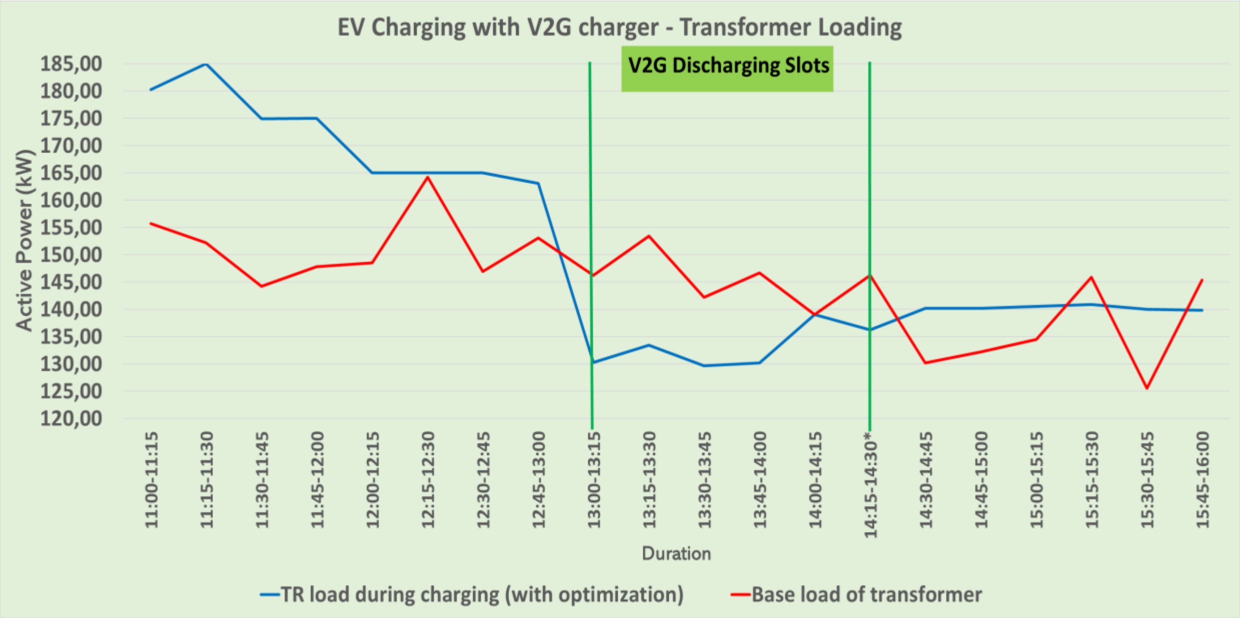


Figure 47 Transformer base load and final load comparison during the study

The charge and discharge curves that were carried out on an equipment basis throughout the process have been monitored via IoT platform and according to the data below graphs created. Visualization of the data can be viewed in Figure 48, Figure 49 and Figure 50.

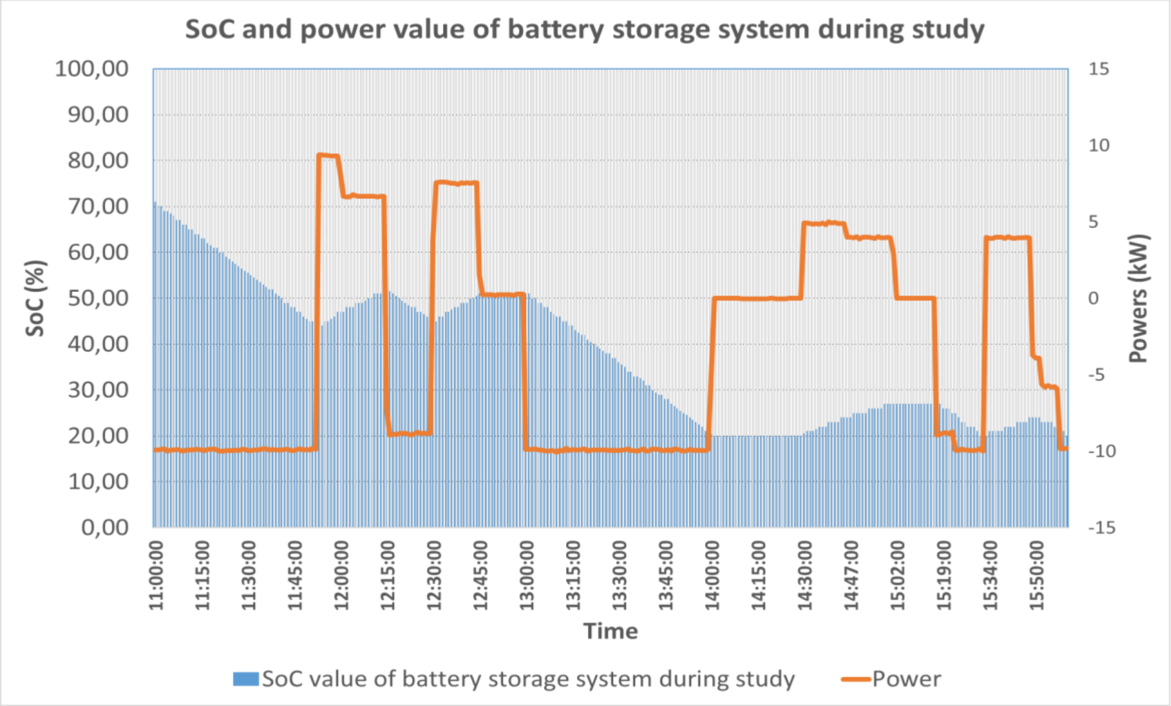


Figure 48 Battery storage system charging/discharging power curve and SoC relation during optimization

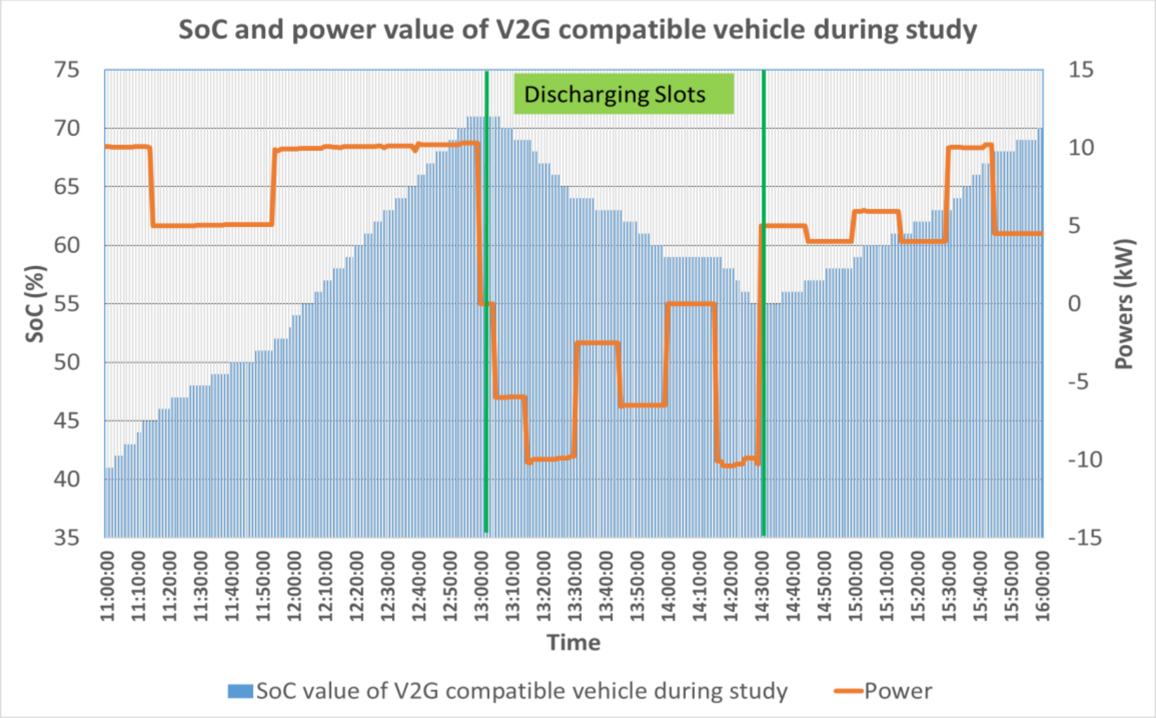


Figure 49 V2G charger charging/discharging power curve and SoC relation during optimization

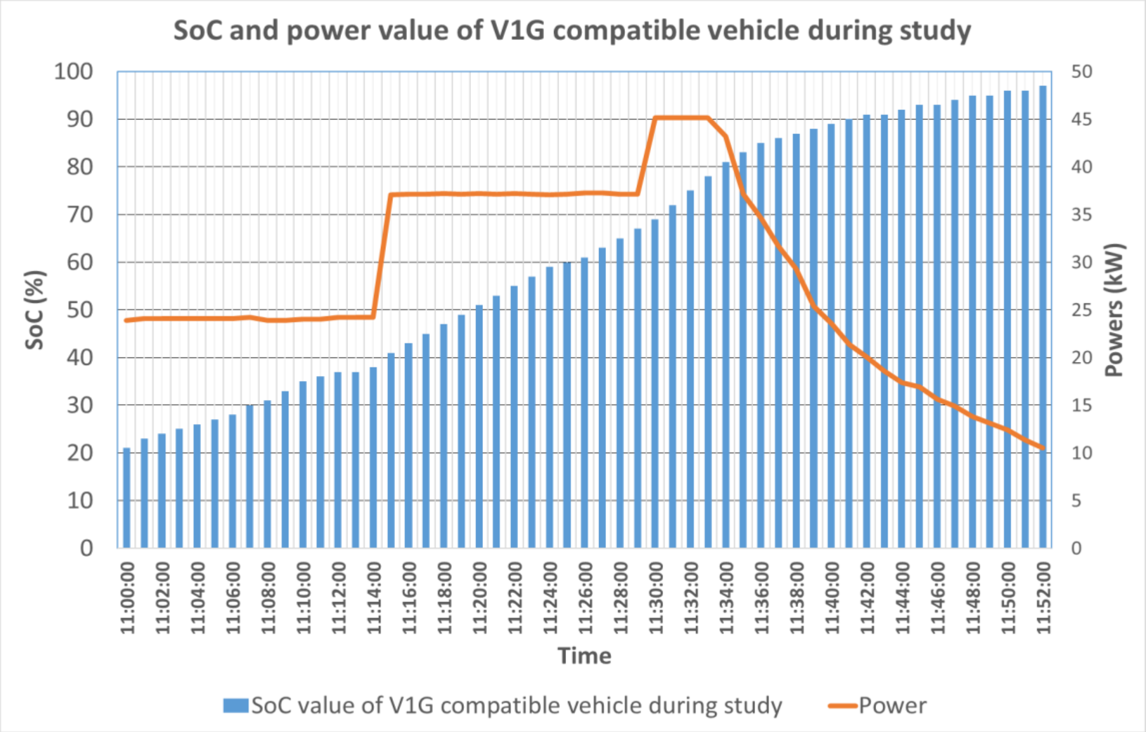


Figure 50 DC charger charging power curve and SoC relation during optimization

- **Discussion**

Mentioned scenarios were demonstrated with whole system together using with the FlexiGrid IoT platform and the OEDAS EV management platform to provide flexibility to local distribution grid. The key findings of the study were as follows:

- The designed business model and the system/technologies used have been shown to be simultaneously applicable to the entire system. The importance of management platforms for utilizing the flexibility potentials of flexible assets has been demonstrated in the study. The relevant system demonstrated in the demo can be applied to a larger number of assets and in a wider geography.
- Since the same assets were used in this test case as in the other test cases, the outcomes presented in the other test cases are also applicable to this one.

3.2 HES campus

3.2.1 Introduction

This section presents the different test cases which were implemented at the demo site in Switzerland. All test cases along with their objectives are listed in Table 13 and were already presented in deliverable 8.1. With these test cases, the whole flexibility supply process is demonstrated, and various assets are tested.

Table 13 Different test cases at HES campus

Number	Test case name	Main objective
8.1	Flexibility potential estimation	Demonstrate that an accurate flexibility potential prediction can be performed.
8.2	Communication with OIKEN	Test the communication between HES and OIKEN using the EFLEX platform developed by Emax in WP7.
8.3	Reliable flexibility offer using batteries	Demonstrate the ability to offer flexibility using batteries.
8.4	Reliable flexibility offer using heat pumps	Demonstrate the ability to offer flexibility using heat pumps.
8.5	Reliable flexibility offer using the power-to-gas plateform	Demonstrate the ability to offer flexibility using the power-to-gas platform (simulation twin and small-scale fuel cell).
8.6	Optimization of self-consumption	Demonstrate the ability to use the whole system in order to optimize the self-consumption of local electricity (PV) production.
8.7	Reliable flexibility offer using the whole system	Demonstrate the ability to offer flexibility using the whole system available at the HES pilot site.

3.2.2 Test case implementation

Test cases were implemented at the Energypolis campus in Sion using the infrastructure described in *Section 2.* Concretely, the test cases presented hereunder can be split in two categories:

1) **TC 5.9 to TC 5.13:** These test cases were elaborated and described in detail in deliverable D5.1 of WP5. They concern more basic aspects of the demonstration, such as assessing the monitoring, visualization and control of the different assets available on the campus. It was decided to present them in deliverable D8.3 to gather the demonstration activities of the Swiss pilot.
2) **TC 8.1 to TC 8.7:** These test cases were elaborated and described in detail in deliverable D8.1. They deal with general aspects associated to the procurement of flexibility such as flexibility potential estimation, communication between HES, the flexibility service provider (FSP) and OIKEN, the local DSO but also aim to study the potential for flexibility supply of different assets in terms of volume and reliability.

3.2.2.1 TC 5.9 Real time monitoring & TC 5.10 Real time visualization

- **Description of the test case**

TC 5.9 and TC 5.10 are grouped together as they both aim to meet the same objective: to demonstrate that the important variables are monitored and can be visualized in real time in order to enable the proper control of the different assets of the campus.

- **Proposed scenarios for implementation**

In order to implement this test case, data are visualized using the tool Grafana. The latter allows one to connect a timeseries database and visualize different values. Historical as well as real time values can be retrieved helping one to properly monitor the different installations.

- **Outcomes**

Measurements and data communication are performed using different instruments specific to each device:

Batteries: The local control of the batteries is performed by an inverter and the management / communication is ensured by an hardware in the loop device (OPAL-RT). Data and setpoints are shared via CloudIO, a cloud service developed by HES in the framework of a past project.

PVs: Energypolis campus' grid being robust, PV production is only monitored, not controlled. Data are retrieved using SolarEdge's API, the PV management system deployed on the campus.

Heat pumps: Different quantitites such as mass flows, temperatures or electrical power are measured and gathered by the local supervision of the heat pumps. They are then retrieved via ModbusTCP.

All this data is collected locally and shared to Flexigrid partners via CloudIO. An example of data visualization is given in Figure 51.

Figure 51 : Screenshot of the measurement data represented using Grafana

- **Discussion**

The different communication protocols and control systems as well as the variety of the controlled devices result in different data resolution. Data resolution can even be variable for some quantities (when data transfer is triggered by the variation of a quantity exceeding a specified value, e.g. when the temperature variation exceeds 0.1°C). Usage of tools such as Grafana easily enable the visualization of such data by interpolating the different values. In general, the main issue remains data resolution. Indeed, processes such as primary reserve require a high reactivity. However, all demonstrations taking place in Switzerland aim to provide balancing services resulting in rather low requirements regarding resolution. For this reason, simple data monitoring and visualization as presented here is considered as satisfactory.

3.2.2.2 TC 5.11 Control of PV production and battery storage

- **Description of the test case**

This test case aims at demonstrating the proper control of the battery storage. As already mentioned in the previous section, it was decided to solely control the batteries, the PV control being irrelevant for the Swiss demo case.

- **Proposed scenarios for implementation**

For this test case, it was decided to send the following control signal to the batteries in order to check their responsiveness:

i) Power charging setpoint of 50 kW during 2mn
ii) Power charging setpoint of 100 kW during 2mn
iii) Power setpoint of 0 kW during 2mn
iv) Power discharge setpoint of -50 kW during 2mn
v) Power discharge setpoint of -100 kW during 2mn

- **Outcomes**

The obtained results are presented in Figure 52.

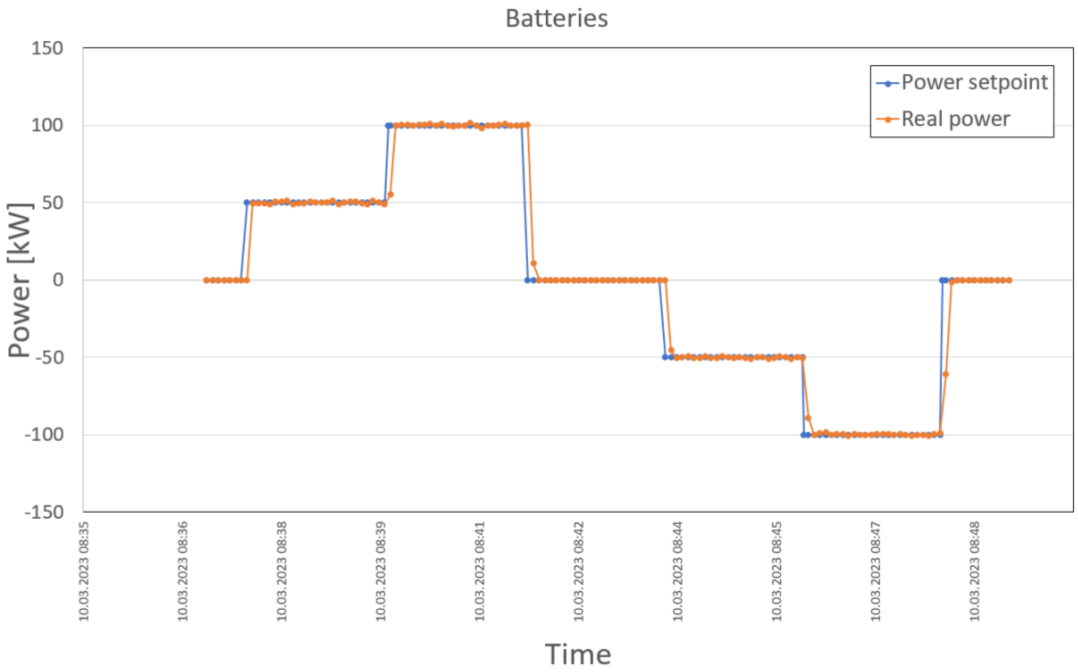


Figure 52: Results of the battery storage control test

- **Discussion**

This test case shows that the battery storage reacts well to control setpoints. Indeed, it can be controlled both in charging and discharging modes and behaves as expected. Not only does the battery have a very stable power profile, but it also reacts very quickly to received setpoints, allowing for a fine control of this asset. The exact response time of the batteries cannot be precisely evaluated as the acquisition system used has a resolution of 5 seconds and the batteries have a higher responsiveness.An interesting point is that this test characterizes the physical characteristics of the battery storage, but it also verifies that the PID controller managing the asset was well calibrated. Poor calibration could have led for example to slow ramp ups, overshoots or oscillating power profiles.

3.2.2.3 TC 5.12 Control of HP

- **Description of the test case**

This test case aims at demonstrating the proper control of the heat pump. As previously described, one heat pump supplies each building. The heat pump of building 19 hosts two compressors (on / off compressors) while the heat pumps of buildings 21 and 23 have only one compressor which is associated to a frequency variator allowing for a more accurate control of the device.

- **Proposed scenarios for implementation**

In order to demonstrate the control, profiles with staging at 0%, 50% and 100% of the maximal power are tested for heat pumps 19 and 23 (21 is not tested as it is similar to 23).

- **Outcomes**

The obtained profiles are presented in Figure 53 and Figure 54.

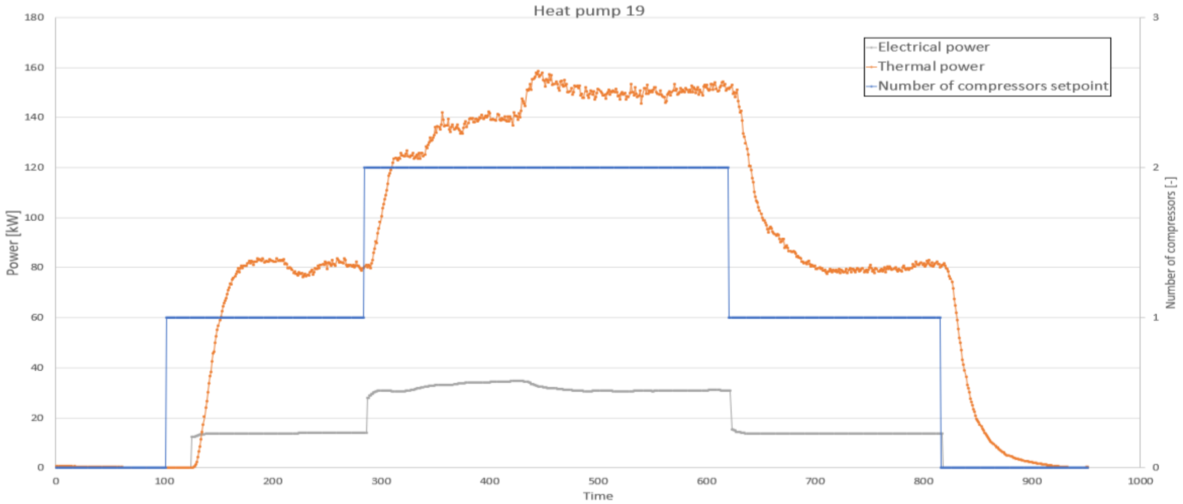


Figure 53: Results of heat pump 19 control test

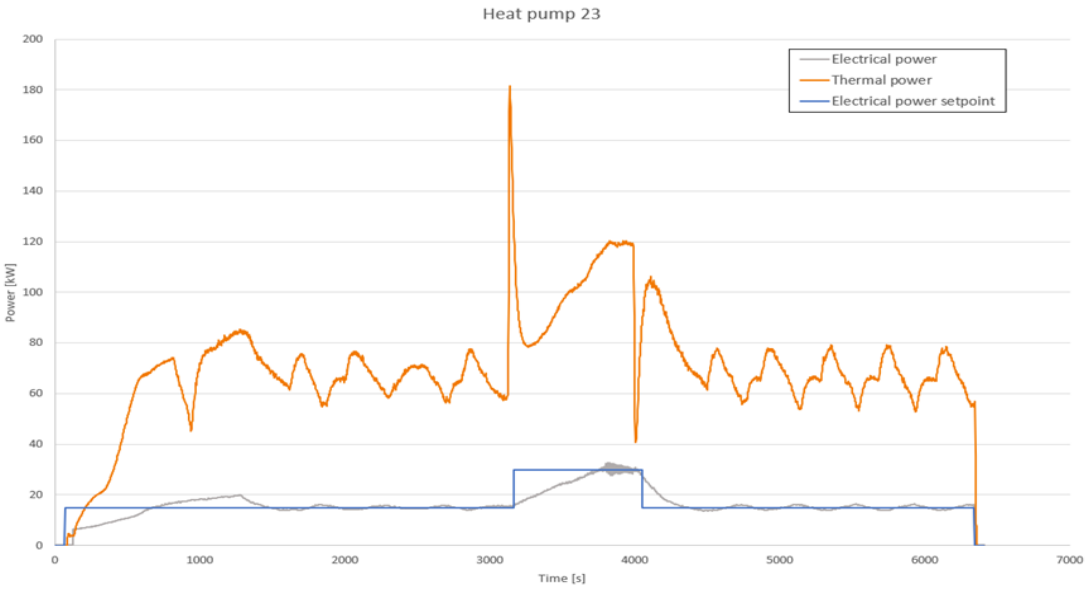


Figure 54 : Results of heat pump 23 control test

- **Discussion**

<u>Heat pump 19</u>

This heat pump shows interesting features despite the fact that its two compressors can only be turned on/off:

- There is a short delay between the actual sending of a setpoint and the start of a compressor (about 45 seconds for a start-off of the first compressor, almost 0 for the start of the second compressor)
- The change in electrical power following the start / shutdown of a compressor is almost instantaneous. Then, the electrical power consumed is reasonably stable. This should result in an accurate flexibility supply.
- The start of the first compressors leads to an electrical consumption of about 14kW, while the start of the second leads to a total of 35kW, meaning that the controllable states of the heat pump correspond to 0%, 40% and 100% of its maximum power.
- There is a minimum delay of 20mn between two starts of the heat pump from 0%. This limitation was set directly from the manufacturer to limit short cycles.

While supply flexibility using the heat pumps of the campus, this heat pump will be preferably used as it presents the highest reactivity.

<u>Heat pump 23 (21)</u>

Heat pumps of building 21 and building 23 are similar so only the profile for heat pump 23 is presented here. These heat pumps work with only one compressor so one could expect a finer control. However, this appears not to be the case at least for the test presented here:

- There is a short delay (about 1mn for the 0->50% setpoint) between the actual sending of a setpoint and the start of the compressor, but this does not impact the performance of the heat pump for flexibility supply.
- Overall, the ramps following a setpoint appear to be slow. This is probably due to a limitation imposed by the manufacturer and additional efforts will be made to improve this aspect.
- A non-optimal tuning of a PID results in an overshoot when ramping from 0kW to 15kW. This then slowly converges (oscillations) towards the desired value.

3.2.2.4 TC 5.13 Control of P2G

- **Description of the test case**

Initially, this test case was designed to test the control possibilities of a P2G platform including a reversible fuel cell. However, this platform is not ready at the moment and will not be ready by the end of the Flexigrid project. For this reason, this test case is adapted and the original reversible fuel cell is replaced by a digital twin of a Solid Oxide Fuel Cell (SOFC) and a Solid Oxide Electrolysis Cell (SOEC), and tests are performed on a small-scale SOFC. The SOFC is used to convert electrical power into gas (in this case hydrogen – H2) and the SOEC is used to convert gas (hydrogen) into electrical power.

First, results of the digital twins control are presented. The digital twins of the SOEC and SOFC systems are based on a transient model to reproduce the behaviour of a real system. Tests profiles are generated and correspond to a limited number of operating modes of the (partial-load and full-load modes). The outputs of both the SOEC and SOFC systems are controlled by adjusting different input variables. For the SOEC, these are the electrical current, the steam flow rate and the air flow rate; the system outputs are the electrical power consumption and the flow rate of produced hydrogen. In this test case, the capacity of the SOEC system model is equal to 20 kW electric. The input variables of the SOFC are the electrical current, the flow rate of hydrogen and the air flow rate; the system outputs are the produced electrical power and the flow rate of produced steam. In this test case, the capacity of SOFC system model is equal to 6 kW electric.

Then, to validate the digital twin of the P2G system, simulation results are compared to the real data of a small-scale SOFC stack. The latter has a power capacity of 300 W. This comparison with real data provides a strong validation of the P2G model's accuracy and effectiveness in simulating the behavior of the SOFC system.

- **Proposed scenarios for implementation**

In the proposed scenario for implementation, each simulation model was used to produce 6 profiles of electricity consumption (SOEC) respectively production (SOFC) of a system starting in an “idle state” (i.e. at an initial stack temperature of about 600°C for the SOEC and 650°C for the SOFC) and transiting towards a steady state of operation at a given electrical power. The cluster manager can then choose one of the 6 profiles to offer flexibility based on the profile requested by the DSO.

The models are used to determine the sets of input variables (current, steam flow rate and air flow rate for the SOEC; current, hydrogen flow rate and air flow rate for the SOFC) that provide the offered flexibility with the best system efficiency given the system’s technical limitations. These inputs variables are the ones given to the asset for it to follow the corresponding profile.

- **Outcomes**

Figures 55 and 56 provide four samples of the 6 profiles produced by the simulation models for respectively a 20 kWel SOEC system and a 6 kWel SOFC system. These profiles have a time step of 2 seconds over an operation of one hour. The corresponding input variables for the SOEC are:

A) I = 30 A, Steam flow rate = 1.3 L/min, Air flow rate = 10 L/min
B) I = 20 A, Steam flow rate = 0.85 L/min, Air flow rate = 10 L/min
C) I = 10 A, Steam flow rate = 0.45 L/min, Air flow rate = 10 L/min
D) I = 5 A, Steam flow rate = 0.21 L/min, Air flow rate = 10 L/min

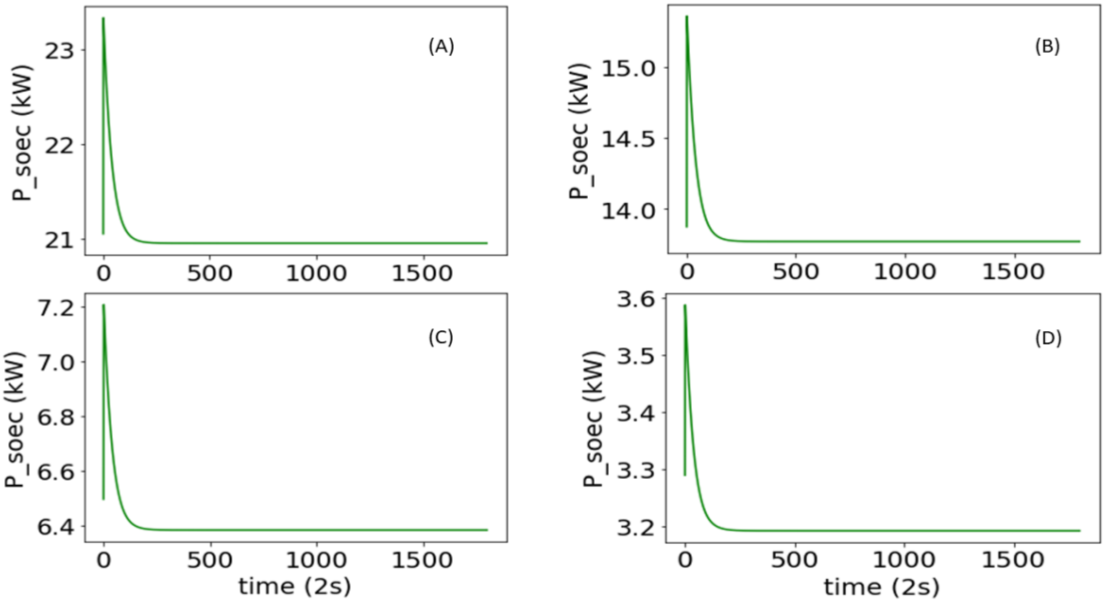


Figure 55 The four simulated test profiles of the SOEC system

The corresponding input variables for the SOFC are:

A) I = 30 A, Hydrogen flow rate = 1.3 L/min, Air flow rate = 10 L/min
B) I = 20 A, Hydrogen flow rate = 0.9 L/min, Air flow rate = 10 L/min
C) I = 10 A, Hydrogen flow rate = 0.45 L/min, Air flow rate = 10 L/min
D) I = 5 A, Hydrogen flow rate = 0.22 L/min, Air flow rate = 10 L/min

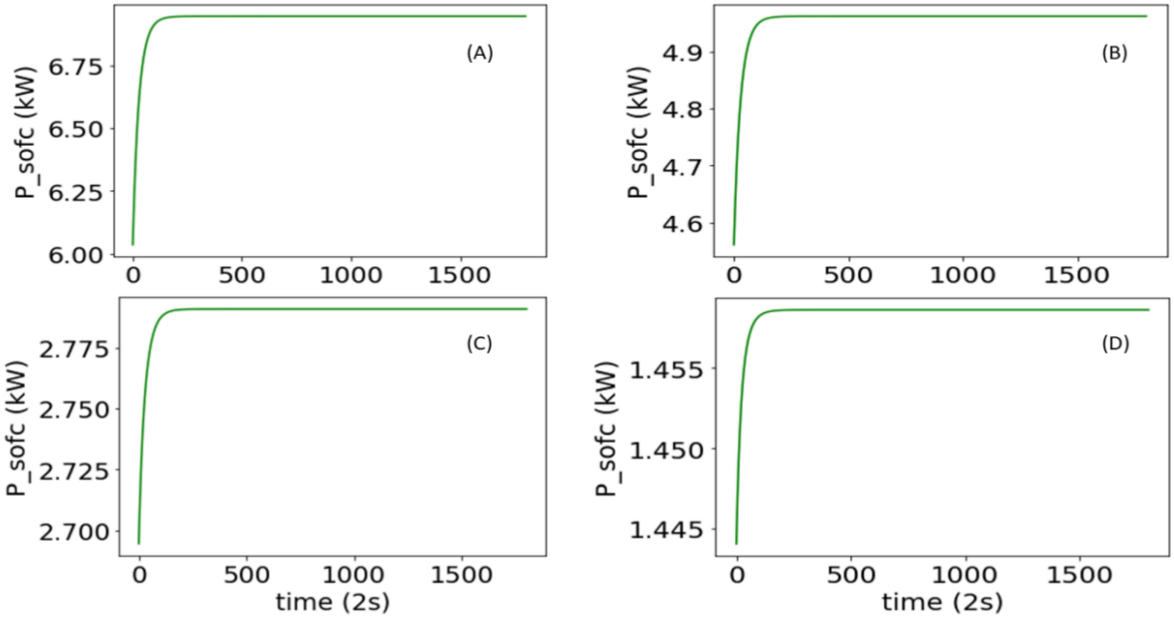


Figure 56 The four simulated test profiles of the SOFC system

Figure 57 demonstrates the validation of the digital twin model of the SOFC stack that was developed to simulate the transient behavior of a small-scale solid oxide fuel cell. The figure depicts the output power and cell voltage of the SOFC, measured with varying SOFC current over time. These measured data are compared with the simulated data from SOFC model.

The initial set points and parameters from the SOFC test case are provided in Table 14. Notably, the digital twin model used the same initial parameters and set points as the actual test, which allows for easy comparison with real-world data.

Table 14: Initial parameters for the SOFC test

Current	Fuel utilization	Hydrogen flow rate	Tinlet_Air (Temperature)	Tinlet_Fuel (Temperature)	Air flow rate
I [A]	-	L/min	°C	°C	L/min
30	0.7	4.48	600	620	30

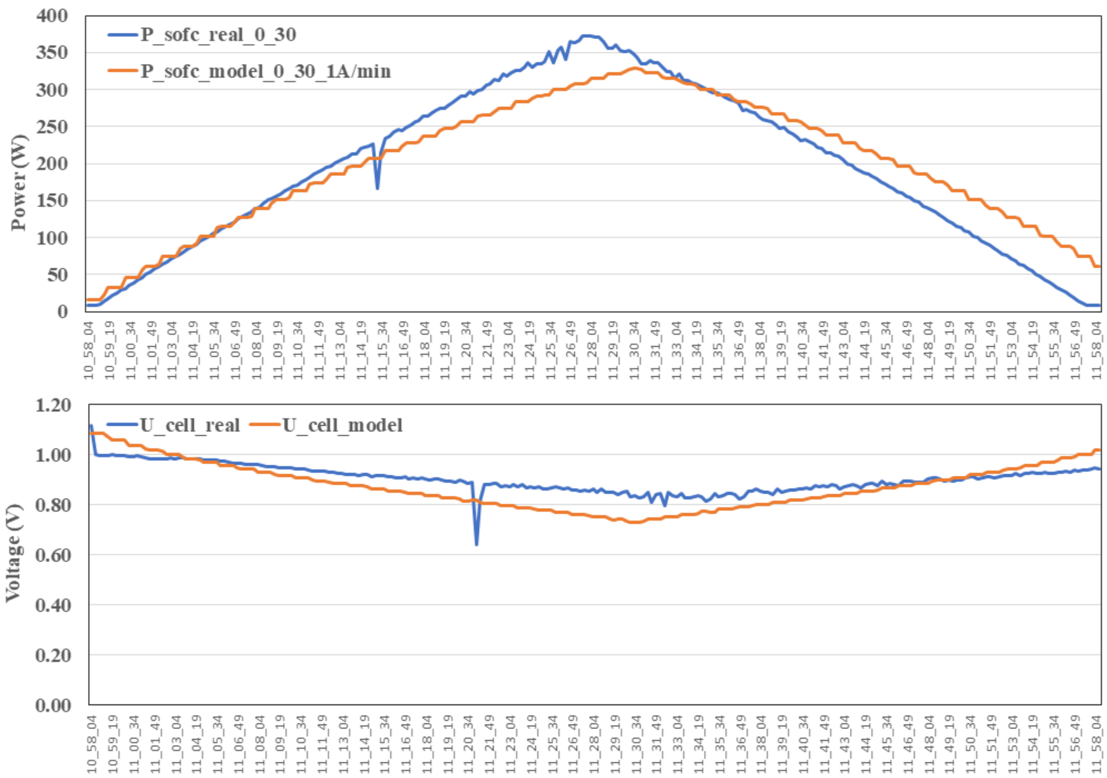


Figure 57 : Measured power and voltage of the real SOFC stack and comparison with its digital twin

- **Discussion**

SOEC and SOFC systems can be used to provide respectively negative and positive flexibility by running them at a given load profile. Given that no real assets are currently available for testing models of a 20kWel SOEC system and of a 6kWel SOFC system were developed and calibrated 1) to produce 6 modes of operation (i.e. load profiles) of each system to be used for offering flexibility, 2) to determine the input variables that allow the system to transit from an idle state to the required power level of each mode of operation and 3) finally to simulate the use of a real asset by producing the expected profile of the asset. Figures 56 and 57 provide 4 of these 6 profiles.

To validate and calibrate the digital twin model of SOFC, a real small-scale test case of a 300 Wel SOFC was conducted. The results demonstrated that the power in both the real test case and the model increased with increasing SOFC current until 30 A. However, the SOFC cell voltage decreased as the current increased due to the increasing potential losses of the SOFC cell, including ohmic, concentration, and diffusion losses. During one hour of operation, the accumulated energy obtained from measuring the SOFC power was 197.32 kWh, whereas the model calculated this amount to be 200.10 kWh. The error between the yield energy from the model and the real test case was 1.74%, which is an acceptable margin of error. In summary, the comparison between the real test data and the model data demonstrated that the developed transient model is accurate, reliable, and capable of simulating dynamic system behavior.

3.2.2.5 TC 8.1 Flexibility potential estimation

- **Description of the test case**

In this test case, the cluster manager (HES) receives a request from the local DSO (OIKEN) and then calculates the potential of flexibility offer based on the all the assets at its disposal. After that, the maximum offer of flexibility potential by the HES along with its price is sent to the DSO.

Following this estimation of the potential for flexibility, and provided that the DSO accepts the flexibility offered, the cluster manager (HES) will then 1) send the relevant input variables to ”static assets” such as heat pumps and SOEC/SOFC systems assuming they will follow the predicted load profiles and 2) control battery assets in ”real-time” in order to counter discrepancies between real and predicted load profiles of these static assets. Finally the load profile effectively implemented will be compared to the promised load profile for validation of the flexibility offer and its payment (see ”3.2.2.11 TC 8.7 Reliable flexibility offer using the whole system”).

An algorithm, shown in Figure 58, has been developed for calculating the flexibility potential that the cluster manager can offer given the current state of its assets and the request coming from the DSO. The algorithm works by minimizing the difference between the requested energy over the flexibility period (i.e. average load profile) and the best choice of flexibility profiles of the static assets (based on a set of predetermined profiles) and the batteries (limited in terms of ramp-up and ramp-down power as well based on the batteries current state of charge). For this test case, the set of available assets consists of three heat pumps (installed in buildings 19, 21 and 23), a SOEC/SOFC system and a bank of batteries.

In first step, the set of different possible operating modes (i.e. load profiles) for each asset are calculated for all three heat pumps and the SOFC and SOEC systems. These different operating modes include shutting down, turning on and switching between partial loads. All of these profiles are stored in profile database and sent to the main file for it to select the best profiles of each asset according the given flexibility request sent by the DSO sent to the cluster manager (HES).

There are two types of request coming from the DSO:

1) a request is considered to be negative when the DSO needs the cluster manager to consume more electrical power than forecasted (i.e. more than its “baseline”). In this case the SOEC system (power-to-gas) starts running to consume electrical power, heat pumps increase their load and batteries store electricity.
2) a request is considered to be positive when the DSO needs the cluster manage to consume less electrical power than forecasted (i.e. less than its “baseline”). In this case the SOFC system (gas-to-power) start running to produce electrical power, heat pumps reduce their load and batteries release stored electricity.

After the best profiles are chosen for the static assets by the ”Select_Asset Profiles” module,

An optimal battery operation is produced to cover the difference between the requested energy and the stacked profile of the static assets. For this purpose, an optimization technique is used to minimize the mentioned value by considering the battery’s initial state, its ”baseline”, and its technical limitations. Finally, a flexibility offer potential is calculated as well as the maximum potential of flexibility which the HES is able to offer during the flexibility period.

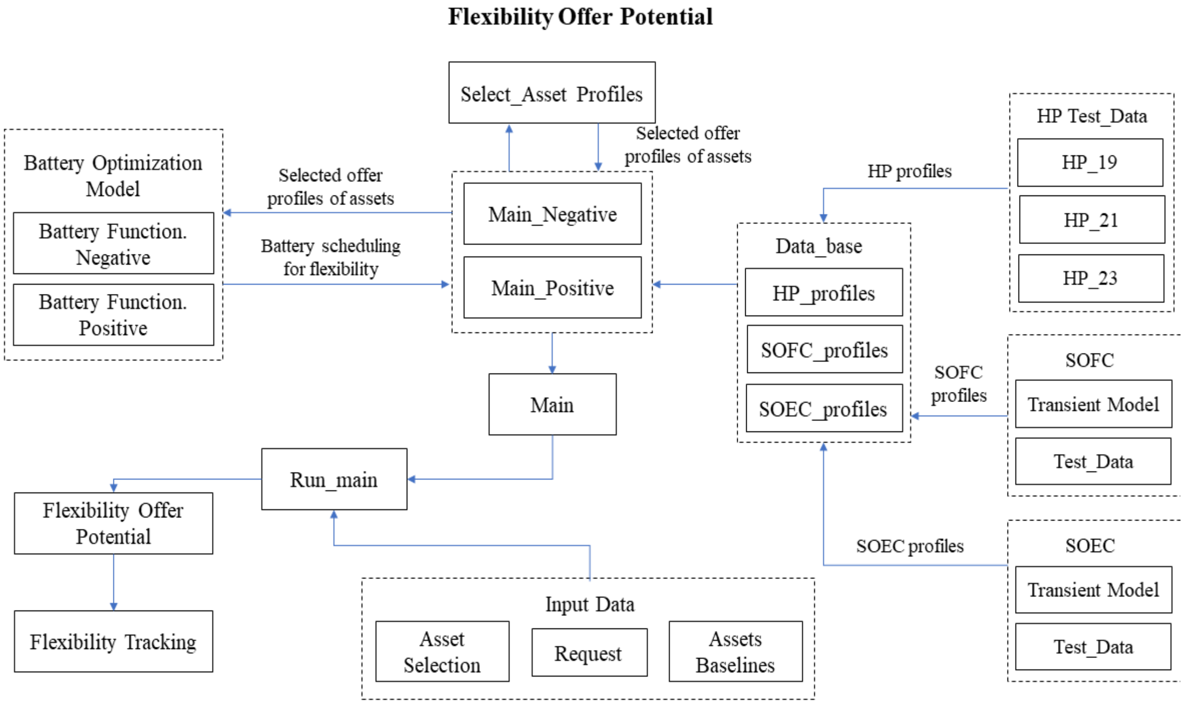


Figure 58 The methodology of flexibility offer potential

- **Proposed scenarios for implementation**

In this test case, proposed scenarios for the implementation of the flexibility offer potential are presented based on the timing of offering the flexibility potential, the flexibility period, and measuring the baselines, as shown in Figure 59. As shown, the DSO sends a flexibility request which is received by the cluster manager (HES) one hour before flexibility period. In this time, the proposed algorithm of Flexibility Offer Potential (described above) is run based on the value of request, a selection of asset types and measured baselines of each asset. It is important to note that the baselines of different assets are measured and saved one hour before the request is received.

After that, the maximum offer of flexibility potential by the HES along with its price is sent to the DSO. If the DSO accepts the flexibility offered by HES, at the beginning of flexibility period, the cluster manager (HES) will then 1) send the relevant input variables to ”static assets” such as heat pumps and SOEC/SOFC systems assuming they will follow the predicted load profiles and 2) control battery assets in ”real-time” in order to counter discrepancies between real and predicted load profiles of these static assets.

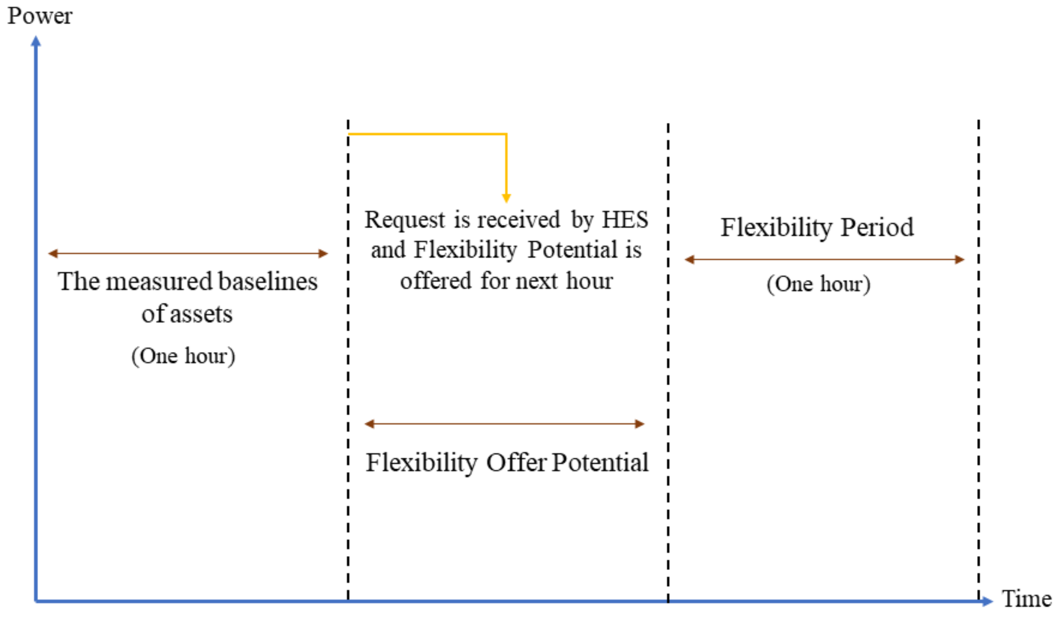


Figure 59 Timing of offering the flexibility potential

- **Outcomes**

In this section, the proposed algorithm of flexibility offer potential is run by considering the different values of requests and asset baselines. The participating assets in this test case include three heat pumps (hp_19, hp_21, and hp_23), P2G systems (SOFC and SOEC), and a battery bank. The baselines of these assets are considered as input data for the algorithm. The outputs of the algorithm are categorized based on the value of request and they are presented in Figure 60 and Figure 61 for negative and positive requests respectively.

In Figure 60, although all request values are negative, they are presented as positive to provide a better understanding. In this figure, the flexibility profiles provided by each asset are shown as well as the total flexibility offer by the sum of all assets.

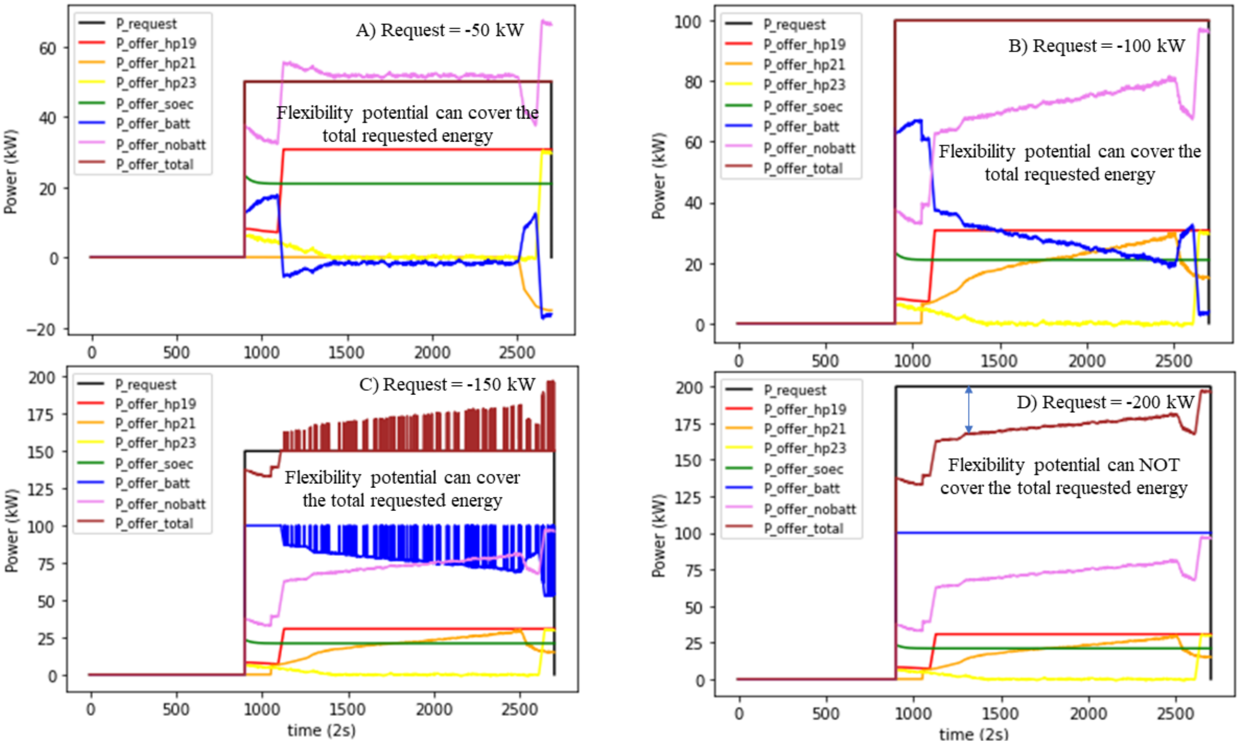


Figure 60 The potential of HES flexibility offers for Negative Value of Request

In Figure 61, all of request values are positive and the flexibility offers provided by each asset are shown as well as the total flexibility offer by the sum of all assets.

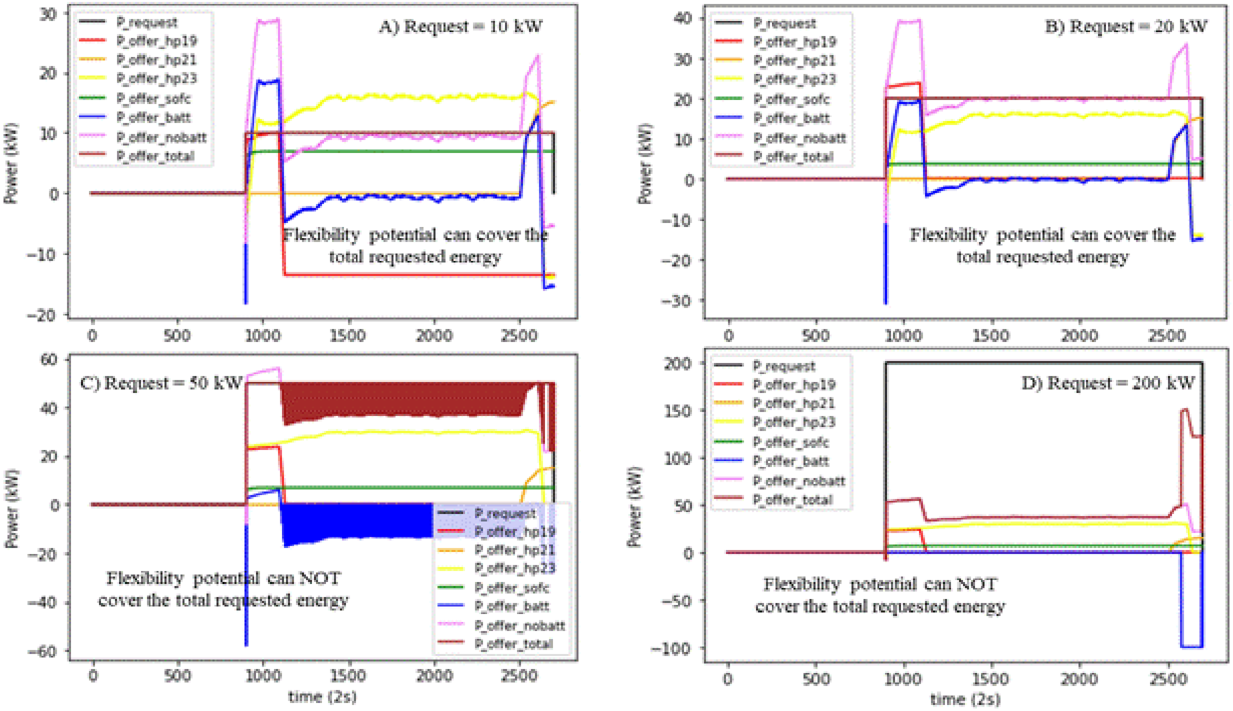


Figure 61 The potential of HES flexibility offers for Positive Value of Request

- **Discussion**

As it can be observed in above figures, the proposed algorithm for flexibility offer potential is effective in predicting the amount of flexibility offer in response to the DSO request within the proposed timing. The baselines and initial states of the assets were measured and saved one hour before the flexibility period.

When the request is negative, the cluster manager (HES) tries to offer the flexibility by increasing the power consumption of its assets: hp_19, hp_21, hp_23, power to gas system (SOEC) and battery. In this case and when the value of request is -50 kW, -100 kW and even -150 kW, the HES flexibility offer predicted by algorithm, can cover all the energy requested by the DSO during the one hour of flexibility period (50 kWh, 100 kWh and 150 kWh, respectively). But in the case where the request is -200 kW, the HES cannot totally cover all of energy requested from DSO but only 84.58 % of total requested energy. In this case, as it shown in above figure, HES uses maximum capacity of its assets to offer the flexibility (for example the battery is charged at each time step within its maximum power charging limit and maximum SOC limit.

When the request is positive, the cluster manager (HES) tries to offer the flexibility by consuming less power and/or producing the power with its own assets: hp_19, hp_21, hp_23, power to gas system (SOFC) and battery. In this case and when the value of request is 10 kW and 20 kW, the HES flexibility offer which is predicted by the algorithm, can cover all the energy requested from DSO during the one hour of flexibility period (10 kWh and 20 kWh). But in the case where the request is 50 kW or higher than 200 kW, the HES cannot totally cover all of energy requested from DSO; it can cover 90.54% and 22.63% of total requested energy respectively. In this case, as it is shown in above figure, the HES uses the maximum capacity of its assets to offer the flexibility (for example the battery is discharged at each time step within its maximum power discharging limit and minimum SOC limit.

Overall, the results suggest that the proposed algorithm can effectively predict the flexibility offer potential of the assets in response to DSO requests, thereby enabling it to produce a reliable flexibility offer of the integrated system.

3.2.2.6 TC 8.2 Communication with OIKEN

- **Description of the test case**

This test case aims to test the communication between HES and OIKEN using the EFLEX platform developed by Emax in WP7.

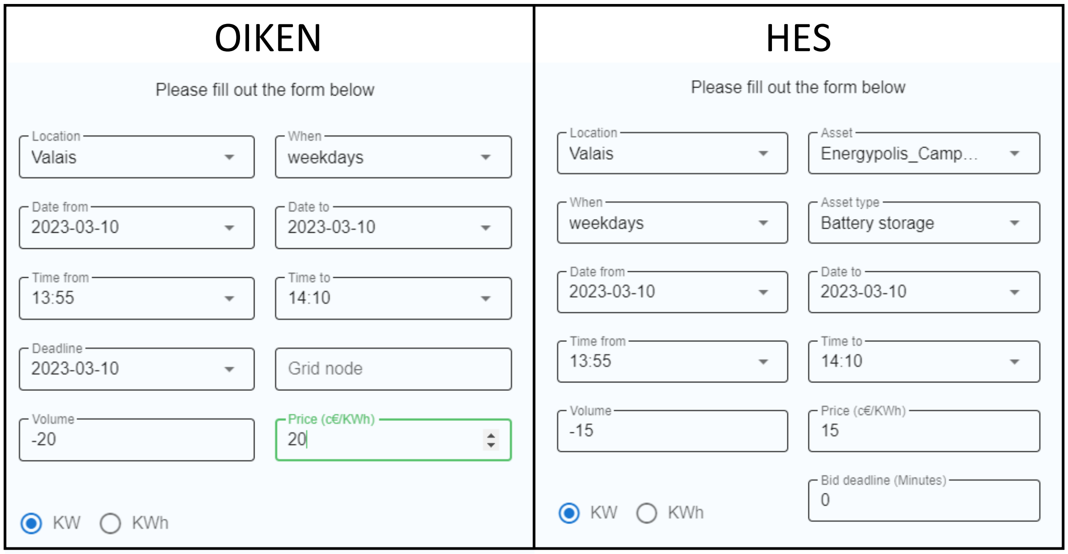
- **Proposed scenarios for implementation**

In this scenario, the whole flexibility exchange is tested using the EFLEX platform, as described in TC8.2 of deliverable D8.1. The flexibility exchange process implemented on the EFLEX platform works with offers and requests. OIKEN, the local DSO, produces a forecast every hour during its everyday operation to estimate its balancing needs and then posts a flexibility request on the EFLEX platform. Following this HES generates a flexibility offer. In order to do so, HES makes a flexibility potential prediction aiming to generate an offer which is as close as possible to OIKEN’s request and that could then potentially reduce its load imbalance.

- **Outcomes**

The whole communication process was successfully tested. Some insights are given here even if a more detailed description of the process is provided in D7.3, as this deliverable focuses on the platform. In its current configuration, the EFLEX platform hosts different accounts for DSOs and flexibility service providers (FSPs). The FSP can then easily add an offer using either an online formular or by uploading an Excel file. An example of flexibility request / offers posted by OIKEN / HES is provided in Figure 62. Basically, it allows the DSO to specify a period, a location, a volume and a price. For the FSP, additional specifications are available:

- Asset / asset type: Allows one to select the asset with which the offer will be performed. This is used mainly during the validation as EFLEX needs to know which data have to be considered.
- Bid deadline: Allows one to specify a deadline before which one needs to have received the flex offer acceptance confirmation.



OIKEN

Please fill out the form below

Location: Valais
When: weekdays
Date from: 2023-03-10
Date to: 2023-03-10
Time from: 13:55
Time to: 14:10
Deadline: 2023-03-10
Grid node
Volume: -20
Price (c€/KWh): 20
● KW ○ KWh

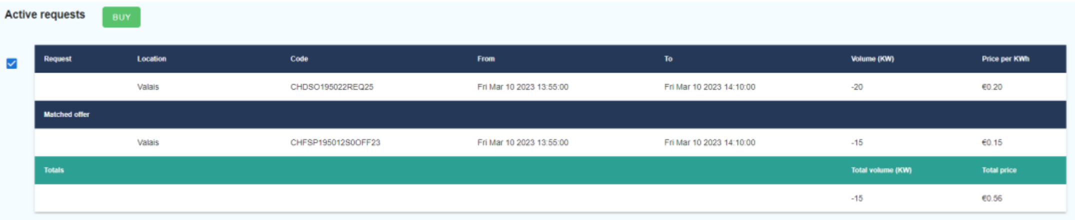
HES

Please fill out the form below

Location: Valais
Asset: Energypolis_Camp…
When: weekdays
Asset type: Battery storage
Date from: 2023-03-10
Date to: 2023-03-10
Time from: 13:55
Time to: 14:10
Volume: -15
Price (c€/KWh): 15
Bid deadline (Minutes): 0
● KW ○ KWh

Figure 62:Example of flexibility request (left) and flexibility offer (right)

Once the flex request and offer have been posted, the DSO can match the interesting offers and buy them (see Figure 63).



Request	Location	Code	From	To	Volume (KW)	Price per KWh
	Valais	CHDSO195022REQ25	Fri Mar 10 2023 13:55:00	Fri Mar 10 2023 14:10:00	-20	€0.20
Matched offer						
	Valais	CHFSP195012S0OFF23	Fri Mar 10 2023 13:55:00	Fri Mar 10 2023 14:10:00	-15	€0.15
Totals					Total volume (KW)	Total price
					-15	€0.56

Figure 63: Flex request / offer matching

Following this step, both DSO and FSP receive a confirmation by email that the offer was accepted (see Figure 65). Finally, once the delivery period has ended, the DSO has the opportunity to validate the transaction and thus to pay the FSP.

Dear,

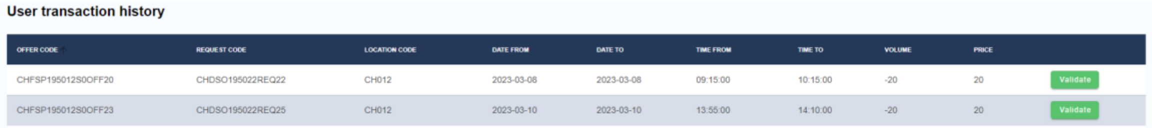
Your offer has been accepted by .

Offer code:	CHFSP195012S0OFF23
From date:	2023-03-10
To date:	2023-03-10
From time:	13:55
To time:	14:10
Day type:	weekdays
Price per kWh:	0.15 €
Volume:	-15.0 KW

Kind regards,

eFlex support team

Figure 64: Example of flex offer acceptance notification



User transaction history

OFFER CODE	REQUEST CODE	LOCATION CODE	DATE FROM	DATE TO	TIME FROM	TIME TO	VOLUME	PRICE	
CHFSP195012S0OFF20	CHDSO195022REQ22	CH012	2023-03-08	2023-03-08	09:15:00	10:15:00	-20	20	Validate
CHFSP195012S0OFF23	CHDSO195022REQ25	CH012	2023-03-10	2023-03-10	13:55:00	14:10:00	-20	20	Validate

Figure 65: Validation of the flexibility offer

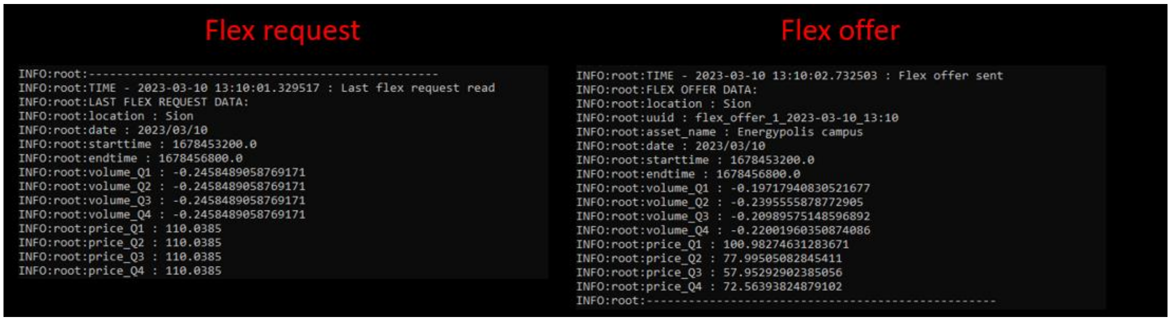
- **Discussion**

The EFLEX platform developed by EMAX behaves as expected and fulfils the needs of the demo case in Switzerland. Offers / requests can be posted for positive or negative volumes, an intelligent matching simplifies the choice of interesting offers and the location of the assets is considered.

However, a few aspects can be discussed:

- Initially, HES / OIKEN had planned to use (and had developed) an API to post flex offers / requests, in order to automate the exchange. An example of automated flex request / offer posting is provided in Figure 66. Offers / requests are posted every hour. Unfortunately, it is not possible to integrate this process into the EFLEX platform, notably due to constraints linked to the use of blockchain technology. This represents a large disadvantage as it does not allow for a regular exchange of flexibility. Indeed, as OIKEN generates balancing need predictions every hour, it would be too time consuming to manually set up every request / offer (the Excel loading simplifies the process if one wants to add multiple requests / offers at the same time, but it does not solve the issue).

- The platform is based on crypto currency for all transactions; as of now, for development purposes, it uses dummy crypto currency (Goerli and then Sepolia test network). The use of blockchain and cryptocurrency results in an overall process being rather slow : transactions have to be performed for any event (for example, even for the edition of an offer) and are slow.



Flex request

```
INFO:root:--------------------------------------------------
INFO:root:TIME - 2023-03-10 13:10:01.329517 : Last flex request read
INFO:root:LAST FLEX REQUEST DATA:
INFO:root:location : Sion
INFO:root:date : 2023/03/10
INFO:root:starttime : 1678453200.0
INFO:root:endtime : 1678456800.0
INFO:root:volume_Q1 : -0.2458489058769171
INFO:root:volume_Q2 : -0.2458489058769171
INFO:root:volume_Q3 : -0.2458489058769171
INFO:root:volume_Q4 : -0.2458489058769171
INFO:root:price_Q1 : 110.0385
INFO:root:price_Q2 : 110.0385
INFO:root:price_Q3 : 110.0385
INFO:root:price_Q4 : 110.0385
```

Flex offer

```
INFO:root:TIME - 2023-03-10 13:10:02.732503 : Flex offer sent
INFO:root:FLEX OFFER DATA:
INFO:root:location : Sion
INFO:root:uuid : flex_offer_1_2023-03-10_13:10
INFO:root:asset_name : Energypolis campus
INFO:root:date : 2023/03/10
INFO:root:starttime : 1678453200.0
INFO:root:endtime : 1678456800.0
INFO:root:volume_Q1 : -0.19717940830521677
INFO:root:volume_Q2 : -0.2395555878772905
INFO:root:volume_Q3 : -0.20989575148596892
INFO:root:volume_Q4 : -0.22001960350874086
INFO:root:price_Q1 : 100.98274631283671
INFO:root:price_Q2 : 77.99505082845411
INFO:root:price_Q3 : 57.95292902385056
INFO:root:price_Q4 : 72.56393824879102
INFO:root:--------------------------------------------------
```

Figure 66: Example of flex request / offer exchanged via local API

3.2.2.7 TC 8.3 Reliable flexibility offer using batteries

- **Description of the test case**

This test case aims to demonstrate that flexibility can be offered by the batteries of the Energypolis Campus

- **Proposed scenarios for implementation**

A flexibility request of 50kW over 1 hour is posted by OIKEN. The flex offer generation algorithm computes that a maximum of 17.36 kW during the whole hour can be offered by the batteries and the offer is posted. The baseline of the battery is 0kW. OIKEN accepts the offer and the batteries offer flexibility.

- **Outcomes**

The obtained results are presented in Figure 67 both in terms of flex offer, flex request and battery profile.

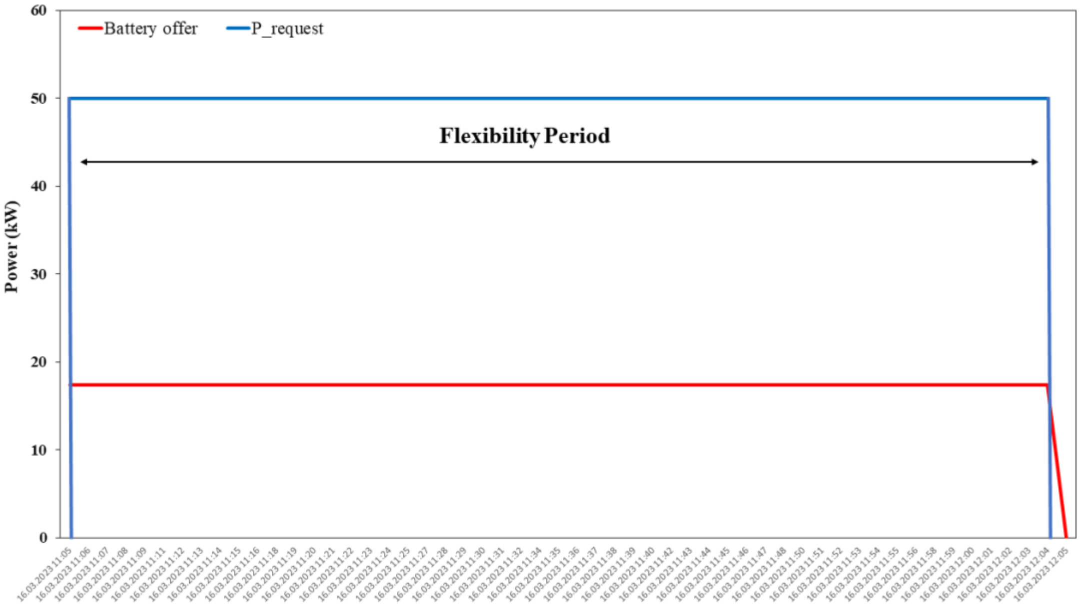


Figure 67 : Flexibility supply using the batteries

- **Discussion**

As expected, the batteries react extremely fast (independently of charging /discharging) and the delivery rate is 100%. A setpoint is sent every second, which results in an accurate control of the asset. What is more interesting is the volume of the offer. In this case, the posted offer was really less than what was desired by the DSO. A volume of 17.36kWh is extremely small as the batteries have a total capacity of about 250kWh. This is a result of the initial state of charge, which was close to the accepted limit. During the last days, the batteries were only in the same direction (batteries were discharged), resulting in an available volume rather small.

3.2.2.8 TC 8.4 Reliable flexibility offer using heat pumps

- **Description of the test case**

This test case aims to demonstrate that flexibility can be offered by the heat pumps of the Energypolis Campus.

- **Proposed scenarios for implementation**

Heat pump of building 19 is controlled to offer flexibility to OIKEN. Two tests are performed:

1. A positive flexibility request of 50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 31.6kW and OIKEN accepts it.
2. A negative flexibility request of -50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -30.28 kW and OIKEN accepts it.

In the other test, heat pump of building 23 is controlled to offer flexibility to OIKEN. Two other tests are performed:

3. A positive flexibility request of 35kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 28.92kW and OIKEN accepts it.
4. A negative flexibility request of -23kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -19.33 kW and OIKEN accepts it.

At the end, all heat pumps of building 19, building 21 and building 23 are controlled to offer flexibility to OIKEN. Two tests are performed:

5. A positive flexibility request of 65kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 60.95kW and OIKEN accepts it.
6. A negative flexibility request of -80kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -68.95 kW and OIKEN accepts it.

- **Outcomes**

The following profiles are obtained for tests 1 and 2 by heat pump of building 19:

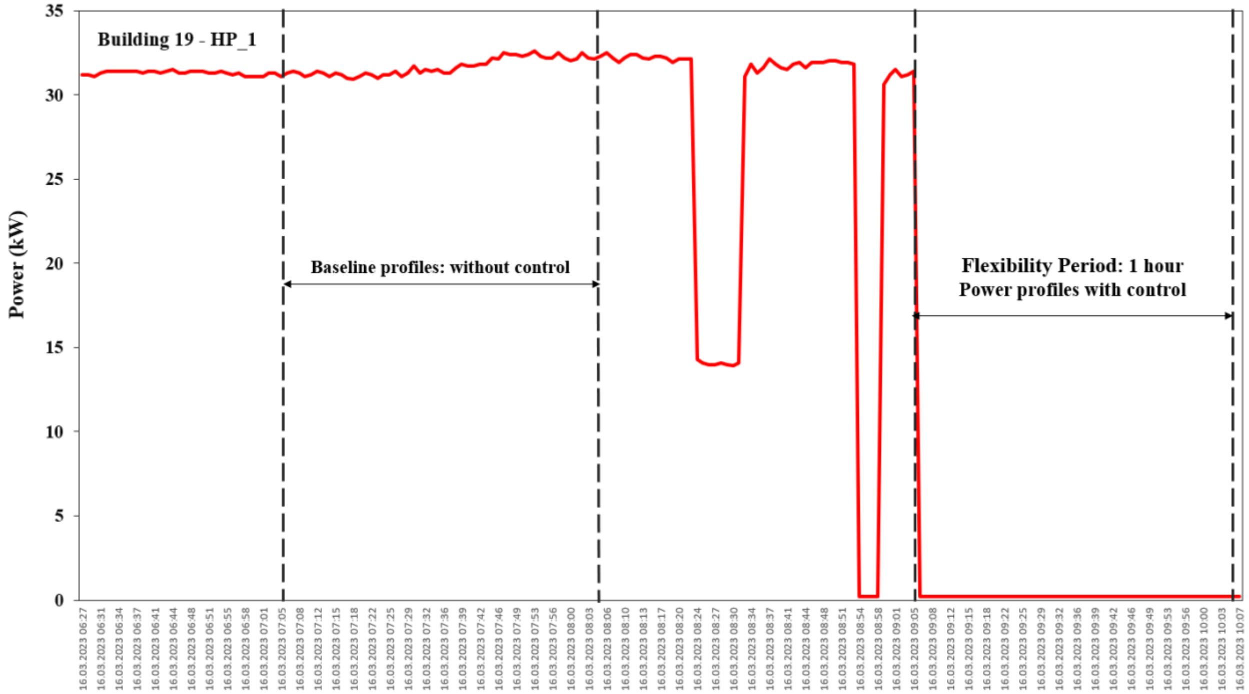


Figure 68 : Results of test 1

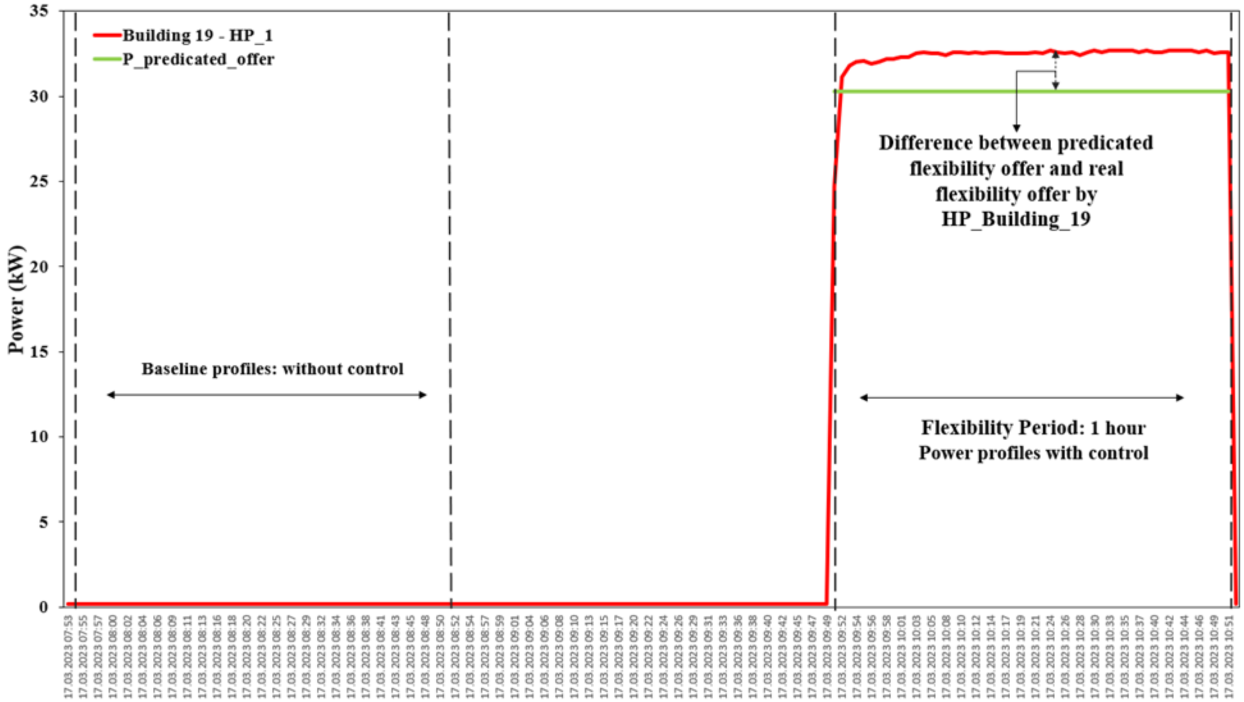


Figure 69 : Results of test 2

The following profiles are obtained for tests 3 and 4 by heat pump of building 23:

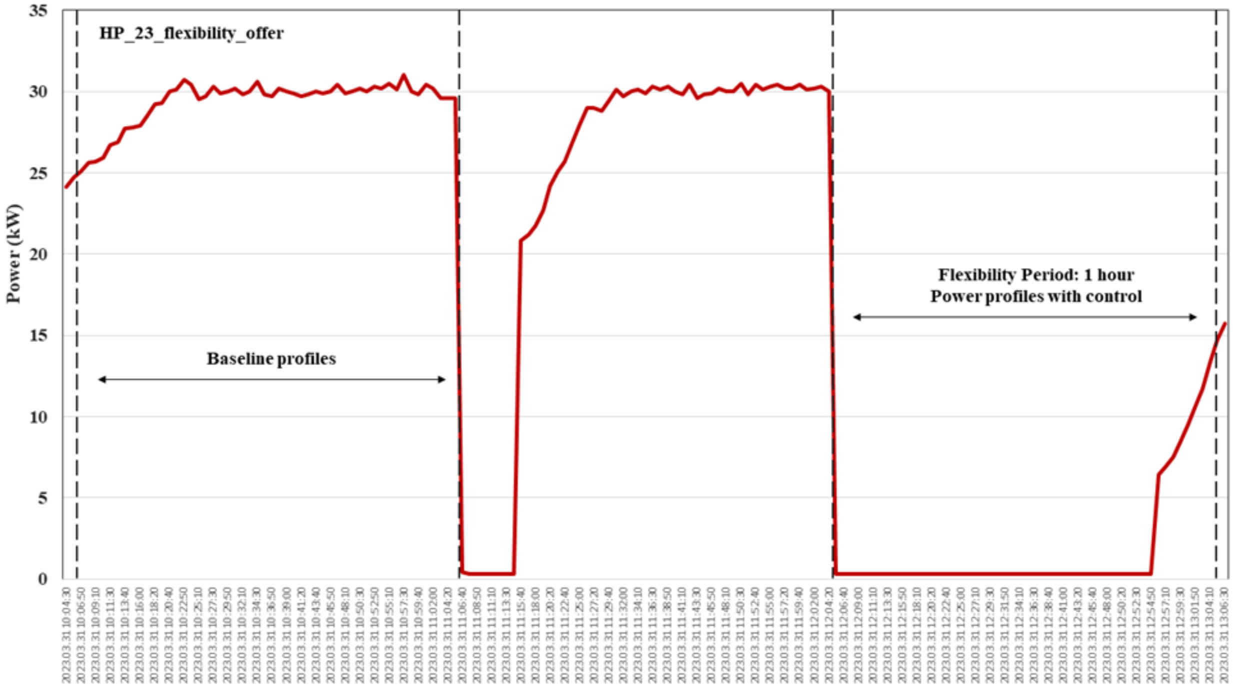


Figure 70 Resulted Power flows from test 3

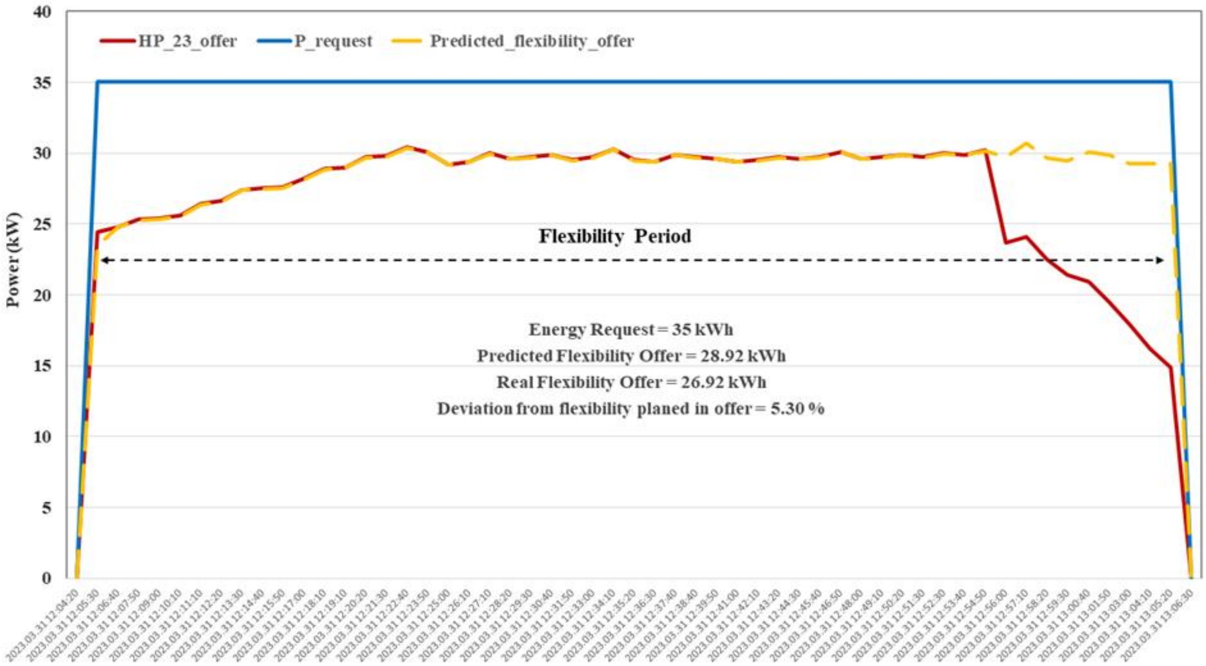


Figure 71 Resulted Flexibility Offer from test 3

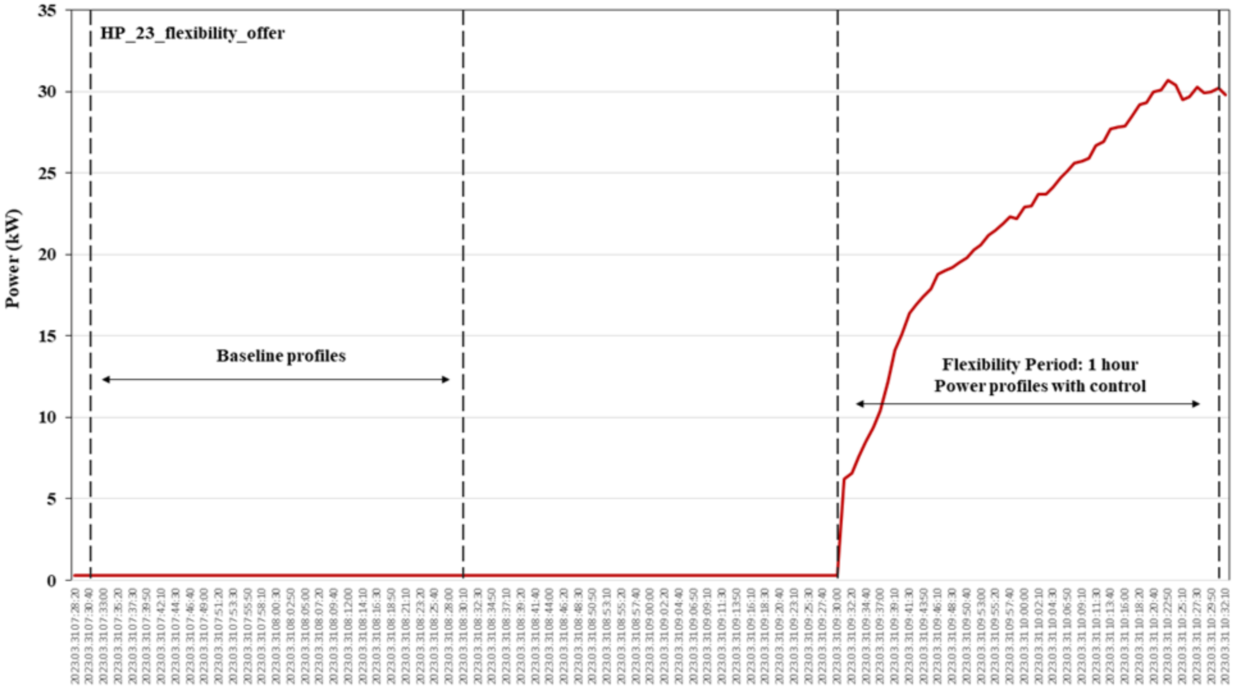


Figure 72: Resulted Power flows from test 4

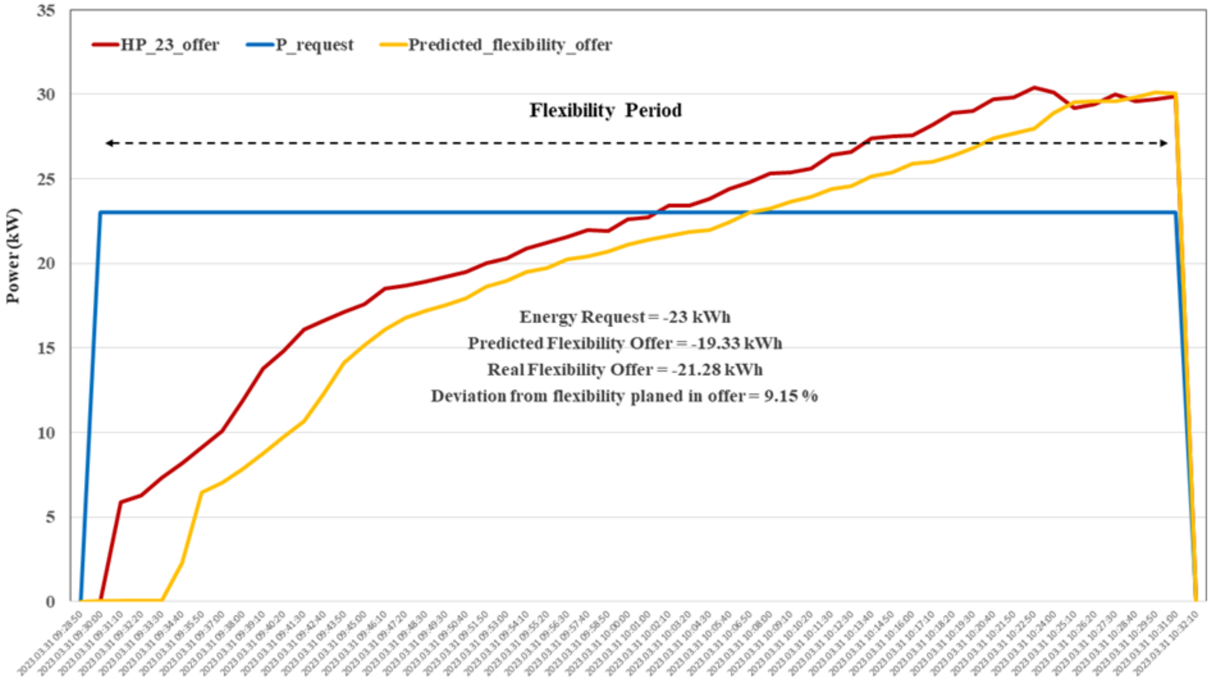


Figure 73 Resulted Flexibility Offer from test 4

The following profiles are obtained for tests 5 and test 6 by all heat pumps of building 19, building 21 and building 23:

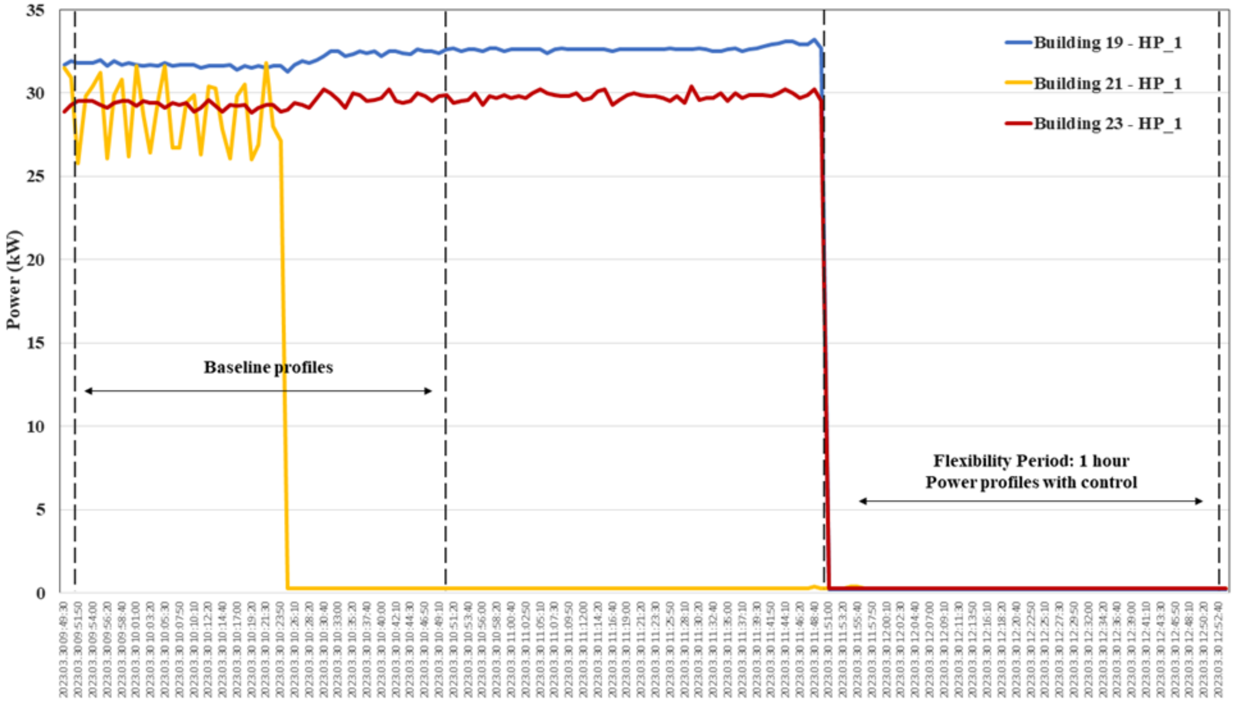


Figure 74 Resulted Power flows from test 5

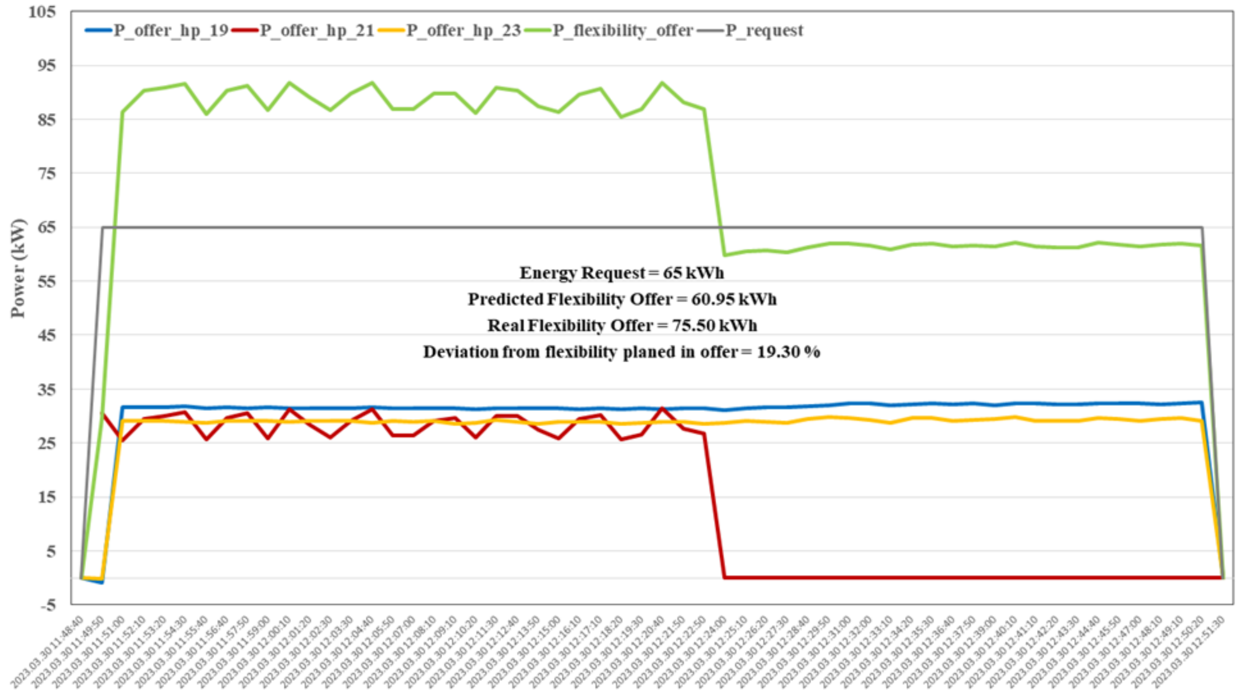


Figure 75 Resulted Flexibility Offer from test 5

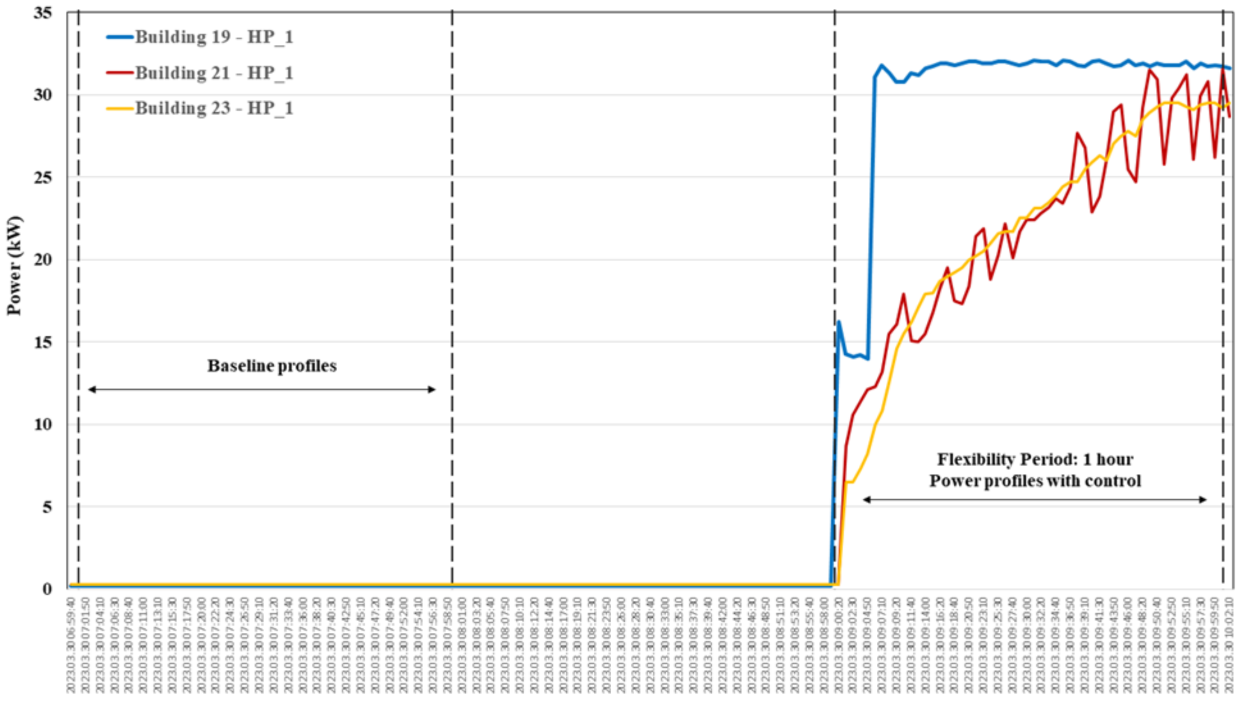


Figure 76 Resulted Power flows from test 6

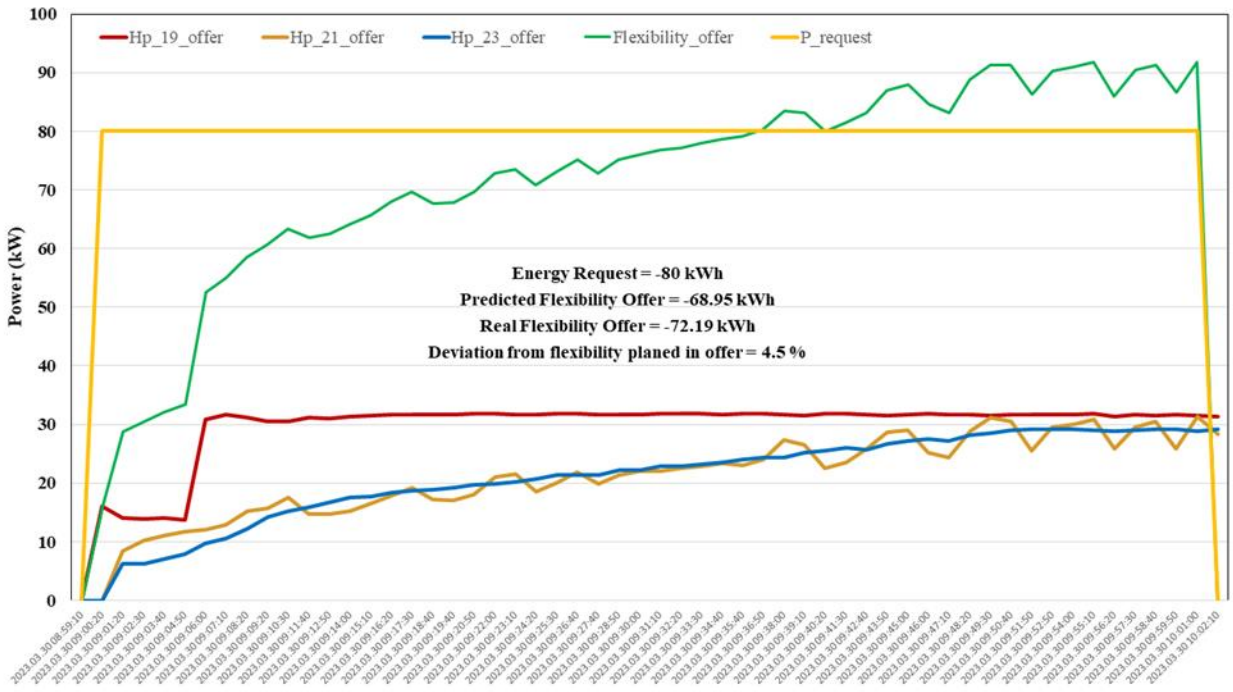


Figure 77 Resulted Flexibility Offer from test 6

- **Discussion**

➢ Test 1, 2:

As already observed in the control test cases 1 and 2, the heat pump of building 19 reveals to be reliable. For test 1, heat pump 19 behaved as expected and delivered 100% of the flex offer. As the heat pump was in the same state at the beginning of the control period as during the baseline, the two compressors were simply shut down to reduce the consumption. For test 2, the situation is quite different. Indeed, in this situation the flex offer resulted in a start of the heat pump, which turned on at the desired time. However, the electrical power which is obtained is higher than expected, resulting in a delivered volume equivalent to about 106% of what was planned in the offer. This difference is a result of the method which was used to generate the flex offer. Concretely, the flex offer generation is based on the selection of typical profiles of the heat pump (see TC 8.1), solely considering the electrical power profile. Nevertheless, the return and supply temperatures of the heat pump influence its COP, resulting in a different electrical consumption at full load. During the flexibility supply, temperature conditions are set to be similar to the ones that were observed during the typical profiles generation, but differences occur. Also, the PID controller of the circulation pump and of the heat pump may also justify this difference. To sum up, differences will occur, but as demonstrated by this test, these should remain acceptable.

➢ Test 3, 4

In the plots of control test cases 3 and 4, it is evident that the heat pump in building 23 is reliable. It's important to note that the heat pumps in buildings 23 and 21 differ from the one in building 19, so their reliability also differs. In fact, the response of the heat pump in building 19 is quicker than the other two. For test 3, OIKEN requested a positive consumption by the cluster manager, which means consuming less. Consequently, the heat pump in building 23 was shut down at the beginning of the flexibility period to reduce electricity consumption. In this case, the flexibility offer has well matched with the predicted flexibility offer. However, towards the end of the flexibility period, the heating demand in the building increased, causing the heat pump to start working again. In this test case, the HES delivered energy equivalent to 94.70% of what was planned in the offer. In test 4, OIKEN requested a negative consumption, meaning that more electricity had to be consumed. The heat pump in building 23 was run from the start of the flexibility period to consume more electricity. The plots in Figure 72 and Figure 73 show that the heat pump in building 23 takes longer to reach full load compared to the one in building 19, heat pump in building 19 takes a 1-3 minuets while the heat pump of building 23 takes 40-45 minutes. At the beginning of the flexibility period, the supplied flexibility was lower than the predicted offer, but towards the end, it exceeded the offer. In this test case, the HES delivered energy equivalent to 109.15% of what was planned in the offer. Overall, the flexibilities revealed by the heat pump in building 23 differ from the predicted flexibility offers, but the results show that they are acceptable.

- Test 5, 6

In control test cases 5 and 6, all heat pumps in buildings 19, 21, and 23 were controlled together to provide flexibility, and the results demonstrate that the flexibility provided by all heat pumps is reliable. In test 5, OIKEN required HES to consume less electricity, and all heat pumps were controlled to shut down at the start of the flexibility period. As shown in Figures 74 and 75, two heat pumps (buildings 19 and 23) were shut down from full load mode exactly at the start of the flexibility period, and they provided flexibility according to their baselines in the baseline period. However, the situation with the heat pump in building 21 was different. It was shut down at the end of the baseline period due to building demand and thechnical limitations, and it remained shut down during the flexibility period. Thus, the mode of the heat pump in building 19 at the start of the flexibility period was not the same as its baseline. Consequently, the selected profile of the heat pump in building 21, which was determined in the flexibility offer algorithm, was shut-down mode to shut-down mode, while the actual flexibility provided by the heat pump was limited to the times when it was in full load mode during the baseline period. The flexibility provided by all heat pumps in this test was 119.3% of what was planned in the flexibility algorithm, and the difference occurred due to the shut-down of the heat pump in building 21. In test 6, OIKEN required HES to consume more electricity, and all heat pumps were controlled to run at full load at the start of the flexibility period. As shown in Figures 76 and 77, all heat pumps started to run at the start of the flexibility period, going from zero mode to full load mode. As mentioned before, the heat pump in building 19 reached full load faster than the two other heat pumps in buildings 21 and 23. The flexibility provided by all heat pumps in this test was 104.5% of what was planned in the flexibility offer algorithm, which is closer to the request of OIKEN.

In summary, the flexibilities provided by all heat pumps differed from the flexibility offers predicted before, but the results show that they were within acceptable ranges.

3.2.2.9 TC 8.5 Reliable flexibility offer using the power-to-gas platform

- **Description of the test case**

This test case aims to demonstrate that flexibility can be offered by the power to gas and gas to power systems. At present no 20 kWel SOEC nor 8 kWel SOFC assets are available for demonstration and the demonstration relies on 1) simulation models representing the dynamical behaviour of both systems, 2) a small-scale 300 Wel SOFC. On the one hand, the models are used to determine the input variables needed to control the real assets but also to simulate how these assets would behave given those input variables. Capabilities and reliability of the developed model are explained in TC 5.13. On the other hand, the small-scale fuel cell allows to demonstrates the possibilities of a real fuel cell.

- **Proposed scenarios for implementation**

Scenario 1:

The real small-scale 300 Wel gas to power system (SOFC) has been run to offer flexibility for a positive request from OIKEN.

Scenario 2:

The simulated large-scale power to gas (SOEC) and gas to power (SOFC) systems are controlled to offer flexibility to OIKEN. Two tests are performed:

  - A positive flexibility request of 8 kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 6.93 kW by gas to power system (SOFC) and OIKEN accepts it.
  - A negative flexibility request of -24 kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -21 kW by power to gas system (SOEC) and OIKEN accepts it.

More detailed SOEC and SOFC models are used for the simulation of the “real” asset, allowing thus to simulate differences between the real flexibility supply and the forecasted supply.

- **Outcomes**

Scenario 1:

Table 15 presents the initial conditions and parameters that were set up for testing the real SOFC and for determining the flexibility offer. The electrical current profile and measured cell voltage of the SOFC during a one-hour flexibility period are presented in Figure 78, while the measured output power is shown in Figure 79.

Table 15: Initial parameters for the SOFC test case

Number of Cells	Current range	Current increase rate	Fuel utilization	Hydrogen flow rate	Tinlet_Air (Temperature)	Tinlet_Fuel (Temperature)	Air flow rate
-	I [A]	[A/min]	-	L/min	°C	°C	L/min
15	11.8-17	11.8-17	0.66	2.68	600	620	30

Figure 78 : Electrical current and cell voltage of the real SOFC vs. SOFC model

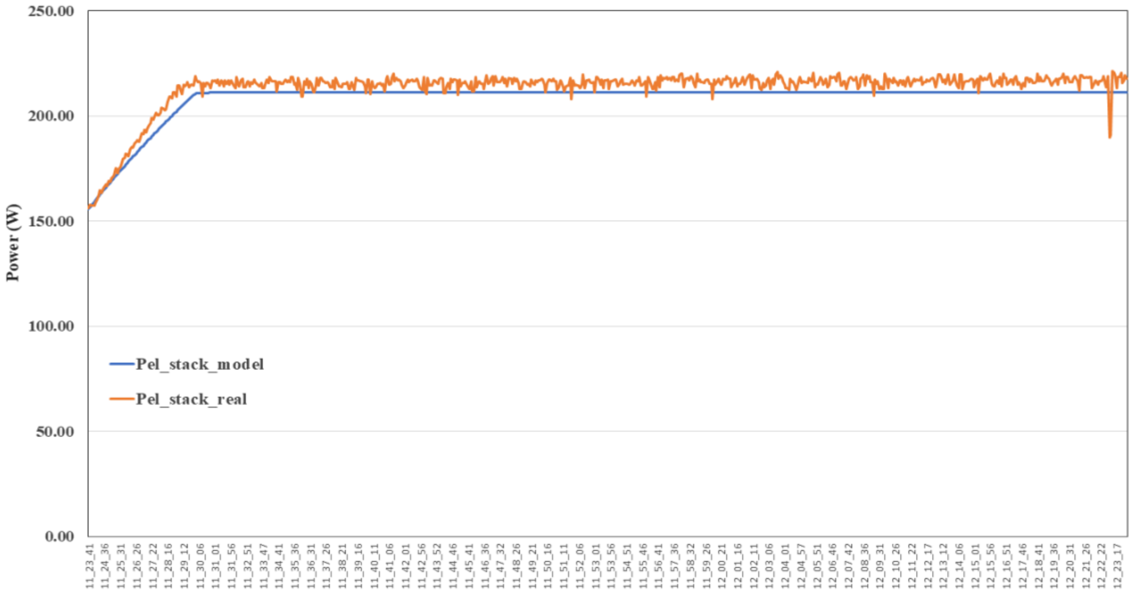


Figure 79 : Electrical power of the real SOFC vs. SOFC model

<u>Scenario 2:</u>

The following profiles, in Figure 80 and Figure 81, are obtained for tests 1 and test 2 by large-scale gas to power and power to gas models, respectively.

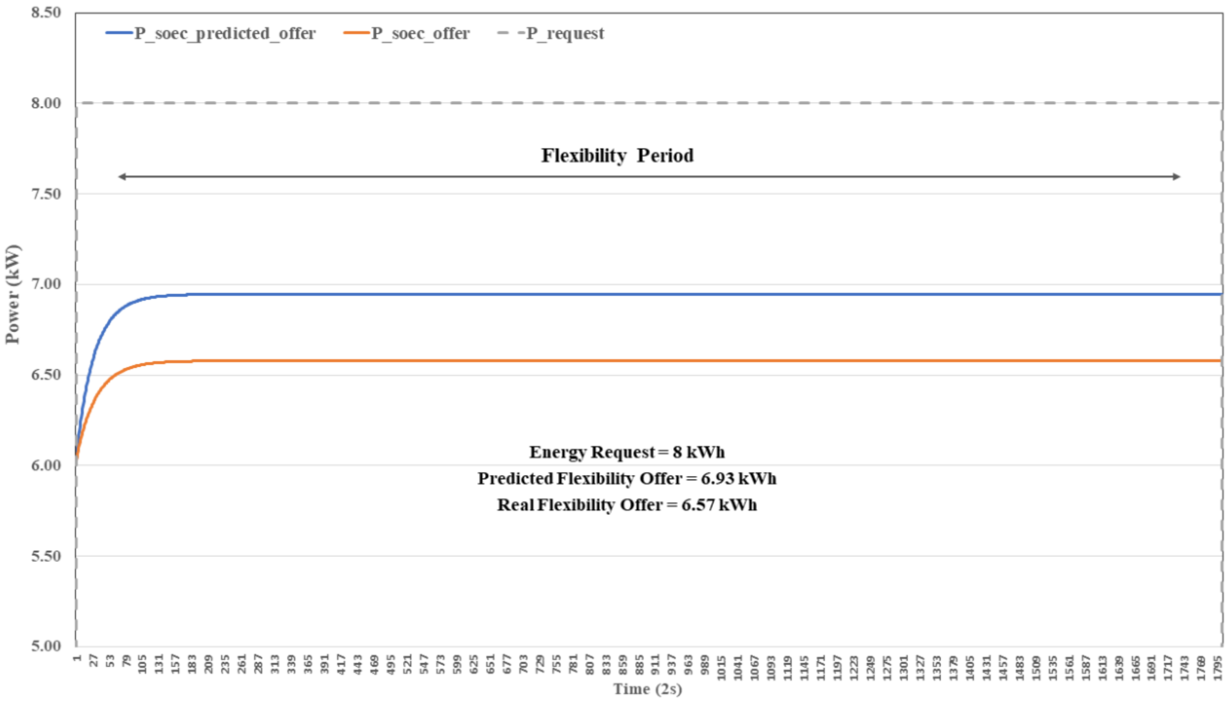


Figure 80 : Flexibility offer vs. flexibility offer prediction (test case 1, SOFC)

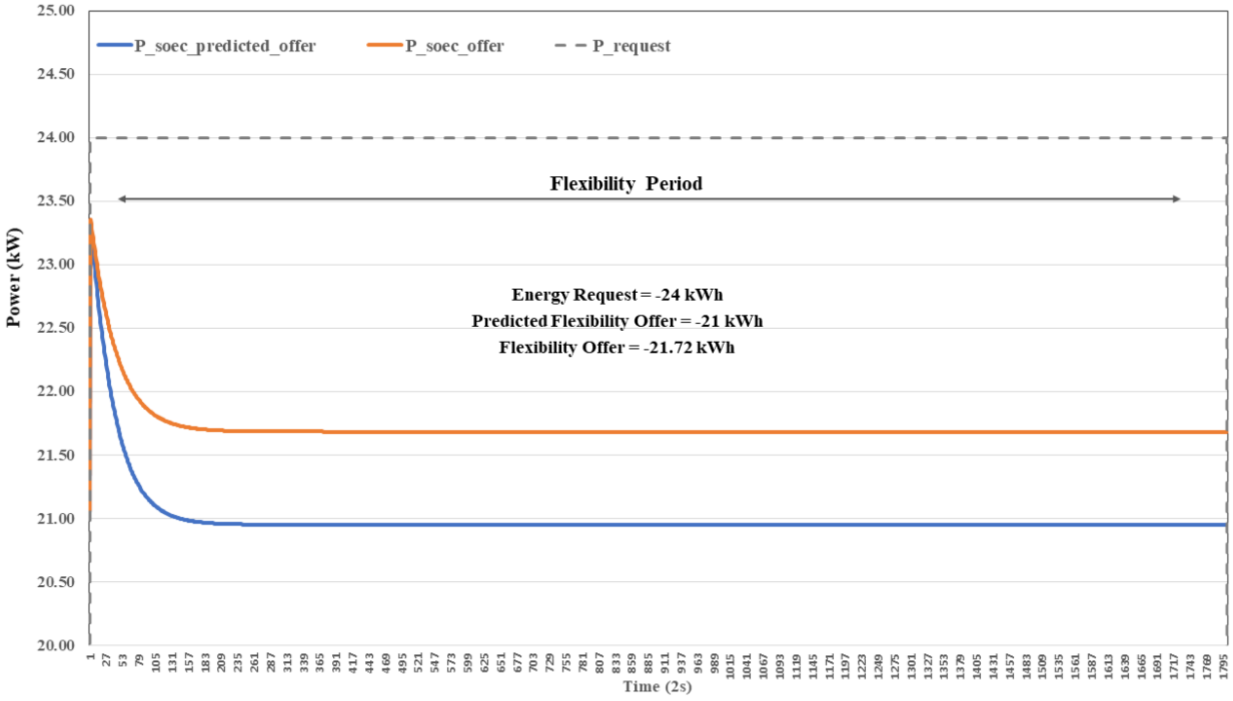


Figure 81 : Flexibility offer vs. flexibility offer prediction (test case 2, SOEC)

- **Discussion**

Scenario 1:

As expected, the cell voltage decreases with an increase of the electrical current of the SOFC due to the increase in potential losses (i.e., ohmic, concentration, and diffusion losses) in the SOFC.

Figure 79 illustrates the measured output power and simulated power of the SOFC, which are considered as the flexibility offer and predicted flexibility offer, respectively. The total produced energy in the flexibility period by the real test is 214.10 Whel, whereas the simulated model produced 209.17 Whel. The error of 2.35% is acceptable and indicates that the gas-to-power system SOFC can be considered a reliable and promising asset for flexibility applications.

Scenario 2:

Figure 80 shows that the flexibility offering by the gas-to-power system (SOFC) is 5.5% less than the predicted flexibility offer. However, this difference is rational and acceptable. The reason for this difference is due to the use of different models during flexibility offering and response times. As previously mentioned, the model used to simulate the system's dynamic behaviour is more comprehensive and provides a better representation of the system's operation. Specifically, in the energy balance part of the SOFC model, two convective and conductive mechanisms of heat transfer are considered in addition to radiation, resulting in less power produced by the SOFC compared to the predicted power from the flexibility offer algorithm.

Figure 81 indicates that the flexibility offer by the power-to-gas system (SOEC) is 3.43% higher than the predicted flexibility offer, which is also acceptable. In this case, the model used during flexibility time considers three heat transfer mechanisms instead of just radiation in the energy balance part, resulting in more power consumed by the SOEC than the predicted power offered.

3.2.9.10 TC 8.6 Optimisation of self-consumption

- **Description of the test case**

This test case was elaborated prior to the construction of the Energypolis campus and is thus unfortunately rather irrelevant in the actual context. Indeed, the total consumption of the campus being relatively high, the whole PV production is consumed most of the time without any optimization of the self-consumption. An example of the net consumption profile (consumption – PV production) for the two first weeks of April 2023 is given in Figure 82. As mentioned, the net consumption is high and never below 0. Nevertheless, an adapted scenario is proposed, aiming at testing the start of a heat pump and the charging of batteries during a high PV production period. Discussion will then be focused on the possibilities and limitations of self-consumption increase.

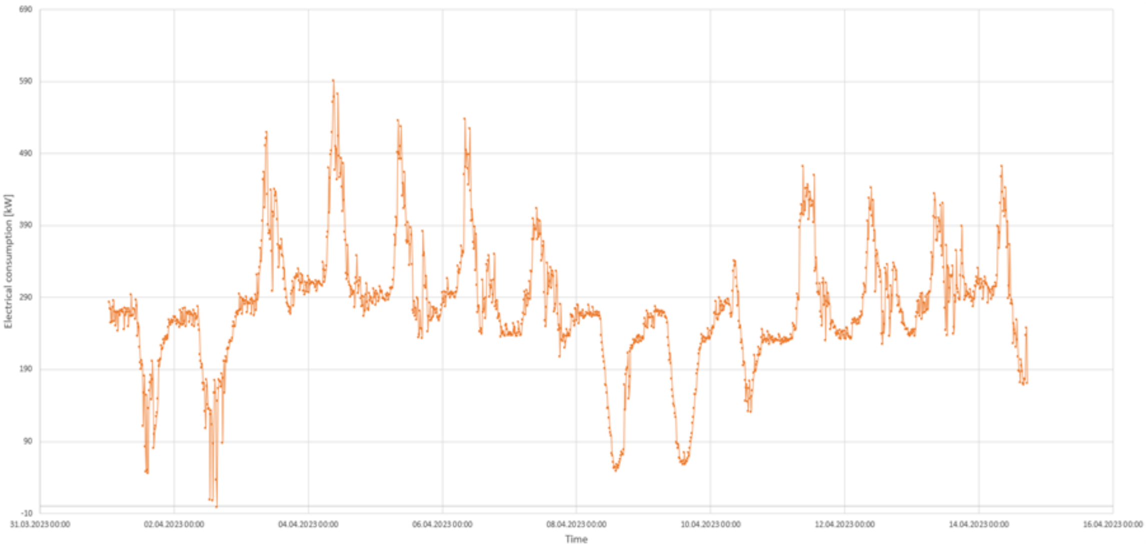


Figure 1: Consumption profile of Energypolis campus (2 firsts weeks of April 2023)

Figure 82: Consumption profile of Energypolis campus (2 firsts weeks of April 2023)

- **Proposed scenarios for implementation**

For this adapted scenario, a simple case with a PV production forecast, the start of heat pump 23 and the charging of batteries during the expected high PV production period is tested.

- **Outcomes**

The obtained results are presented in Figure 83.

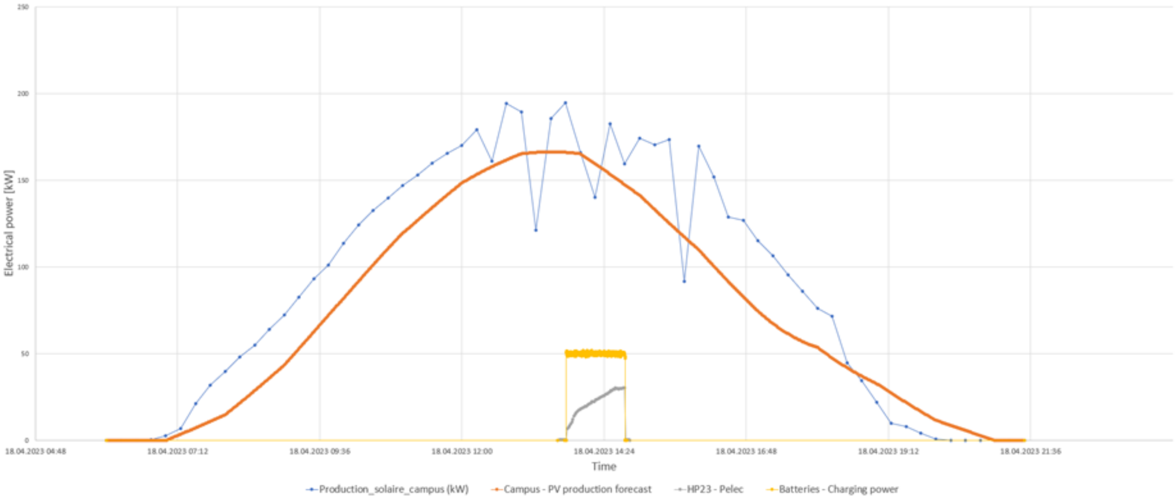


Figure 83: Start of heat pump 23 and batteries during a high PV production period

- **Discussion**

The results show that the heat pump and the batteries were successfully activated during a period of high PV production. This is a result of the accurate prediction (the assets were simply scheduled to be turned on for a duration of 1h during a period of high PV production) and good control of the assets (already presented in previous test cases). Nevertheless, a few aspects inherent to this test case can be pointed out:

- Optimization of self-consumption at the campus scale is not relevant, but it might be at the neighbourhood level for example. In the case of the campus, the large consumption can notably be attributed to the ventilation units of the laboratories. The building affectation will most of the time dictate the self-consumption possibilities; for instance, residential buildings with PVs are much more suited for self-consumption optimization.
- The availability of the batteries will depend on their state of charge at the beginning of the day, meaning that their overall usage / usefulness highly depends on the consumption / production ratio as well as on their size. Also, their availability largely depends on the activities for which the batteries are used. In this case, the batteries were reserved during a specific period for the Flexigrid project activities, ensuring high availability.
- The availability of the heat pumps is mainly influenced by the weather (external temperature) and by the control system of the considered building. During the period of the test (April, already inter-season), stopping the heat pump during most of the day did not cause any issue as thermal losses are low. However, turning on the heat pump at the hottest part of the day reveals to be trickier. Indeed, in the case of the Energypolis campus, two conditions are required so that the heat pumps can be turned on: 1) the installations have to be in “heating mode”, meaning that the mean temperature over a couple of hours should not be too high, 2) a heating demand has to be sent from the building supervision to the heat pump, allowing it to operate. This second point is often the crucial when trying to maximize the self-consumption. In this case, three main tricks were found to simulate a “dummy” heating need: 1) to stop the recuperation on the ventilation units (this solution is not considered as acceptable as it generates an overconsumption of the building, but it is the most efficient), 2) to send a “fake” external temperature measurement to force the installations to provide water at a higher temperature (the installations follow a heat curve based on the external temperature), 3) to directly increase the supply temperature of the water send to the concrete slabs. This solution should be the one allowing to store the most energy due to the thermal mass of the concrete. Overall, these solutions are extremely system-specific and seem difficult to generalize to any system.
- The presence of a water tank could increase the flexibility / self-consumption possibilities as hot water could be produced and simply stored (for example at a higher temperature and mixed with return water when used).
- From a financial point of view, using batteries solely for self-consumption increase seems to be difficult due to the high cost of storage as of today. However, the increase of self-consumption using heat pumps could reveal to be interesting for the installations owner since heat has to be produced anyway to ensure thermal comfort. Two interesting test cases could be considered: 1) Displacement of space heating production cycles in the winter period, 2) Displacement of domestical hot water production cycles (e.g., anti-legionellosis cycles).

3.2.2.11 TC 8.7 Reliable flexibility offer using the whole system

- **Description of the test case**

This test case aims to demonstrate that flexibility can be offered by all the combined use of all assets of the Energypolis Campus: batteries, heat pumps and a P2G system.

- **Proposed scenarios for implementation**

The heat pump of building 19, modelled P2G systems (SOFC and SOEC) and batteries are controlled to offer flexibility to OIKEN. Two tests are performed:

1) A positive flexibility request of 70kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 70kW and OIKEN accepts it.
2) A negative flexibility request of -50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -30.28 kW and OIKEN accepts it.

- **Outcomes**

The output of test 1 is presented in Figure 84 and Figure 85.

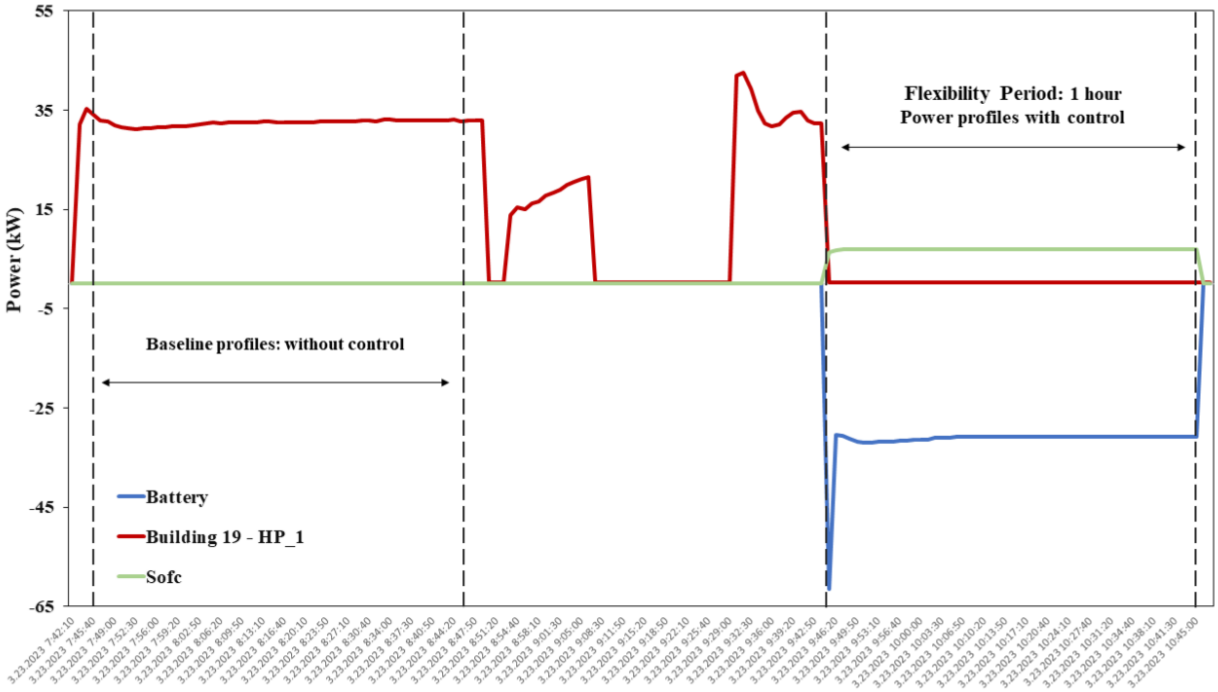


Figure 84 Resulted Power flows from test 1

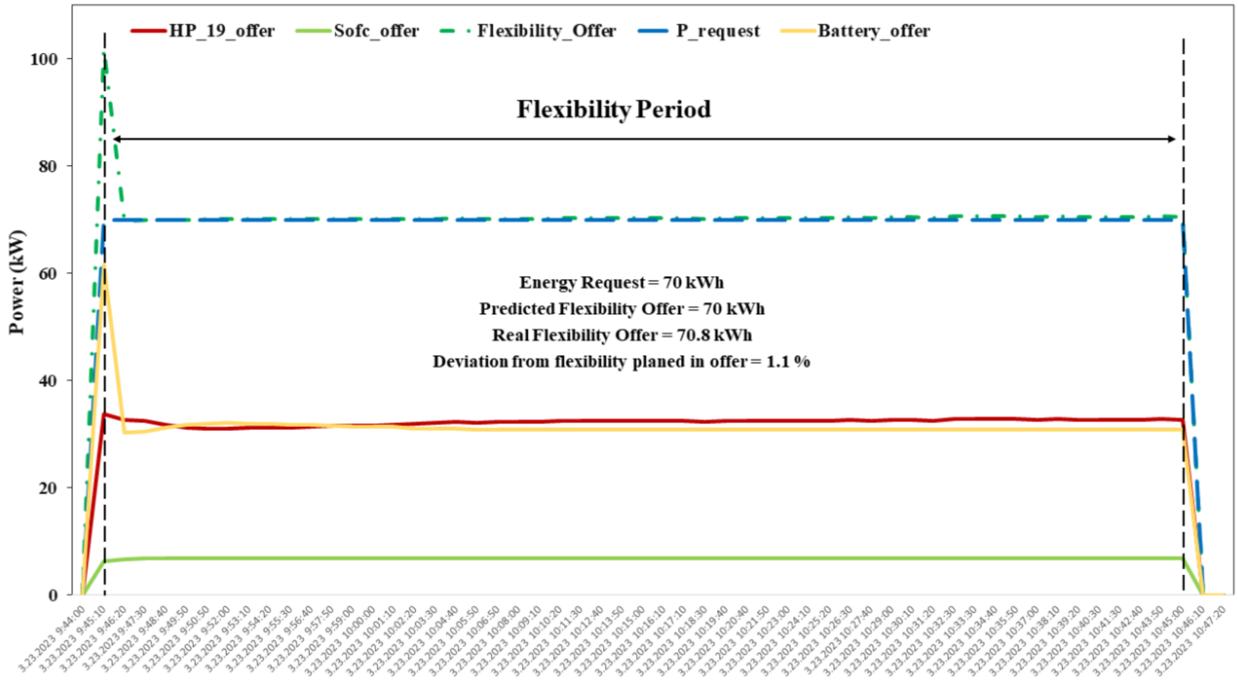


Figure 85 Resulted Flexibility Offer from test 1

The output of test 2 is presented as Figure 86 and Figure 87.

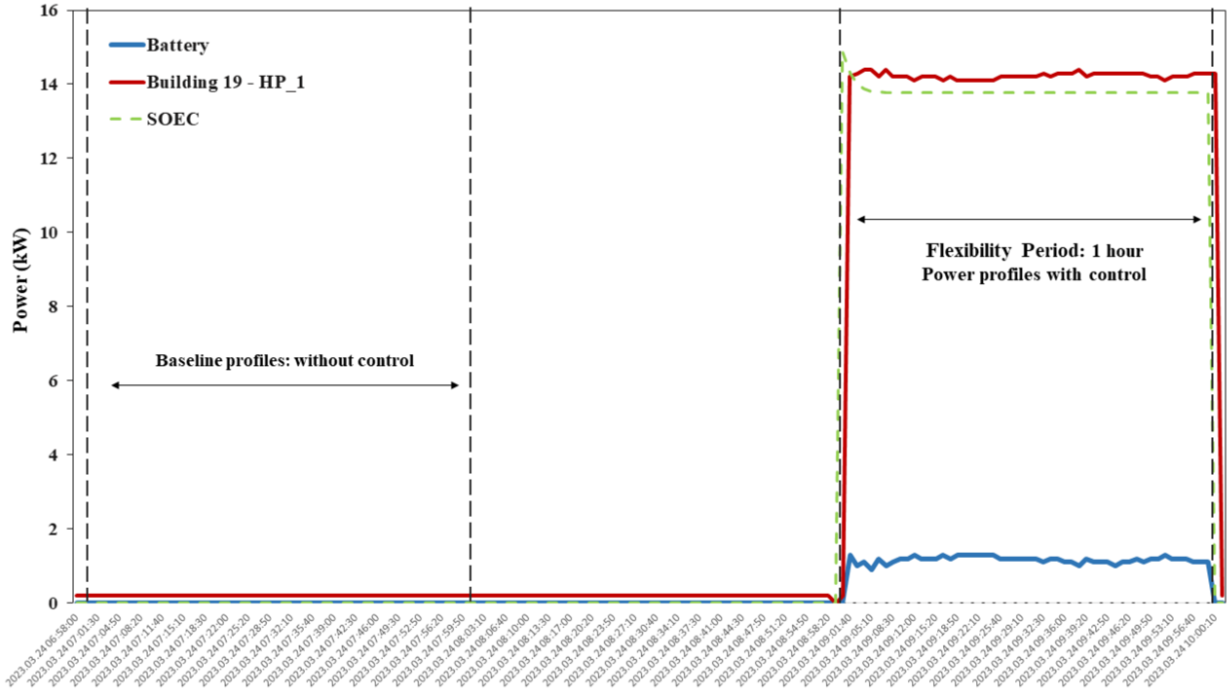


Figure 86 Resulted Power flows from test 2

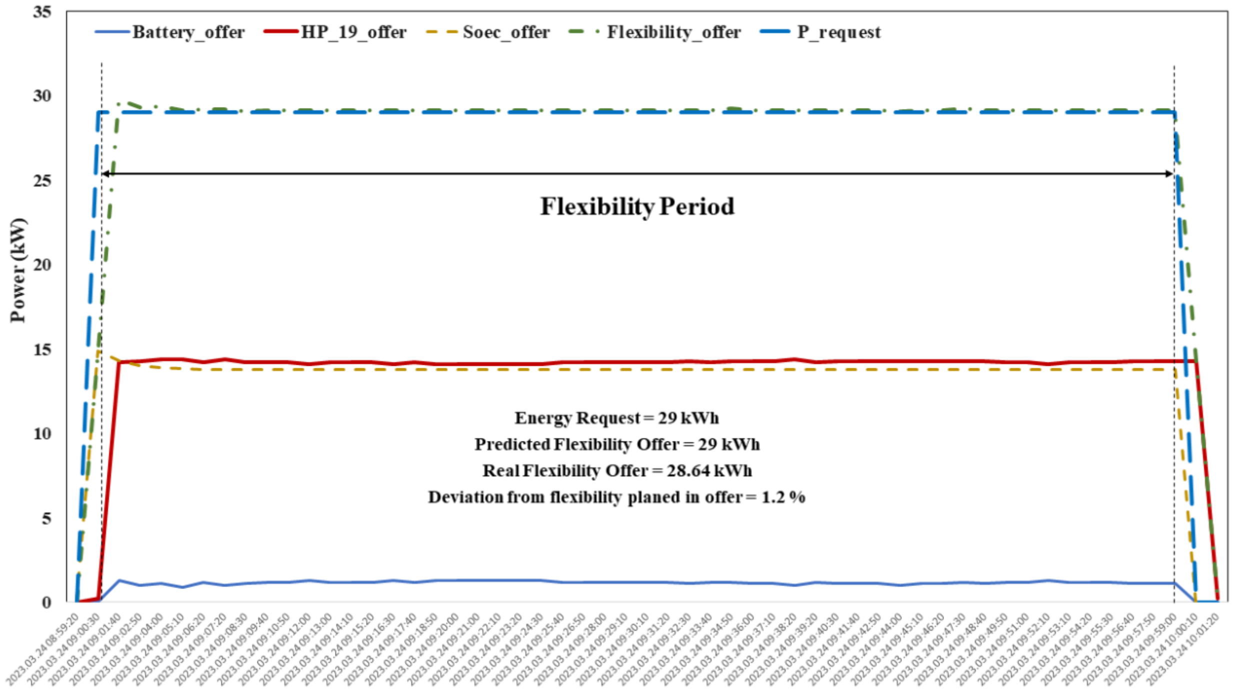


Figure 87 Resulted Flexibility Offer from test 2

- **Discussion**

Tests 1 and 2 have demonstrated that the cluster manager's (HES) assets - building 19's heat pump, batteries, and P2G (SOFC and SOEC) - provide reliable flexibility.

In test 1, the assets delivered 101.1% of the expected energy volume during the flexibility period. In this test, the request from the DSO is positive; it means there is a need to consume less power or produce power using the site's assets. The heat pump followed its planned profile, with two compressors being shut down to reduce consumption. The battery discharged power quickly to deliver the required energy. Also, the gas to power system (SOFC) produces power and follows its selected profile during the flexibility period (as would be expected from a simulated asset). However, there was a delay in the heat pump's power consumption reaching zero, with the battery discharging more power until the heat pump's power consumption reached zero. In this case, the request volume of DSO was 70 kWh, the offer was planned to be 70 kWh. The actual flexibility offered of 70.8 kWh had a 1.1% deviation from the planned offer, which is acceptable.

In test 2, the DSO requested negative energy, requiring more power consumption or energy production by the assets. The assets delivered 98.75% of the expected energy volume during the flexibility period. The heat pump again followed its planned profile, with two compressors being run to increase consumption. However, the batteries had a slower response in charging mode during the first few seconds of the flexibility period. Also, the power to gas system (SOEC) consumes power and follows its selected profile during flexibility period (as would be expected from a simulated asset). In this case, the request volume of DSO was 29 kWh, the offer was planned to 29 kWh. The actual flexibility offers of 28.64 kWh had a 1.2% deviation from the planned offer, which is acceptable.

Overall, the test results show that there are only minor differences between the planned flexibility algorithm and the actual flexibility offers. Therefore, the HES cluster manager can deliver flexibility as planned.

4. Summary and conclusions

This report presents the successful demonstration of the different test cases elaborated in deliverable 8.1 and is the result of consequent preliminary effort in terms of development, communication and infrastructure. The main goals reached and presented in this deliverable are:

Turkish pilot:

With the demonstration studies conducted, it has been shown that possible grid congestion problems (based on transformer load value) at the LV level can be solved through coordination between DSO and end user/FSP by activating demand side participation. In this direction, the interoperability of real assets and energy management platforms in preventing grid congestion problems has been emphasized with the demonstrated scenarios.Key achievements of the Turkish demo have been listed below:

- **Monitoring and visualization of the system variables:** All required measurements are performed and saved Data are shared to the IoT platform and can be visualized either with the local visualization tool or with the dashboard available at the IoT platform.
- **Testing of EV Management platform:** To manage the charging/discharging sessions of EVs and batteries, an energy management compatible platform was tested to activate demand side participation and unlock the flexibility potential of assets.
- **Dynamic control of EV chargers and batteries:** Control signals can be sent remotely either in an automated process or manually. Testing control signals were sent and followed satisfactorily by the different assets. Limitations in the control possibilities were identified.
- **Performing of V1G and V2G charging with EV chargers:** Smart charging concept was demonstrated in real environment with various use cases which focus on load and price based optimization scenarios.
- **Demonstration of flexibility delivery with EVs and batteries:** According to the flexibility need of DSO in a certain period of time, flexibility provisioning were performed with demand response scenarios by using EV Management platform and FlexiGrid IoT platform
- **Validation of “sample” flexibility trading between DSO and “potential” FSP:** A flexibility exchange process was established within the scope of demo studies and the market platform EFLEX developed by EMAX allowed to formalize the exchange of flexibility (flex offer / request posting, matching, validation, billing).

In conclusion, the study demonstrates the flexibility potential of assets engaged in the demo studies, and showes that a significant flexibility potential could be created for the DSO as such assets become more widespread. OEDAS will continue to run tests with the specified assets. Longer tests will be conducted, and results will be reported in the T8.4 "***Assessment, evaluation, and lessons learned***" section of the work package 8 according to the designated KPIs.

Swiss pilot:

- **Monitoring and visualization of the system variables:** All required measurements are performed and saved Data are shared to the IoT platform and can be visualized either with the local visualization tool or with the dashboard available at the IoT platform.

- **Control of different heat pumps and batteries:** Control signals can be sent remotely either in an automated process or manually. Testing control signals were sent and followed satisfactorily by the different assets. Limitations in the control possibilities were identified.
- **Development of a P2G model allowing to simulate the offer of flexibility:** Two P2G models were developed and allowed to simulate the offer of flexibility and the discrepancy between the forecasting and the actual results.
- **Tests on a small-scale fuel cell :** Tests were performed on a small-scale fuel cell and allowed to calibrate the model and to provide a flexibility service proof-of-concept.
- **Development of flexibility offer potential algorithm:** The algorithm is developed to predict the best possible flexibility offer can be provided by all assets at a certain time. The flexibility is offered according to the amount of request, selection the type of assets, test profiles and baselines of each asset.
- **Validation of the flexibility exchange process with the local DSO OIKEN:** A flexibility exchange process was established in cooperation with OIKEN and the market platform EFLEX developed by EMAX allowed the Swiss partners to formalize the exchange of flexibility (flex offer / request posting, matching, validation, billing).
- **Positive and negative flexibility supply to the local DSO OIKEN**: Assets were controlled to offer positive and negative flexibility to the local DSO OIKEN, either individually (e.g., only 1 heat pump) or combined (e.g., heat pumps combined to batteries). Flexibility services for balancing purposes were successfully provided to OIKEN.
- **Analysis of the reliability of the different assets:** The delivery rate of the different assets was analyzed, both for negative and positive flexibility services.

Also, the main lessons learnt during these demonstrations are:

- Communication process establishment is time-consuming and could jeopardize the development of flexibility at a large scale.
- Automated flexibility offers / requests exchange is required for a deployment at a large scale.
- Large differences appear in the flexibility potential and reliability of the different assets.
- During flexibility supply combining different assets, batteries can compensate for the lack of precision of other assets but at a high cost.
- The use of P2G for flexibility supply is possible, especially combined to batteries.

Nevertheless, the achievement of these demonstrations at the Swiss pilot was realized through pre-designed test cases and due to specific characteristics of the demo site, some results (notably the control and reliability of specific assets) can only be generalized within certain limits. These points will be part of the discussion carried out in the next deliverable 8.4 ***“Assessment, evaluation and lessons learned”***.

5. References

[1] ELDER. Türkiye Akıllı Şebekeler 2023 Vizyon ve Strateji Belirleme Projesi. 2018.