one network for Europe

Report on demonstrations

D10.4

Authors:

Ákos Baldauf (BME)

Bálint Hartmann (BME)

Gábor Péter Mihály (E-ON EDE)

Boris Turha (Elektro Ljubljana)

Matej Malenšek (GEN-I)

Luka Nagode (GEN-I)

Dominik Falkowski (EOP)

Robert Kielak (PSE)

Wojciech Lubczyński (PSE)

Ewelina Makuła (PSE)

Endika Urresti Padrón (NCBJ)

Grzegorz Pława (NCBJ)

Nermin Suljanović (EIMV)

Václav Janoušek (ČEZ)

Daniela Clarke (ČEPS)

Martin Chytra (EG.D)

Responsible Partner	BME
Checked by WP leader	Primož Rušt (ELES), 29/9/2023
Verified by the appointed Reviewers	Jukka Rinta-Luoma (FING), 13/09/2023 Anastasis Tzoumpas (UBE), 18/09/2023
Approved by Project Coordinator	Padraic McKeever (Fraunhofer), 04/10/2023

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About OneNet

The project OneNet (One Network for Europe) will provide a seamless integration of all the actors in the electricity network across Europe to create the conditions for a synergistic operation that optimizes the overall energy system while creating an open and fair market structure.

OneNet is funded through the EU's eighth Framework Programme Horizon 2020, "TSO – DSO Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation" and responds to the call "Building a low-carbon, climate resilient future (LC)".

As the electrical grid moves from being a fully centralized to a highly decentralized system, grid operators have to adapt to this changing environment and adjust their current business model to accommodate faster reactions and adaptive flexibility. This is an unprecedented challenge requiring an unprecedented solution. The project brings together a consortium of over seventy partners, including key IT players, leading research institutions and the two most relevant associations for grid operators.

The key elements of the project are:

1. Definition of a common market design for Europe: this means standardised products and key parameters for grid services which aim at the coordination of all actors, from grid operators to customers;
2. Definition of a Common IT Architecture and Common IT Interfaces: this means not trying to create a single IT platform for all the products but enabling an open architecture of interactions among several platforms so that anybody can join any market across Europe; and
3. Large-scale demonstrators to implement and showcase the scalable solutions developed throughout the project. These demonstrators are organized in four clusters coming to include countries in every region of Europe and testing innovative use cases never validated before.

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List of Abbreviations and Acronyms

Acronym	Meaning
FSR	Florence School of Regulation
aFRR	Automatic Frequency Restoration Reserve
AGNO	Aggregated Network Offers
AMR	Automatic Meter Reading
ANM	Active Network Management
API	Application Programming Interface
BSP	Balancing Service Provider
BESS	Battery Energy Storage System
BUC	Business Use Case
CEEGEX	Central Eastern European Gas Exchange
CEEPS	Central Electro-Energy Portal
CHP	Combined Heat and Power
CM	Congestion Management
CP	Coupling point area
DAM	Day-ahead Market
DANO	Disaggregated Network Offers
DGIA	Dynamic Grid Impact Assessment
DER	Distributed Energy Resources
DSM	Demand Side Management
DSO	Distribution System Operator
DSR	Demand Side Response
EV	Electric Vehicle
ESS	Energy Storage System
FMP	Flexibility Market Party
FMS	Flexibility Management System
FSP	Flexibility Service Provider
FR	Flexibility Register
GUI	Graphical User Interface
HV	High Voltage
HUPX	Hungarian Power Exchange
LV	Low Voltage
mFRR	Manual Frequency Restoration Reserve
M2M	Machine to Machine
MV	Medium Voltage

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MQ	Message Queue
MQTT	Message Queuing Telemetry Transport
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SLP	Standard Load Profile
SO	System Operator
SUC	System Use Case
POD	Point of Delivery
PV	Photovoltaic
RR	Replacement Reserve
REMIT	Regulation (EU) 1227/2011 on Wholesale Energy Market Integrity and Transparency
ONC	OneNet Connector
OPF	Optimal Power Flow
UI	User Interface
VC	Voltage Control
TSO	Transmission System Operator
TTF	Title Transfer Facility

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Executive Summary

This deliverable introduces the eastern cluster demonstrations that include the Czech Republic, Poland, Slovenia and Hungary. All four demonstrations were concluded successfully. The deliverable aims to provide the reader with an overview on how these demonstrators defined their areas, selected the services and products for the transmission/distribution network and/or system balancing flexibility market and how they implemented the research and development work in their respective IT environment.

Regarding the **Czech demo** the first phase of the demonstration and tests was done in autumn 2022. The second phase, the main parts of the demonstration activities of the CZ demo, took place during the 2nd and 3rd quarter of 2023. The initial part of the test included implementation of the network traffic light scheme according to test scenarios reflecting various grid issues. These scenarios considered both different grid states (network element unavailability states) and relevant KPIs (especially considering planned and unplanned grid outages). The traffic light scheme test has met our expectations in terms of benefits for energy market and especially for the FSPs. The feasibility of this concept is reflected in its implementation into the real operation. The second part of the tests involved EV charging infrastructure tests and the creation of a platform for non-frequency services. The platform testing took place during April and May 2023. The tests considered non-frequency flexibility needs in relevant (nodal) areas. There have been procured/traded volumes of non frequency flexibility according to scenarios reflecting flexibility needs in given nodal areas. As discussed in the CZ demo's BUCs, tests didn't include activation and billing. The main tested site in this was the platform itself. Only exception goes for the EV charging infrastructure. This particular were physically installed and tests included activation as well. The tests proved the ability of the platform to deliver the relevant amount of flexibility needed through a market-based environment. The CZ demo demonstration proved that a market-based approach can involve more FSPs in flexibility provision/procurement and, to the existing FSPs, provide a more comfortable environment reducing market entry barriers. That goes for the non-frequency services which is a specific kind of market addressing many of the future network operation challenges.

The primary objective of the **Polish demonstration** was to practically validate and showcase the potential of supporting Distribution System Operator and Transmission System Operator operations through resources connected to Medium and Low Voltage networks via market services, thereby enhancing network flexibility. To realise this goal, the DSO identified specific regions for conducting demonstrations, where the Aggregator undertook campaigns to enlist customers who were willing to participate in the project's tests. Three key demonstration areas were chosen for the High, Medium and Low Voltage networks within the operational jurisdiction of ENERGA-OPERATOR SA, serving as representative zones. The project recruited end users from the industrial and service sectors, local authorities, and prosumers to participate. In addressing Photovoltaic installations, which constituted the most significant cluster of flexibility sources within the demonstrator, specialized devices for remote power control were developed. Given the limited or absent regulations pertaining

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to services that enhance network flexibility and the flexibility market itself in Poland, the Polish demonstration necessitated the creation of mechanisms for such a market from the ground up. This also involved establishing protocols for collaboration with Poland's energy market, as a whole, particularly the balancing market. The range of services and products that underwent testing as part of the Polish demonstration by DSOs and TSOs was meticulously defined. Both BUC and SUC were formulated to mirror the devised processes and protocols. Building upon these foundations, a prototype flexibility platform was created. This platform was conceived as an open environment that offers easy accessibility to market actors. One of the key OneNet project components – the OneNet System Connector was implemented on the platform facilitating data exchange. Diverse coordination mechanisms between DSOs and TSOs were devised to bolster the security of the DSO grid. An algorithm was developed to optimize the utilization of available resources, while upholding an appropriate level of DSO network security. This algorithm was then put to the test and refined. In the course of the demonstration, dry-run tests, real activation tests, and simulations for intricate scenarios that were not encountered during the demonstration were conducted by DSOs and TSOs. The outcomes of these tests were meticulously analysed, yielding valuable insights and conclusions. From the activities carried out during the Polish demonstration, and in particular from field tests, it can be observed:

- Aggregators possessing the requisite skills and technical solutions play a pivotal role in shaping the flexibility market, especially concerning resources situated within the lower voltage network.
- Services based on active power represent an effective tool for enhancing the power system's efficiency, but they necessitate a sufficient number of customers providing these services to yield the intended impact.
- Establishing an adequate level of visibility into the distribution network is a prerequisite for constructing an efficient flexibility market for both DSOs and TSOs. This ensures smooth operation without jeopardizing network integrity.
- Algorithms designed to optimize and coordinate the activities of DSOs and TSOs within the flexibility market facilitate the optimal utilization of flexibility sources and enhance overall energy market efficiency.
- While it is feasible to employ renewable sources connected to the low-voltage network to provide services, there is a susceptibility to errors due to unpredictable operating patterns.
- Utilizing solutions such as the OneNet system to facilitate information exchange between different countries presents the opportunity to share insights about local markets and enables potential future participants to enter the market with greater ease.

The **Slovenian pilot** demonstrates the planning, procurement, and use of flexibility services, especially congestion management and voltage control, in the distribution grid. It includes three demonstration sites with flexibility assets (heat pumps, PV and battery systems) in households and active consumers that have agreed to participate in the project. During the three years of the demonstration, the demonstration system has been systematically improved by increasing the number of participating consumers, automation (moving from manual activation to automatic), interoperability (using CIM for information exchange), observability of the grid (new meters and metering data are processed to determine when the flexibility product needs to be activated), and infrastructure IT (flexibility assets upgraded with new equipment to become controllable). The Slovenian demo also includes a local flexibility market platform implemented as an extension of the national metering data hub. In this way, a large number of consumers were addressed to offer their flexibility. This approach provides sustainability as this platform is now in normal operation and will continue to be used in the future. The flexibility products were aligned with the frequency products for TSOs (aFRR, mFRR), which allows aggregators to integrate more easily into the local flexibility market platform. The Slovenian pilot project is successfully connected to the OneNet platform and publishes the results of local market trading via this platform. It can be concluded that Slovenian demo successfully proved benefits of the flexibility services for DSOs and end consumers. Furthermore, from field tests we observe:

- Even though congestion management as a flexibility service for DSO can be used effectively in the distribution grid, it requires appropriate number of flexibility resources (e.g. heat pumps in the case of Slovenian demo) to make this service effective.
- Observability of the grid is necessary for adequate activation of the flexibility product.
- Automating the whole process of activating flexibility services increases the activation success rate.
- Interoperability, common data modelling and harmonisation of flexibility products facilitate integration between systems (TSO, DSO, aggregator etc).
- The effective use of batteries and the limitation of PV generation have proven to be effective for voltage regulation in the distribution grid.
- A simple TLS (Traffic Light System) can be implemented to inform the market (TSO, aggregator), that some distribution grid area has constraints in the use of flexibility of the consumers connected to that grid area.
- Using a communication platform (in this case OneNet system) is an effective tool to publish data European wide about local flexibility markets and potential and open new business opportunities (e.g. for aggregators and flexibility service providers).

The motivation for the **Hungarian demonstration** is based on the regulatory intentions of the Clean Energy Package, but a significant role is also played by the difficulties in system operation caused by the rapid increase of solar photovoltaic in-feed. According to the latest mean estimation of the Hungarian Energy and Public Utility Regulatory Authority, installed PV capacity has reached 5000 MW in summer 2023 (with the yearly peak load around 6500 MW). Approximately 75% of these capacities are connected to medium-voltage distribution networks in the form of 0.5 MW or below capacity generators (stand alone and at prosumers). This causes

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significant burden on voltage management of distribution networks. The Hungarian medium-voltage overhead line networks are characterized by long feeders and relatively small line ampacities, making them also prone to congestions. To tackle these challenges, four functional extensions to the Hungarian distribution grid flexibility platform were proposed, demonstrated. These four functional extensions are the definition of additional potential standardised flexibility services, the elaboration of related product and grid prequalification processes, the conceptualization of location-based service activation and the coordination of access to local and system-level services. However, due to technical reasons and regulatory delays, the start of operation of the Hungarian flexibility platform was delayed from 2021 to 2023. This change did not allow the implementation and validation of the functional extensions according to the original timeplan. To keep the technical scope as close as possible to the planned one, the Hungarian partners have opted to create a simulation environment that allows complete validation of the functional extensions. Validation in the real operational environment will be carried out when the Hungarian flexibility platform is operational, which is expected in the fourth quarter of 2023.

The demonstration was conducted in two key HV/MV substation supply areas. These areas were selected due to their saturated network conditions and the associated voltage management challenges. The demonstration's primary objectives were the mitigation of HV/MV transformer overload and the management of overvoltage on MV lines. Real network topology and historical market and weather data were utilized to ensure the demonstration's relevance and accuracy. The importance of effective communication between TSOs and DSOs are also emphasized, showcasing the need for information exchange for grid stability. A significant aspect of the Hungarian demonstration was its use of simulation methodologies. These simulations provided insights into potential scenarios and challenges, encompassing real network topology and historical data. They were crucial in understanding the functional extension demonstration. Integration with the OneNet Connector was a technical aspect of the Hungarian demo. This integration ensured that data from the Hungarian demonstration could be exchanged with the broader OneNet system, allowing for a more cohesive understanding and analysis of the demonstration's outcomes within the larger project framework. In conclusion, the Hungarian demonstration provided insights into the challenges and potential solutions of flexibility markets in the context of increasing PV in-feed. The demonstration highlighted the importance of effective communication, structured processes, and the role of simulations in understanding and addressing grid challenges. The integration with the OneNet system, particularly through the OneNet Connector, ensured that the findings from the Hungarian demo were accessible and could be analysed in the context of the broader project.

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1 Introduction

The Eastern demonstrator of OneNet saw the active participation of multiple TSOs, DSOs, research institutes, and aggregators. The Eastern demonstrator cluster comprises the Czech Republic, Poland, Slovenia, and Hungary, all of which are integral parts of the highly interconnected region of Continental Europe's Core regional synchronous zone. While these countries share certain similarities, particularly in the evolution and maturity of their electric power systems, they each grapple with unique challenges stemming from the ongoing energy transformation. This has led to varying motivations for the initiation of flexibility markets.

The deliverable describes how these demonstrators delineated their areas of focus and pinpointed the services and products essential for the transmission/distribution network, and flexibility markets. It also presents the methodologies employed to integrate the research and development work within their respective IT environments.

Furthermore, the OneNet project, as a whole, aims to foster seamless integration across all electricity network actors in Europe, with the OneNet Connector playing a pivotal role in this integration. This tool bridges the gap between different systems, ensuring smooth communication and data exchange. The vision is to cultivate a synergistic operation that optimizes the entire energy system while ensuring an open and equitable market structure. OneNet's objectives are underpinned by defining a common market design for Europe, establishing a Common IT Architecture and Interfaces, with the OneNet Connector being a cornerstone of this architecture. The demonstrators, spread strategically across Europe, are testing innovative use cases, many of which have never been validated before, all while leveraging the capabilities of the OneNet Connector to ensure seamless operations.

1.1 Objectives of the Work Reported in this Deliverable

The Eastern demonstrator aimed to focus on harmonized information exchange, common process descriptions and full transparency while addressing technical issues through standardised TSO and DSO (or frequency and non-frequency) services. During the demonstration period, various compositions of such grid services were offered through flexibility markets, while monitoring related market and grid data to enable the calculation of key performance indicators as well. The design and testing of processes for product and grid pre-qualification are carried out, and the coordination between TSO and DSO entities are elaborated to avoid conflicting activations. The Eastern demonstrator assembled use cases to cover all voltage levels from low-voltage to high-voltage, to present issues related to congestions and voltage control, and to demonstrate the use of active and reactive power-based services.

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A pivotal component introduced by the Eastern demonstrator was the OneNet Connector. This tool was designed to standardise and facilitate the exchange of energy information, ensuring that all involved parties, from the Czech Republic to Hungary, interpret and utilize the data consistently. The OneNet Connector can be likened to a universal adapter, ensuring seamless connectivity across diverse systems.

A summary of the key services and tools demonstrated by WP10 Eastern Cluster is depicted in Figure 1-1 and grid service use cases realised by each flexibility market platform by voltage levels are summarized in Figure 1-2.

	Czechia	Poland	Slovenia	Hungary
Prequaification process	Demonstrated	Demonstrated	Demonstrated	Demonstrated (by simulation)*
Non-frequency market platform	Demonstrated	Demonstrated	Demonstrated	Demonstrated (by simulation)*
Flexibility register	Demonstrated	Demonstrated		Demonstrated (by simulation)*
Traffic light system	Demonstrated	Demonstrated**	Demonstrated	Demonstrated (by simulation)*
Flexibility management system with direct asset control			Demonstrated	
Aggregator functions			Demonstrated	
TSO-DSO communication		Demonstrated		Demonstrated (by simulation)*
TSO-DSO bid share		Demonstrated (by simulation)		
Balancing market platform for MV/LV		Demonstrated (by simulation)		

Developped and implemented within OneNet (was non-existent before)

Implemented in OneNet (was not developed within OneNet)

*Also implemented by EON's flexibility platform

** in DEMO PL it is more advance solution that typical TLS, which include coordination and optimisation mechanism for the selection of the best available offers set

Figure 1-1: Key services and tools demonstrated by the Eastern Cluster

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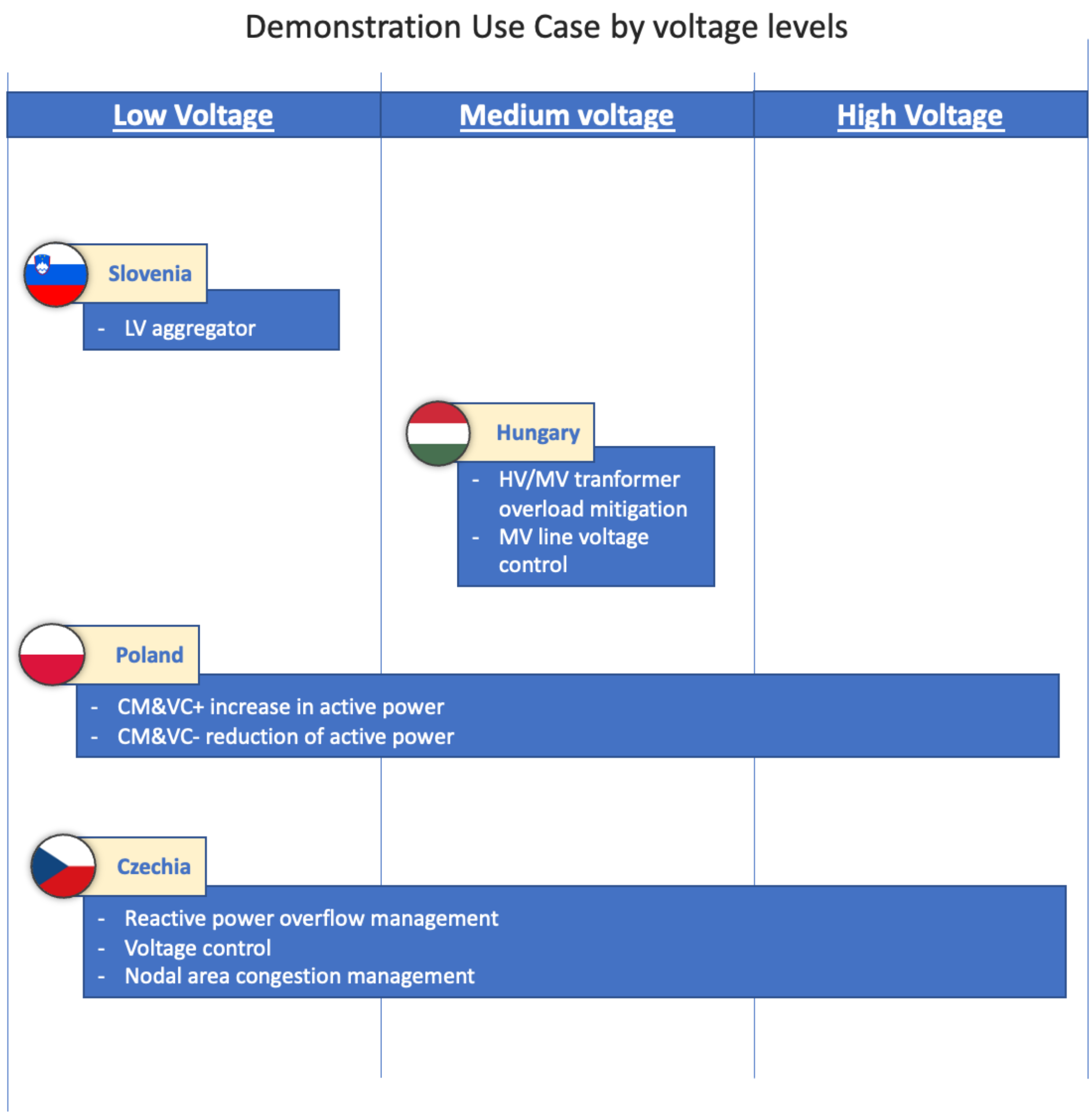

Figure 1-2: Grid service use cases realised by each flexibility market platform

1.2 Outline of the Deliverable

The D10.4 document offers an in-depth exploration of the demonstrations conducted in the eastern cluster countries for the OneNet project, covering the Czech Republic, Poland, Slovenia, and Hungary.

Introduction: The introduction sets the foundation, providing readers with a clear understanding of the OneNet project, its overarching objectives, and the significance of the demonstrations in the eastern cluster countries.

Czech Demo (T10.4.1): The Czech demonstration is starting with background information that encompasses the locations, stakeholders, and schedule. The section then transitions into the solutions that were implemented

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in the Czech Republic, such as the flexibility register module and the traffic light system. A timeline for the Czech demo is also woven into this section, marking significant milestones and providing insights into the progression of the demonstration.

Slovenian Demo (T10.4.3): The Slovenian demonstration section delves deep into the background, detailing the locations, stakeholders, and schedule. The demonstration of services and products in Slovenia is explored, highlighting the innovative solutions and methodologies employed. The section also provides an in-depth discussion on the IT architecture, emphasizing the flexibility procurement system and the technical nuances that made the demonstration successful.

Hungarian Demo (T10.4.4): The Hungarian demonstration is presented with a focus on the challenges and solutions related to the high penetration of solar photovoltaic generation on the MV distribution network. The section unfolds by describing the demo area selection process, the network topology, and the rationale behind choosing specific sites, especially considering the saturated network and voltage management challenges. The demonstration of services and products is comprehensive, detailing the functional extension demonstration, TSO-DSO communication, and bid generation. The demonstration methodologies, IT solutions, and the use of the OneNet system for flexibility market results are also intricately discussed.

1.3 How to Read this Document

This document, D10.4, provides an overview of the work conducted in the eastern countries for the OneNet project, specifically focusing on the Czech Republic, Poland, Slovenia, and Hungary. We've structured the content to be both informative and straightforward.

While this report offers a broad understanding, it doesn't dive deep into every aspect of the Business Use Cases (BUCs). For more detailed insights, please see [5].

D10.4 builds upon the foundation laid by WP10 and other WP deliverables preceding this document. These earlier documents set the business and technical tasks that D10.4 addresses. The D10.2 [9] and D10.3 [10] in particular, played a pivotal role in defining the objectives and setting the stage for the demonstrations and findings presented in this report. Therefore, for readers seeking a holistic understanding of the project's evolution and the context in which D10.4 operates, it would be beneficial to familiarize themselves with other WP10 documents. Figure 1-3 explains the structure of WP10 Eastern Cluster and the interaction between key OneNet WPs.

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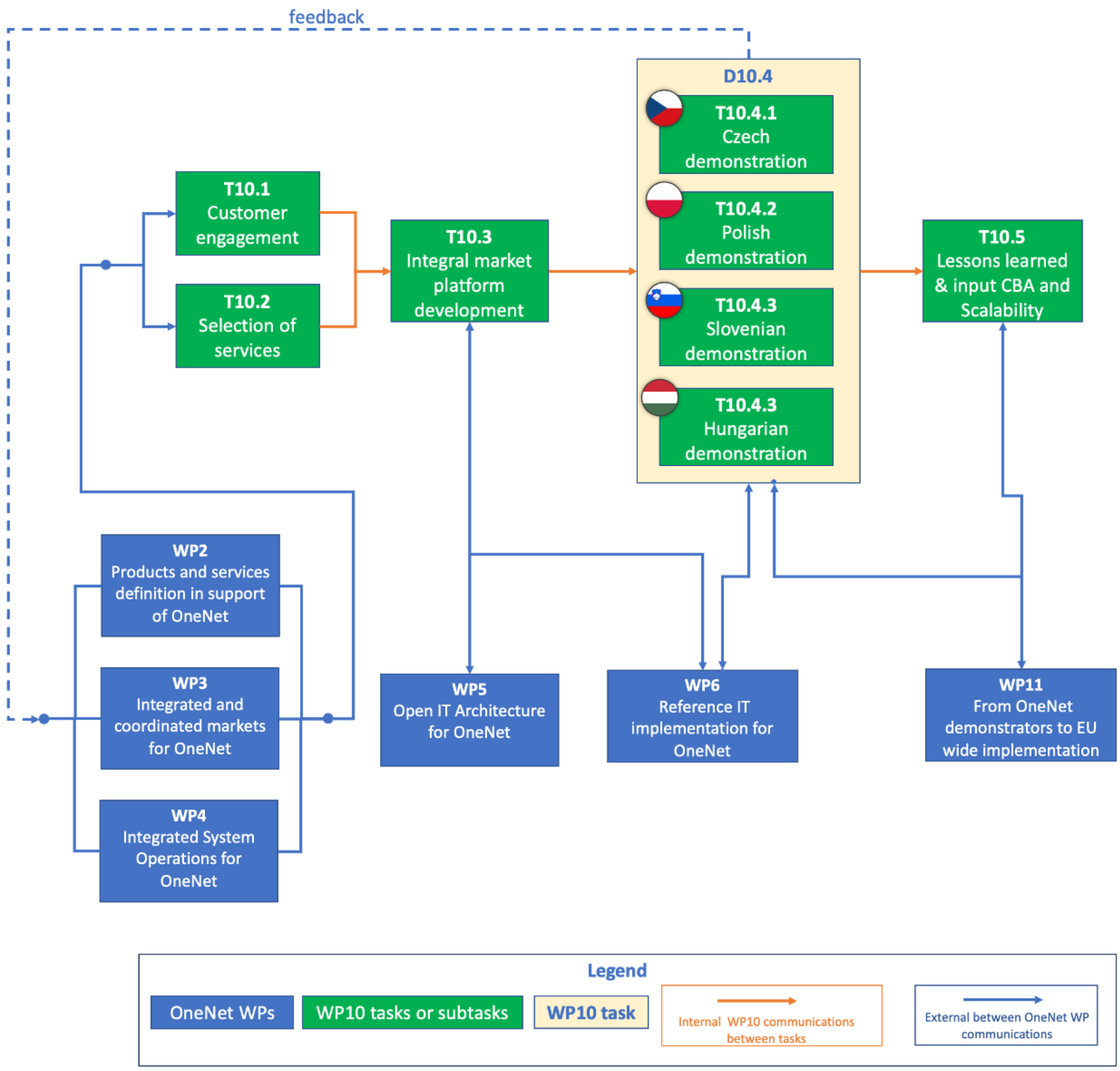

Figure 1-3: Structure of WP10 Eastern Cluster and the interaction between key OneNet WPs

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2 Czech demo (T10.4.1)

The Czech demo is a joint effort of the 2 main Czech DSOs (ČEZ Distribuce, EG.D), the TSO (ČEPS) and 2 aggregators (ČEZ ESCO, E.ON Energie). The main aim of the demo was to develop standardised solutions to improve TSO-DSO-Customer cooperation and to test a market-based approach to purchasing non-frequency services by DSOs.

To achieve this, the demo aimed to:

- Define and standardise technical parameters of new grid services
- Set up market mechanism and TSO-DSO cooperation
- Analyse and determine solutions for dealing with grid issues through procurement of non-frequency grid services
- Test involvement of active customers in the market through aggregators (Small DER, DSR, BESS, EV)

Expected results:

- Enabling market-based procurement of non-frequency grid services
- Appropriate TSO/DSO coordination through dedicated IT solutions (platform) for data exchange
- Active network management from DSO/TSO side by utilization of grid services
- Development of environment for active customers and new business models
- Increase in grid hosting capacity for RES and decentralized generation

These goals were achieved through two system use cases and three business use cases described in further detail in Deliverable 10.1 (Report on customer engagement) [8] and Deliverable 10.2 (Report on selection of services) [9]:

- SUC1: Development of a traffic light system prototype and
- SUC2: Development of a non-frequency ancillary services platform prototype including the definition of the services and concrete products to be traded
- BUC1: Reactive power overflow management
- BUC2: Voltage control
- BUC3: Nodal area congestion management.

The following market participants were involved in the demo:

- Involved market participant: DSO, TSO, Aggregators, Customers (connection points)
- Area/location: All distribution areas of 2 DSOs (in cooperation with 1 TSO)
- Customers connected: 2 Aggregators
- Connection points (nº): 129

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- Voltage: HV, MV and LV

2.1 Demo background – locations, stakeholders and schedule

The increasing number of decentralized and distributed energy power sources brings new challenges to the electricity network and its operation. It demands closer coordination between the TSO and DSOs and brings new challenges in managing the quality of power supply.

Most renewable sources are connected to the low and medium voltage levels which can result in power flow changes. Other changes in distribution grid operation, such as increasing share of underground cables, raise reactive power flows in the distribution grids and lead to overflows from lower to higher voltage levels (especially, from the distribution to the transmission system).

The reactive power increases transmission system losses and lowers operational capacity. Consequently, the Czech Transmission System Operator (TSO) ČEPS, a.s., needs to adjust the transmission system configuration or activate additional tools and services, resulting in increased operational costs on their part. In case of lack of sources providing ancillary services connected to the transmission system, the TSO is not able to compensate the reactive power overflows without any additional devices.

2.1.1 Demo solutions

The SW solution for the demo is a Non-frequency ancillary services platform (also referred to as AccessNet market platform). It comprises several modules of which key are the Network Traffic Light system (which also includes a Flexibility register) and a Flexibility market module (also described as the Trading module). The platform was developed in two phases – firstly the Network Traffic Light system and the Flexibility register were completed and subsequently the remainder of the platform including the Trading module.

2.1.2 Flexibility register module

The flexibility register module is where flexibility providers register specific information about their units:

Table 2-1 - Example of information from the Flexibility register

consumptionMrid	powerConsumption	name	desc	dso	bspList	stat	productionMrid	powe
859182400407982126	53	Flexibility provider unit 001	E_LN_0201	27VCEZD-SEMAFORI	27X--CEZESCO---D	active	859182400407980412	800
859182400511655787	108	Flexibility provider unit 002	E_NJ_0480	27VCEZD-SEMAFORI	27X--CEZESCO---D	active	859182400511655770	600
859182400609470438	35	Flexibility provider unit 003	E_BE_0249	27X-EGD---CZ---L	27XEON-ENERGIE-Z	active	859182400609470421	600
859182400609351072	30	Flexibility provider unit 004	E_BN_0319	27X-EGD---CZ---L	27XEON-ENERGIE-Z	active	859182400609619790	600

2.1.3 Traffic light system

The Network traffic light system was designed to offer crucial information on the availability of the grid to registered flexibility providers. The whole idea was to concentrate all information regarding the availability of

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the system in one place for all market participants to make the whole system transparent and accessible for all. The actual design and further details are discussed below.

2.1.4 Non frequency ancillary services platform (the Trading module)

Currently there is no regular marketplace for non-frequency flexibility services. Relevant services needed are contracted either on bilateral basis between the DSO and the flexibility provider or are provided as mandatory support to the grid as defined in the Czech grid code. This means that the provision of non-frequency flexibility services is limited primarily to large generators/consumers. Steps are being taken to address this through updates to Czech grid codes (see further information below). Selected aspects of these updates are tested in the Czech demo via the Trading module of the Non-frequency ancillary services platform.

In order to standardise non-frequency services, the Commission for operation of distribution grid (non-state expert group consisting of the main Czech DSOs) defined the types of non-frequency flexibility services in a supplement to the „(Distribution) Grid Code" approved by the NRA and adopted by all major players. The services defined are black start, island operation, nodal area congestion management, reactive power management and voltage control. The development of these common criteria removed one of the main regulatory obstacles to non-frequency ancillary services trading and is therefore the first step in facilitating transparent market procurement of non-frequency flexibility services. The second step is creating a marketplace (a platform) where such services could be traded. This is the aim of the second system use case of the Czech demo. To test if such a platform would have a positive effect on the number of FSPs and if it would open the market to aggregators and smaller providers. The participants in the simulations consist of two aggregator portfolios (ECE and ČEZ ESCO) comprising generators, consumers, batteries and EV charging stations.

2.1.5 Demo areas

The demonstration area comprises of the whole distribution network of the 2 main Czech DSOs. It thus covers almost the entire Czech electricity network. Generally speaking, DSOs in the Czech Republic operate the electrical system up to 110 kV. The demo testing portfolio includes 155 FSPs consisting of units >0.5MW (small hydro, batteries, CHP, EV charging stations). These units are connected at the LV, MV and HV voltage level. This portfolio belonged to both aggregators involved in the CZ demo: ČEZ ESCO and E.ON Energie. Part of EV charging stations belonged to the ČEZ Distribuce – as it is in line the relevant EU regulation allowing DSOs to have charging installation for its own use.

The demo is divided into two key parts based on the defined system use cases (the Traffic light system and the Non-frequency ancillary services platform). The design and creation of the traffic light scheme included (apart from the main Czech demo partners) also an "informal" partner PRE distribution, who operates the distribution area of the capital city Prague. This was needed as the design of the Traffic light scheme (intended

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for real operation) required input of all main system operators in the country. The test environment of the Non-frequency ancillary services platform, on the other hand, includes only FSPs connected into the ČEZ distribution and EG.D network.

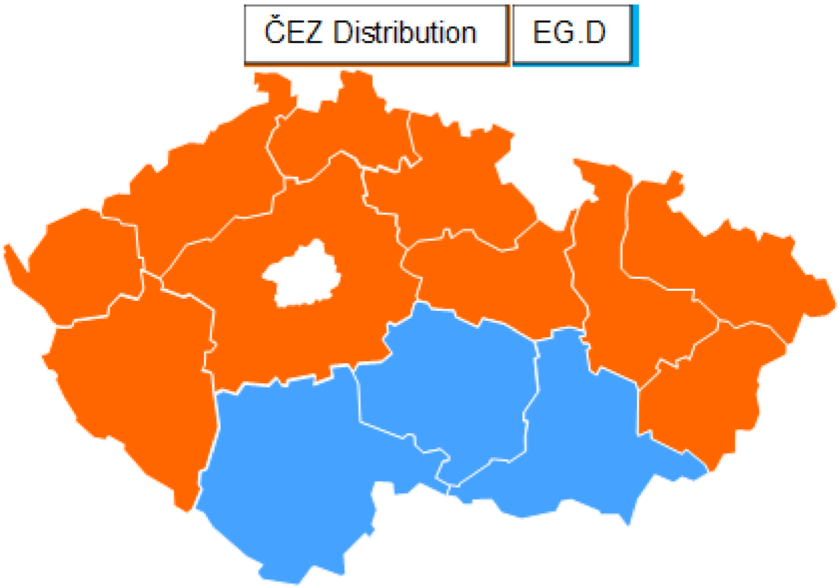

Figure 2-1: Distribution network areas in the Czech Republic

2.1.5.1 EG.D locality

Within the project several locations with the highest share of reactive power overflows were analysed. Focus was on HV and MV lines. Especially locations near to substation from HV to MV. The whole area of EG.D is fed from nine primary substations. On the distributional area of EG.D are located six primary substations with a transformation 400/110 kV (Kočín, Dasný, Slavětice, Sokolnice, Čebín and Otrokovice) and two 220/110 kV substations (Tábor and Sokolnice). Substation Mírovka is geographically outside of the EG.D distribution area. Nevertheless, this substation presents an essential role in supplying the area of Vysočina region where major part belongs to the distribution area of EG.D. Besides the above-mentioned substations, EG.D region is supplied from local power plants. The tested AccessNet market platform for non-frequency services was open to all areas for testing the potential of flexibility providers.

The distribution area of EG.D consists of urban areas with predominantly cable grids (like Brno, České Budějovice and Zlín) and of rural areas as well with a majority of overhead lines (Vysočina region). Due to the constantly increasing significance of reliability parameters, overhead lines in villages and district areas are replaced with cables; cable grid share is expected to rise continually. The share of cables varies with the voltage level. Presently there are 99.4 % overhead lines on the 110 kV level (only 14 km of a cable, which is located in the district of Brno), on high voltage level the share of overhead lines is 82 % and it reaches 38 % on low voltage level.

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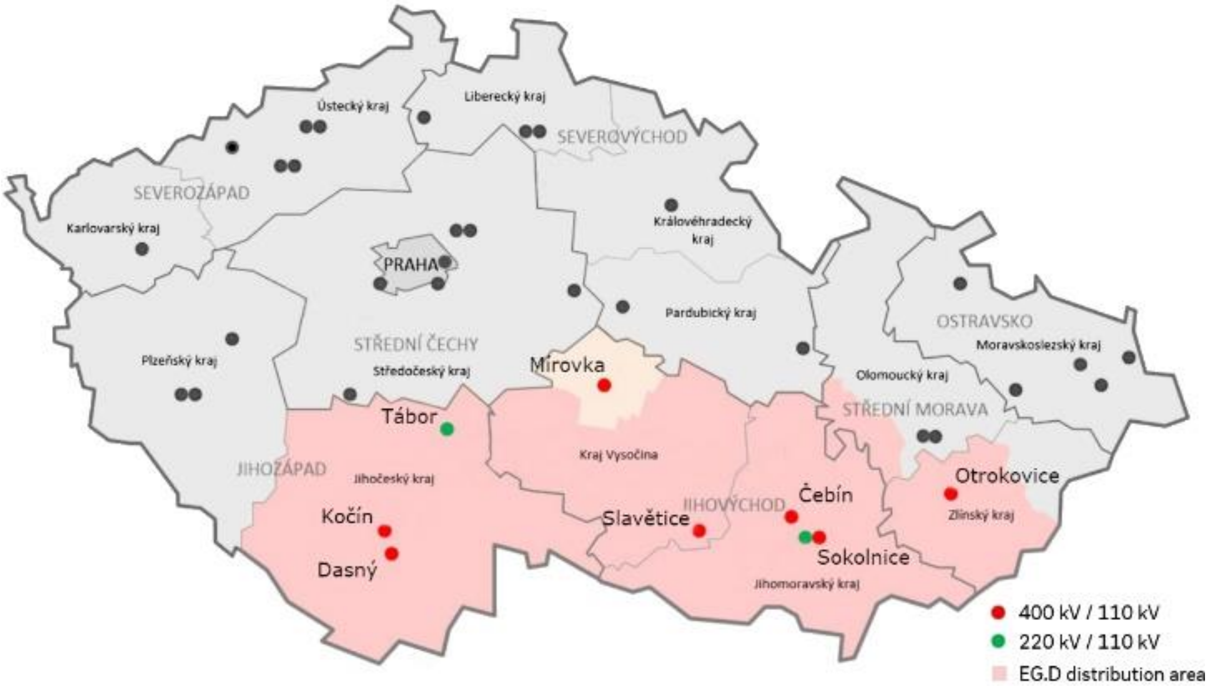

Figure 2-2: Distribution area of EG.D

2.1.5.2 ČEZ Distribution locality

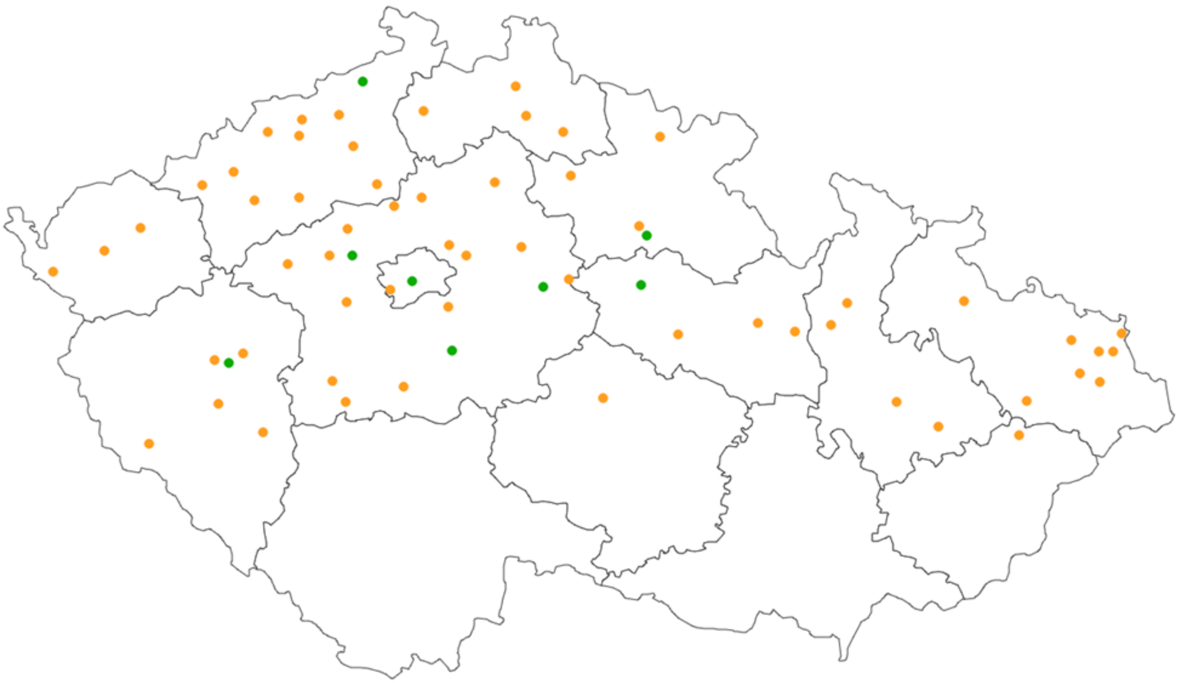

Figure 2-3 – EV charging points (green points are directly involved in the demo, yellow points are planned)

The specific task addressed by ČEZ Distribuce is to build several EV charging points to enable the testing of active power-based flexibility. As shown in Figure 2-3: green marked areas represent localities directly involved in the demo (there are 70 wall boxes and 4 fast charging stations with available contracted power for consumption/tests 707,25 kW). Yellow marked areas show localities that are under construction and will be included into the flexibility provision in the near future.

Figure 2-4 – EV charging points

The Czech demo will implement a specific system of load management (from EV charging points), while the capacity of available load is predicted/calculated by an external EV charging management system (Driivz) and this available amount of flexibility is further offered on the market.

2.1.6 Demonstration schedule

The CZ Demo activities defined in the grant agreement started immediately after the commencement of the project, in part due to the ambition to deploy the Network traffic light system in 2022.

The work on the IT solutions was staggered. It started with the design of the Flexibility register and Network traffic light system, where several differences between the ICT systems of each SO needed to be resolved. Following a period of development and testing, the Network traffic light system (including the Flexibility register) was deployed in 2022.

The design work on the remainder of the AccessNet platform (the Trading module) started in mid 2021, with final testing completed in May 2023.

Timeline for CZ Demo:

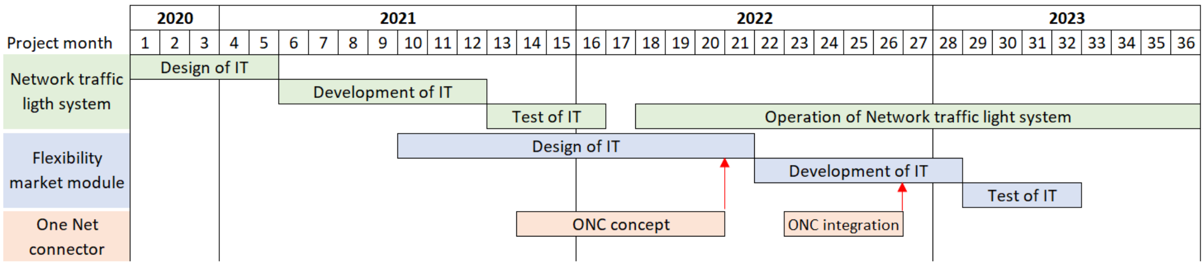

Figure 2-5 - CZ Demo timeline

2.2 Demonstration of services and products in CZ Demo

As referred to in the previous section, one of the main concerns of the CZ demo was the development of the environment allowing market-based procurement of non-frequency services. Thus, the goal was not the definition of services as such but more so the creation of a platform at which these services could be exchanged and the testing of specific products could take place. Our assumption was that the platform will enable transparency (as all bids/offers will be communicated through one marketplace) and thus increase the number of FSPs involved in this new market.

2.2.1 Services

Non-frequency services are defined through the national Distribution Grid Code (as already discussed) and are used by DSOs on a regular basis. The aim of the demonstration was to design a platform (marketplace) in order to implement specific features which non-frequency services have. The platform needed to reflect namely the fact that, non-frequency services address local issues and, additionally, that reactive power-based services must have a fast reaction time (which requires direct communication means between the DSOs and FSPs). Moreover, in principle, non-frequency services are mostly suited for long-term contracts but are, in some cases, only used on rare occasions. Having this in mind, we included in the test those services that have the most potential in real market environment: Reactive power overflow management, Voltage control and Nodal area congestion management (please note that the latter is not a regular non-frequency service according to the national Distribution Grid Code).

2.2.1.1 Nodal area congestion management

Nodal area congestion management involves testing aggregated load control in specific nodal areas using EV charging infrastructure. This includes 70 wall boxes and 4 fast charging stations with an installed capacity of 1740kW and available contracted power for consumption 707,25 kW.

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2.2.1.2 Voltage control (U and Q)

Voltage control is tested through management of reactive power provided by units (generators/units) connected at the Middle/High Voltage levels. The product is meant to keep voltage in given limits in terms of quality of supply.

2.2.1.3 Reactive power overflow management

The control of reactive power at the high voltage level enables the prevention of frequent “overflows” of reactive power at the so called “connection points” between the distribution and transmission networks.

2.2.2 Products

For reactive power-based services (Voltage control and Reactive power overflow management), the platform can receive bids/offers which include locality, capacity and duration. As mentioned above, such services are currently supplied by HV connected units, contracted on a bilateral basis or as mandatory support to the grid. The DSOs approach relevant FSPs directly, there is no public tender. In addition, reactive power-based services are location specific (they address mostly local issues), therefore only FSPs in a given locality are relevant for the service provision. Moreover, for effective use of these services, long-term contracts are required. Due to highly variable RES production, it is not possible to anticipate the amount of reactive power needed at a particular point in time over a longer timeframe. The ambition of the tested solution is to verify, if under given requirements, the bids/offers submitted on the platform are able to satisfy the DSO needs for relevant nodal areas and therefore whether (within the simulated market conditions) it is possible to obtain these services on market basis.

Active power-based service product (for congestion management purposes) was tested in the same environment. Unlike the reactive power-based services, this product is not used on a regular basis by the DSOs – it is tested as a pilot concept only. From the platform perspective this is a different exercise, as this product is volume based and relevant for short-term grid issues. Therefore, product definitions and the way bids/offers are entered are different. Assets involved in the tests were EV charging stations as it was expected that the growing numbers of EV charging infrastructure will have a significant impact on the quality of supply. The tested solutions were bids/offers exchange via the platform and a system for the prediction/algorithm of charging patterns through a dedicated interface (which is not part of the platform).

As the main concern was the creation of the dedicated marketplace for simulation of market based non-frequency flexibility exchange, we did not include measurement, evaluation/assessment of the provided service.

Further information regarding the selection of services is available in Deliverable 10.2.

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2.3 IT architecture of CZ Demo

2.3.1 High-level architecture

The figure below depicts the high-level architecture of the AccessNet Market Platform (Platform).

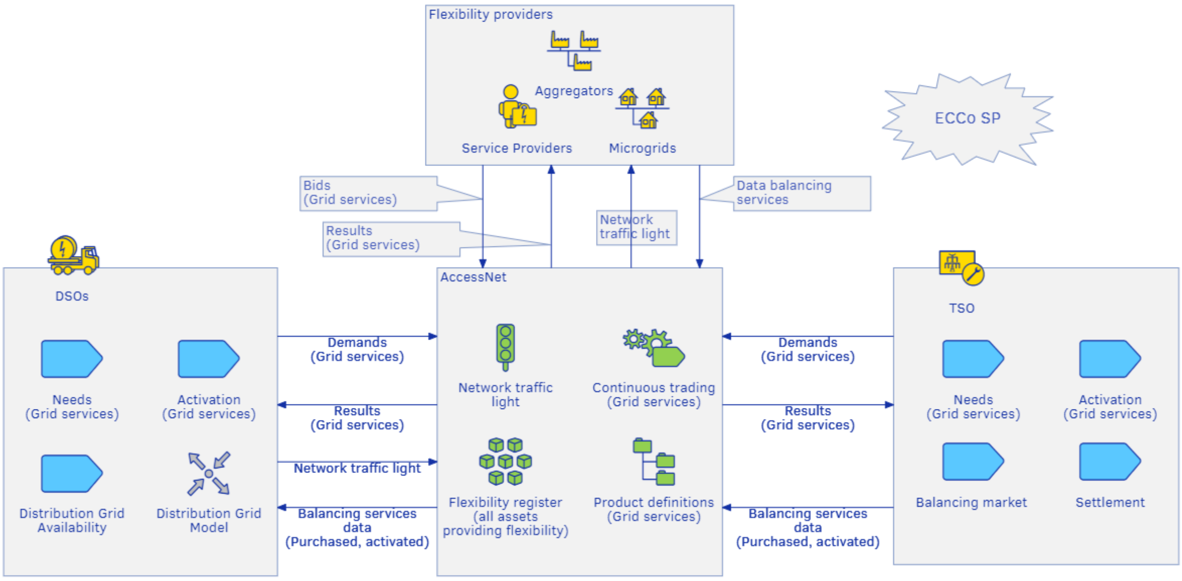

Figure 2-6: High-level picture of the AccessNet platform

2.3.1.1 Actors

There are 3 major business actors in the systems.

- **DSOs**
  - Submit the network traffic light data to the platform and submit the needs for grid services.
  - Receive
    - Information about new needs for respective assets.
    - Trading results of grid services auctions.
- **FSP**
  - Receives
    - Consolidated information from the platform about the network traffic light for the respective assets.
    - Trading results of grid services auctions.
  - Submits the bids for the needed grid services.
- **TSO** – Not assumed to act in the demo. But it can:
  - Submit - Needs for grid services.

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    - Receive
        - Trading results of grid services auctions.

Beside those there are also:

- Platform - which main role is to consolidate, transform and distribute the respective data to the actors.
- Administrators – Manage the organizations, users and monitor the platform.

2.3.1.2 Main Modules

The AccessNet market platform is built using microservice architecture and Unicorn Enterprise Platform (UEP) providing the set of system components which are used by the platform.

The figure below shows which services are already in place (green) in the platform demo and which shall be prepared in the future on top of the demo (blue). Platform features are accessible either by GUI or via REST API or by Messaging using the ECP endpoint.

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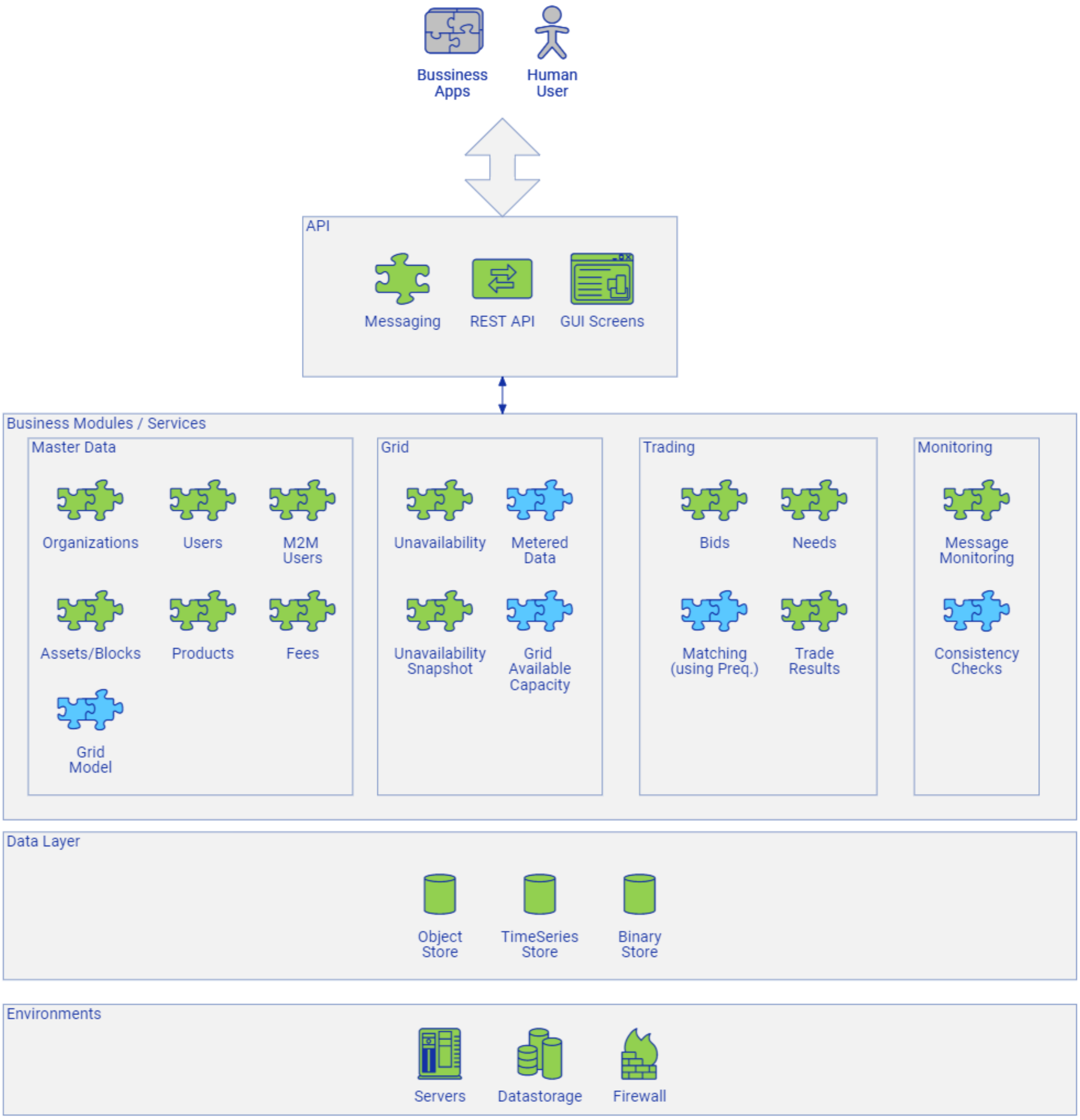

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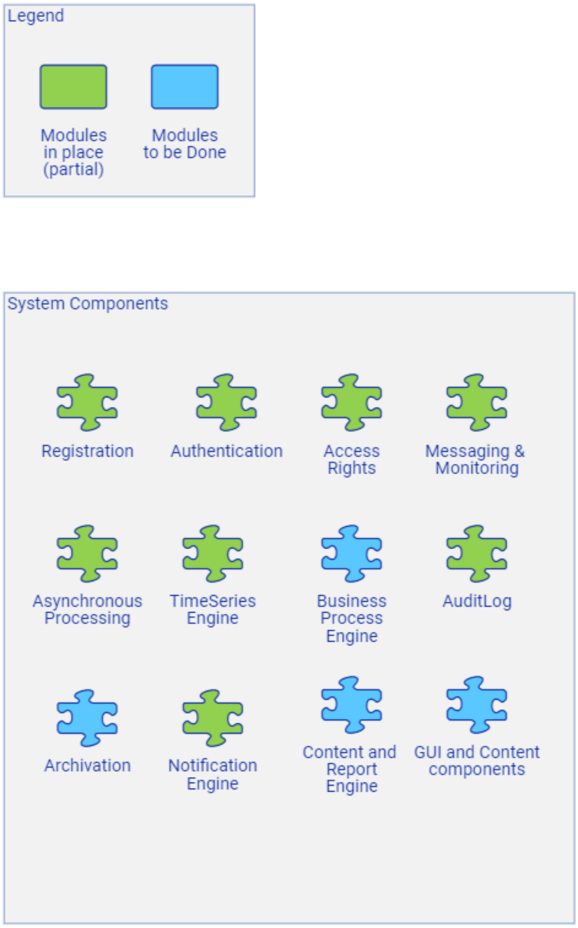

Figure 2-7: Main modules of the AccessNet platform

- **Master data** – Management of the objects used within the business. Organizations, Users, M2M users, assets and blocks, products, Fees.
- **Grid** – Provides Unavailability and Unavailability Snapshot management via Messaging (ECP). Enables DSOs to report the Unavailability Messages (UM), system consolidates UM and publish UM to the respective BSPs and to the TSO. The TSO also has the ability to download the Unavailability Snapshot prepared regularly by the platform as a support for the delivery evaluation. Grid, metered data and available capacity are not currently managed in the platform, now this is being managed by DSOs.
- **Trading** – the core of the market platform. Provides to the users GUI and REST API to manage auctions, needs, and bids and the manual matching. The platform itself creates the trades, manages the auction workflow according to the GCT and distributes the notifications about auction events.
- **Monitoring** – the platform provides message Monitoring via GUI and REST API which enables the users based on the access rights to monitor respective incoming and outgoing messages. Reprocess not processed messages, see the processing log, validations. Ability to download the message file and upload

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the file in case the primary ECP connectivity is out of service. Further improvements would be the support of consistency checks especially in relation of incorporation of the grid model, metering and evaluation.

Future potential improvements to the developed concepts and solutions will be considered as part of the works surrounding the national solution mentioned in section 2.4 below.

System Components

UEP provides listed system components which made the implementation of the platform faster. Further improvements would be to fully incorporate the Business Process Engine and Reporting using the Content Report Engine, enabling the administrators to create the reports mainly from time-series data rendered into content components composed by WYSIWYG editor. Architecture

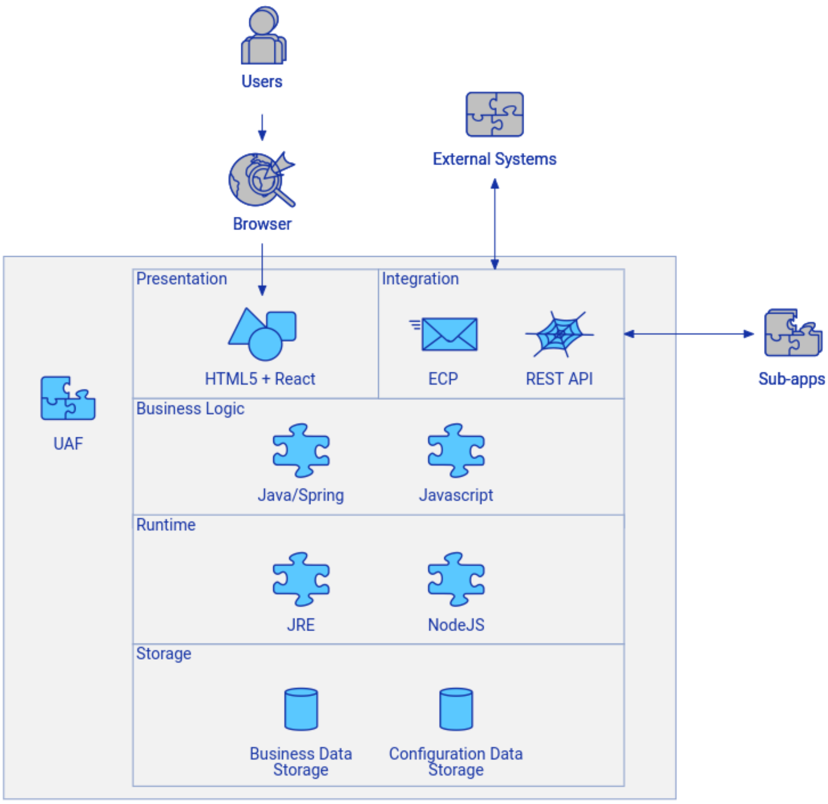

Figure 2-8 Overview of the AccessNet platform architecture

The Platform is based on the microservice architecture and is operated in +4U cloud[1] which provides enterprise NFR. The Platform is composed of particular modules which are represented by microservices. Every module has its own schema in data storage and can be deployed separately. This enables either further

[1] https://www.plus4u.net/en/

extension of the platform by new modules or vertical and horizontal performance scaling on the level of the services.

- The **presentation layer**, represented by screens created in React technology as Single Page Application (SPA) components.
- A **layer of business logic**, created as a Java or NodeJS server application, which provides a clear and documented REST API for the presentation layer or possibly for use by surrounding modules.
- The **data layer**, represented by a schema in the data store.

The application ensures data consistency across data repositories thanks to the use of database transactions and a reliable communication mechanism between individual microservices and surrounding systems.

2.3.1.2.1 Presentation layer

Provides a graphical user interface. Users use web browsers to interact with the application and get feedback without having to install additional software. This layer is built on top of HTML5, JavaScript, and the React framework, making it easy to build modern, responsive, and easy-to-use apps. Some microservices have no graphical user interface and only provide functionality to other sub-applications or external modules by exposing APIs.

2.3.1.2.2 Application layer

Implements all functions and logic that fulfil business needs. Business logic is implemented either in Spring framework/Java technology (e.g. for messaging) or in NodeJS/JavaScript technology. Microservices architecture allows us to choose the best choice of technology for the purpose.

2.3.1.2.3 Data layer

Provides an abstraction to business layer components for data storage and ensures the secured way of manipulation with the data.

The platform uses 3 kinds of data storages:

- Object Store – For entities. Built on MongoDB 5.
- Time Series – For time series data. Can use the PostgreSQL, MS SQL, Oracle or MongoDB as a storage.
- Binary Story – Mainly for the messages.

2.3.1.3 Availability

Cloud enables high-availability (HA), however for the purposes of the Demo high-availability is not required and therefore not ensured.

Cloud can provide up to 99.9% availability and B/G deployments.

2.3.1.4 Performance

Performance is scalable. Vertically by dedicated resource groups in cloud and horizontally by deploying applications on an additional application nodes to spread the load.

2.3.1.5 Security

Cloud is regularly verified by penetration tests, is compliant with GDPR and processes are in compliance with ISO 27001. Applications are being certified by internal authority and tested by penetration tests as part of the delivery. Incoming communication to the cloud is restricted to just HTTP and HTTPS. Outgoing connectivity is not limited.

The platform is secured on several levels to protect the data, users and availability of the system. Further paragraphs summarize main design decisions related to the above-mentioned areas.

2.3.1.5.1 Transport Level Security

The application is accessible only on secured HTTPs protocol

- The HTTPs is secured using modern TLS protocol – TLS 1.2
- The servers are authenticated by server-side X.509 certificates

Any communication between the deployed sub applications (microservices) is protected by TLS. With TLS, any data in transfer is encrypted.

2.3.1.5.2 Authentication

All sub applications are authenticated using OpenID Connect protocol (https://openid.net/connect/). For authentication, the platform uses the Plus4U OIDC service. This product has the possibility to integrate 3rd party authentication services. Currently we support Google, Microsoft and Facebook identity and we are ready to integrate other authentication providers for the Platform.

Our Plus4U OIDC service is already compliant with OWASP ASVS 4.0.3, so all security features like auditing of login attempts, configuration of login policy (maximum number of login attempts, lock timeout after maximum number attempts), configuration of password policy, encryption of all personal data is already implemented.

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2.3.1.5.3 Authorization

The Platform functionality is protected by access rights configuration, leveraging role-based access control mechanism. Assignment of users to roles is configurable.

Please note that the set of privileges for roles is not configurable by the end user, but only by the technical administrator of the Platform.

2.3.1.5.4 Security of Interfaces

All REST APIs published by the system are authenticated and authorized. Messaging is authenticated on ECP level and on application level M2M user authentication is being verified.

2.3.1.5.5 Audit

Due to the importance of security, the platform naturally incorporates audit log. The audit log message contains information related to the invoked application use case:

- audited application use case
- unique RequestID, enables to pair audit log record with records in other logs (trace, performance, access, etc.) or find all audit records per one UC execution
- session id, enables to search all the records in scope of single login session
- timestamp
- message severity
- unique identifier and name of authenticated user requesting the UC execution
- duration of request (in milliseconds)
- extracted metadata of use case input object
- use case execution status.

The audit or the telemetry log records from the platform are automatically stored in every platform microservice and automatically transferred to the central service that is used for collecting log records from applications and which provides a stable and secure storage for log records.

2.3.1.5.6 OWASP

Standard is that application targets to meet security requirements defined in OWASP Application Security Verification Standard 4.0.3 for security level 2. For the demo purpose this was not the goal.

2.3.2 Dataflows API, Format

The Platform enables the dataflows listed in Figure 2-9 below and described in Table 2-2. Note REST calls are synchronous. ECP communication is processed asynchronously.

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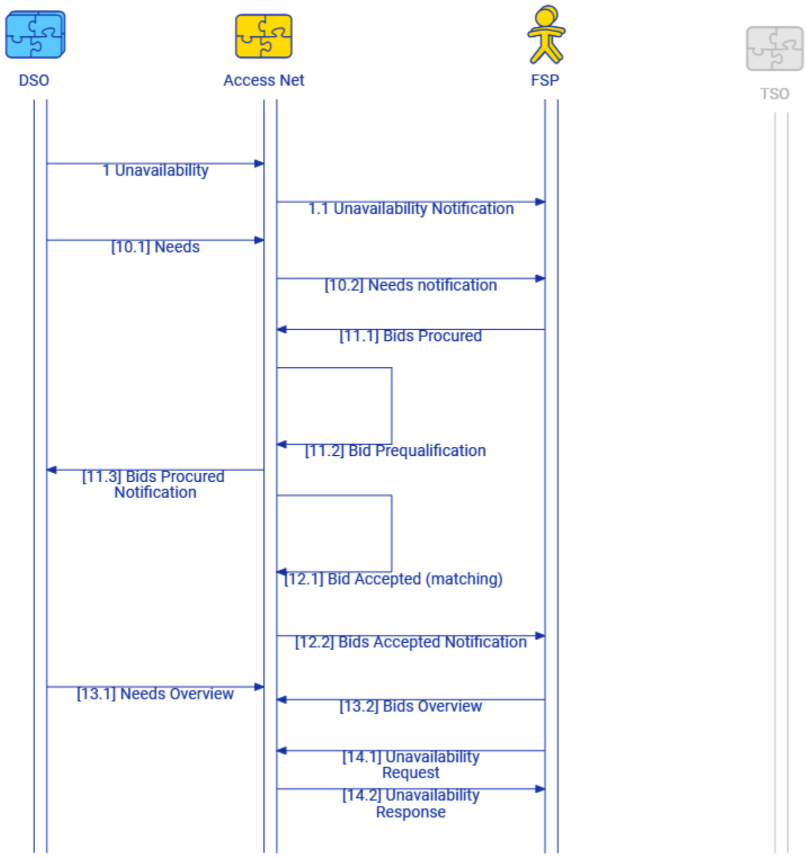

Figure 2-9 The AccessNet platform data flow overview as tested in the project. TSO data flows were added subsequently.

Table 2-2 - AccessNet Dataflow description

Dataflow	Channel/Format	User	Description
1 Unavailability	ECP/CIM XML	M2M	Reporting the UM to platform.
1.1 Unavailability notification	ECP/CIM XML	M2M	Publication of UM for respective Assets. FSP Own. TSO all.
10.1 Needs	GUI, REST/JSON	Human	Auction with need for grid services
10.2 Needs notification	EMAIL, Activity	Platform M2M	Notification about an auction on respective assets of the FSP.
11.1 Bids Procured	REST/JSON	Human	Bid in the auction for required grid service.

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11.2 Bid prequalification	GUI, REST/JSON	Human	Information about issue about prequalification. Unavailability on the asset indicated. Either planned or ongoing error.
11.3 Bids procured notification	EMAIL, Activity	Platform M2M	Notification about the bid in the auction for the auction owner.
12.1 Bid accepted	GUI, REST/JSON	Human	Matched volume.
12.2 Bid accepted notification	EMAIL, Activity	Platform M2M	Notification about the bid acceptance for the bid owner, when auction concluded.
13.1 Needs Overview	GUI, REST/JSON	Human	List the auction or trades for the concluded auction.
14.1 Unavailability Request	ECP/CIM XML	M2M	Request for the unavailability list for the defined filter.
14.2 Unavailability Response	ECP/CIM XML	M2M	Response for the Unavailability Request.

2.3.2.1 OneNet Connector

The integration with the OneNet Connector is for the demo purpose realised by GUI channel. On the OneNet Service Catalogue will be registered service for trade results for the given auction id. Results will be provided in EXCEL format with information about the need, bid required, bidded, and accepted volume and the trade price.

In the further production operation where M2M integration could be realised, there can be used REST services provided for the registration into the service catalogue of the OneNet Platform.

2.3.3 Infrastructure and Deployment

The Platform will be hosted in cloud Unicorn Plus4U (SaaS), which ensures secure, performant, flexible and reliable operation of the solution. Plus4U is a cloud management platform based on Kubernetes operated in Microsoft Azure. All applications are operated at Azure West Europe Region (Netherlands) and our standard off-site backup is hosted in the Czech Republic.

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2.4 Demonstration results- summary for CZ Demo

The demo successfully completed testing of both SUCs and of all three BUCs. The SUC Traffic light system was, following an upgrade, implemented into real life operation in January 2022.

Currently a robust platform encompassing all flexibility exchange including both grid and trade flexibility is under discussion and shall be included into the new version of the Czech Energy Act. The experience and knowledge developed in the OneNet project will feed into this new solution. It will, among others, include the "Network Traffic Light" scheme developed in OneNet.

2.4.1 SUC1: Traffic light system

The developed traffic light system module contains a flexibility register of all flexibility sources of 0.5 MW installed power or above, connected into the distribution grid and of large consumers connected to 110 kV.

It is a central point that provides up to date information on network outages (planned and unplanned) to flexibility service providers, aggregators, DSOs and the TSO ČEPS. It enables the DSOs to signal aggregators and flexibility providers whether they are/will be able to provide flexibility at a particular point in time. The traffic light scheme was considered as mature enough to be implemented in a real environment – therefore the Traffic Light System developed in the project was upgraded with a data privacy and security solution and the whole scheme was integrated into the SCADA systems of all major system operators in the Czech Republic.

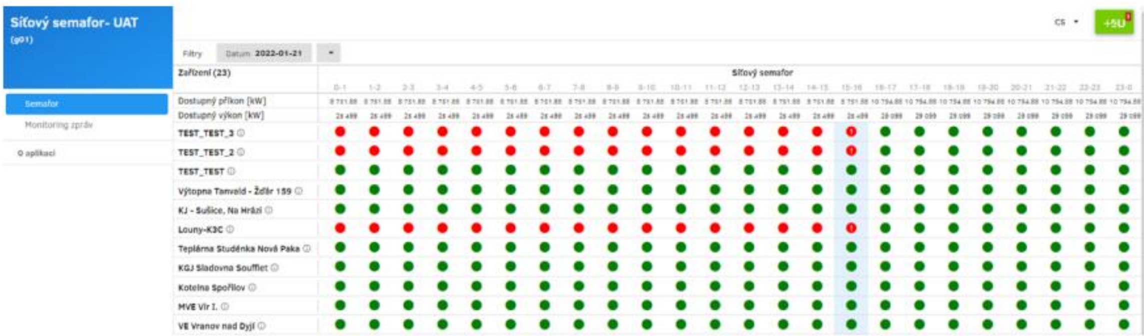

Figure 2-10 - The traffic light system – flexibility resource overview

In addition to the data submitted into the scheme by the DSOs, the TSO sends into the platform information concerning procured/contracted services. The flexibility service provider (aggregator) sends into the platform information about activated services detailing all participating units/resources. This is important for the DSOs in terms of quality of supply in nodal areas. The data on planned/activated flexibility from the Network Traffic Light system is used by the TSO to assess the quality of the provision of ancillary services by the FSPs.

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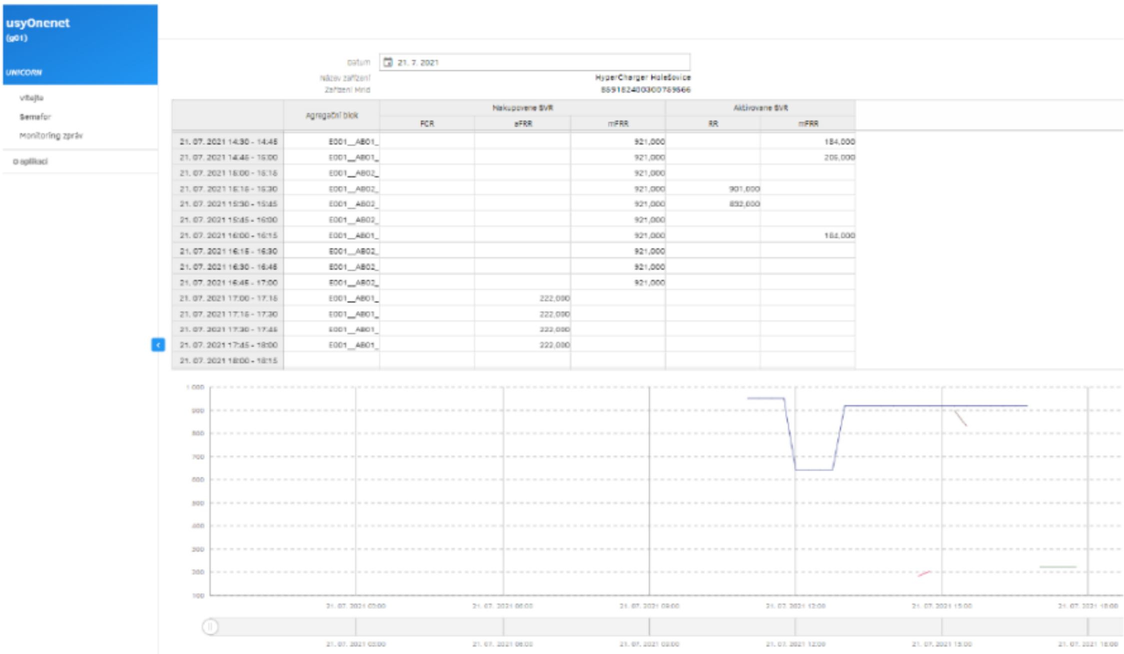

Figure 2-11 - Report of planned and activated flexibility units

2.4.2 SUC2 Non-frequency ancillary services platform (Trading module)

Phase 2 builds on phase 1 (Network Traffic Light system) and uses (in a test regime) some of its modules/functionalities, including the database of units/resources available as well as the indication of the availability of the grid.

The system tested a specific environment which had to accommodate different services addressing local issues. As the DSOs cannot disclose the grid topology for security reasons, the bids are passed directly to the resources relevant for a given nodal area. Since non-frequency flexibility services are capacity driven, bids must include the required capacity (in MWh for active power and in MVAr for reactive power) and the duration of the contract. To this end the design of the bids placement system solution was adapted accordingly.

The marketplace was designed by the CZ demo IT provider Unicorn. As indicated in Figure 2-6, there is an administrative section with a register of flexibility units and information about relevant nodal areas. The market module contains information on flexibility services contracted/provided.

Unlike for the previous phase of the project (the Network traffic Light scheme and the Flexibility register), a decision has been made to not implement phase two of the platform (the Trading module) into real operation. Despite that, the ambition to pilot a scheme in which DSOs can procure, in a market-based way, non-frequency flexibility services has been fulfilled and the knowledge gained will be utilised during the development of the national solution mentioned above.

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2.4.3 KPIs

To measure the achievements of the CZ demo and the given solutions, both demo-specific and common KPIs were selected. Further information regarding CZ demo KPIs is available in Deliverable 2.4 (OneNet priorities for KPIs, Scalability and Replicability). Generally speaking, the introduction of a centralized solution was expected to create better awareness and involvement of flexibility providers. In addition, the platform was supposed to bring benefits to the providers – to provide access to advanced/close to real time information concerning grid availability.

2.4.4 Conclusions

The preliminary data suggest that the number of flexibility service providers has increased considerably since the commencement of the project and the introduction of the Network Traffic Light system in early 2022. An additional benefit concerns access to a more accurate time schedule of planned grid outages for FSPs. This will enable flexibility sources to allocate flexibility capacities in a more efficient way and brings more certainty for aggregators in terms of portfolio utilization. According to the common KPIs, CZ demo also increased capacity for provision of active energy through the installation of the EV charging points (which was one of the "core" tasks of the demonstration projects). The Business Use Case of non-frequency reactive power-based services tested (and verified) the broader availability of this capacity for the energy market through the new environment – this goes namely for management of the "reactive power overflow" at the DSO/TSO connection points. Because of this common environment where all the bids/offers can be shared amongst all market participants, SOs can easily access the needed flexibility. The tests verified that the AccessNet platform enabled to bring both more liquidity to SOs and unlock the potential of flexibility providers.

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3 Polish demo (T10.4.2)

3.1 Demo background – locations, stakeholders, and schedule

The Polish demonstration was strongly focused on the business use cases defined during the project that stem from System Operators' (both DSO and TSO) needs for managing the network and system balancing. The main scope of the DSO in the OneNet project was congestion management and solving issues with voltage limits violations due to the high penetration of distributed energy resources. In the case of DSOs, the purpose of the demonstration was to test the possibility of using flexibility resources to increase the efficiency of the distribution network in real network operation conditions.

The variability of the dynamics of the power system operation and the general increase in demand for electricity, forces the TSO in Poland to constantly search for new solutions for balancing and controlling the frequency in the system.

The balancing services demonstration was planned to test three variants of the component environment and was carried out as simulations without affecting the real balancing market operated by the TSO. The simulation conditions reflected, as far as possible, the balancing guidelines and the requirements for the second milestone of the balancing market reform that is still taking place in Poland to fully implement the Electricity Balancing Regulation [1].

Due to the REMIT Regulation [7], only publicly available regulations (approved or submitted for consultation) could have been used for the demonstration of balancing conditions.

The main purpose of the demonstration in the balancing case was to verify various algorithms of technical feasibility in the context of DSO network security and optimization in the case of using flexibility resources from MV and LV networks.

The areas for the demonstration were jointly selected by the EOP and ENSP based on the analyses done by both partners. First, the DSO performed an analysis of the problems that it wanted to investigate as part of the project and selected the network areas where the identified phenomena occurred (line overloads, overvoltage and voltage drops). For these pre-selected areas, an analysis of potential resources and customers who could provide services under the pilot was performed. On the basis of the collected network and potential FSPs information, a customer recruiting campaign was carried out. The results of the campaign and the analysis of the feasibility of using those customers' resources in the tests allowed for the selection of final demonstration areas for the OneNet project. An important factor in the selection of these areas was the EOP's other research projects conducted in a given area, especially customers centric and flexibility-increase projects from the H2020 programme.

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Kalisz area (HV)

The pilot in the area between the towns of Kalisz and Konin covered the DSOs 110 kV HV network, which consisted of three critical HV lines connecting the northern and central areas of the ENERGA-OPERATOR SA network. Demonstration and tests with real activations concerned the linear sequence in the relation: Konin - Konin Południe - Rychwał - Stawiszyn - Kalisz Północ - Kalisz Dobrzec branch.

Figure 3-1 - Demonstration area near Kalisz

In the identified area of the HV network, problems with maintaining the voltage in the HV network in the required range appeared in the past. At an environment temperature in the range of 20°C - 25°C, the lines operate in a ring system (as a typical mesh network) without overloads in the "n" system, but with threats for the "n-1" systems. At temperatures above 25°C, network overloads may occur already in the "n" state, which requires the introduction of an abnormal, radial arrangement of network topology. Depending on the network situation, restrictions on energy consumption or generation are also introduced. In addition, in situations with abnormal grid operation topology and switching at the MV grid level, transformers may be overloaded in some HV/MV primary substations.

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As part of the demonstration, two business customers were recruited, connected to the MV network, powered by the Stawiszyn HV/MV primary station - marked with the red arrow on the figure above. These customers provide the power demand reduction service as part of the DSR service for the TSO on a daily basis. Additionally, during the project two cogeneration units were installed on the customer side, which were used as a part of the demonstration for providing services for DSO and TSO.

Puck area (MV)

The pilot area in the vicinity of Puck covered the 15 kV and 30 kV MV networks supplying the following towns: Swarzewo, Gnieżdżewo, Puck, Połczyno and a small part of Władysławowo. The area is supplied mainly by three MV lines:

1. 03900-7-098000 line direction Piaśnica (field 7 No. 908000 GPZ Władysławowo)
2. 03900-16-096500 line direction Swarzewo Treatment Plant (field 16 No. 906501 GPZ Władysławowo)
3. 03900-06-093100 line direction Reda (field 6 No. 903100 GPZ Władysławowo).

Figure 3-2 - Demonstration area near Puck

The MV network consists of overhead lines and MV cable lines, made of different materials, in different technologies and with different diameters of wires - from aluminium ALF 6 35mm^2 lines to cables with a cross-section of 240 mm^2. The network was built as a mesh network but works as a typical radial topology. If necessary, it is possible to reconfigure the network topology. Connected to the MV network are some bigger generating units, that can cause network instability at abnormal operation state, i.e., wind farms, gas and biomass power

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plant. To support network stability, an energy storage system was developed by the DSO a few years ago, as part of a research project.

In the MV network, problems with maintaining voltages in the required range and the overload occurred in the past, when the network operates in an abnormal configuration. In "n-1" states and with a changed power supply system, the permissible voltage at the ends of the supply lines may be exceeded. At the peak of load, with an abnormal network operation, some parts of the MV line may be overloaded.

The key FSP in this area is a gas-fired power plant connected to the HV/MV primary substation in Wladyslawowo with a total installed power of 5,4 MW. As a part of the demonstration 2MW of active power was available for the provision of service purposes.

Mława area (LV)

The LV pilot area in the town of Mława included a housing estate of terraced houses, powered from the MV/LV station T761725 Mława Podmiejska I. The estate is powered directly from the station by the nnYAKXS 4x240 cable line. Each of the houses is equipped with a photovoltaic installation and a heat pump. The power of PV installations ranges from 7.29 kW to 12.5 kW.

Figure 3-3 - Demonstration area in Mława

High saturation of photovoltaic installations means that at the moment of peak generation, the permissible voltage is exceeded, which results in the disconnection of the customers' PVs. In extreme cases, with a very high level of generation and a minimum level of energy consumption by customers, temporary overloads of power cables occurred in the past.

In the selected area, a total of 5 individual customers were acquired to provide services to DSOs and TSOs as part of the project.

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Figure 3-4 - Power supply scheme for the demonstration area in Mława

Przywidz area (MV and LV)

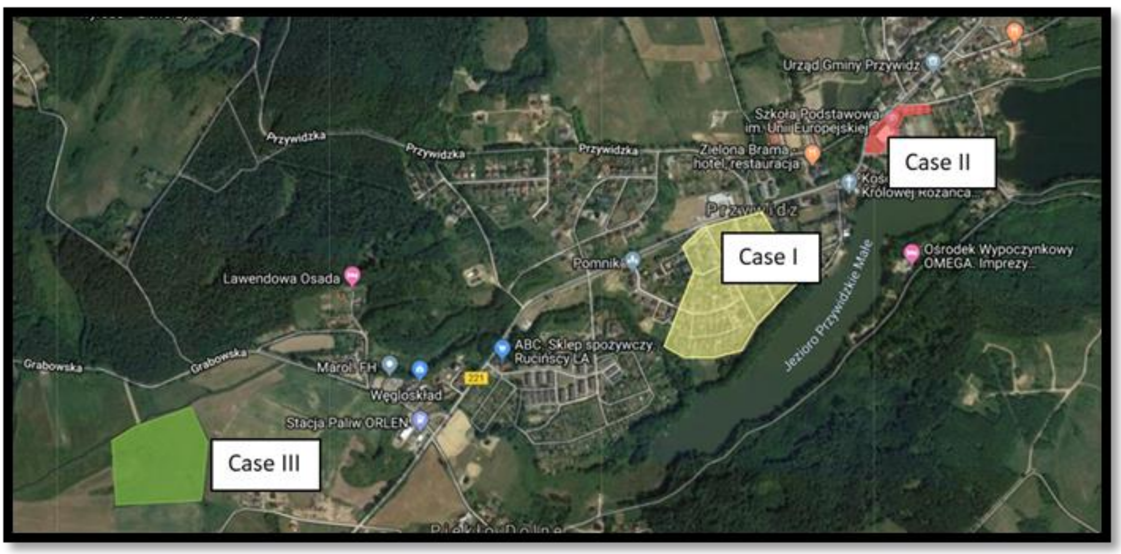

Figure 3-5 - Demonstration area in Przywidz

The demonstration area in Przywidz covered the 15 kV MV grid and a section of the LV grid in the area of the town and in its close vicinity. Przywidz in a normal grid operation system is energized from three different primary substations (HV/MV) with three long MV lines. For the purposes of the project, the network topology was changed to create an isolated energy island powered by only one MV line no. 07400-19-603100, powered from the Skarszewy primary substation. The pilot area of the LV network was located within the 5393 Przywidz Osada MV/LV substation. The major part of the MV and LV networks was built as an overhead network. The demonstration area was highly saturated by PV installations connected to the MV and LV networks.

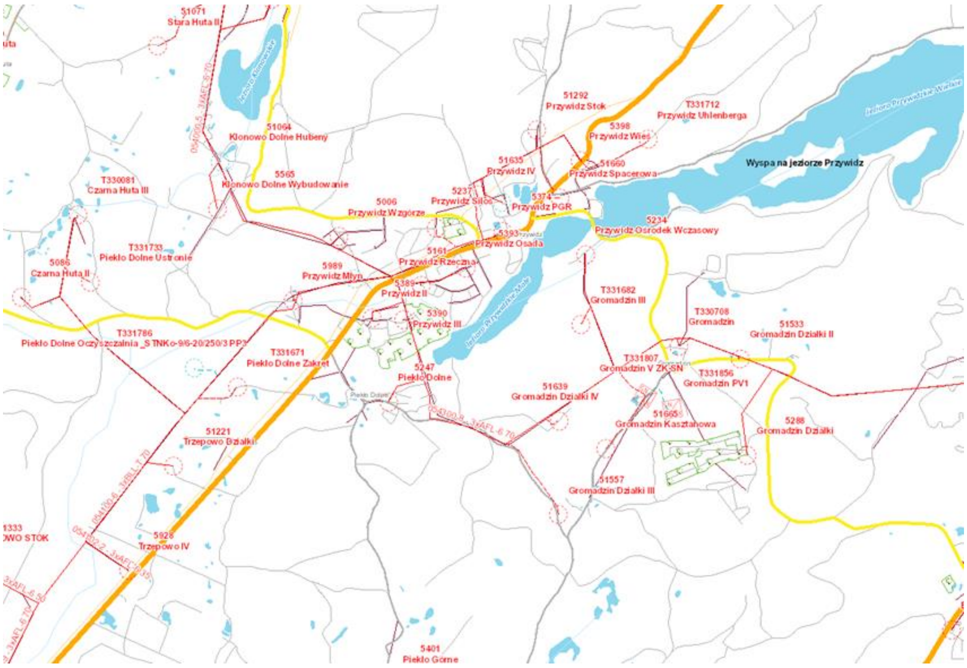

Figure 3-6 - Power supply scheme for the demonstration area in Przywidz

Due to the introduced abnormal network operation and the power supply to the town of Przywidz with one power supply line, problems with maintaining the voltage level within acceptable values in the network occurred in the past. This applies to both MV and LV networks.

In the selected area of the network, two groups of customers who wanted to provide services for DSOs and TSOs were recruited. The first group consists of facilities owned by the Commune of Przywidz (local authority), i.e., the Commune Office, a school with a sports and entertainment hall, a kindergarten, a hydrophore plant, a sewage treatment plant and a social welfare centre. All of these facilities have different possibilities to influence the network with various resources (PV installations, heat pumps, DSR). The second group consists of household customers who have the status of prosumers. Those customers have different varieties of PV installations, that have the possibility for the remote control of input power. The main area for the LV network test is marked in yellow (case I) on the figure above. Resources available for the test are installed in this area and are connected to one MV/LV substation. The other marked areas (Case II and III) are mainly buildings owned by the Local authority, with significant connection power. Case II has a school with a big PV installation, an EV charging station

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and heat pumps. Case III has a modern sewage treatment plant with PV, a diesel engine for emergency power supply and potential possibilities of providing the DSR service based on the technological process.

As described above, the most common FSP type in the Polish demo are prosumers with PV installations. As part of the project, a device for the PV control was developed and installed on the FSPs' side to provide remote control of devices and output power. This new control unit dedicated to the PV installation can operate in different configurations (power of PV installation and different solution) and allow the aggregator (or any entity, that would like to control the PV installation) to automatically change the output power of the PV installation. The device is directly connected to the inverter of the PV installation via RS485 and uses common protocols, implemented in most inverters for communication and sending control signals. The communication between the operator and the control unit is based on the standard LTE communication, that ensures minimal delays in the activations (few seconds).

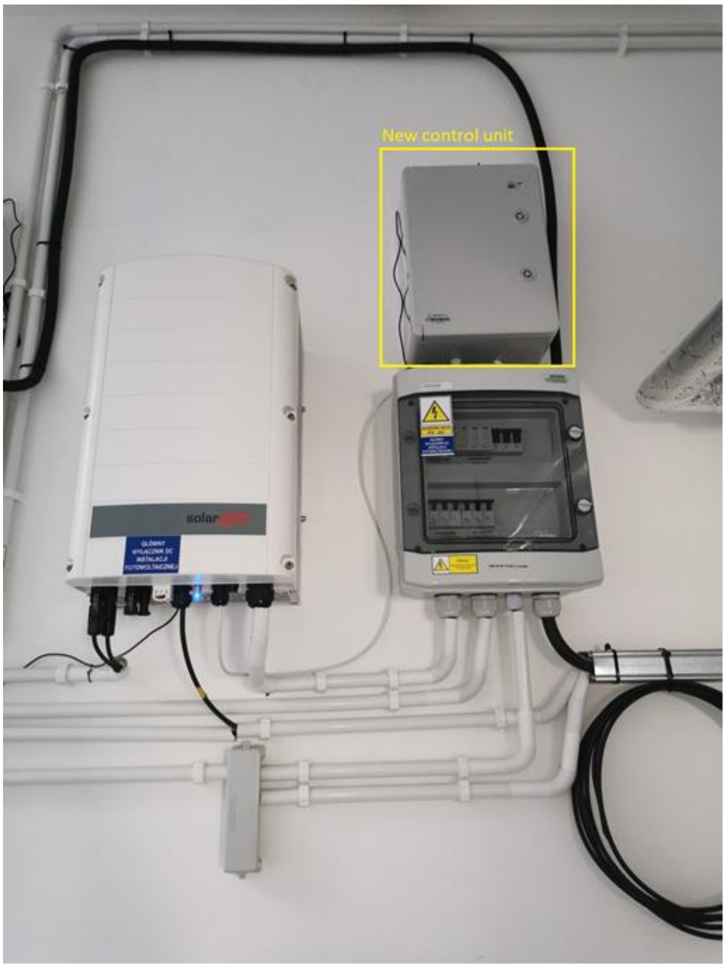

Figure 3-7 - New control unit installed on the customers' site in the garage.

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Figure 3-8 – New control unit installed on the outdoor installation.

Figure 3-9 - Online visualization of measurements from PV installations participating in the project

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For the needs of the test and demonstration in the OneNet project, Enspirion – aggregator company involved in the Polish Demo[2] - has created a dedicated online tool for controlling photovoltaic installations by sending a signal to the controllers via the API. The power level control is in the percentage range of 0% to 100% in relation to the rated power of the inverter.

In addition, the portal builds a minute graph of active power values, records measurement values from each device with one minute resolution to the database (and converts them to 15-minute and hourly data). In addition, the tool allows the addition/removal of users and measurement points.

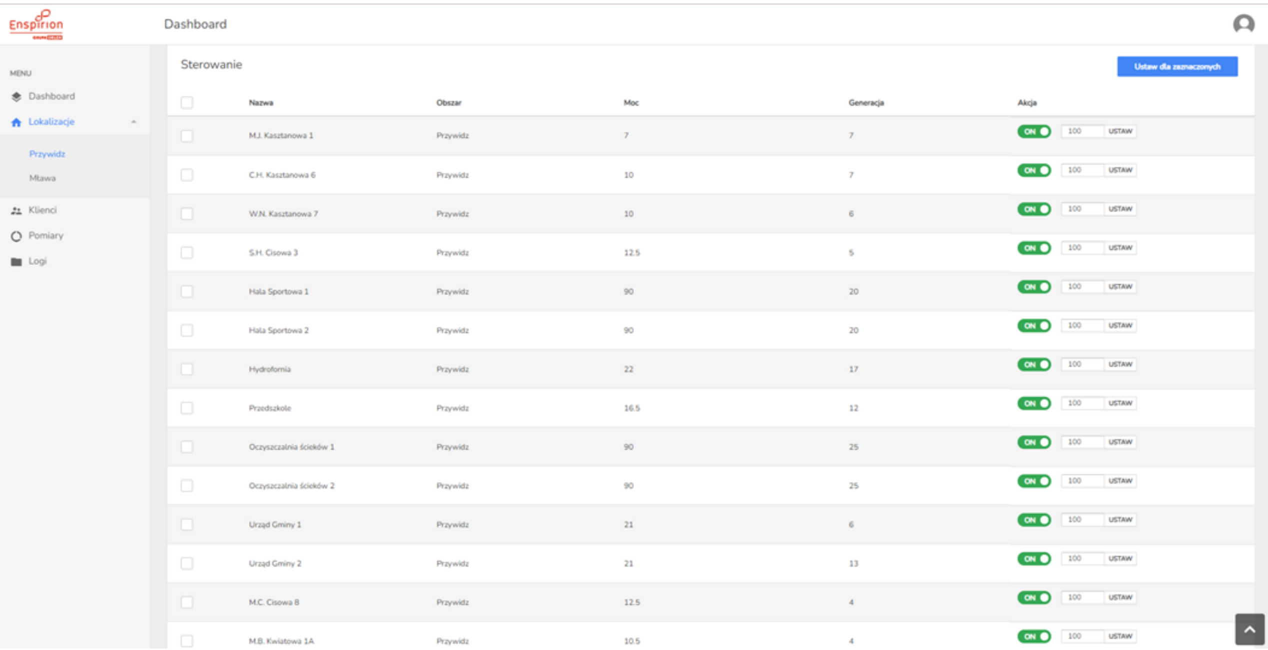

Figure 3-10 – View of controlling individual PV installations from the Enspirion application.

3.2 Demonstration of services and products in PL Demo

3.2.1 Demonstrated services

As part of the demonstration, the DSO tested two products (in fact, one product in two variants), which were based on managing the active power of electricity consumers and producers connected to the ENERGA-OPERATOR grid. These products were used both for Congestion Management services to limit the current flowing through the distribution network and for Voltage Control services to maintain the voltage level within the required range. During the demonstration, both products were abbreviated as CM&VC (congestion management and voltage control). The use of a specific product by the DSO and the launch of the auction were

[2] https://enspirion.pl/

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related to network needs. Products were used for both auctions for the next day (day-ahead auctions) and a week in advance (for the purposes of planned works). Both products can be used as support for DSOs in increasing work efficiency and managing HV, MV and LV networks. The products are defined as follows:

CM&VC+ increase in active power at the resource connection point - active power volume resulting from an increase in consumption or a decrease in active power supplied at the connection point, in relation to the baseline profile.

CM&VC- reduction of active power at the resource connection point - active power volume resulting from a decrease in consumption or an increase in active power supplied at the connection point, in relation to the baseline profile.

As part of the Polish demo, balancing services for the TSO were also tested, using resources connected to the MV and LV networks. These are the following standard balancing products [1]:

mFRR+ (Manual Frequency Restoration Reserve - injection)

mFRR- (Manual Frequency Restoration Reserve - withdrawal)

RR+ (Replacement Reserve - injection)

RR- (Replacement Reserve - withdrawal)

The subject of the tests was also balancing energy (EB), for which the direction (injection or withdrawal) was specified in the offer.

After grid and product prequalification of a specific distributed energy resource (DER) owned by the FSP, the FSP was able to participate in the auctions for the chosen products, and his asset was prequalified. The essential element of the offer was the self-schedule of the DER and the bid. One FSP could possess more than one DERs, so for every DER prequalification was needed before participating in any auction. If the FSP would like to participate in the balancing market, its resource(s) need to be attached to one of the scheduling units managed by the BSP and which operates on the market balancing its resources on behalf of the FSP.

The DERs' flexibility information was gathered into the scheduling unit offer before being submitted to the balancing market. Nonetheless, the scheduling unit offer may contain information from DERs in different locations. The procurement of some DERs might endanger the DSO network security, whereas other DERs from the same scheduling unit might be secure. Thus, the algorithms must always consider the information of the DER offers (with their location) instead of the scheduling units offers. The BSP must disaggregate the information of the scheduling unit offer (e.g., price and power) per DER in the flexibility platform.

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Demonstrated CM&VC services for DSO

The Polish demo use case describes the process of purchasing congestion management and voltage control services based on the active power by DSO in two-time frames: day-ahead horizon and week(s) ahead horizons. The DSO purchases services from customers through auctions launched on the flexibility platform developed as part of the project. The auction was called by the DSO only when the need for such action was identified in the distribution network. Auctions in the day-ahead horizons were used to solve the operational problems related to the changing of the forecast (load and generation). The week(s) ahead auctions were used to support the maintenance work planned ahead by the DSO.

During the demonstration, the DSO was contracting in one auction the capacity and energy at the same time. This approach that was used to simplify the demonstration and separated markets for capacity and energy could be established in the future (similar to the Polish balancing market).

The key element for the DSOs' actions was the detection of the network constraints in advance and making the decision of whether the flexibility services are needed to solve the problem or the problem could be solved with other technical solutions. The Active Management System developed as part of the project, as a SCADA system addition, includes the power flow analytic tool that was used by the DSO to perform network analysis in the demonstration areas. The forecast calculations of the network in the demonstration areas were based on historical data, current network conditions and the weather forecast. The tool allowed the identification the areas and times of occurrence of specific problems in the network.

After identifying the problem in the Polish demo area, analysing the actions that would help in maintaining the network and making a decision to use market solutions to solve congestion or voltage problems, the DSO was calling an auction.

Auctions were called for specific areas and dedicated products that were a solution for the particular problem. The areas could be a HV/MV primary substation, one or group of MV/LV substation(s), one or more LV connection points.

Because the congestions and voltage problems in the distribution network have local character, during the call for the auction, the DSO selected only specific nodes and only those FSPs that were supplied from these nodes could put their offers. This allowed to minimize the number of offers that the DSO had to verify in the grid impact assessment step and to analyse only those offers that are able to support the DSO in solving network constraints.

After the gate closure of the auction, the DSO downloaded the list of offers from the market platform. The offers were exported from the market platform as an excel file, which contained the basic information needed to verify the offers: ID of the offer, location of the DER (grid node), value of the power offered by DER in kW for each of the timestamps (i.e., hour).

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The offers were used to modify the DSO forecasted data of active power generation and load that were used for network stability and security analysis. The value of the active power in the specific node was modified according to the offers. Based on that action, the impact of solving the network problem for each of the offers was verified. As a result of the power flow calculation, each of the offers received a positive or negative impact note for solving the problem. In the event that none of the single offers was able to solve the network problem, the DSO started a more complex analysis to identify which set of offers could remove the network constraints.

After the grid impact assessment analysis, the DSO marked on the market platform the offers applicable to the removal of network constraints and, based on the price, chose those with whom they intend to conclude a contract.

After receiving information about winning a specific auction, the customer was obliged to perform the energy management activities declared under the auction.

On the service delivery day, the DSO supervised the service delivery process based on the AMS/SCADA network monitoring system and verified the information on an ongoing basis with the aggregator representing a given customer. Depending on the type of resource providing the service, the energy performance was changed automatically from the aggregator's (PV) systems or manually (locally) by the FSP.

After the test was completed and the service delivery was performed, the correctness of the service performance was verified based on historical measurement data (AMI remote reading meters, SCADA measurements, aggregator monitoring systems). Data analysis was the basis for settlement with the FSP.

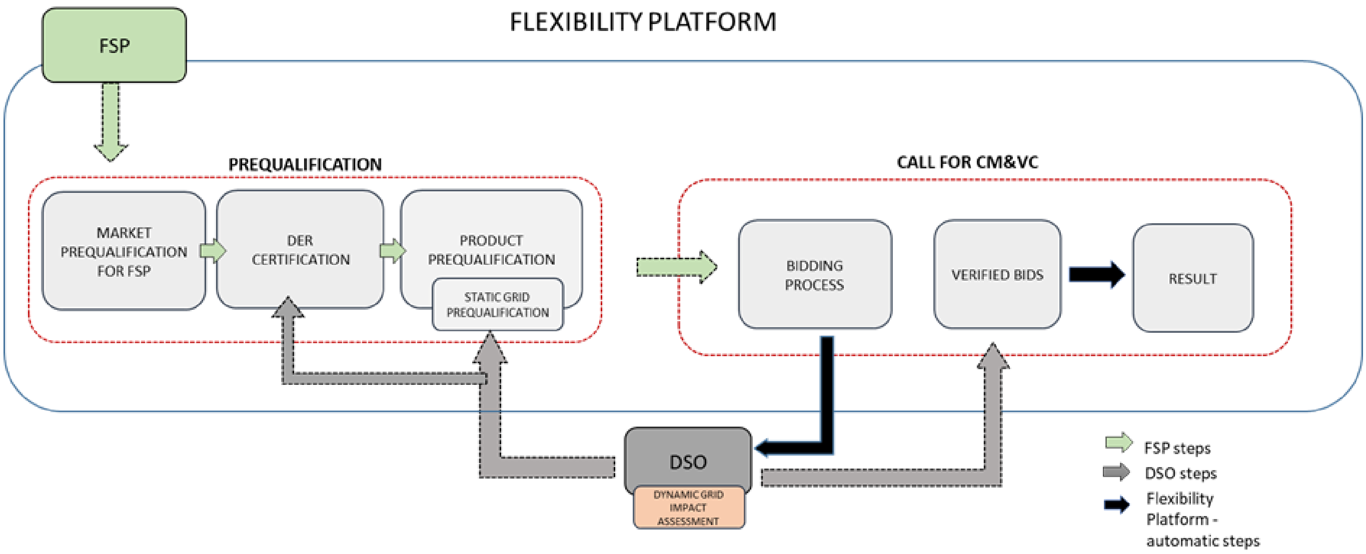

Figure 3-11 - A simplified diagram of the purchase of services by DSOs

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Demonstrated balancing services for TSO

One of the main purposes of the demonstration was to verify various algorithms of technical feasibility in the context of DSO network security and optimization in the case of using flexibility resources from MV and LV networks.

Due to the schedule of the implementation of the new method of functioning of the balancing market in Poland, demonstrations of balancing services were carried out using real resources activations in three scenarios and without direct contact with balancing market in Poland, and without affecting the nowadays balancing market operated by the TSO. The simulation conditions reflected, as closely as possible, the functioning of the future energy market in Poland, which is currently being changed. The simulations took into account all publicly available information from the balancing guidelines[2] and the requirements for the second milestone (MS2) of the reform of the balancing market in Poland [3].

The structure of the energy market used in the Polish demonstration is presented below. More information about the Polish energy market, including assumptions for future flexibility market are found in the OneNet project public deliverable: [D3.1 Overview of market designs for the procurement of grid services by DSOs and TSOs](#).

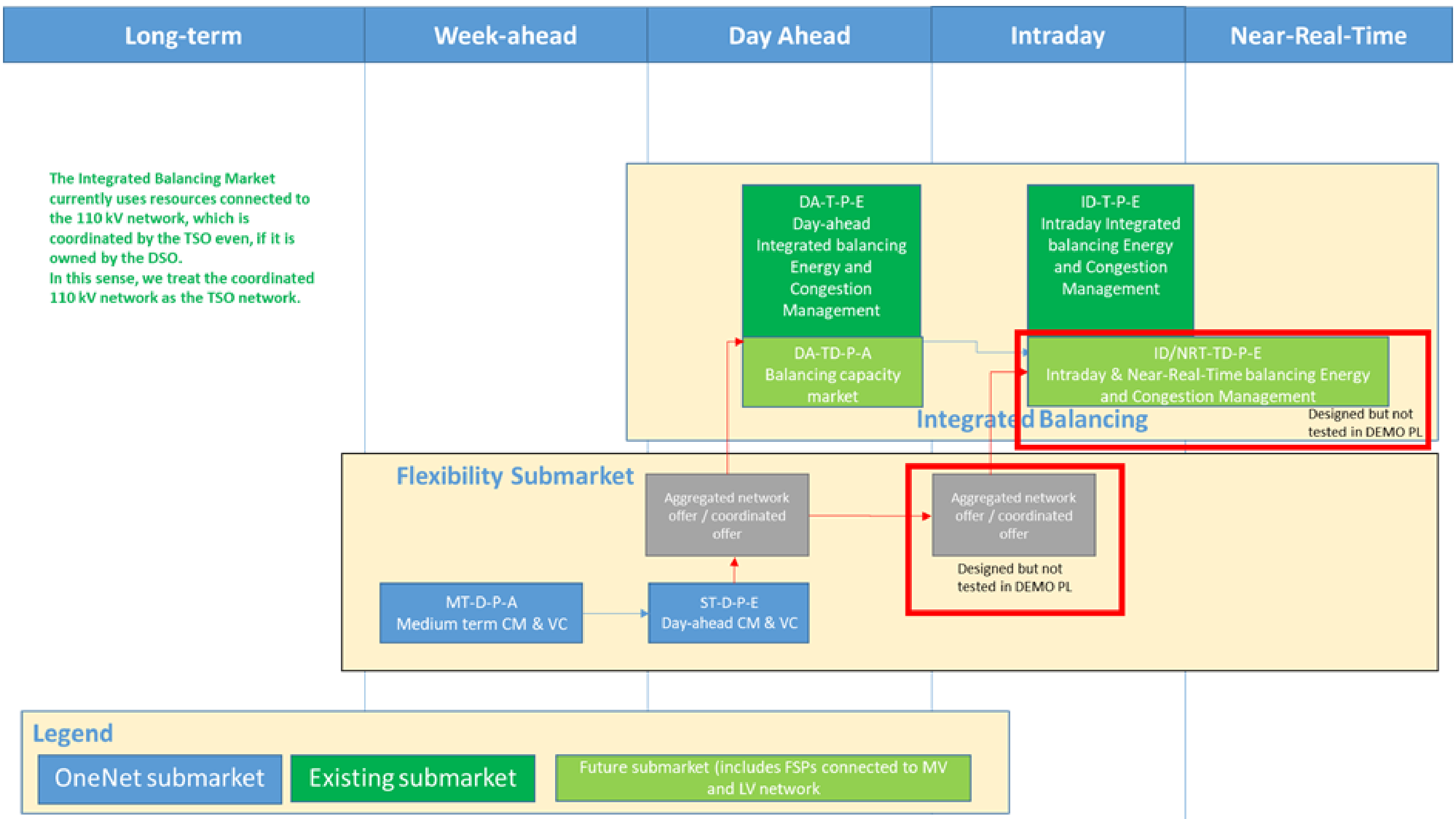

Figure 3-12 – Polish demo market design

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Due to the REMIT Regulation [7], only publicly available regulations (approved or submitted for consultation) were used during the demonstration of balancing conditions.

As part of the demonstration, three different scenarios (AGNO - aggregated network offers, DANO - disaggregated network offers and SETO - set of offers) were tested that differ in the:

- arrangement of scheduling units.

- method of assessing the impact of the activation of a given resource (DER) on the DSO network (based on the optimization algorithms or DSO's own actions).

In the case of the optimization algorithms, several of them were developed for different scenarios and products, such as:

- Pure AGNO.

- AGNO for DGIA (dynamic grid impact assessment).

- AGNO for reserves.

Those algorithms are described in detail in section 3.2.3.

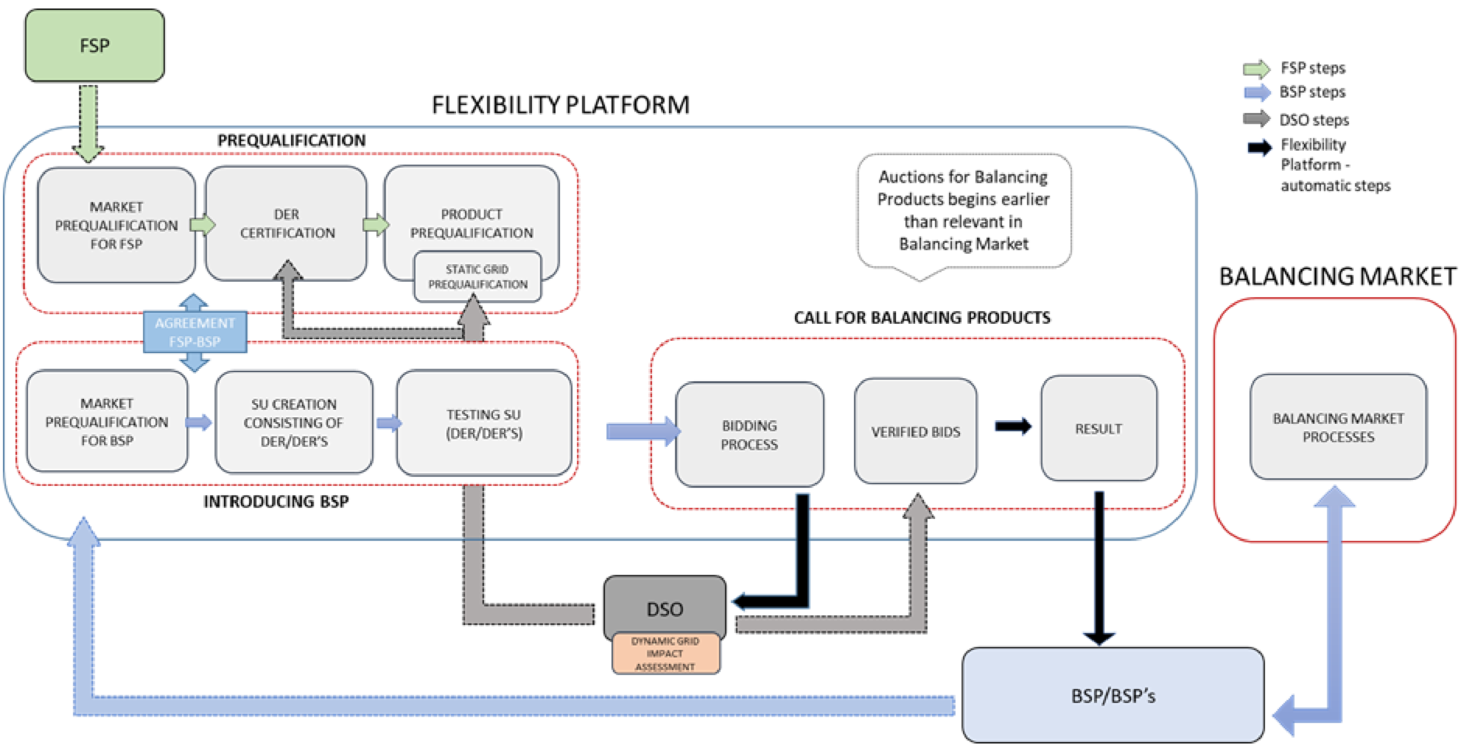

Figure 3-13 - Simplified diagram of purchase of services by TSO with the DSO playing the main decision actor

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The scheduling units used in the tests complied with the rules set out in the draft Regulation of the Ministry of Climate and Environment published in April 2022 on detailed conditions for the operation of the power system.

Two main approaches for contracting the balancing services by the TSO were tested as a part of the Polish demonstration and are presented in the diagrams below.

In the first approach, the DSO is responsible for the verification of offers by performing a dynamic grid impact assessment using Active Management System and removing offers that may create problems in the DSO network - congestions or voltage violations. The bid verification results are then sent back to the flexibility platform.

In the second approach, bids are verified on the flexibility platform, using a coordination and optimization algorithm for the selection of the best set of offers, taking into account the security and stability of the distribution network operation. In this case, the DSO sends the required network topology information and the network measurements needed for the grid analysis. In the Polish demo, the day-ahead forecast prepared by the DSO using AMS system and forecast data from the smart meters were sent.

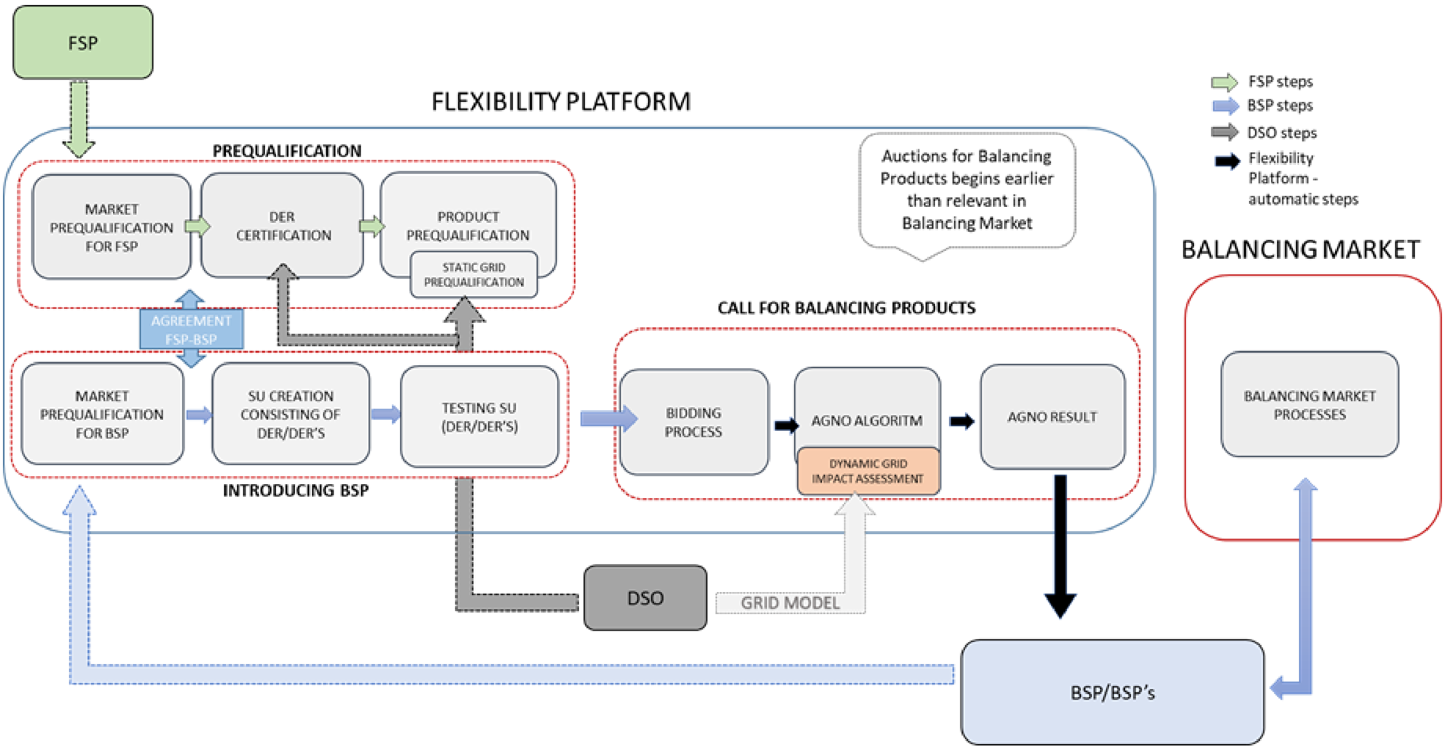

Figure 3-14 - Simplified diagram of TSO service, where market algorithm plays the main role for bid selection.

For the first approach, the SETO scenario and the configuration of scheduling units described in section 3.2.2 were suitable.

For the second approach, two scenarios and different configurations of scheduling units were possible. The first scenario was the AGNO scenario and the second was the DANO scenario. Both scenarios are described in section 3.2.2.

3.2.2 Scenarios tested and simulated

AGNO scenario

The scenario assessed the impact of the activation of a given resource on the DSO network through the Pure AGNO algorithm and AGNO for reserves performing the power flow calculations on the flexibility platform based on network data provided by the DSO. The algorithm assumed only one scheduling unit (JG) in a given DSO network are connected by a single node to the TSO network (coupling point = DSO and TSO network interconnection point, which defines a coupling point area), which is presented in Figure 3-15.

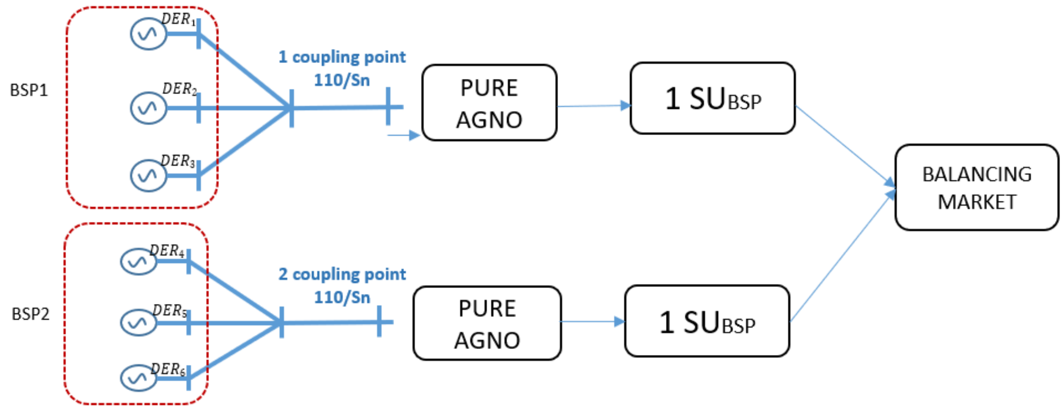

Figure 3-15 - Structure of scheduling units and the Pure AGNO algorithm in the AGNO scenario

DANO Scenario

The scenario assessed the impact of activation of a given resource on the DSO network through an algorithm that performs power flow calculations on the flexibility platform based on network data provided by DSO. In this scenario, there are no restrictions on the number of scheduling units (JG) for different BSPs in a coupling point area, which is in line with the assumptions of the new national Terms and Conditions related to balancing. It also enables one scheduling unit to use resources connected to different nodes of the network. This is presented in Figure 3-16.

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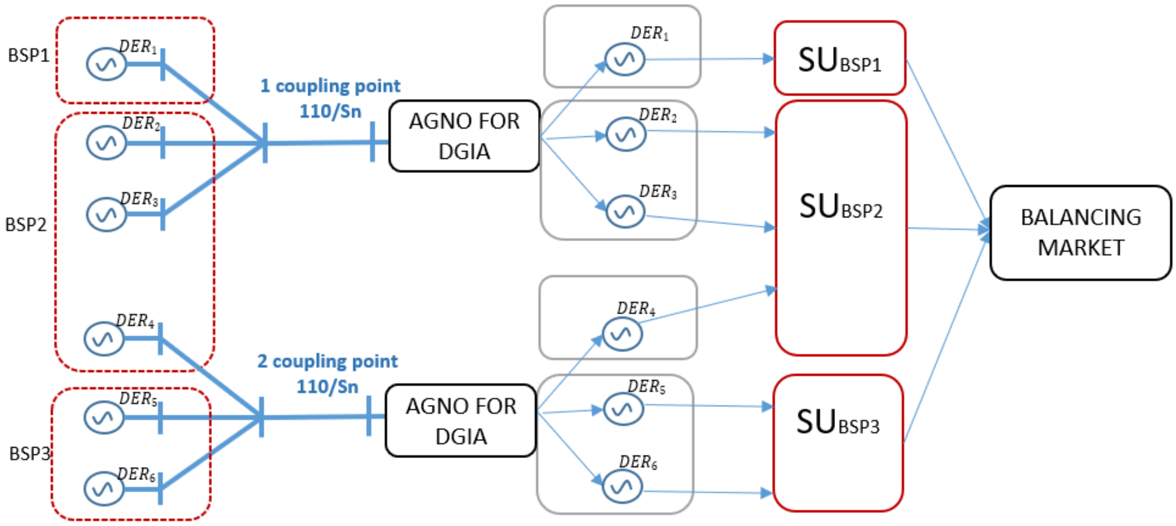

Figure 3-16 - Structure of scheduling units and the AGNO for DGIA algorithm in the DANO scenario

SETO scenario

The scenario evaluates the impact of activation of a given resource by DSO performing power flow calculations. A set of offers of individual resources is sent by the flexibility platform to the DSO and then, after verification, the DSO sends to the flexibility platform a verified set of offers taking into account the potential network constraints of the DSO. In this scenario, there are no restrictions on the number of scheduling units (JG) for different BSPs in a network node (coupling point = DSO and TSO network interconnection point). It also allows one scheduling unit to use resources connected to different nodes of the network. This is presented in Figure 3-17.

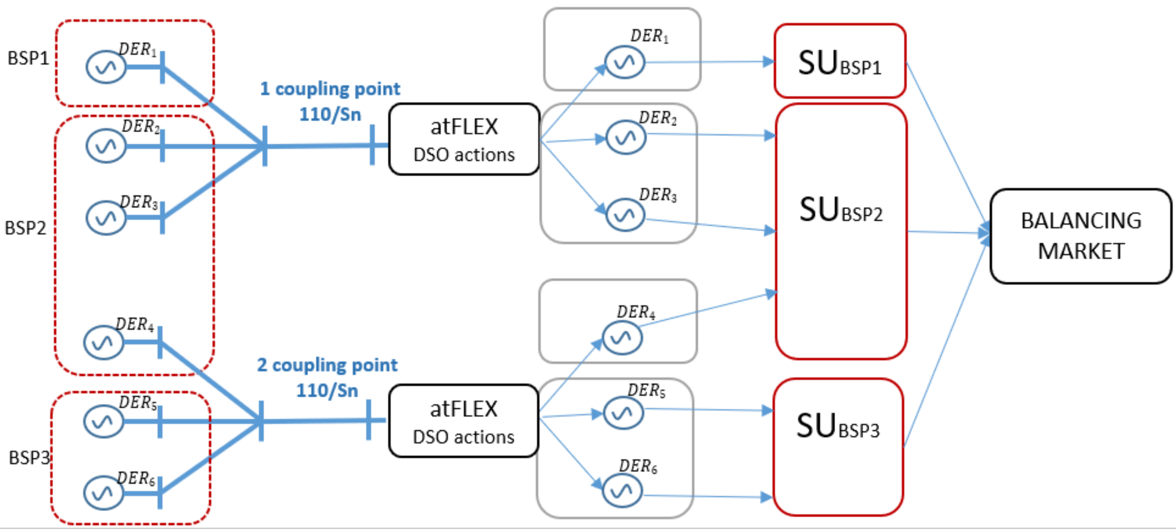

Figure 3-17 - Structure of scheduling units in the SETO scenario

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In the case of the SETO scenario, the DSO is responsible for verifying the offers and their potential impact on the security of the DSO network.

After closing the gate for the day-ahead balancing product auction, the DSO extracted a set of offers for the given auction and performed the grid impact assessment. The offers were exported from the market platform as an excel file, which contained the basic information needed to assess the impact of the offer on the grid: ID of the offer, location of the DER (grid node), the value of the power offered by the DER in kW for each of the timestamps.

The offers were used to modify the active power generation and load data forecast by the DSO, which were used to analyse network stability and security analysis. The value of the active power in the given node was modified according to the offers. The impact of all offers on the DSO's network was verified in one simulation for all offers together. If no network constraints were detected during the analysis, the DSO marked all offers on the market platform as valid. If any network constraints were detected during the offer validation, the DSO tried to identify the offer or offers responsible for the network stability violation. Each offer was verified separately and the impact of each offer on the network was analysed. If any of the offers was responsible for congestion or voltage violation in the network, the DSO excluded this offer from further analysis and performed the grid impact assessment again for the rest of the offers. The process is repeated until all the congestion in the network and voltage violation were removed. Subsequently, the DSO made the results of the grid impact assessment available on the market platform, marking accepted and rejected offers from the network stability point of view (by clicking a checkbox).

Finally, the DSO confirmed that it had validated the offers and their impact on the network, marking it on the market platform.

As part of the Polish demonstration, many tests were performed for all scenarios, with simulations for the AGNO scenarios and real activations for the DANO and SETO scenarios. The results of these tests are presented in section 3.4.

3.2.3 Algorithm description

This section presents the optimization algorithms applied in each scenario. There are two types of algorithms depending on the market process for which it was designed.

1. Algorithms applied to the Balancing Market. Those algorithms aim at ensuring that the balancing energy offers are not endangering the DSO network. There are two ways of ensuring it:
    a. Pure AGNO: it creates a new offer (Aggregated Network Offer) for the coupling point area which contains the information of all the secure procurements of the DERs.

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b. AGNO for DGIA: it performs a dynamic grid impact assessment before the balancing market. In other words, the DGIA reduces the DER offer power when there is a potential danger in the DSO network.

2. Algorithms applied to the Balancing Capacity Market. The algorithms aim at ensuring that the activation of the reserve offers is not endangering the DSO network.

    a. AGNO for reserves: It reduces the balancing capacity offers whose activation may endanger the DSO network. The reserve activation follows a hierarchical approach based on the estimated savings of procurement cost.

The algorithms are designed to analyse all the DER offers at the same time of one coupling point area per each imbalance settlement period (current hour) independently.

3.2.3.1 Pure AGNO

The pure AGNO algorithm analyses the DER offers and the DSO network in order to create one equivalent aggregated network offer (scheduling offer) per coupling point area (CP area) in order to select the optimal combination of offers for the balancing market, while not allowing to endanger the DSO network.

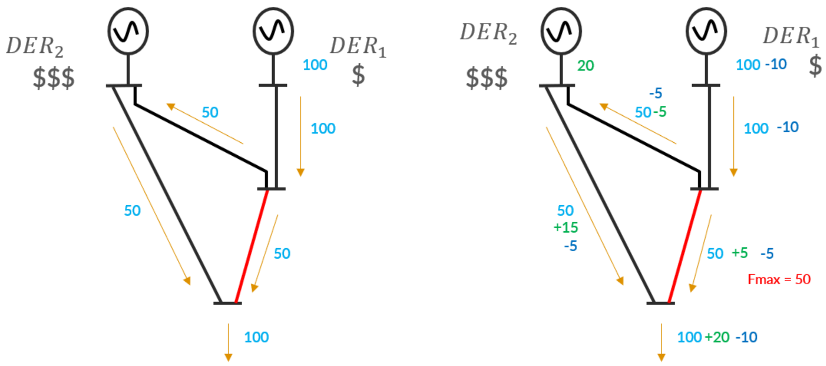

Figure 3-18 – Simple example that shows that coordinating the DER procurements in the coupling point area can increase the maximum flexibility for the balancing market.

The pure AGNO algorithm aggregates all the DERs offers into one offer per CP area. It allows internal coordination of the flexibility that increases the optimality and maximum flexibility of the CP area. In order to illustrate this in more detail, an example is presented above. There are two DERs: DER_1 is cheaper than DER_2. Both DERs provide flexibility to the balancing market through one coupling point based on pure AGNO (one scheduling unit). The left figure shows the optimal procurements when the balancing market demands 100 units of power, all of them are obtained by DER_1 which distributes them through the network based on the impedance of the grid (simplified numbers with no losses). The red branch represents a congestion. The right figure shows the optimal procurements when the balancing market demands 110 units of power, DER_2 provides 20 units of power and DER_1 provides 90, which is lower than the left figure even if it is the cheapest DER. However, the

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congestion of the branch in red does not allow to extract more from DER_1 thus, the only way is to provide 20 by DER_2 and reducing 10 from DER_1, which distributes them through the network based on the impedance of the grid (simplified numbers with no losses). Without DERs coordination, the maximum flexibility of the coupling point would be 100 units coming from DER_1 exclusively.

The coordination of offers in the example is a result of the algorithm co-optimizing the DSO network problems and balancing price at the same time. In other words, the pure AGNO allows to perform the DSO congestion management while procuring the balancing market.

Due to the applicable regulation on the balancing market, the flexibility platform cannot provide the AGNO information from the coupling point directly to the balancing market. Instead, it must be the BSP directly which provides the offer data to the balancing market. Hence, the pure AGNO algorithm can only be applied when there is one scheduling unit for the entire coupling point (implying one BSP per coupling point area too), allowing the BSP to change the offer based on the AGNO results from the flexibility platform. Nevertheless, it was included as one of the scenarios (i.e., AGNO scenario) in the Polish demo to show its potential, the learnings and regulation barriers found by this algorithm proposal.

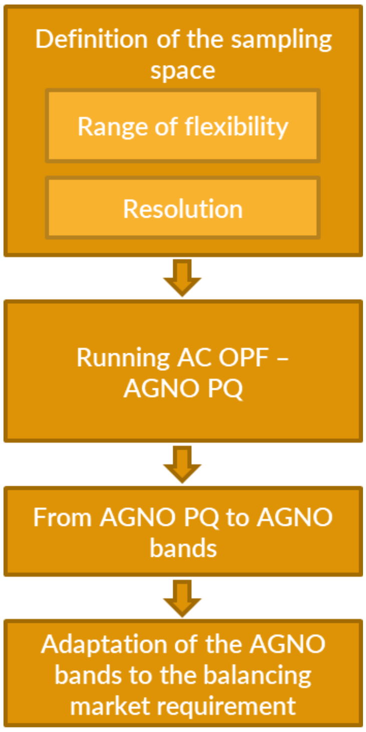

Figure 3-19 - Pure AGNO - Algorithm steps.

However, if it is forced by the regulation to select one BSP per coupling point area, it may complicate the competition of the BSPs per DER. Since all the DERs of one coupling point area are forced to select one BSP only.

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In addition, with more BSPs per coupling point area, the settlement process should be adapted to consider one AGNO for the balancing market in order to define rules of responsibilities in case of imbalance of one BSP over the others.

The general steps of the algorithm are described below:

1. Definition of the sampling space: it is defined as the sampling space of power in the coupling point for which the algorithm selects the optimal procurement of DER offers. The sampling space is defined by two steps:

    a. Range of flexibility: it identifies the maximum and minimum active and reactive power at the coupling point, in other words, the borders of the PQ sampling space, i.e., P_{max}^{CP}=20MW, P_{min}^{CP}=-10MW,Q_{max}^{CP}=5MVAR, Q_{min}^{CP}=-5MVAR . The range of flexibility can change in each imbalance settlement period due to different offers being submitted and possible network topology changes.

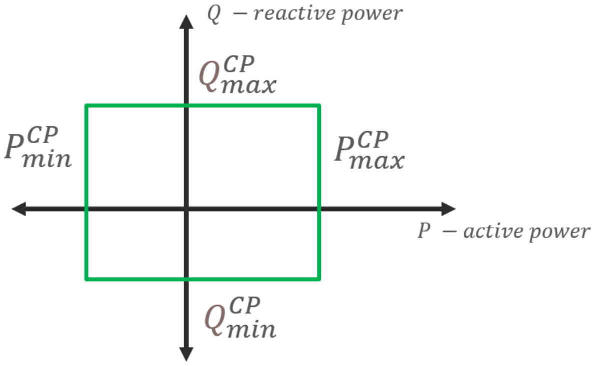

Figure 3-20 - The range of flexibility defines the square of the PQ points of the sampling space. It is defined by 4 values.

    b. Resolution: The resolution defines the granularity of the sample space - number and distribution of each PQ sample. The higher the resolution, the higher the accuracy of AGNO results.

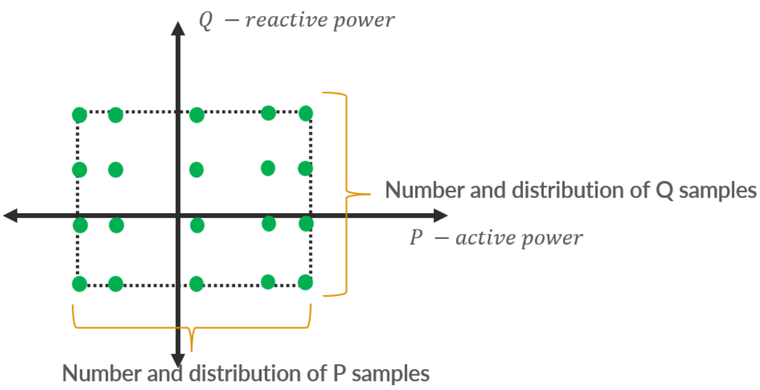

Figure 3-21 - Resolution definition.

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The figure shows an example of resolution where 4 points of reactive power are equally distributed per P point and 5 points of active power with a distribution which is more focused on the borders of the sampling space.

2. Running AC OPF – AGNO PQ: the second step of the algorithm computes AC OPF results[3] per each PQ sampled point defined in the previous step. The computation of each AC OPF is as follows:

    a. Fixing the coupling point injection according to the sampled points

    b. Run AC OPF per sampled point[4]

    The feasibility results of the ACOPF computations create the AGNO PQ space.

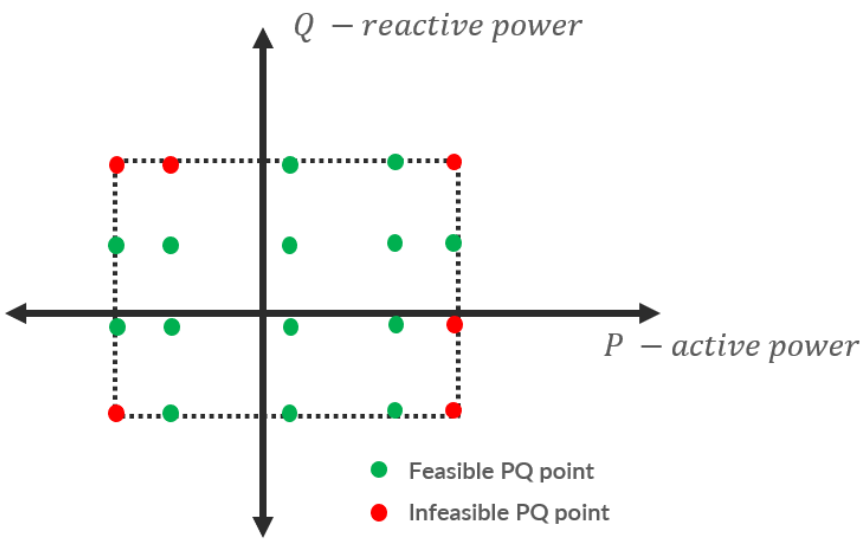

Figure 3-22 - AGNO PQ region.
The results of the AC OPF allow us to identify the feasible and infeasible PQ points

3. From AGNO PQ to AGNO bands: The third step aims at calculating the AGNO based on the AGNO PQ results.

    a. Calculate AGNO self-schedule ($AGNOss$): Calculate the power in the coupling point when all the DERs are generating their self-schedule, which is named AGNO self-schedule.

    b. Calculate the price per each active power: Each sample point has defined their price depending on the pricing mechanism (e.g., marginal cost, maximal offer price from the procurement, etc.). From the set of active power points (e.g., $P^{CP} = 10MW, Q^{CP} = [5MVR, 0MVAR, -5MVAR]$ where the superindex CP represents the coupling point), the cost of the cheapest sample is extracted. Since it is assumed that the reactive power can be set to the desired one.

[3] https://pandapower.readthedocs.io/en/v2.2.0/opf/pypower_run.html#ac-opf
[4] With all the typical input data of Optimal Power Flow

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c. Define AGNO bands: the prices of each active power point are aggregated into bands with the same price, e.g., $P^{CP} = [20MW, 10MW]$ with a price of [150PLN/MW, 150PLN/MW] are aggregated into one band. The direction of the bands (i.e., up or down) is defined depending on the AGNO self-schedule.

4. Adaptation of the AGNO bands to the balancing market requirement. There is a maximum of 10 bands per offer provided to the balancing market. Conversely, pure AGNO algorithm defines the number of bands based on the offers and sampling space. Thus, when there is a higher number of bands that the BM allows, part of the AGNO bands are merged into one with the highest price and summing the amount of power, e.g., band 1 [20MW, 150PLN/MWh] and band 2 [10MW, 200PLN/MWh] are merged into band12 [30MW, 200PLN/MWh].

After the balancing market, the results of the AGNO offer (scheduling unit) procurements are disaggregated per DER by launching in the flexibility platform an AC OPF with the procurement results as coupling point injections to calculate the optimal disaggregation of the results per DER.

3.2.3.2 AGNO for DGIA

The dynamic grid impact assessment (DGIA) module was designed and implemented into the flexibility platform in order to coordinate the TSO and DSO needs. Hence, an algorithm performing the DGIA is presented, taking into account the optimal procurements calculated by the AGNO calculation.

AGNO for DGIA algorithm provides a reduction of the DER offers based on the secured maximum procurement of the DER based on the optimal procurement from other DERs (based on the offers price). In other words, what the maximum procurement of DERs is without endangering the DSO network, independently of other DERs procurement.

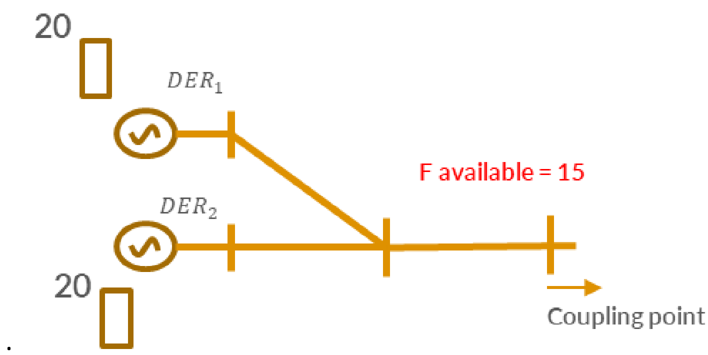

Figure 3-23 – Simple example that shows the potential results of the dynamic grid impact assessment without offers considerations as AGNO for DGIA.

The main difference from typical dynamic grid impact assessment is that it includes the information of the offer prices. Thus, it allows the reduction the offers in the most optimal way. Let's present the importance of

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this with the figure above (to simplify the explanation, the losses of the system are ignored). It represents a simple DSO network, where there are two DERs with the offer power (20 power units). Nevertheless, it is seen that the DSO network only allows 15 as a maximum from any of them. If the dynamic grid impact assessment ignores the offer prices, then the results may be to accept only 15 from the DER_1 or to accept only 15 from DER_2 or any combination of that both doesn't surpass the limit of the network (15). On the other hand, AGNO for DGIA considers the DERs offer price, thus being clearer which one is the optimal one.

It is an algorithm which may be performed with the current regulation without limiting the number of BSPs per coupling point area.

The lack of coordination of DERs offers provides lower flexibility than the pure AGNO algorithm.

The general steps of the algorithm are presented below.

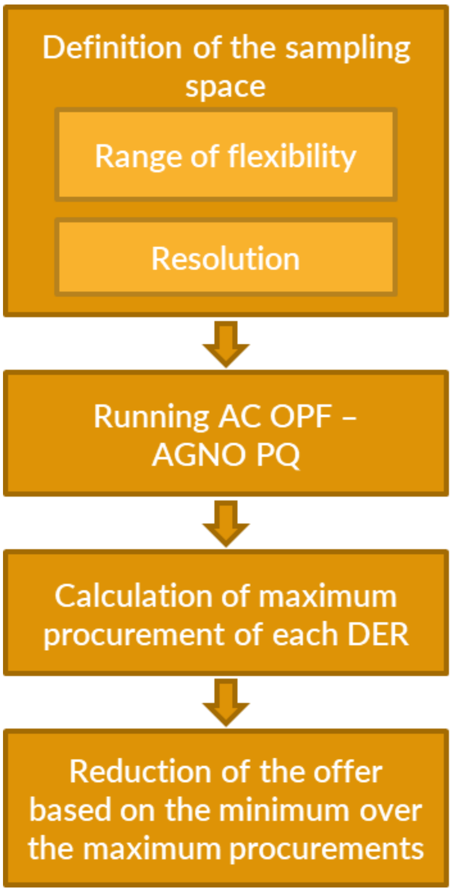

Figure 3.24 - AGNO for DGIA - Algorithm steps.

1. Definition of the sampling space: it is defined as the sampling space of power in the coupling point for which the algorithm selects the optimal procurement of DER offers. The sampling space is defined by two steps:

    a. Range of flexibility: it identifies the maximum and minimum active and reactive power at the coupling point, in other words, the borders of the PQ sampling space , i.e., $P_{max}^{CP} = 20MW$,

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$P_{min}^{CP} = -10MW, Q_{max}^{CP} = 5MVAR,\ Q_{min}^{CP} = -5MVAR$. The range of flexibility can change each imbalance settlement period due to the different offers' submission and possible network topology changes.

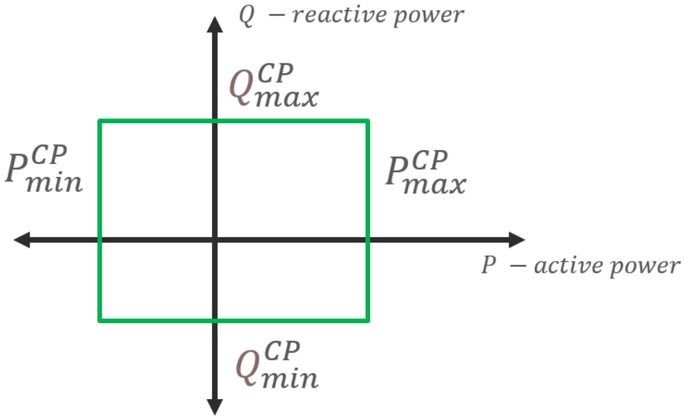

Figure 3-24 - The range of flexibility defines the square of the PQ points of the sampling space. It is defined by 4 values.

b. Resolution: The resolution defines the granularity of the sample space - number and distribution of each PQ sample.

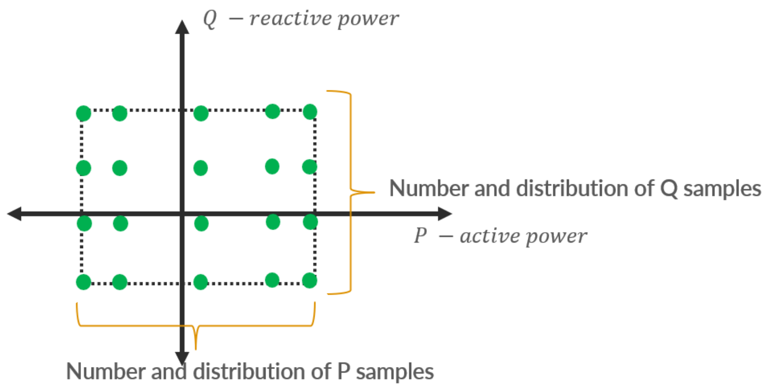

Figure 3-25 - Resolution definition.

The picture shows an example of the resolution where it is seen 4 points of reactive power equally distributed per P point and 5 points of active power with a distribution which is more focused on the borders of the sampling space.

2. Running AC OPF – AGNO PQ: the second step of the algorithm computes AC OPF results[5] per each PQ sampled point defined in the previous step. The computation of each AC OPF is as follows:

[5] https://pandapower.readthedocs.io/en/v2.2.0/opf/pypower_run.html#ac-opf

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a. Fixing the coupling point injection according to the sampled points

b. Run AC OPF per sampled point[6]

The feasibility results of the ACOPF computations create the AGNO PQ space. The AC OPF obtains the operating points of all the DERs in each PQ sampled point.

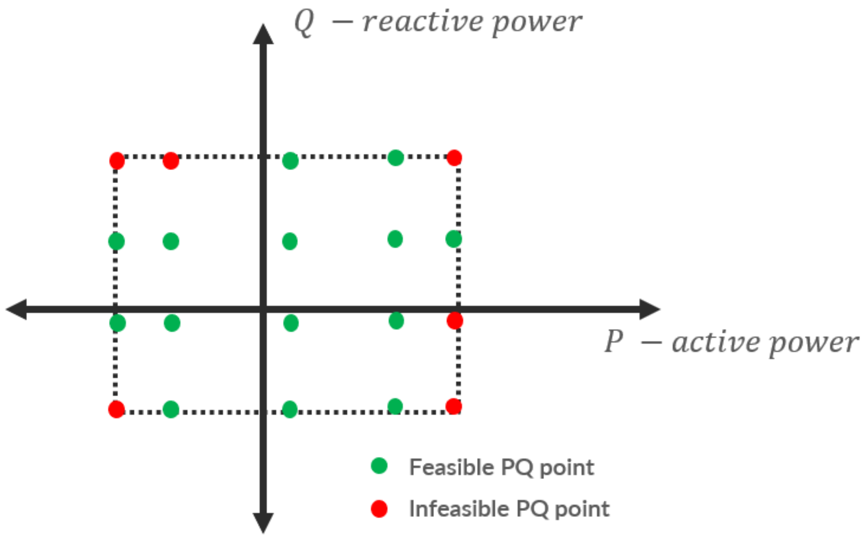

Figure 3-26 - AGNO PQ region.

The results of the AC OPF allow us to identify the feasible and infeasible PQ points

3. Calculation of maximum procurement of each DER in the optimal procurement. An optimization problem is built per DER and per PQ sample point that maximizes the procurement of each DER maintaining the rest of the DER power setpoints fixed, based on the optimal procurement calculated by AGNO PQ results.

$$P_{max}^{DER_i} = \max\ P^{DER_i}$$
$$subject\ to{:}\ \ \forall\ DER_j \neq DER_i\ \ P^{DERj} fixed,$$
$$Power\ flow\ constraints^7$$

Where:

P_{max}^{DERi} is the maximum power output of DER_i that is secure from the DSO network perspective, while maintaining the rest of the DERs fixed, based on the optimal procurements.

P^{DERi} is the optimization variable which represents the power output of DER_i.

P^{DERj} is the parameter that represents the power output of DER_j in the optimal procurement of the PQ sample. It is obtained in the 2nd step of the algorithm.

[6] With all the typical input data of Optimal Power Flow.
[7] The power flow constraints are based on the AC model of the OPF. They verify the limits of power flow in the branches of the network and voltage limits in the nodes. The equations are non-linear.

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4. Reduction of the offer based on the minimum over the maximum procurements per each active power sampled. The minimum of all the maximum procurements ($\min P_{max}^{DERi}(P^{CP})$) over all the sample points per each DER provides us a value of procurement that is secure regardless of the rest of the DERs considered in the optimal procurement. In addition, due to the limited number of samples of the AGNO PQ, that value cannot be higher than the generation of the DERs at the border of the feasible AGNO PQ.

   The results of this step are the reduced DER offers. Later, those results are included in the Scheduling Unit offer that is to be forwarded to the balancing market.

3.2.3.3 AGNO for reserves

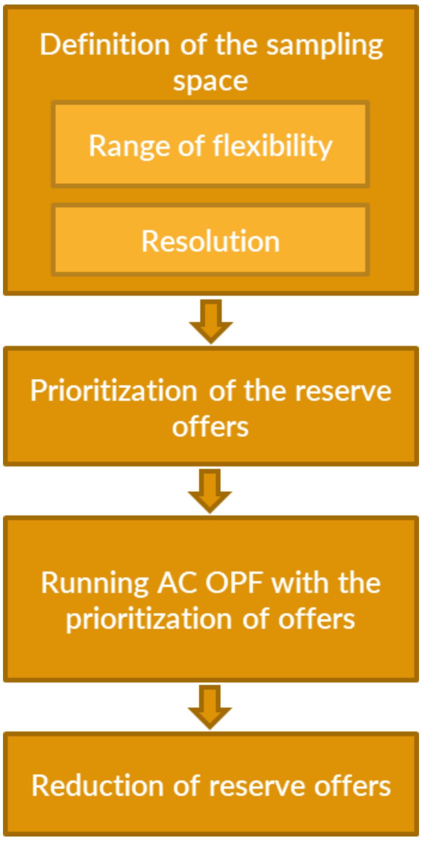

Figure 3-27 - AGNO for reserves - algorithm steps.

To ensure that the potential activation of the reserve products is not dangerous for the DSO network is really challenging since it depends on the energy procured on the network and also on the results of the reserve procurements. Those are not accurately known (only forecasts) when the coordination algorithms are to be applied. However, ideally, we would only like to allow the reserve procurements that are safe for the DSO network before. Thus, the AGNO for reserve algorithms provides the innovative idea of applying a forecast of the reserve prices in order to prioritize the reserve procurements based on the savings (most likely to be procured and potentially activated). Consequently, the errors of the forecast price impact the optimality of the algorithm results. Analogously as before, several market runs can be a possible solution.

The general algorithm steps are as described below.

1. Definition of the sampling space: it calculates the samples of PQ injections in the coupling point (PQ points) that would be evaluated in the third step. The target is to find a set of PQ points that allows us to identify the maximum secure potential activation of reserves offers up and down. The sampling space is defined by two steps:
   a. Range of flexibility: it identifies the maximum and minimum active and reactive power at the coupling point, in other words, the borders of the PQ sampling space , i.e., $P^{CP}_{max} = 20MW$, $P^{CP}_{min} = -10MW$, $Q^{CP}_{max} = 5MVAR$, $Q^{CP}_{min} = -5MVAR$. The range of flexibility can change with each imbalance settlement period due to different offers being submitted and possible network topology changes.

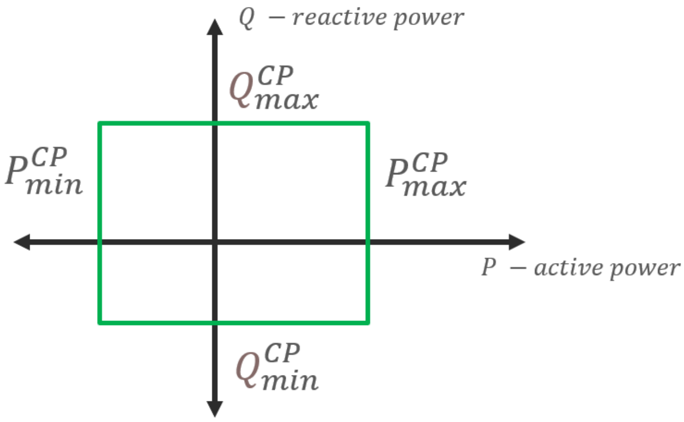

Figure 3-28 - The range of flexibility defines the square of the PQ points of the sampling space. It is defined by 4 values.

   b. Resolution:

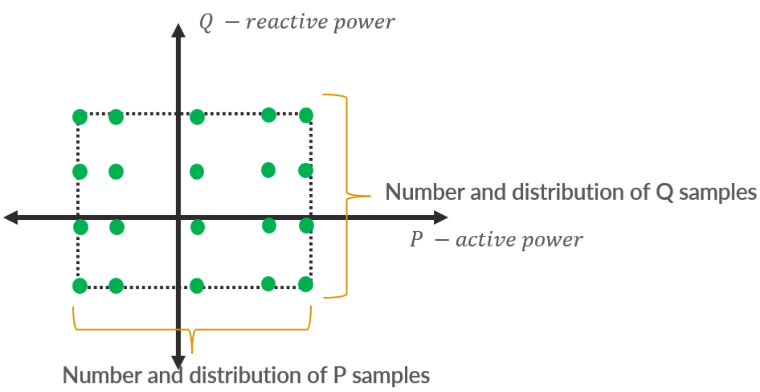

Figure 3-29 - Resolution definition.

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The figure shows an example of resolution with 4 points of reactive power equally distributed per P point and 5 points of active power with a distribution which is more focused on the borders of the sampling space.

The resolution defines the granularity of the sample space - number and distribution of each PQ sample. It is defined differently for active power and reactive power. For instance, there may be higher resolution over the active power than the reactive power. The higher the resolution, the higher the accuracy of AGNO results.

2. Prioritization of the reserve offers: the order of potential activation of reserves is defined based on the estimated savings. The savings are calculated based on the difference between the forecasted reserve product prices and the reserve offers cost. The savings are applied in the next step of the algorithm.

$$\forall_{u,r} \; S_{u,r} = \widetilde{p_r} - rop_{u,r}$$

Where:

u – DERs participating in the DA Balancing Capacity Market.

r – reserves types, i.e., FCR, mFRR, aFRR, RR.

$\widetilde{p_r}$ – forecasted price of the r reserve type.

$rop_{u,r}$ – reserve offer price of the DER u and for the reserve type r.

$S_{u,r}$ – savings of the procurement cost.

3. Running AC OPF with the prioritization of offers: the PQ points which are at the borders of the sampling space represent the maximum potential activation of the reserve offers up and down. The AC OPF is performed in those PQ points. However, the objective function of the AC OPF is changed in order to maximize the savings of the offers (New Objective Function =max $\sum_{u,r} S_{u,r}$). The results of the AC OPF provide us with the information of which reserve offers could not be activated in any of the PQ points in the borders (for up and down).

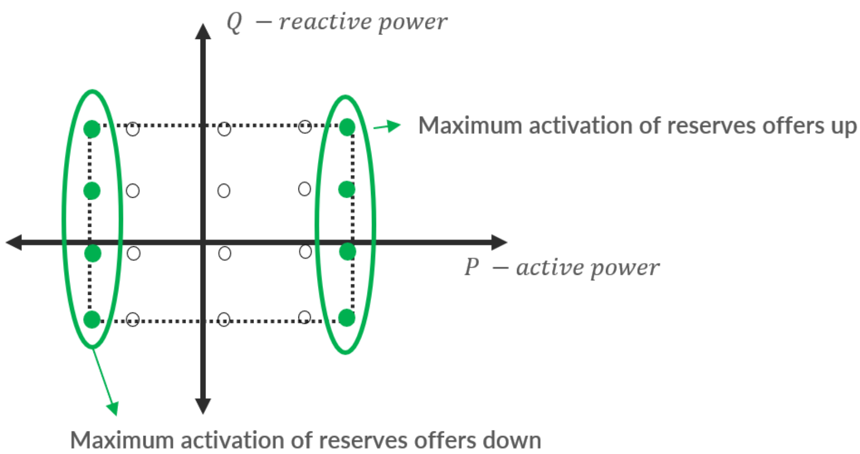

Figure 3-30 - The maximum activation of reserve offers is found in the extremes of the sampling space.

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4. Reduction of reserve offers: the reserve offers up and down (or part of them) which could not be activated in the PQ border are reduced and not provided to the Balancing Capacity Market.

3.2.3.4 Alternative version of the algorithms -AGNO P - reducing the Q dimension of the sample space.

All the previous algorithms contain the following common steps:

- Definition of the sampling space
- Run AC OPF

Those two steps are focused on the AGNO PQ sampling space. However, the algorithms can be analogously performed with only the active power dimension - AGNO P sampling space. The equivalent steps are as follows:

1. Definition of the sampling space: it is defined as the sampling space of active power in the coupling point for which the algorithm selects the optimal procurement of DER offers. The sampling space is defined by two steps:
    a. Range of flexibility: it identifies the maximum and minimum active and reactive power at the coupling point, i.e.,
    $$P_{max}^{CP} = 20MW, \quad P_{min}^{CP} = -10MW, Q_{max}^{CP} = 5MVAR, \quad Q_{min}^{CP} = -5MVAR$$
    The active power range limits the sampling space of the following step. On the other hand, the reactive power range defines the maximum limits of reactive power while running ACOPF (next step).

Figure 3-31 - The range of flexibility defines the P points of the sampling space and the reactive power limits in the coupling point.

    b. Resolution: The resolution defines the granularity of the sample space - number and distribution of each P sample. The higher the resolution, the higher the accuracy of AGNO results.

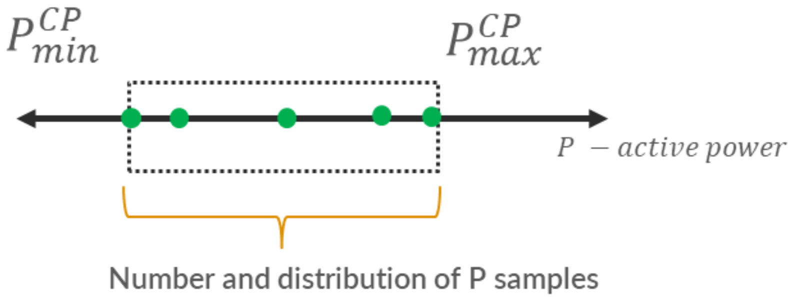

Figure 3-32 - Resolution definition.
The figure shows an example of resolution where 5 points of active power have a distribution which is more focused on the borders of the sampling space.

2. Running AC OPF – AGNO P: the second step computes AC OPF results per each P sampled point defined in the previous step. The computation of each AC OPF is as follows:
    a. Fixing the coupling point injection according to the P sampled point.
    b. Defining the maximum limits of reactive power of the coupling point based on the range of flexibility.
    c. Run AC OPF per sampled point

    The feasibility results of the ACOPF computations create the AGNO P space..

Later, the rest of the steps are performed analogously as a particular case of AGNO PQ when there is only one reactive power sample per active power, i.e., AGNO PQ with only one Q per each P.

3.2.4 Conclusions and lessons learnt from optimization algorithms tests

Several algorithms were developed and tested in the Polish demo to ensure a market-based DER procurement in the Balancing Market without jeopardizing the DSO network.

The alternative dynamic grid impact assessment to the algorithms is the DSO actions focused on the maximum range of flexibility.

- It doesn't verify the entire range of flexibility as pure AGNO and AGNO for DGIA. Hence, it might ignore violations of the DSO network security in the middle of the flexibility range.
- The bigger the number of DERs, the higher the complexity of the DSO verification. The proposal of an automatic and parallelizable[8] algorithm scales better with higher integration of DERs.

Optimization algorithms allow in addition to disaggregate the procurement results of the balancing market into particular DERs. In the case of pure AGNO, the disaggregation rule may differ depending on the balancing

[8] Parallelization of the AC OPF simulations through procurements of flexibility, different DSO network (CP) and different timestamps. Different platforms could deal with different areas.

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market procurement value. Hence, the flexibility platform performs the disaggregation to the DERs of the scheduling units AGNO procurements by launching another AC OPF computation (only one AGNO PQ point of the feasible region).

The algorithms are designed conservatively from the point of view of the DSO network security. All the errors and simplifications prioritize the security of the DSO network against the optimality. In other words, the algorithm may reduce the DER offers more than it should, rather than not reducing them enough.

On the other hand, several market runs are a possible solution to correct the results of the algorithm with the proper settlement process in order to prevent gaming strategies, i.e., providing a competitive market offer first to block other offers.

The algorithm ensures the security of the DER procurement based on the DSO data regarding:

- DSO network models.
- DSO injection forecast of the demand and DERs not participating actively on the balancing market.

The errors on the DSO data directly compromise the security and optimality of the algorithm results. It is recommended to monitor and control those errors (minimizing them). On the other hand, as mentioned above, several market runs are a possible solution to correct the results of the algorithm when the forecast is more accurate.

The experience of the Polish demo showed that the reactive power availability from the DERs can be crucial to extract the highest active power flexibility from the DERs for the balancing market purposes. Thus, it is recommended to facilitate, incentivize and/or encourage the participation of the DERs to providing reactive power to the DSO network. Alternatively, the DSO may invest in reactive power control devices to allow the access of that flexibility, which means that the DSO should control the reactive power devices based on the balancing market results.

The AGNO algorithms' core is based on the computation of the feasible region of the coupling point area, which represent how is the flexibility in the DSO area that can be passed to the balancing market. There are two versions of algorithms (i.e., AGNO PQ and AGNO P) depending on the dimensions of the flexibility range to be examined: active power or active power and reactive power.

For the scope of the Polish demo where the flexibility is applied to compute the active power offers that can be procured by the balancing market, both applications are valid. However, the AGNO P version performs generally better (finds bigger feasible region and thus more flexibility to the balancing market) when there is a lack of reactive power flexibility on the DSO network. On the other hand, the AGNO PQ can provide higher information to the DSO and TSO for different applications when the reactive power flexibility knowledge is required, e.g., DSO or TSO congestion management process.

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Regarding the computational performance of those two versions, the AGNO PQ considers more dimensions on the flexibility range, which implies higher computational time than AGNO P.

Technical implementation limitations and improvements.

I. The algorithms could include the information about the DSO reactive power control devices in order to optimize the settings to maximize the flexibility provided to the balancing market and later support the DSO in the control of them.

II. All the algorithms are based on collecting information from AC OPF simulations. Those simulations are discrete samples from the range of flexibility of each coupling point area. There is a natural error due to the discretization of the flexibility range, between two samples it is not known the optimal point. On the other hand, it assumes conservatively based on the information from the closest samples the security and optimality. A solution to minimize this error is to increase the granularity of the sample space by the user. However, it impacts the performance of the algorithm.

III. The AC OPF simulations on the algorithms consider the non-linear AC PF equations. It is the most accurate power flow representation of the network. Nonetheless, finding a solution of the non-linear AC PF may be challenging and may even depend on the machine applied, especially when it is included on a non-linear optimization problem. Thus, the AC OPF simulations may experience a lack of convergency or even struggle to find a feasible solution even if it exits. Some general non-linear optimization mitigation solutions are:

    a. To provide different initial points to the non-linear optimization solver as a starting point.
    b. To increase the accuracy and tolerances of the solver.
    c. To apply the most updated and powerful solver on the market. Commercial solvers are improving in performance in each release and this may dramatically impact this problem.

    Furthermore, particularly to the AC OPF problem, the following observations were made during the project:

    - The problem of finding a feasible solution may appear more frequently when there is no much flexibility on the DSO network, namely reactive power flexibility. That's why an alternative version of the algorithms was created to address the problems with reactive power.
    - It is not straightforward to identify in which network models it's more difficult to find the solution. As described in the literature [4], it may require analysing the Jacobian and Hessian matrices.

    Hence, a deeper research and improvements of the algorithm may go into the direction to handle those strange cases. Although, since it is a natural non-linear optimization problem, it may be studied to complement it with linear optimization approaches, e.g., iterative linear optimization combined with AC PF verification steps when the non-linear OPF cannot find the solution.

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IV. The DER resolution provides challenges to the operators' network models' accuracy. Normally, the TSO and DSO network models and power flow tools are prepared (and parametrized) for the MV and HV network where the order of magnitude of the injections is around MVA. Nonetheless, the DERs offer bands that are in the order of magnitude of kW or even W. It means between 10^6 and 10^9 times lower values of injections that are applied to the network models and power flow tools. There is a risk that the error of the network models and power flow tools is higher than the resolution of the DERs offers. Furthermore, it may also produce numerical problems to the AC OPF whose constraints were built with the units of the network models (MW) while at the same time it attempts to optimize the kW (or W) offers.

V. The balancing market regulation provides a limit of the number of offer bands per each scheduling unit, i.e., 10 bands per direction. It also applies to the aggregated network offer achieved by the pure AGNO algorithm. Thus, the AGNO must reduce the granularity of the offer bands to fit the regulation (last step of the algorithm in the description), which reduces the competitiveness of the offer in some parts of the offer range.

VI. The algorithms are limited to DSO network models with one coupling point to the TSO network area, as it is the most common the DSO-TSO interface. As a next step, it can be extended to DSO network areas with more than one coupling point.

3.3 IT architecture

3.3.1 High-level Big-picture

3.3.1.1 Actors and interactions

The main interactions between all actors are shown in Figure 3-33.

The actors and interactions presented above are a reflection of Polish BUCs [5], which have been edited into Polish SUCs [6]. Step by step system processes can be found in the following documents:

- EACL-PL-SUC-01 – Prequalification of resources – where the whole process of registration and prequalification is described.
- EACL-PL-SUC-02 – Bidding for day-ahead balancing – where the whole process of DA auctions is described.
- EACL-PL-SUC-03 – Bidding for long-term CM and VC – where the whole process of CM&VC auctions is described.
- EACL-PL-SUC-04 – Introducing BSP – where the whole process of creating relationships between FSP/FSPA is described.

These are the main interactions between all actors on the atFlex platform.

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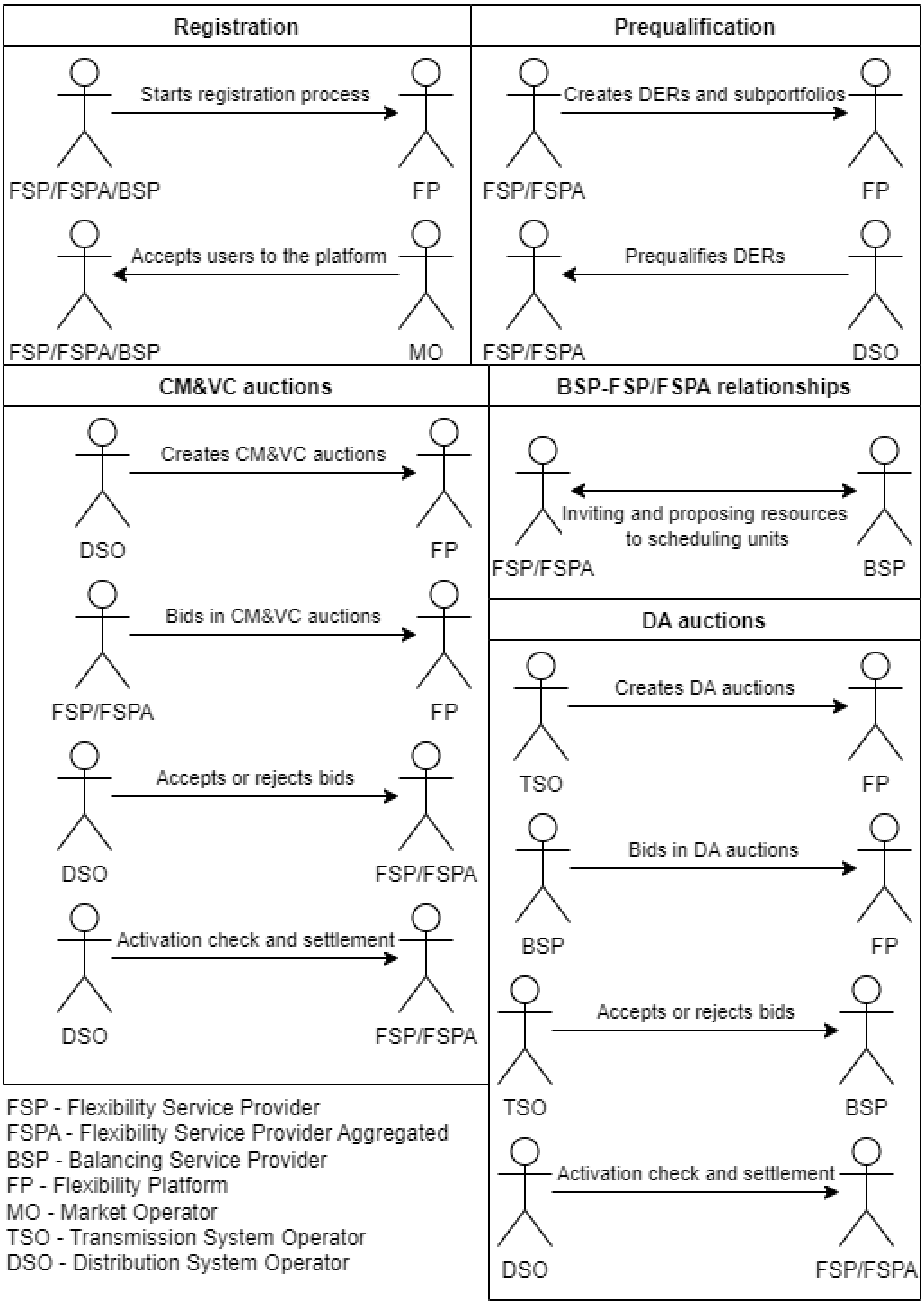

Figure 3-33 – Main interactions implemented on the atFlex platform and main actors of these interactions

FSPs/FSPAs are actors responsible for adding new Distribution Energy Resources (DER) on the platform and for bidding in Congestion Management & Voltage Control (CM&VC) auctions. They can also create flexibility potential objects and make agreements with BSPs.

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BSPs are actors responsible for bidding in Day-Ahead (DA) auctions. They can also make agreements with FSPs/FSPAs to create business relationships, which are needed, because BSPs use FSPs'/FSPAs' resources to take part in DA auctions.

MOs are actors responsible for the whole registrations process for FSPs, FSPAs and BSPs. This actor grants access to the platform.

TSO and DSO are actors responsible for moderating auctions, respectively for DA auctions for CM&VC auctions. Creating auctions, accepting/rejecting bids, monitoring activations – these are the main responsibilities of these actors.

FP is an artificial actor. It reflects all logical processes, which happen under and on the GUI of the platform.

3.3.1.2 Main modules descriptions and its interaction

The PL demo platform – atFlex – consists of many modules, but there are a few, which play the main role. Their interactions are shown in Figure 3-34.

DERs module allows the creation of objects of energy resources by the FSP and the FSPA. They are then certified by the DSO.

The Subportfolio module allows the creation of parties of DERs, which is done by the FSPA. They are then certified by the DSO.

Products module allows the creation of objects of the needs, which can be related to CM&VC needs of the DSO or balancing services of the TSO.

Scheduling unit is the module, where the FSP's/FSPA's DERs and the BSP's scheduling objects are linking with each other. They are then certified by the TSO.

Flexibility potential module confirms that a specific DER can cover the needs for products created by the TSO and the DSO. It allows to take part in CM&VC and DA auctions.

CM&VC auctions module allows the creation of auctions, which is done by the DSO and also allows bidding in these auctions, which is done by the FSP and the FSPA.

DA auctions module allows the creation of auctions, which is done by the TSO and also allows bidding in these auctions, which is done by the BSP.

Activation and settlement module allows the DSO to confirm the amount of volume activated by the FSPs and the FSPAs and also to send information about the settlement amount for each DER.

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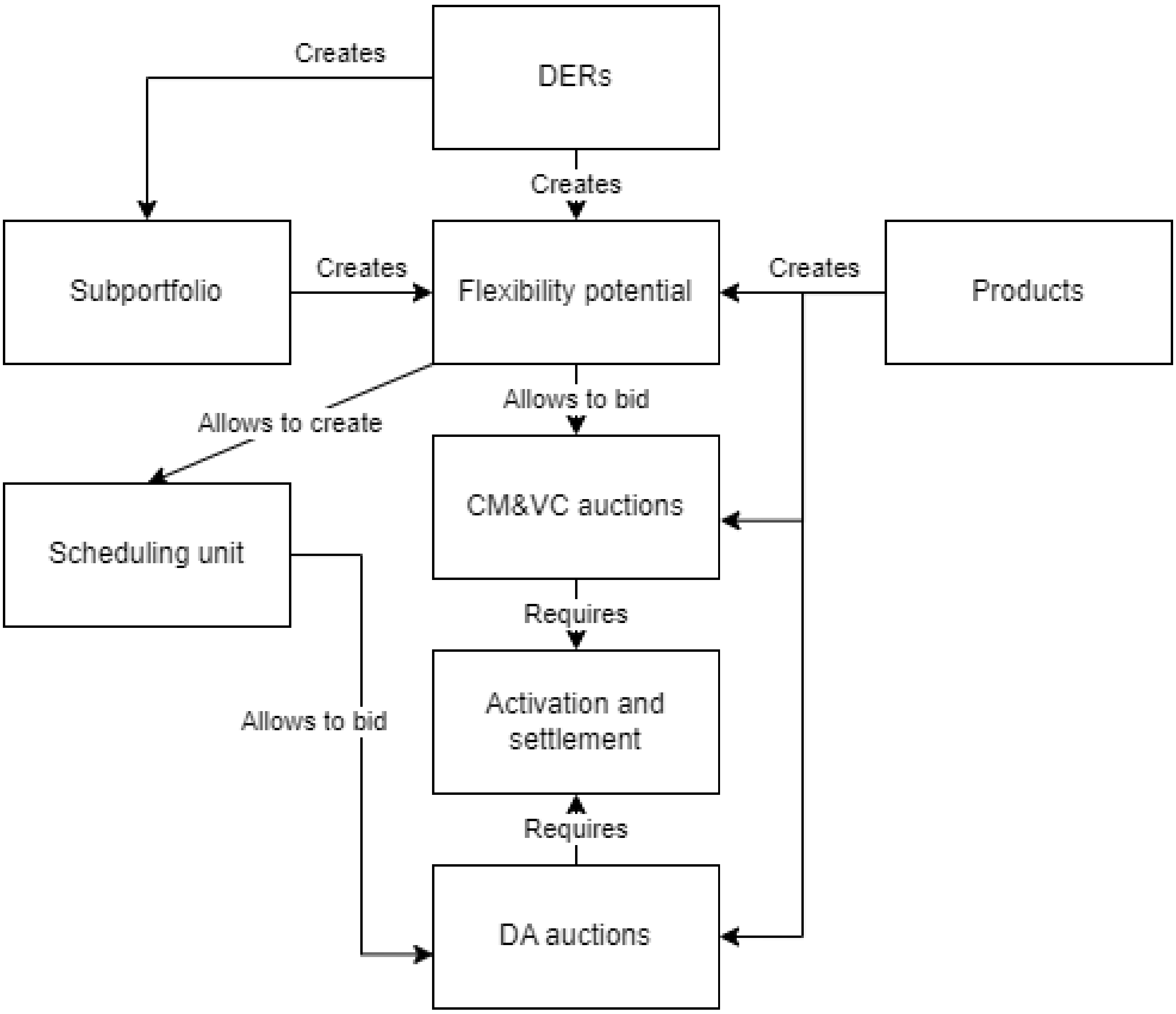

Figure 3-34 – Relations between specific modules (functionalities) of the IT solution

3.3.2 System components used

The technical components used for the current atFlex platform are as follows:

- Java
- Angular
- Spring Boot[9]
- Spring Cloud[10]
- JPA/Hibernate
- REST

[9] https://spring.io/projects/spring-boot
[10] https://spring.io/projects/spring-cloud

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- Websockets
- Oracle[11]

Any other extensions are not taken into consideration at the moment.

3.3.3 Architecture

3.3.3.1 Platform architecture

The Polish demo platform – atFlex – uses both microservices and is designed in 3 tier architecture. The whole architecture looks as follows:

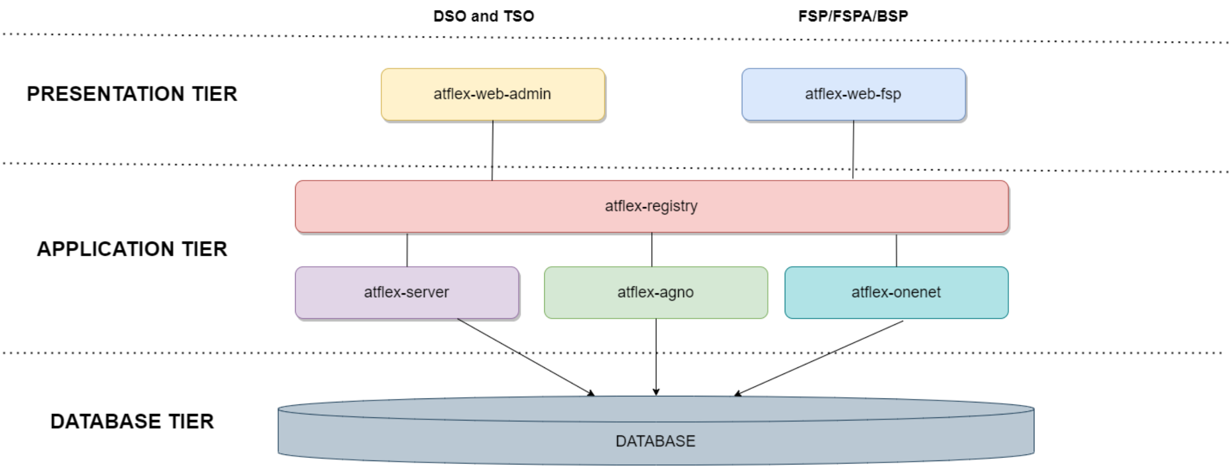

Figure 3-35 – Modules and microservices of specific tiers of the atFlex platform architecture

Module atflex-web-admin is the frontend representation of the admin site used by the administrators – DSO, TSO, MO and Technical Administrator.

Module atflex-web-fsp is the frontend representation of the user site used by the users – FSP, FSPA and BSP.

Module atflex-registry covers all routes for all other modules and enables communication, data exchange and proper localization of endpoint for both sides of communication. This module is the distributor of tasks for all other components.

Module atflex-server covers all the logic behind the application.

Module atflex-agno is responsible for running all the algorithms developed by NCBJ, creating input files for algorithms, reading logs from them and downloading output files.

[11] https://www.oracle.com/cloud/

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Module atflex-onenet covers all task regarding connection with the OneNet System (Connector). More about that in further description.

As a database, the Oracle relational database has been chosen.

3.3.3.2 Non-functional requirements

Availability: the atFlex platform is available only on business days from 8 a.m. to 6 p.m. and only for users who are based in Poland.

Performance: the platform is divided into many microservices. In case of problems with performance we are able to separate some functionalities from the existing microservice and create a new one and also move this new microservice onto the other infrastructure resource. For now, all microservices are located on one infrastructure resource and it does not cause any performance problems. Load balancer is also implemented on the platform. It automatically oversees traffic and in case of an overload, it automatically distributes this traffic across a number of servers.

Security: Strict registration process, which is managed by the Market Operator. In case of authentication, authorization and information exchange everything is secured by JSON Web Tokens. The platform is also restricted to HTTPS protocols only with certificates with an expiration date.

3.3.4 Dataflows API, Format

The atFlex platform does not use any communication channels with any M2M actors. Everything happens on the platform through GUI and import/export actions on excel files.

3.3.4.1 OneNet Connector Integration

The Polish demo atFlex platform is fully integrated through API connections with the OneNet Connector. There is a module developed on the platform, which is desired only for ONC.

ONC is deployed on the same infrastructure resources as the platform and the data exchange is operated through an API, delivered by ONC itself.

On the platform, the following ONC modules are used:

- Authentication module – which allows the addition of the users to the Polish platform and choose the active one, which data will be downloaded through API.
- Consume data module – which allows to view and download data sent by other ONC users, to which active user is subscribed.

- Offered services module – which allows the active user to view services, which he added through ONC GUI and also to provide data for this service.
- Provide data module – which allows the active user to view all data provided by himself for specific offered services and also to provide data for the chosen services.

Every ONC's API functionalities have been incorporated into the Polish demo atFlex platform.

3.4 Demonstration results

The Polish demonstration focused on two main area of services that are crucial for system operators involved in the demonstration. The first one is the balancing services for the TSO. The second one is congestion management and voltage control for DSO.

During the demonstration, a field test with real activation was performed on the different scenarios.

Tests with real activations were performed in February-July 2023. Before starting the tests with real activations, a series of dry run tests were carried out to verify the correct operation of the solutions developed and implemented as part of the OneNet project. The tests mainly covered a prototype market platform for flexibility trading, devices for controlling PV installations and an algorithm optimizing the maximum selection of offers. A total of 70 different test scenarios were done as a part of the dry-run tests.

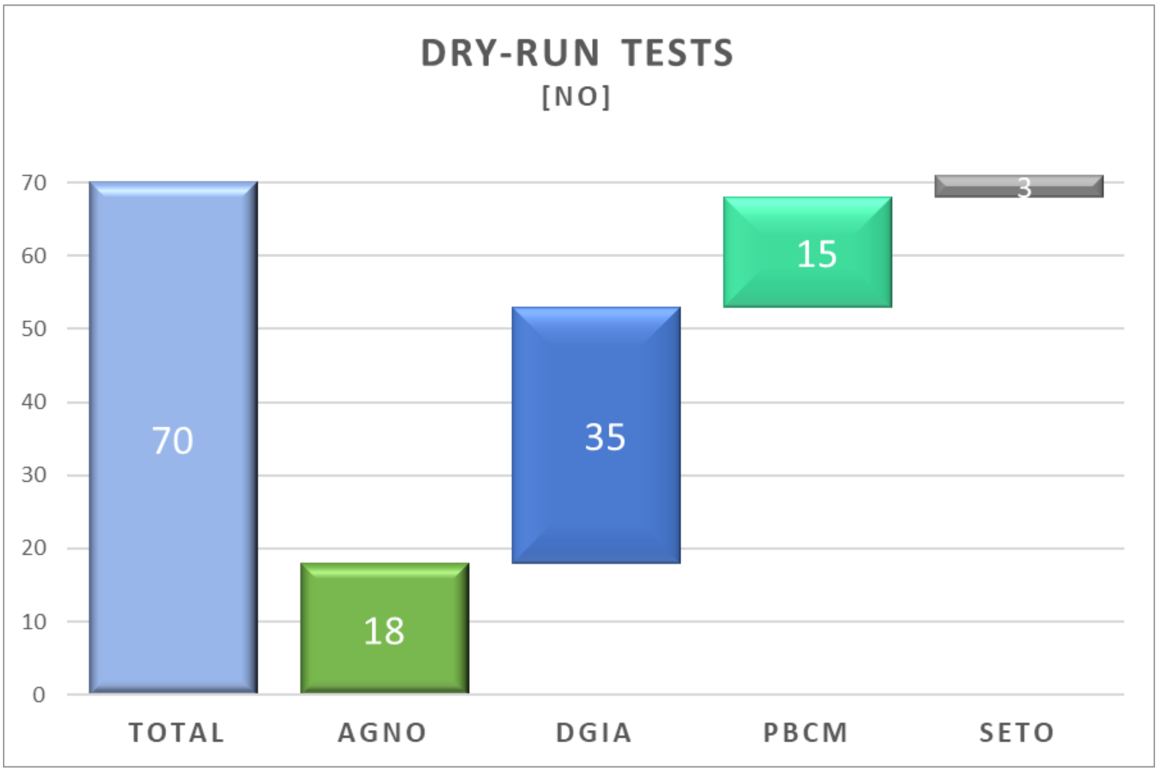

Figure 3-36 – Type of test performed as a dry-run test in the Polish demo

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Tests with real activation of the resources of customers involved in the project lasted up to 2 hours. On the one hand, such a period of time was sufficient to observe the impact of the power change by the FSP in order to eliminate the phenomenon threatening the power grid according to the set scenario but on the other hand it was accepted by the customers that decided to be a part of the project. A total of 30 customers were involved as FSPs in the Polish demo, of which 28 were taking active action in the demonstration period.

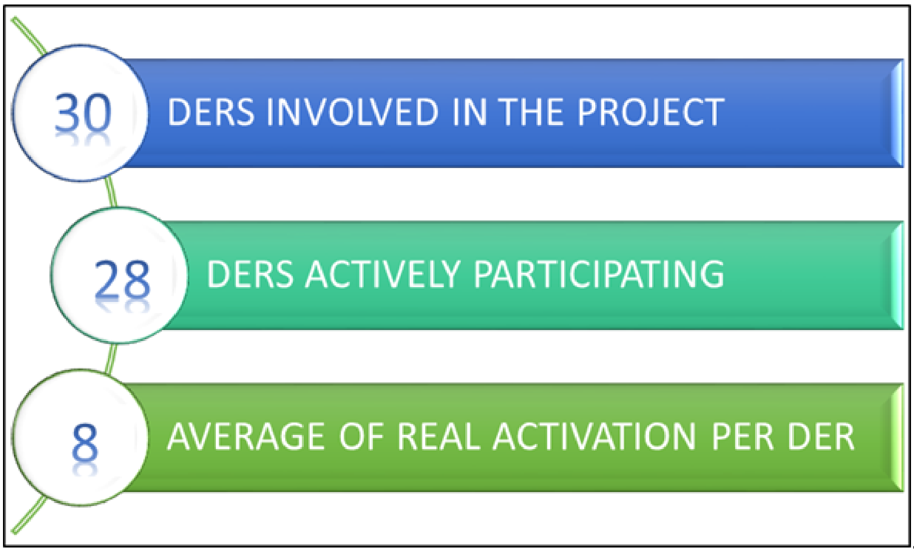

Figure 3-37 – Information about resources uses by the FSPs involved in the Polish demo

During the course of the OneNet project, 29 auctions were organized on the flexibility platform during the tests (in various scopes), of which 100% were successful (no errors on the platform, offers were successfully selected, real activation of customer resources was made).

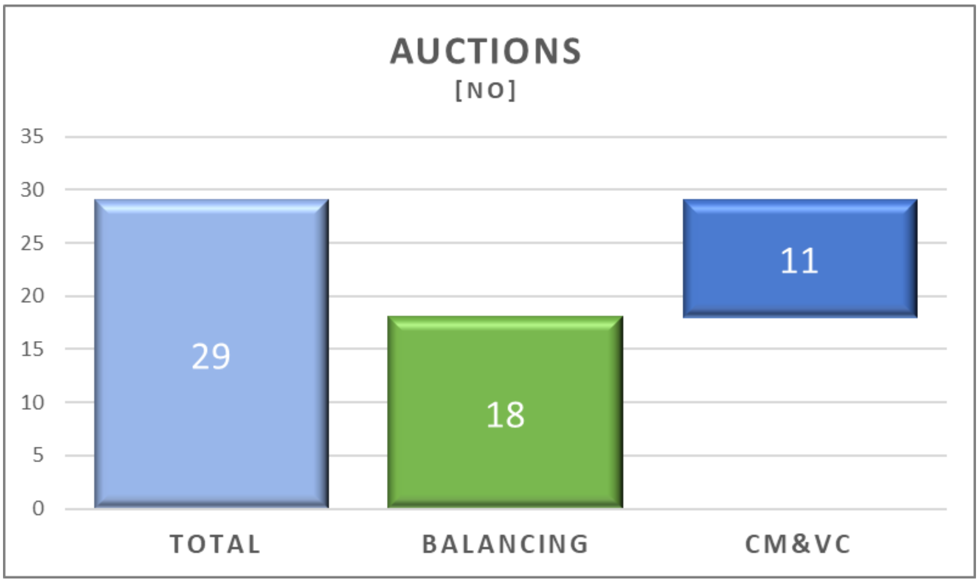

Figure 3-38 – Auctions performed as a real activation during the demonstration in Poland

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Auctions were launched for various products and services, depending on the needs of system operators. The charts and tables below present basic data on the auctions launched as part of the needs of DSOs and TSOs.

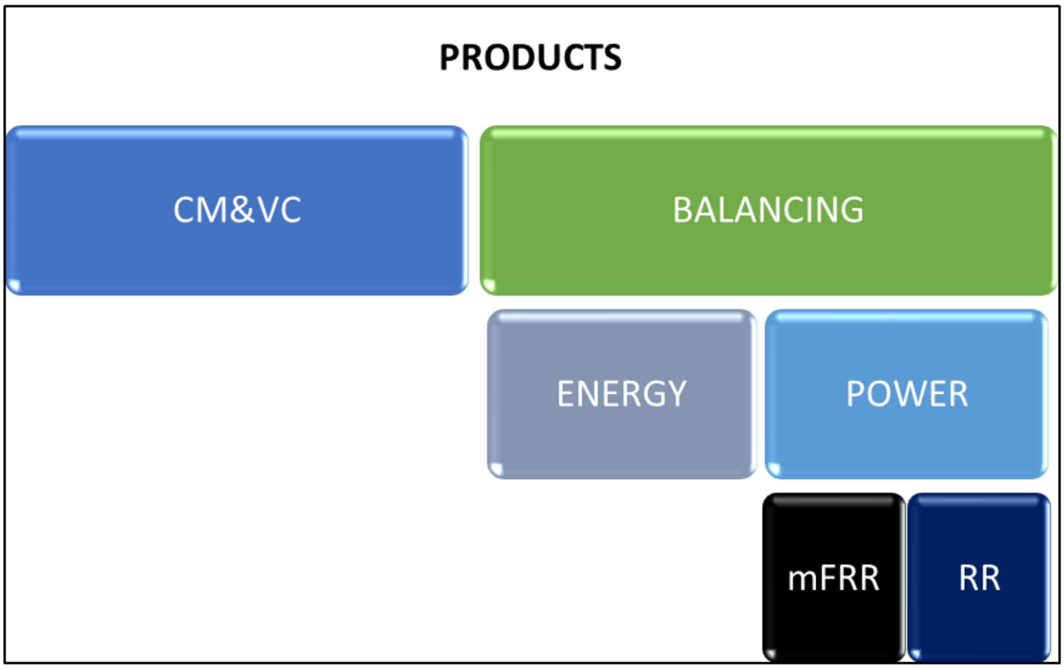

Figure 3-39 – Product uses in the Polish demonstration

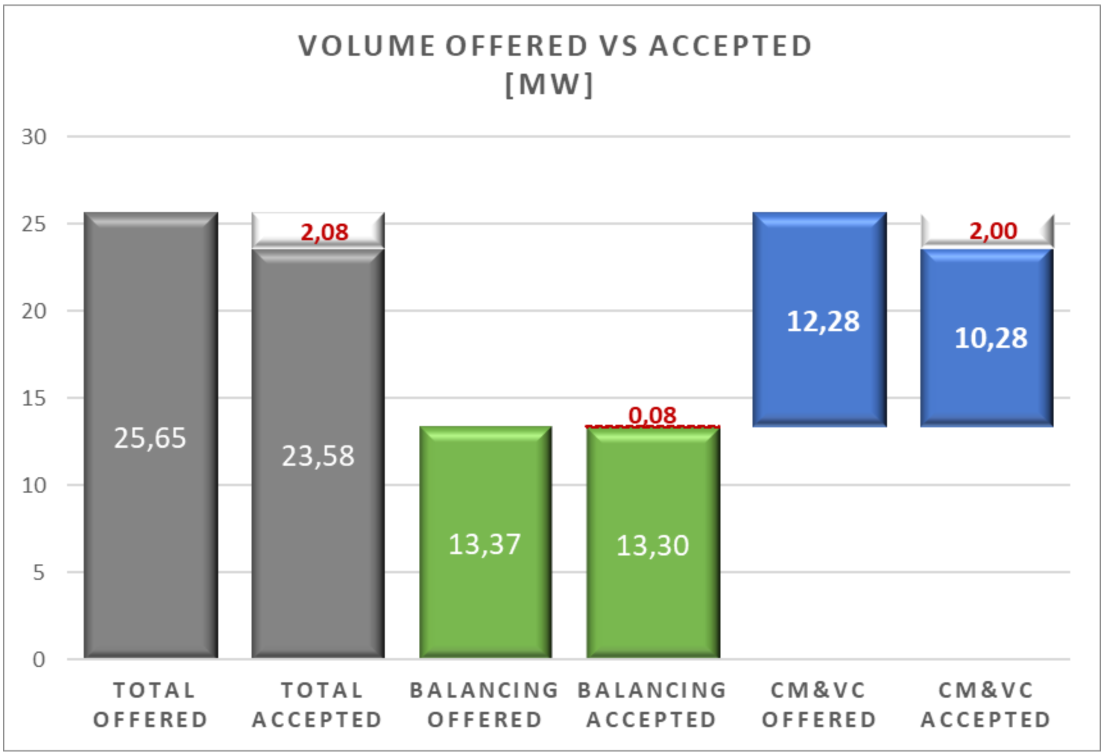

Figure 3-40 – Total amount of power offered by the FSPs in the auctions versus power accepted during the Polish demonstration

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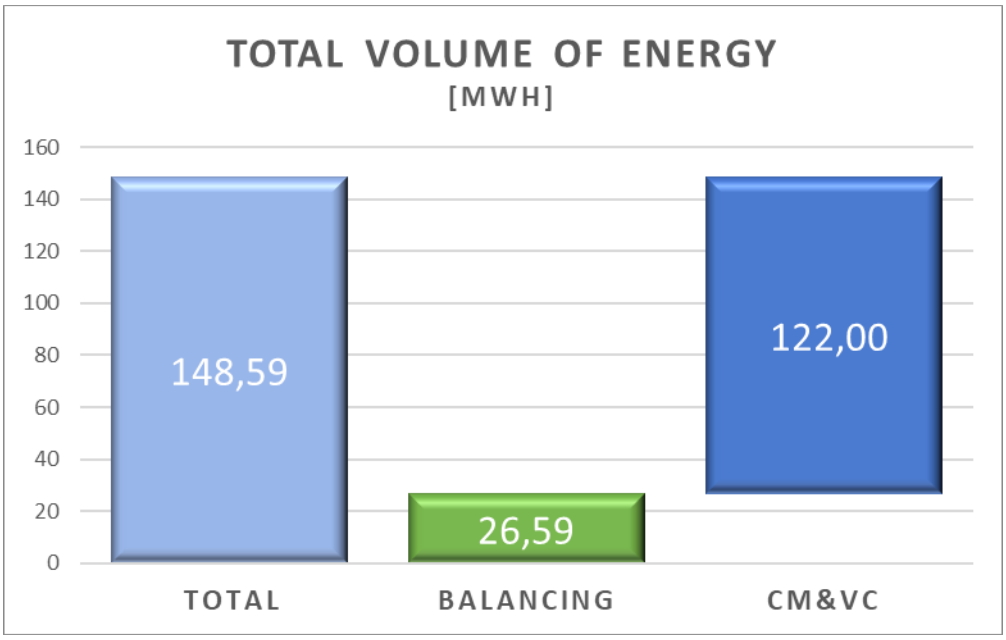

Figure 3-41 – Total amount of energy activated by the FSPs during the Polish demonstration

TSO balancing tests

The tests carried out by the TSO under the OneNet project aimed at testing the possibility of supporting the balancing process of the Polish power system using resources connected to the MV and LV networks. As part of the demonstration, 18 real auctions were carried out, for the total volume of the services provided, 26,6 MWh. Since the transformation of the energy market in Poland was not fully completed during the project, s the operation of the balancing market based on new market mechanisms, which are planned to be announced in the near future, had to be simulated. The simulation did not have a significant impact on the implementation of the tests but made it possible to test the full process of selecting offers on the balancing market. During the demonstration of the TSO's purchase of services from customers connected to the MV and LV grids, network analysis was performed.

In order to ensure that FSPs can provide the widest range of services for system operators, including various grid balancing services, PV installations have been equipped with remote control functionality, taking into account the different requirements for activation and service execution time.

The figure below shows the test of the dynamic change of PV power from the Przywidz area. As part of the test, a gradual reduction of active power generated by PV was carried out between 14.00 - 15.00. Power was reduced gradually every 15 minutes, first to 50% of the installed capacity, then to 20%, then to 5% and then to 0%.

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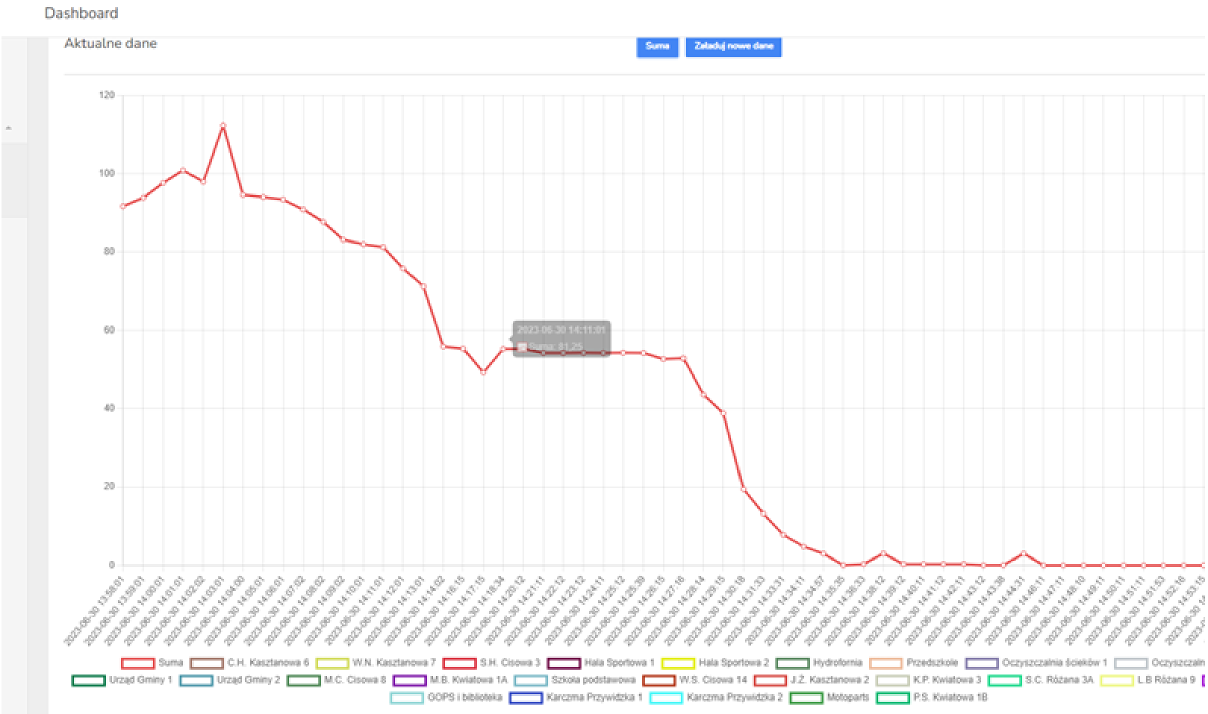

Figure 3-42 – Test of remote control input power of PV installation in the Przywidz area

For the more advanced balancing service, i.e., the mFRR, it is crucial to achieve the appropriate response time of the resource and provide the required power range. As part of the demonstration, the ability to provide services by FSP resources was tested, with different characteristics and response times. Due to technical limitations (lack of balancing market systems in Poland) the mFRR product could not be tested to full extent, but the main characteristic of it was tested. The control devices for remote control of PV installations installed as part of the OneNet project enabled remote control in accordance with the assumed times for individual products, obtaining the required reaction times and resource activation. All resources that participated in the project were positively verified in terms of the possibility of achieving fast response times for more advanced balancing services.

The chart below shows the results of tests of the more advanced control for the more complex balancing services for various resources connected to both LV and MV networks.

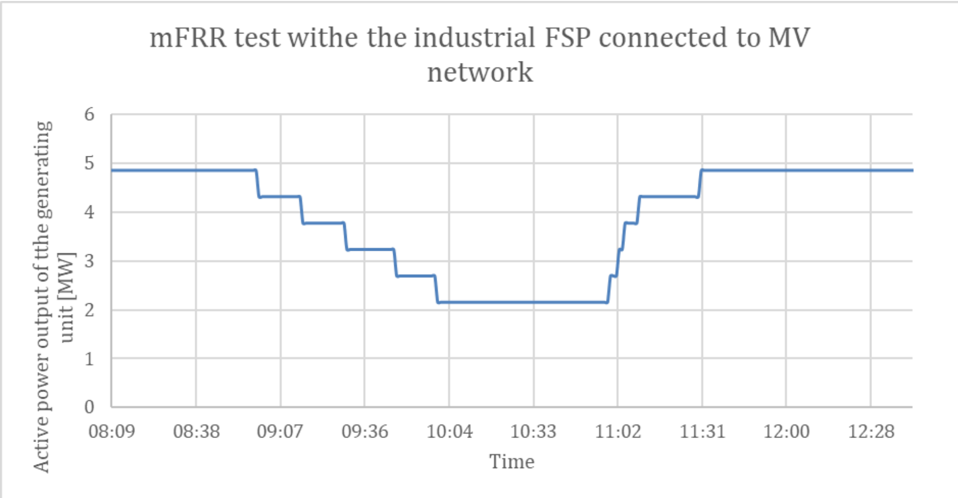

Figure 3-43 – Tests of advanced balancing services with industrial FSP connected to MV network in Puck area

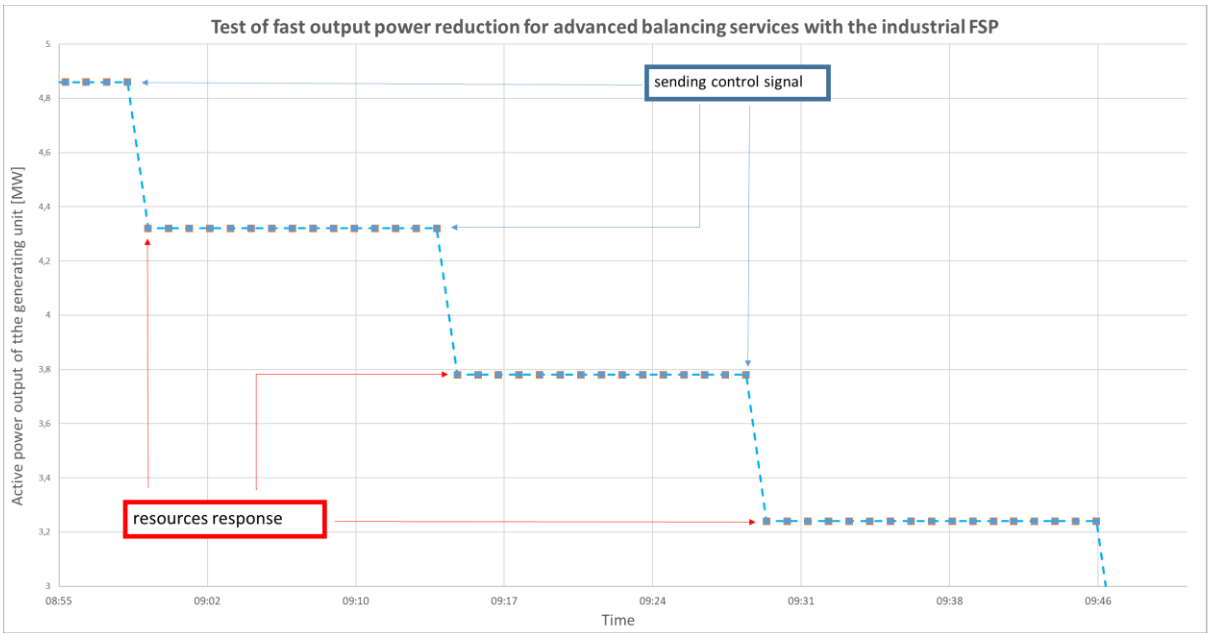

Figure 3-44 More detailed graph of the activation process with the industrial FSP.

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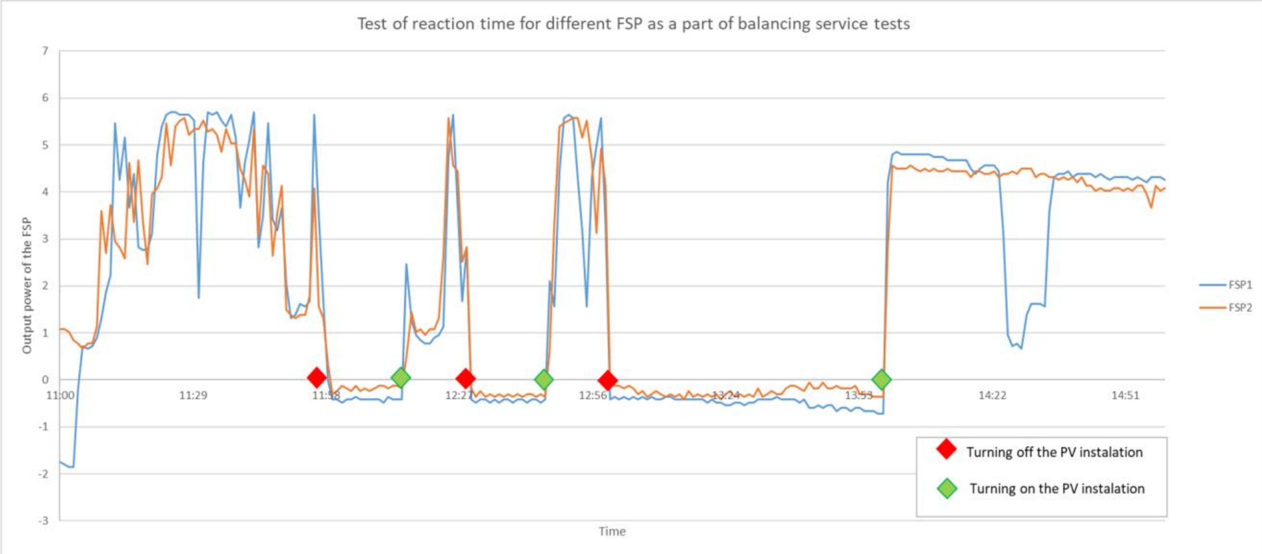

Figure 3-45 – Tests of advanced balancing services with two household FSPs using the PV installation on the customer's side as a source of flexibility

Congestion Management

Short-term and long-term auctions were carried out as part of the tests of services for DSOs. As part of the short-term auctions, the focus was on solving grid voltage and overload problems due to excessive generation of distributed sources, mainly PV installations.

As part of the long-term auctions, tests were carried out under scenarios where the support of flexibility services was required to carry out maintenance work on the network. Various scenarios were assumed in which services were purchased to solve network problems arising from reconfiguration of the network system and working with an abnormal system.

Kalisz area

In the Kalisz area, tests of flexibility services for congestion management in the HV network were performed. As part of the demonstration, real activations were done for scenarios in which the HV/MV transformers in the primary substation were overloaded due to excessive consumption and generation. Due to the fact that there was no situation during the demonstration period that would force the DSO to take remedial actions in connection with the overloading of the HV network, tests were carried out as a scenario. The scenarios assumed that in the HV/MV substation power transformer with the lower nominal power is installed and the transformer could be overloaded during a specific time in the day. The possibility of using services to reduce energy consumption and reduce generation was verified as a part of the scenarios in order to eliminate long-term transformer overloads. In the scenarios, the goal was to decrease the power that flows through the transformer

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power to a level below 4MW in the early day hour. The figure below shows the decrease in power flowing through the transformer as a result of the Congestion Management service purchase test.

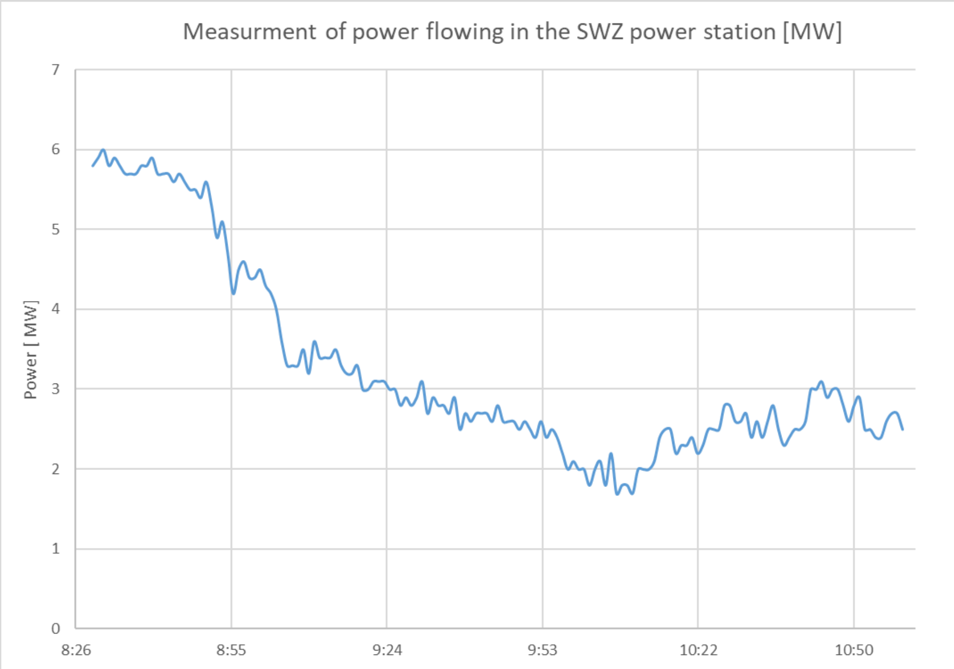

Figure 3-46 – Measurements from the HV/MV substation Stawiszyn for one of the tests. Test performed from 9AM to 10 AM

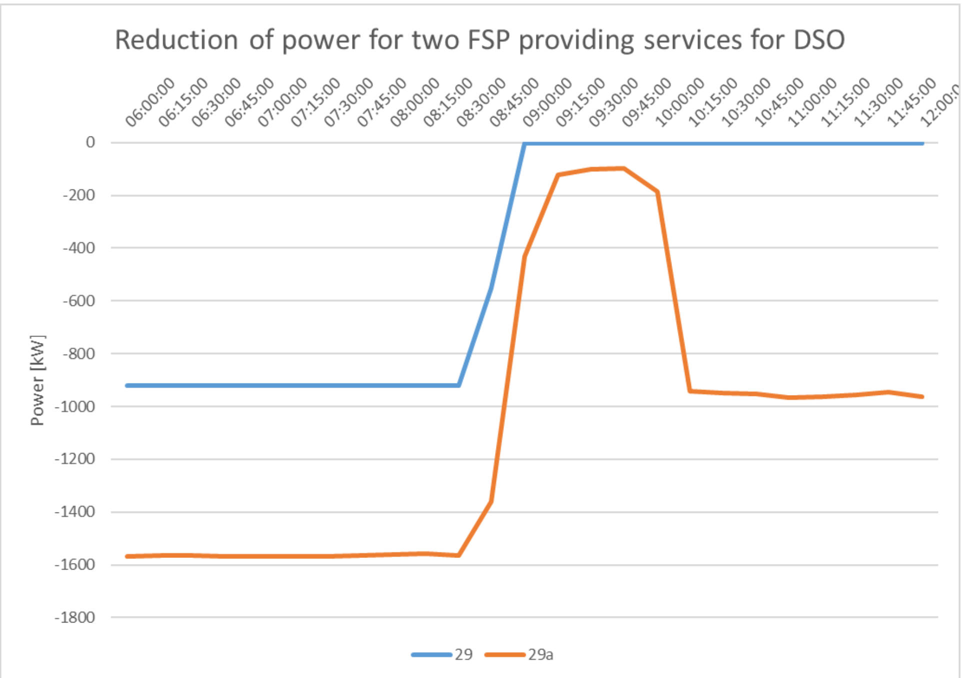

Figure 3-47 - Energy consumption of the FSP providing services for DSO in the Kalisz area. Test performed from 9AM to 10 AM

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The location and volume of FSP power obtained for the needs and real activations in this area was not sufficient to cope with overloads that may occur in real network operating conditions in this area. Nevertheless, the influence of activation on the operation of the HV network can be observed.

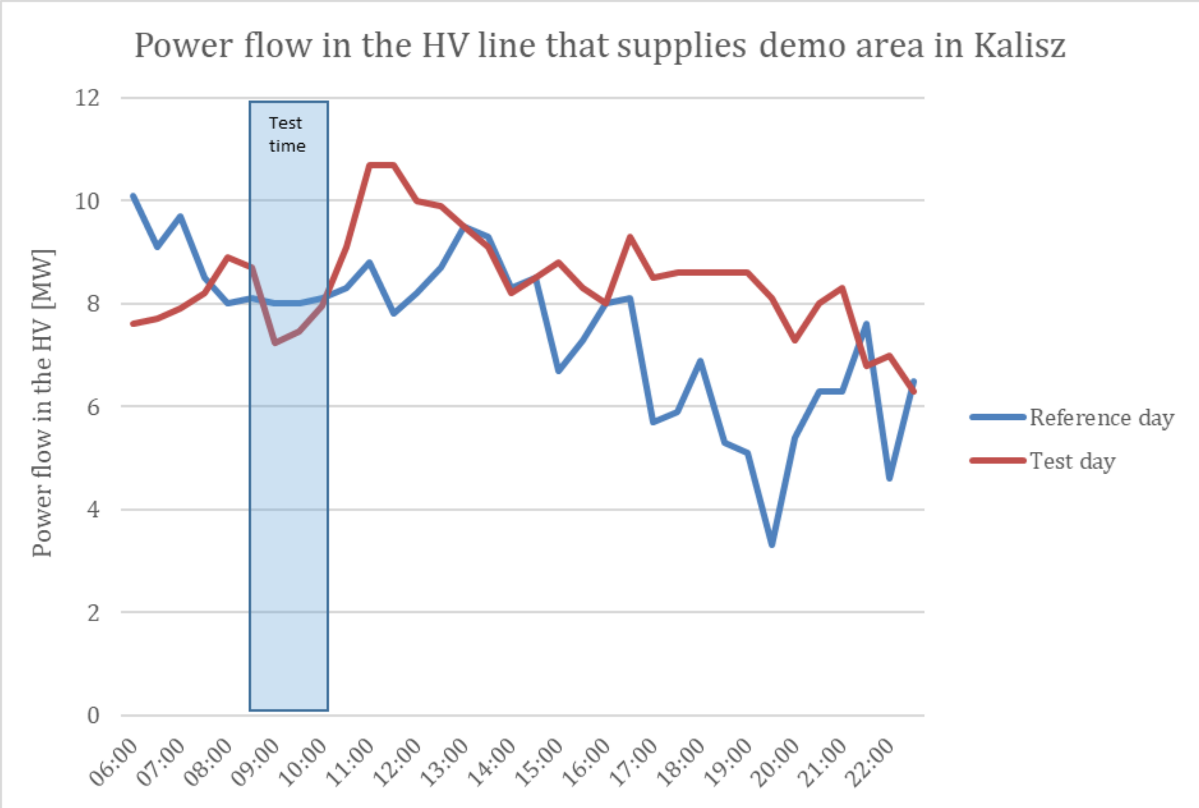

Figure 3-48 - Power flow in the HV lines in the Kalisz area comparison. Congestion management test performed from 9AM to 10 AM.

Puck area

In the Puck area, tests of the use of flexibility services to manage congestion in the MV network were carried out. As part of the tests, real activation was carried out for scenarios in which MV network elements were overloaded due to an abnormal grid operation. The OneNet project demonstrated the ability of DSOs to use the services to support the network management process in the longer term than the next day. In the test scenarios, the purchase of generation reduction services was tested for the purposes of planned works in which the changed grid topology would not ensure the secure operation of the network (voltage violation and congestion). An example may be a scenario in which the DSO has to perform maintenance works in the field of the HV/MV substation from which the FSP was supplied. With a changed MV network operation system, network elements would be overloaded and there would be a problem with maintaining the voltage levels in the network. Therefore, the DSO decided to purchase the service of the generation curtailment in one of the generation units for the duration of the maintenance works. The tested scenario is a specific case, which, however, may occur in

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the everyday operation of the DSOs network and the services provided by customers connected to MV and LV grids can support DSOs.

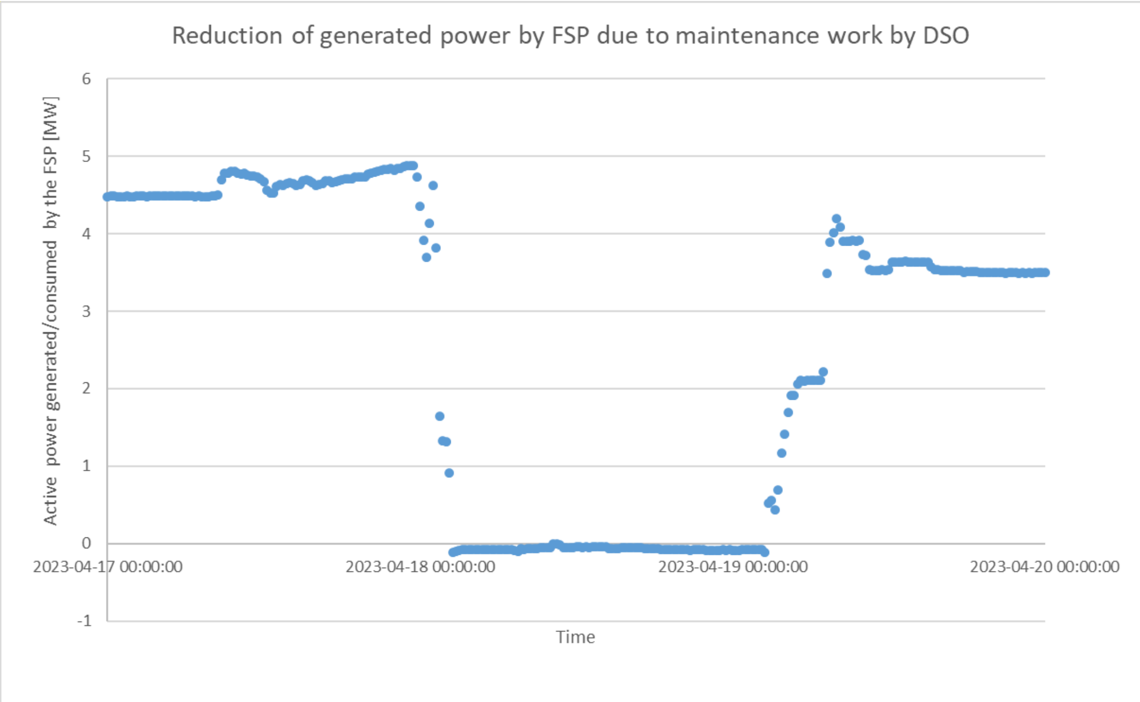

Figure 3-49 - Output power reduction by one of the FSPs as a result of DSO's auction for congestion management due to maintenance work and grid reconfiguration

Voltage control

Tests on the use of services to support the voltage regulation process were carried out mainly at the level of the LV grid, where high saturation of photovoltaics causes problems. The tests focused on the purchase of power reduction services from consumers. Solving voltage problems using active energy is not an ideal solution, as it has a direct impact on balancing. A better solution is to use the possibility of controlling the reactive power of generation sources, i.e., photovoltaics, but it requires much more advanced grid monitoring systems by DSOs, especially for LV grids.

In electricity networks that are characterized by a large number of PV installations connected to them, there may be significant differences in voltage values due to the turbulent nature of this type of source. This problem also mainly exists in the LV networks, where a large number of prosumer PV installations can cause an inverted power flow (from the energy source in the LV network to the MV network). High dependence on external conditions, i.e., the level of insolation, means that even temporary changes in the environment (temporary cloud cover) have a significant impact on the generation level, which translates into the change of voltage value in the grid. These events may affect the tests carried out in real-state conditions and may make it challenging to observe the action's impact on the voltage value in the network. In order to obtain unambiguous results and

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conclusions, it is necessary to limit the number of such events via the conduction of a large number of tests over a significant period of time. Nevertheless, performing tests, even on a small scale, makes it possible to observe phenomena that allow to draw probable theses regarding the impact of specific activities on the voltage values in the network.

Przywidz area

The Przywidz area was the area of the network to which the largest number of customers was connected, which allowed to fully test the impact of flexibility services on the operation of the distribution network. As part of the tests, the impact of the provision of services on the value of voltage in the LV and MV networks was tested. The voltage value measured in the MV/LV substation during the tests was definitely lower compared to other hours of that day during the test and other days during the demonstration period when the tests were not performed. The figure below shows the voltage values during the tests and the difference in the voltage value on the day of the test compared to other days in the period under examination. As the tests were conducted on working days, only days of a similar nature were used for the comparative analysis (holidays, weekends and public holidays were omitted).

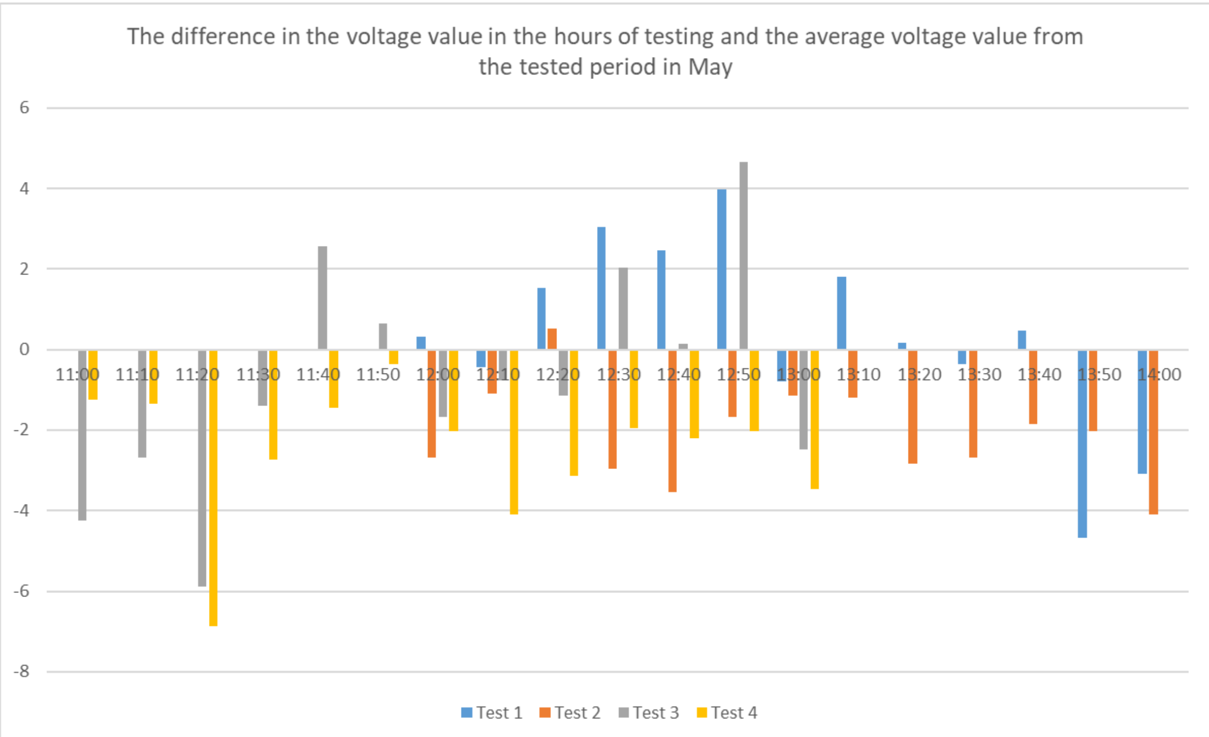

Figure 3-50 - Voltage value during the test in May

The values presented in the table and figures are voltage values measured by AMI meters installed in MV/LV stations and at individual customers. The voltage value is an averaged value for a period of 10 minutes and does not allow for very accurate voltage analyses. Nevertheless, based on the above measurements, it is possible to

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observe the impact of the provision of services by individual customers from the LV grid on the voltage values in the grid.

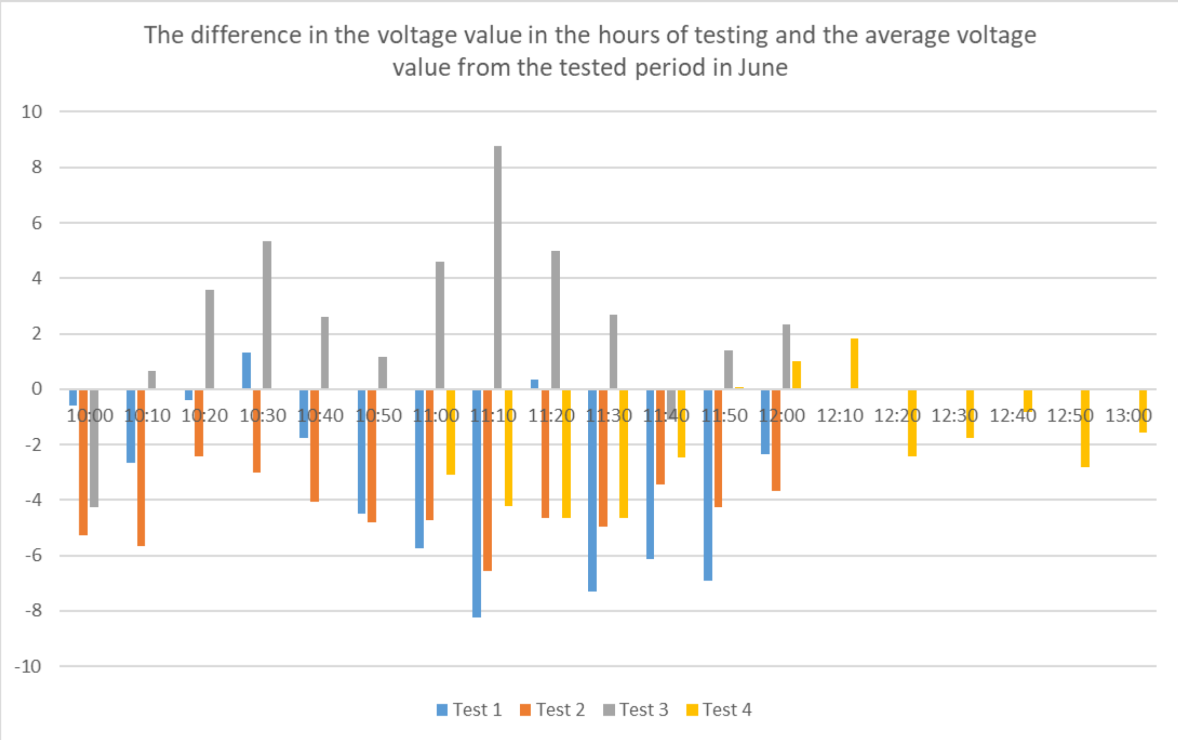

Figure 3-51 - Voltage value during the test in June

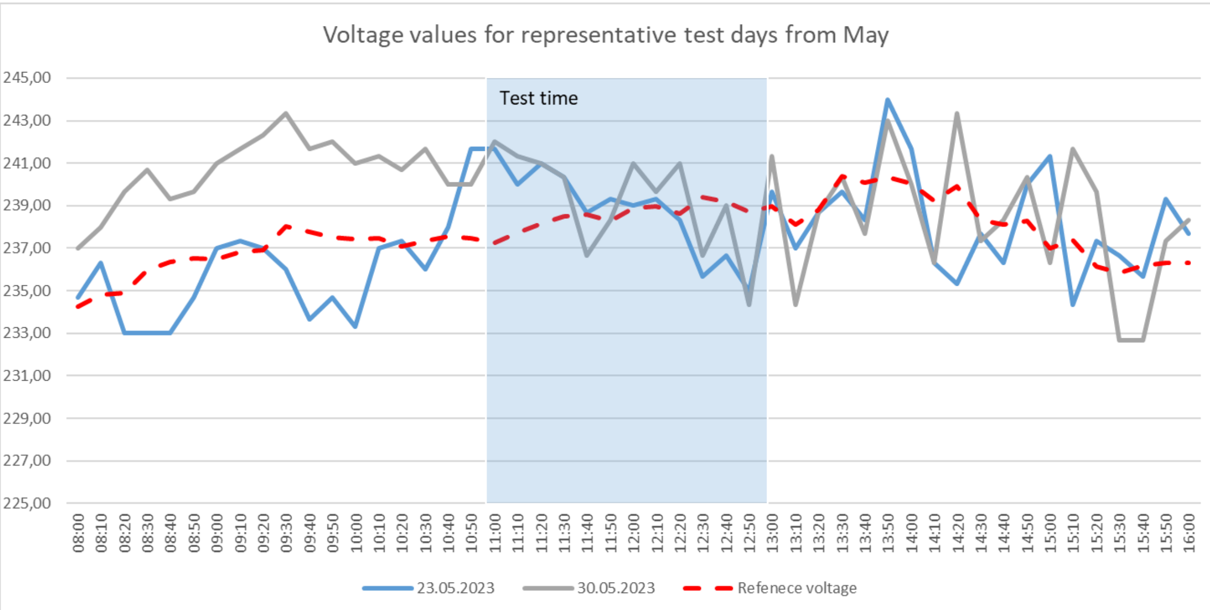

Figure 3-52 – Voltage values for representative test days from May

Figure 3-52 shows the voltage values in the MV/LV substation for two representative days on which the tests of voltage regulation services in the LV network in May and the reference voltage were carried out. The reference voltage value is the average value for the days during the demonstration period (working days, similar atmospheric conditions, excluding other days on which tests were carried out).

Figure 3-53 shows the results of the analysis for one of the representative days on which the tests of voltage control were carried out in terms of comparison with the other days from the demonstration period. The figure shows for each of the three phases a comparison in how many cases the measured voltage at the MV/LV substation in the period under examination was higher than the voltage on the day of the tests. The results are presented as a percentage. The figure shows that in the hours when the tests were carried out, the number of days with higher voltage at a given time increased.

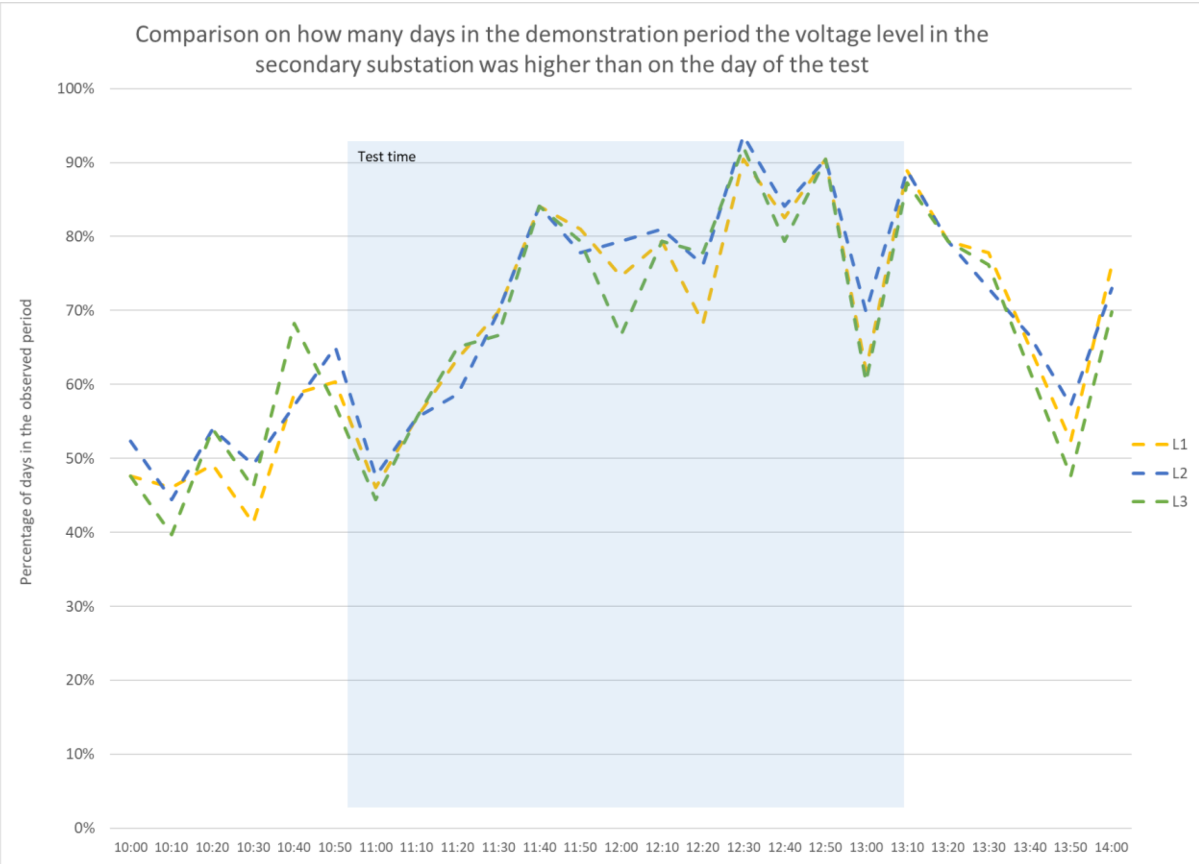

Figure 3-53 Comparison of the number of days during the demonstration period in which the voltage values compared to the test day were higher

Figure 3-54 shows the differences in the voltage values on the representative day on which the voltage management services tests took place and the other days in the control period. The data are presented for specific periods of the day. Each dot represents the voltage level at the specific day and time during the day. The red dashed line shows the number of days when the voltage was lower than on the day of testing.

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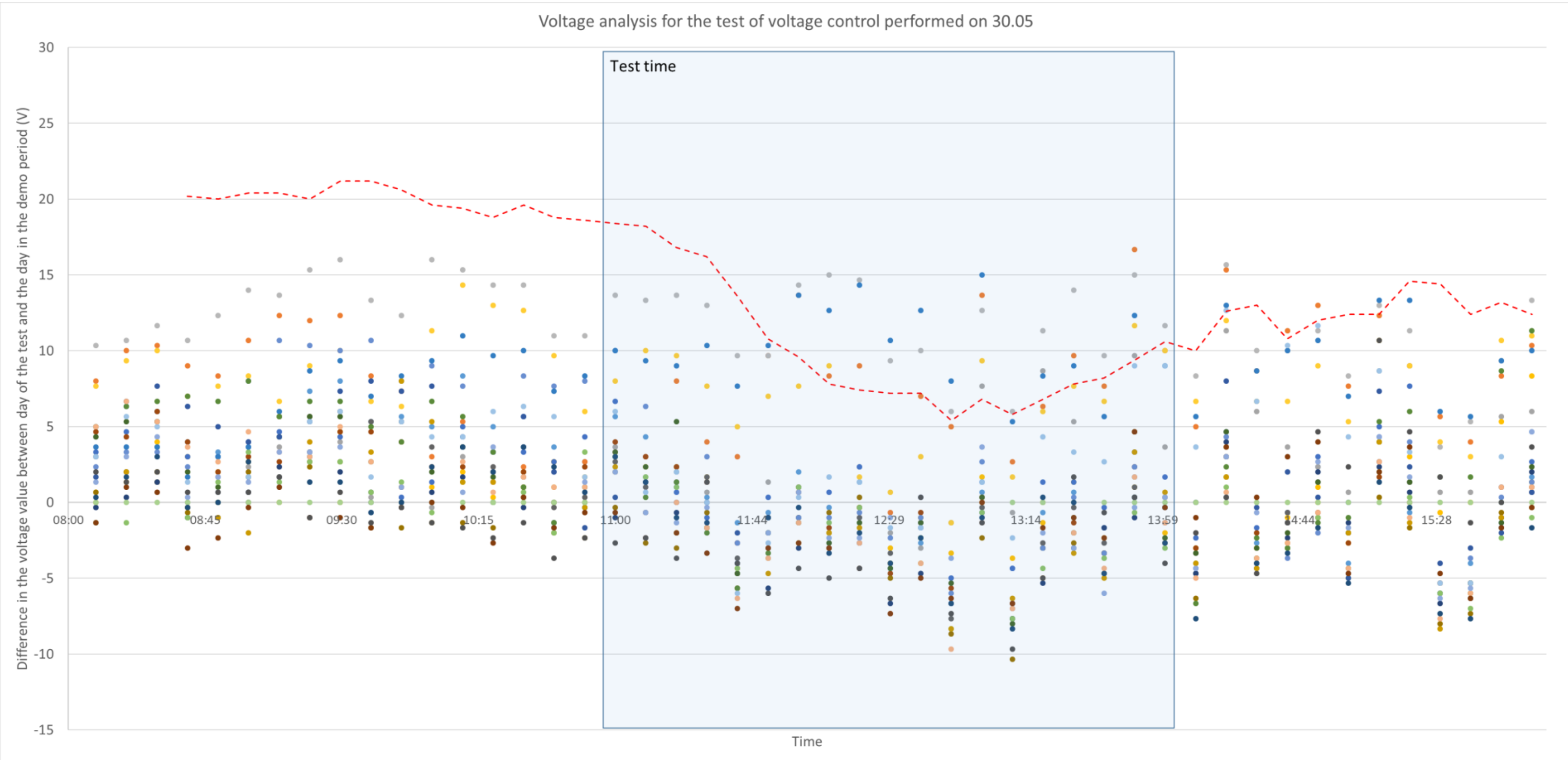

Figure 3-54 Results of voltage analysis and comparison with other days in the analysed period

It can be seen from the figure that during the tests, the number of days when the voltage was lower in the compared period decreased. Differences in voltage during the tests compared to other periods of the day also change - the difference increases due to the decrease in voltage during the tests.

On the chart you can also find days for which the voltage was lower throughout the period. These are the days when there was cloudiness, as a result of which the voltage value was not increased by the very small production from the PV installation.

During the demonstration, not all tests ended with expected results. An example may be the test during one of the days in June, where very heavy cloud cover, that was not forecast the day before occurred on the day of service activation. This limited the output power of PV installations in the demo area and. In the end there was no need to activate the resources as a part of the service, because there were no voltage problems in the network caused by the PV generation. Nevertheless, if such a situation occurred for other types of services, e.g., balancing, it would be impossible for the FSP to provide the service. The occurrence of this type of unpredictable event, which is related to changing weather conditions only highlight an important issue related to the creation of the work plan and the self-scheduling of resources, in particular, forecasting the level of generation from turbulent sources.

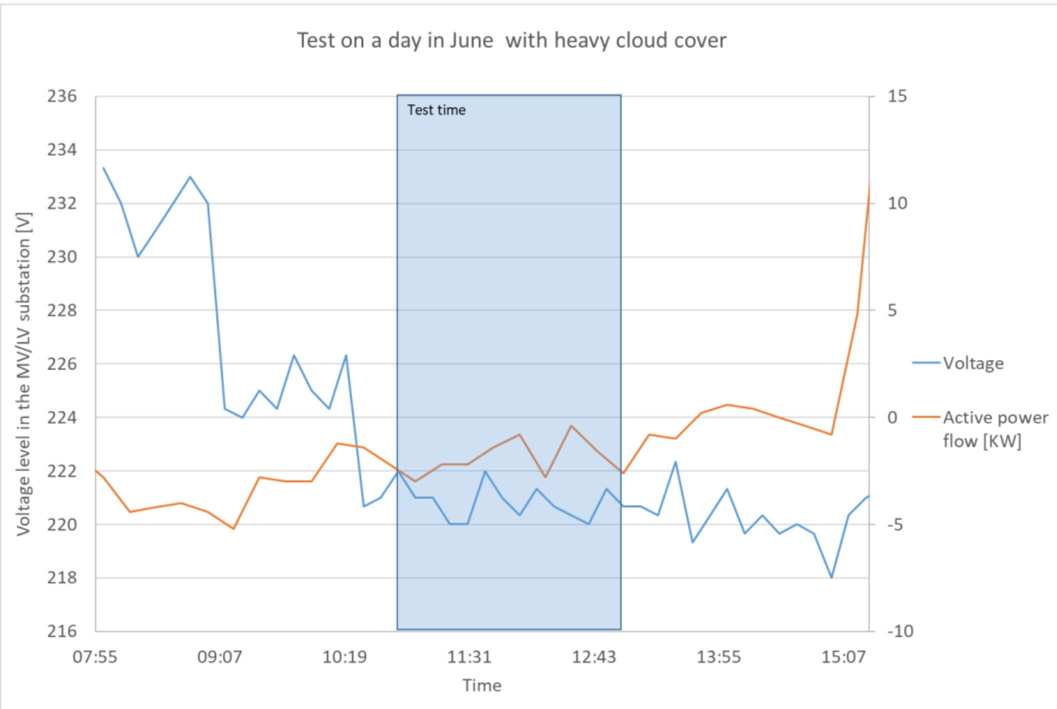

Figure 3-55 - Tests carried out in unfavourable weather conditions - no possibility to control FSP sources

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Mława area

As part of the tests in Mława, the verification of the impact of services on the voltage regulation process by controlling PV installations was based on the installations of 3 out of 5 customers participating in the project. Two customers decided not to participate in the auctions and did not submit bids. The most important tests took place on very sunny days when prosumer installations were sometimes switched off spontaneously due to too high voltage in the network.

Tests conducted on days when the voltage was not extremely high allowed to observe the impact of customer asset activation on the voltage value. Although the activated power within the services was small and insufficient to solve potential voltage problems in the LV grid, it had an impact on the grid voltage.

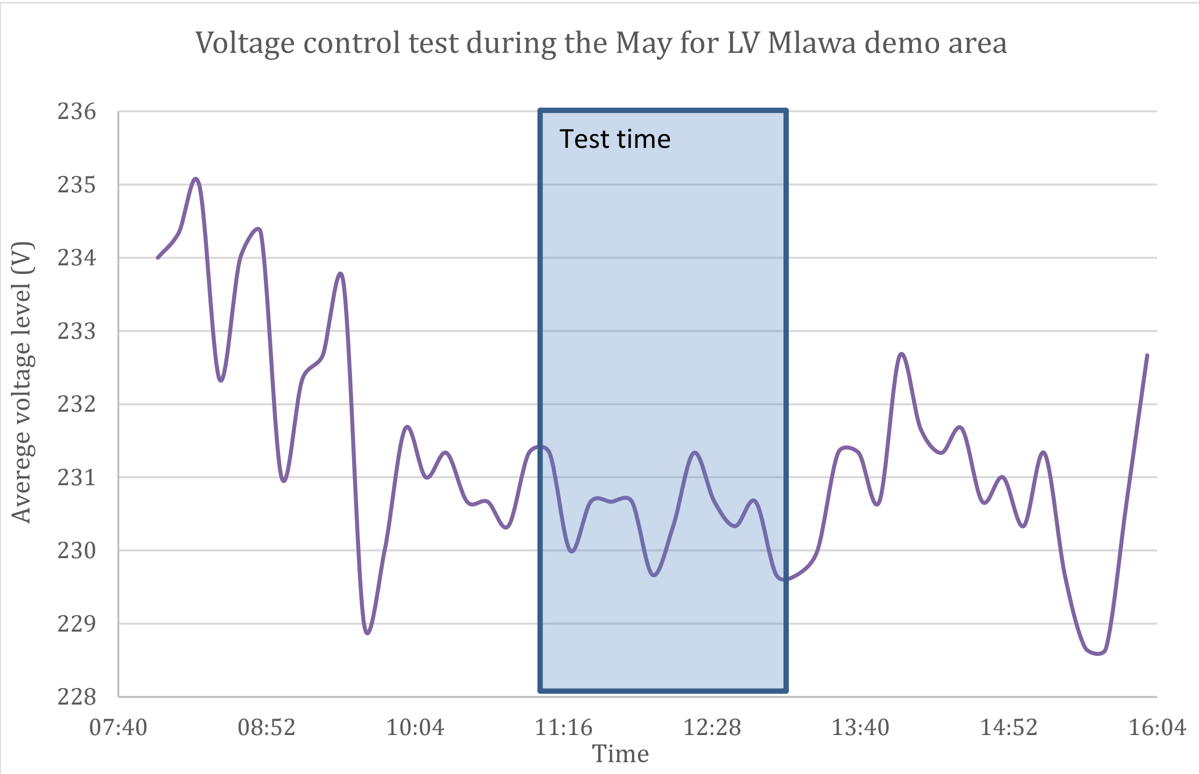

Figure 3-56 - Voltage level in the MV/LV substation in Mława demo area during the test with no extreme weather condition

The limited number of customers participating in the tests did not allow the elimination of the voltage problem during days with extremely high insolation and generation of PV sources. Nevertheless, the tests that were carried out showed the potential of the services in increasing the capacity of the network. As part of the real activations, excluding installations at customers, neither the voltage drop nor the power flowing through the transformer was noticed. On the other hand, there was an increase in the power generated by other customers whose installations were shut down due to too high voltage. Testing the purchase of power reduction

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services by DSOs, made it possible to increase the generation of installations of other prosumers whose installations would normally be disconnected from the grid. This allows the reduction of energy waste and the increase of efficiency of using energy from green sources.

All PV installations in this area are three-phase installations. Therefore, there was no problem with voltage asymmetry as a result of power reduction of generation sources.

3.5 Simulation results – PL Demo

Part of the Polish demo scope were simulated results apart from the real activation cases, where the results of the flexibility platform were performed on the real market participants. The purposes of those simulations were twofold:

- To design more complex scenarios of DSO network constraints and offers that allow to test deeper the correctness of the coordination algorithms applied on the flexibility platform.
- To prove the potential of increasing the scope of the flexibility platform by including the reactive power flexibility of each DER[12]. The coordination algorithms are able to increase the active power flexibility provided to the Polish Balancing Market by considering the reactive power flexibility of the DERs to relieve the DSO network constraints.

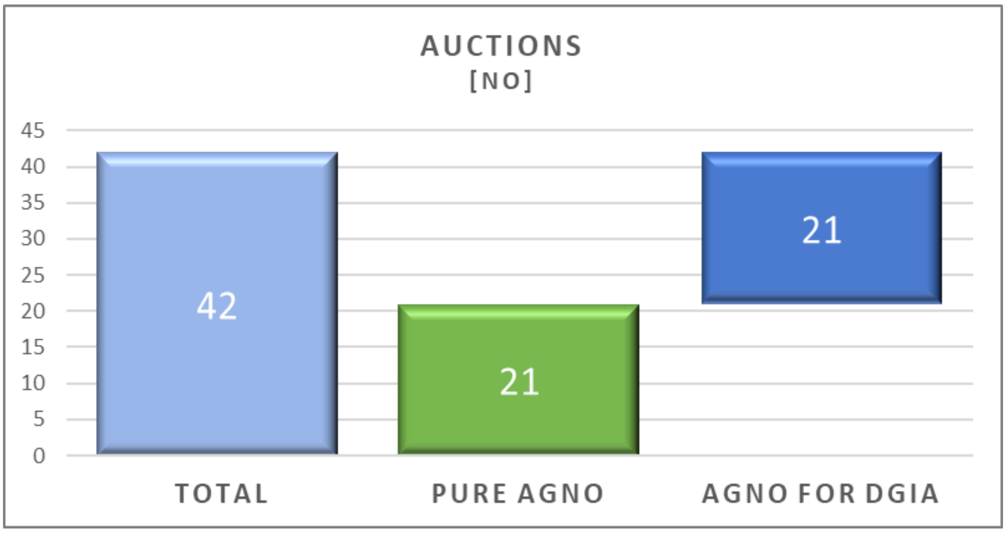

Figure 3-57 – Number of auctions performed for simulations purposes

Hence, in Figure 3-57 - Figure 3-59, the summary of all 42 simulations performed can be seen divided by the algorithms applied (Figure 3-57). From those simulations, there are two simulation sets depending on whether

[12] Today, the real activation of reactive power from the DERs is not possible for the Polish demo.

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the reactive power flexibility of the DERs is included in the coordination algorithms or not (i.e., AGNO PQ or AGNO P version respectively):

- AGNO P version of the algorithms (**Figure 3-58**)
- AGNO PQ version of the algorithms (**Figure 3-59**)

The volume of offers offered versus the volume of offers accepted due to the network constraints per each algorithm is shown.

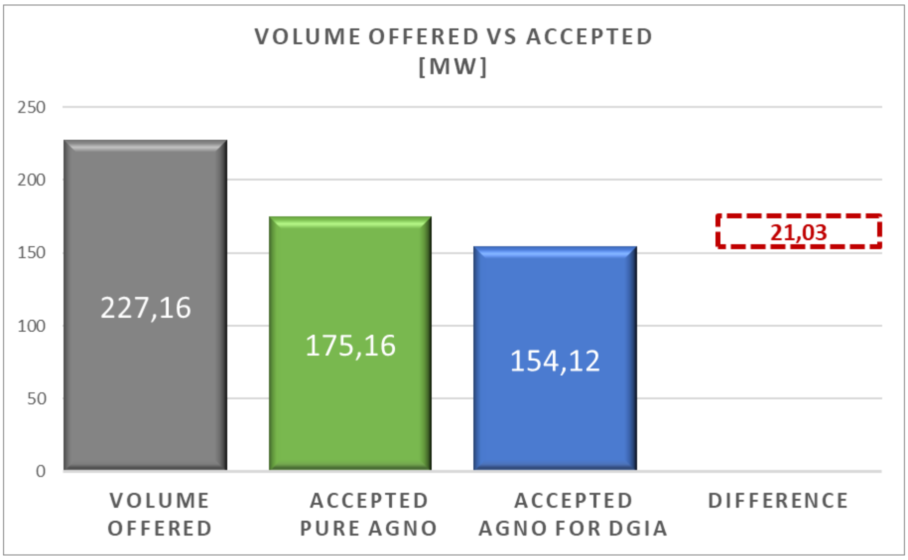

Figure 3-58 – Comparison between results from PURE AGNO algorithm and AGNO for DGIA algorithm (AGNO P version)

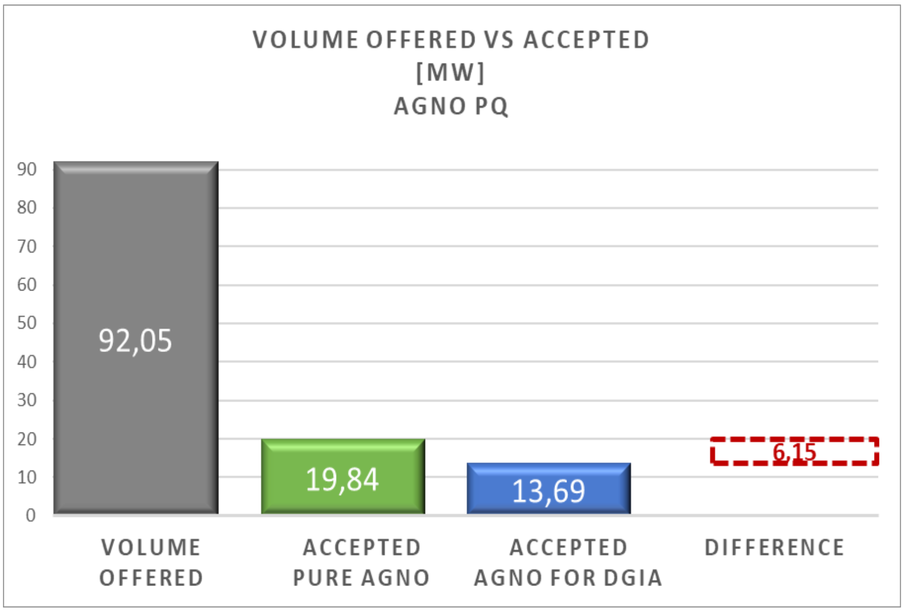

Figure 3-59 – Comparison between results from PURE AGNO algorithm and AGNO for DGIA algorithm (AGNO PQ version)

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3.5.1 TSO-DSO coordination algorithms results and validation

The coordination algorithms perform OPF simulations to consider the security of the DSO network. Within the Polish demo, the power flow results of the algorithms were validated by comparing the results with a commercial tool used by TSOs and DSOs (PLANS[13]).

Furthermore, to ensure that the offer results of the algorithms are secure for the DSO network, additional power flow results with PLANS were performed to all the simulation results. It was validated whether the maximum flexibility of the offers endangers any network constraint. The results of the validation showed that all the simulation results were secure for the DSO network model for both algorithms, i.e., pure AGNO and AGNO for DGIA. This is the most important outcome of the validation of the algorithms (as described on the Algorithms section) since for the operators the security of the network is more important than the optimality of the solution.

For the optimality comparison of both algorithms, the summary of the simulation results on Table 3-1 and Table 3-2 is presented, but it is decomposed below based on the DSO areas, scenarios and the algorithms for balancing energy. Some of them represent DSO network constraints which prevent a secure procurement of the offers and they must be reduced by the TSO-DSO coordination algorithms.

From the results of Table 3-1 and Table 3-2, we can conclude the following:

- When there are network constraints, the input offers are reduced by both algorithms in order to provide secure offers to the Balancing Market.
- The security of those offers was validated by PLANs (operator's commercial tool) for both algorithms.
- When there are no network constraints, the results of both algorithms are the same or within the numerical tolerance of the algorithms.
- When there are no network constraints, in general, the algorithms provide the maximum flexibility.

  There is one exception for Puck scenario 5 offers down, this represents one of the cases mentioned in III in section 3.2.4, when non-finding the non-linear optimization solutions reduces the flexibility of the offers more than it should.[14]

- When there are network constraints, the results of both algorithms can be the same, differ moderately or substantially. This is an effect of the coordination of offers which is possible with pure AGNO algorithm.

[13] http://www.plans.com.pl/?mid=600&lang=pl

[14] However, this result was re-computed with two different machines apart from the flexibility platform and their results shows higher flexibility to be provided in both machines (as expected since there are no constraints) with exactly the same algorithm.

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Table 3-1 - Summary of test results for scenarios 1 to 5 (without grid constraints)

Scenario	Area	Constraints	Offers results of pure AGNO [MW]		Offers results of ANGO for DGIA [MW]		Input offers [MW]	
			UP	DOWN	UP	DOWN	UP	DOWN
1	PRZYWIDZ	NO	0,5750	1,3040	0,5749	1,3039	0,5750	1,3040
	PUCK	NO	6,9400	7,2000	6,9400	7,2000	6,9400	7,2000
	MŁAWA	N/A	-	-	-	-	-	-
2	PRZYWIDZ	NO	0,5750	1,3040	0,5749	1,3040	0,5750	1,3040
	PUCK	NO	6,3400	5,0000	6,3400	5,0000	6,3400	5,0000
	MŁAWA	NO	0,0085	0,0480	0,0084	0,0479	0,0085	0,0480
3	PRZYWIDZ	NO	0,0240	0,0730	0,0239	0,0729	0,0240	0,0730
	PUCK	NO	7,1350	6,3900	7,1350	6,3900	7,1350	6,3900
	MŁAWA	NO	0,0085	0,0480	0,0084	0,0479	0,0085	0,0480
4	PRZYWIDZ	NO	0,0240	0,0730	0,0239	0,0729	0,0240	0,0730
	PUCK	NO	7,7350	8,5900	7,7350	8,5900	7,7350	8,5900
	MŁAWA	N/A	-	-	-	-	-	-
5	PRZYWIDZ	N/A	-	-	-	-	-	-
	PUCK	NO	7,7350	3,5685	7,7350	3,5685	7,7350	8,5900
	MŁAWA	N/A	-	-	-	-	-	-

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Table 3-2 - Summary of test results for scenarios 6 to 10 (with grid constraints)

Scenario	Area	Constraints	Offers results of pure AGNO [MW]		Offers results of ANGO for DGIA [MW]		Input offers [MW]	
			UP	DOWN	UP	DOWN	UP	DOWN
6	PRZYWIDZ	NO	0,5750	1,3040	0,5749	1,3039	0,5750	1,3040
	PUCK +	YES	4,8315	6,6973	4,6687	6,4220	6,9400	7,2000
	PUCK -	YES	6,9400	6,2771	6,9400	6,2766	6,9400	7,2000
	MŁAWA	N/A	-	-	-	-	-	-
7	PRZYWIDZ	NO	0,5750	1,3040	0,5749	1,3039	0,5750	1,3040
	PUCK +	YES	5,8238	4,6252	5,8149	2,0307	6,3400	5,0000
	PUCK -	YES	2,3345	2,6995	2,3345	0,3932	6,3400	5,0000
	MŁAWA	NO	0,0085	0,0480	0,0084	0,0479	0,0085	0,0480
8	PRZYWIDZ	NO	0,0240	0,0730	0,0239	0,0729	0,0240	0,0730
	PUCK +	YES	5,6252	4,8741	4,9674	2,2075	7,1350	6,3900
	PUCK -	YES	3,1295	4,0622	3,1295	3,1019	7,1350	6,3900
	MŁAWA	NO	0,0085	0,0480	0,0084	0,0479	0,0085	0,0480
9	PRZYWIDZ	NO	0,0240	0,0730	0,0239	0,0729	0,0240	0,0730
	PUCK +	YES	6,8362	4,0786	6,7338	1,5880	7,7350	8,5900
	PUCK -	YES	5,5023	4,8362	5,1786	3,2958	7,7350	8,5900
	MŁAWA	N/A	-	-	-	-	-	-
10	PRZYWIDZ	N/A	-	-	-	-	-	-
	PUCK +	YES	1,7477	1,1259	1,7467	0,5624	7,7350	8,5900
	PUCK -	YES	6,8577	2,4035	6,0618	1,8425	7,7350	8,5900
	MŁAWA	N/A	-	-	-	-	-	-

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Therefore, both algorithms provide secure offers for the DSO network to the balancing market. Regarding optimality, the pure AGNO algorithm provides higher flexibility to the balancing market than the AGNO for DGIA algorithm since it considers the possibility of coordinating offers as it was described in section 3.2.3.

3.6 Conclusions

The following results have been achieved:

- Both BUCs and SUCs were formulated.
- Customers of different characteristics were engaged in real activation.
- Grid models of the demonstration area were built.
- PV Inverter controllers were developed and tested.
- A tool for communication with the controllers of PV inverters and relevant software were developed and used.
- Several methods of dynamic grid impact assessment for balancing market (with the use of algorithms) were tested.
  - Those algorithms were designed for different balancing products: reserves and balancing energy products.
  - They were implemented for real activation cases and more simulated cases with higher complexity.
  - The algorithms allow including reactive power flexibility from the DERs in order to increase the flexibility harnesses from the DSO network.
- OneNet platform called atFlex was created and successfully used. It allows the registration of DERs, their prequalification to the service and allows TSO-DSO coordination.
- OneNet Connector has been installed on the atFlex platform and all its components have been fully deployed
- Planned tests and simulations were performed.

The following conclusions can be drawn from the actions mentioned above:

- Aggregators play a pivotal role in acquiring a substantial customer base, necessitating them to possess the marketing skills required for customer acquisition. Their role in providing services to the transmission network operator is especially critical.
- Aggregators should be equipped with IT tools that enable effective control of customer resources, such as PV installations, heat pumps, and recharging stations, in a manner that aligns with the demands of the required service or product.
- The design of the registration process and the pre-qualification of resources by customers on the flexibility platform significantly influence the creation of an open and easily accessible energy market.

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- The capacity to manage the reactive power of resources providing flexibility services enhances the potential of available active power, which forms the foundation of the flexibility service. Services reliant on reactive power have no impact on the energy system's balance and empower DSOs to address voltage level issues in the network, in contrast to services based on active power.
- Congestion management and voltage control services are valuable tools that augment the flexibility of the distribution network. Nevertheless, there exists a certain threshold for the number of customers providing these services, which must be exceeded for the service to have a noticeable effect. Hence, the market's liquidity is of utmost importance.
- The development of flexibility services in the distribution network faces a significant barrier due to the absence of smart meters with sufficient granularity and real-time data capabilities, along with the lack of network models, especially at the Low Voltage (LV) level.
- Limited knowledge of the distribution network's operational status by the DSO can lead to an overly conservative approach aimed at preventing network security violations in all conceivable, albeit improbable, scenarios. Especially, when the other System Operator would like to use those resources i.e. TSO for balancing purposes. To address this, DSOs should develop tools for dynamic flow analysis within their networks to determine permissible flow limits, especially when implementing complex flexibility resource offerings.
- Effective coordination between the flexibility market and the balancing market is essential for achieving an optimal and efficient energy market as a whole. This coordination between DSOs and TSOs is crucial in creating such a market, preventing duplicate service purchases, and mitigating system imbalances.
- Algorithms designed to optimize and coordinate DSO and TSO activities, ensuring operational security in the distribution network while maximizing resource utilization, hold significant potential.
- While limiting PV generation has proven effective for voltage regulation in the distribution grid, it's not always the optimal solution. This approach can also be beneficial for balancing purposes. However, establishing a dependable self-schedule for renewable resources, especially small prosumer PV installations, remains a challenging task.
- Leveraging communication platforms like the OneNet system can effectively disseminate European-wide data regarding local flexibility markets. The exchange of information among flexibility platforms, facilitated by tools such as the OneNet System, streamlines procedures for registering new users in local energy markets.

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4 Slovenian demo (T10.4.3)

4.1 Demo background – locations, stakeholders, and schedule

The main scope of Slovenian demo in the OneNet project is using the flexibility service to address congestion and voltage violations in the low-voltage distribution grid. The grid congestion problem mainly occurs during the heating season (from September to March) and is dominantly caused by the heating electrification (extensive use of household heat pumps). The problem with the voltage violation appears during sunny days, when the household PV production (deployed in the LV grid) is high, while the demand is low. During such days the internal usage of electricity within the household is low, and the excess energy is directed into the local grid. Consequently, when production overreaches consumption in the LV grid, voltage increases above the limits defined by the standard.

GEN-I, the Slovenian demo leader, plays different roles: as electricity supplier to the households, as provider of household PV plants and also as an aggregator. Hence GEN-I has long-standing relationships with the end customers.

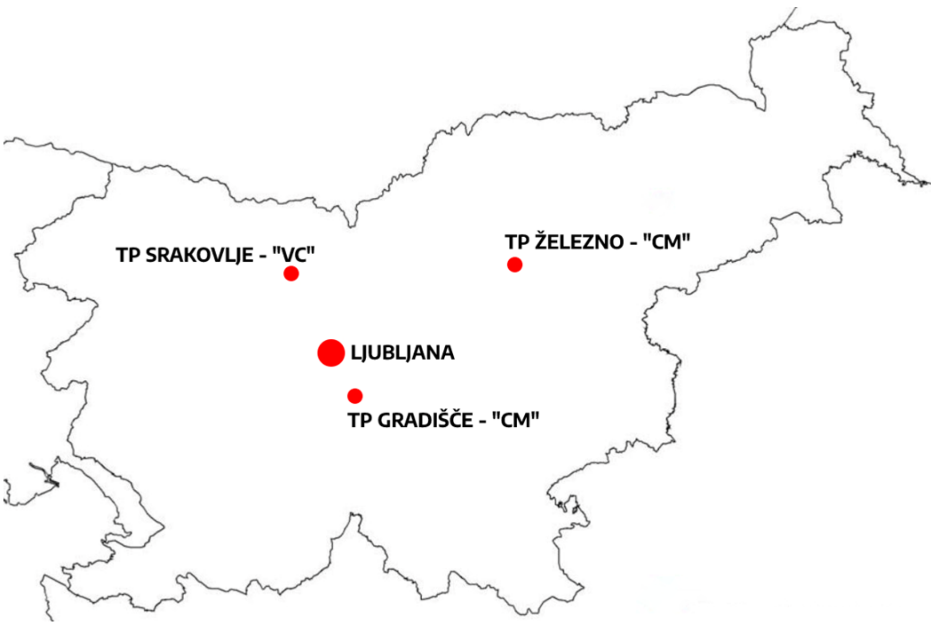

Figure 4-1 - Macro locations of Slovenian demo locations (Source: GEN-I d.o.o.)

Slovenian demo partners have identified multiple suitable locations in the LV grid, to investigate and demonstrate the application of flexibility services. After detailed analysis, the following three locations have been selected:

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- TP Gradišče (DSO Elektro Ljubljana) - Congestion management, heat pumps are used as flexibility assets;
- TP Železno (DSO Elektro Celje) - Congestion management, heat pumps are used as flexibility assets;
- TP Srakovlje ((DSO Elektro Gorenjska) - Voltage control, PVs and batteries are used as flexibility assets.

Figure 4-1 represents geographical locations of pilots in the Slovenian demo.

At each location GEN-I has contacted the customers, presented them the pilot project and proposed them the following benefits to participate in the project:

- Once a year discount on a monthly electricity bill;
- Access to the monitoring portal, to monitor their consumption;
- Reducing the risk of blackouts in their local grid.

The demonstration aim was to prove the concept of the usage of the flexibility services in the distribution grid to ensure security of supply when grid approaches its physical limits, as an alternative to the traditional grid reinforcement methods, such as installation of newer, more powerful substation or cables, etc. With these flexibility services we could temporarily overcome the grid issues and help the DSOs redistribute the grid reinforcement investments over a longer period.

Each consumer participating in the Slovenian demo has been equipped with the newest version of the main smart electricity meter (by the DSO). The DSOs have also installed new measuring devices in each of the MV/LV substations, in order to increase observability of the LV grid with the measurements receiving in real time. For the households participating in this demo, GEN-I has upgraded their end devices (flexibility assets - heat pump, PV plant, battery) with a smart controller, an IoT device connected to the main electricity meter, but also connected to the backend platforms and the virtual power plant (VPP).

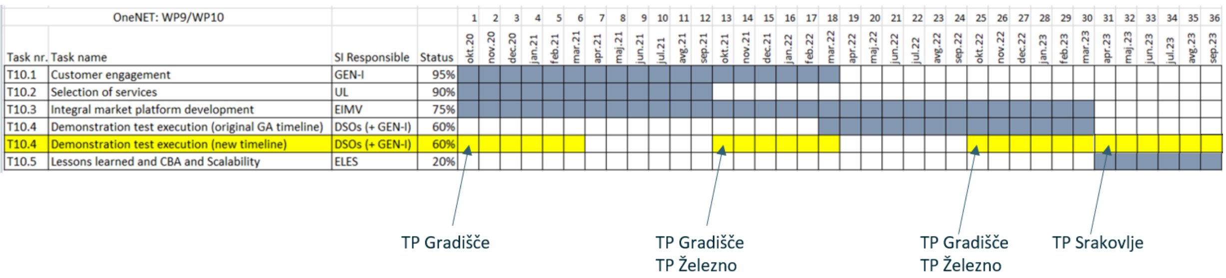

Figure 4-2 - OneNet Slovenian demo Gantt (Source: GEN-I d.o.o.)

4.1.1 TP Gradišče (DSO Elektro Ljubljana) - Congestion management

The MV/LV substation TP Gradišče is supplying 160 households with electricity. Through various public records and GEN-I internal customer records, a total of 24 consumers with installed household heat pump have been identified. The project concept and aims have been presented to 22 consumers, in the end 17 consumers agreed to participate and signed a cooperation agreement. Figure 4-3 provides a topological view of the pilot site – Gradišče. This pilot aimed to demonstrate the usage of the flexibility product – "Congestion management" in resolving the transformer overloading during peak consumption hours.

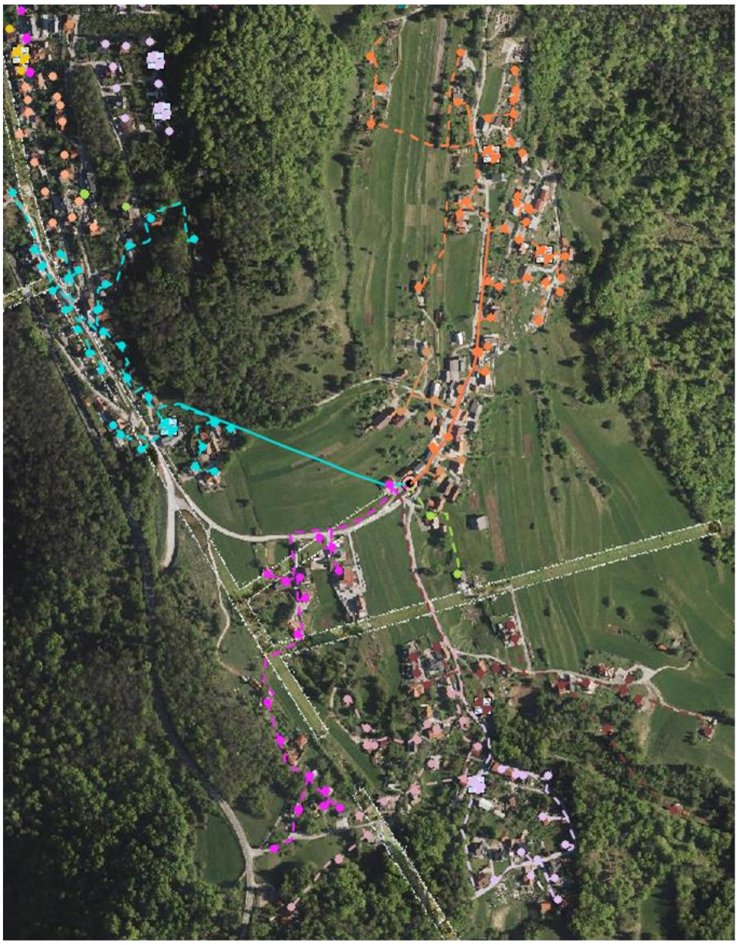

Figure 4-3 - Topological view of TP Gradišče (Source: Elektro Ljubljana, d.d.)

This demo location has been established in September 2020, with the "first season" of using Congestion management service starting in October. At the beginning of 2020, 12 consumers applied to participate in the flexibility service provision.

At the end of the first season (April 2021), five additional customers have been added to the aggregator's portfolio, making a total of 17 customers engaged in the demo during the second (21/22) and third seasons (22/23).

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Among these 17 households there were 10 different types and vendors of heat pumps. All heat pumps have been upgraded with control equipment and included in GEN-I VPP. Additionally, smart meter data (power, phase currents, phase voltages) have been collected from the smart metering utilizing additional IoT device. The collected data IoT device transfers to GEN-I backend database. This installation is presented in Figure 4-4, while the overall data transfer chain is given in *Figure 4-5*

Figure 4-4 - (Left) The main meter with an IoT device, (Right) a controller installed inside a heat pump (Source: GEN-I d.o.o.)

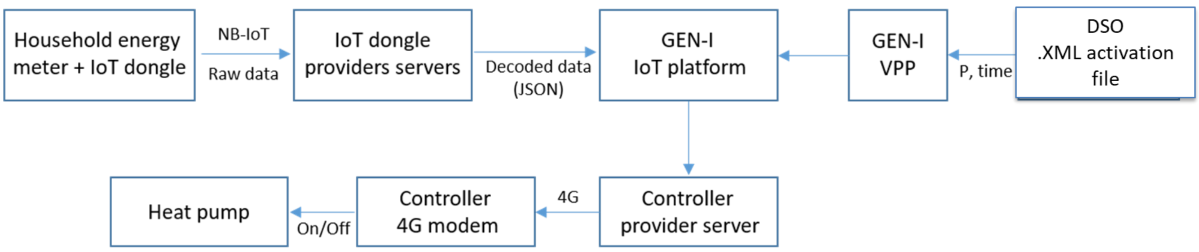

Figure 4-5 - Communication chain from household at TP Gradišče to GEN-I backend (Source: GEN-I d.o.o.)

All acquired data have been stored in the database and visualized with Grafana. This way, availability of each heat pump is monitored, as well as their ability to provide flexibility in a given period of time. Based on the collected consumption data at each household and the grid connection point, the operating time of each heat pump can be optimally set. This dashboard for heat pump operation monitoring is presented in Figure 4-6.

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Figure 4-6 - GEN-I Grafana dashboard for TP Gradišče (Source: GEN-I d.o.o.)

Elektro Ljubljana (EL) (DSO participating in this pilot) is a user of the congestion management service. For the detection of flexibility need and activation of the flexibility service, EL developed and set up the "Flexibility management system" (FMS) and the Traffic Light System (TLS). This system leverages measurement data to make an estimate of the flexibility need and detect a right moment to activate the flexibility service. The FMS receives close to real time measurements with 1 minute resolution of active power (green line in the figure below) from the aggregation meter in MV/LV substation. This meter measures consumption at the LV side of transformer and pushes measurements to FMS via MQTT broker. The FMS also receives temperature predictions (another service) over the Enterprise Service Bus (ESB). Using temperature predictions and predefined transformer model, the FMS calculates the thermal power limit of a transformer (red line in Figure 4-7).

The criteria for the flexibility service activation are the following. The indicator for the activation is defined as the 15-minute moving average of 1 min consumption on LV side of the transformer (green line in Figure 4-7). When this indicator exceeds the threshold (calculated thermal limit of a transformer), the FMS sends an activation signal, and the aggregator begins with the service delivery (denoted with the purple vertical line in Figure 4-7). Immediately after the activation, the FMS publishes restriction messages (TLS) to all interested parties (e.g., flexibility service providers, aggregators and TSO). "Restriction" relates to the grid capability to host other flexibility activations, such as for the balancing purposes of the TSO. For instance, the voltage profile in the grid would be further ruined if some distributed generation is increased, or a load is reduced as part of demand response (DR). The restriction (TLS) message contains the following information: DSO's ID, ID of measurement points which are connected to the overloaded substation, and two 'lights' (red and green). The TLS message indicates if at one LV grid node (measurement point) the load can be decreased or increased. In the case of transformer overload, the TLS message will be decrease=true, increase=false for all the nodes in this substation area.

Activation start time is 15-minutes after reception of the activation signal – ramp time (red vertical line in Figure 4-7). It can be observed in Figure 4-7 that consumption was reaching close to 300 kW but was reduced to

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220 kW after the activation. This is an example of successful activation. When service delivery terminates, a rebound effect occurs. A rebound effect appears since heat pumps are set to replace the heat energy lost during the 1hour and 15 min of activation.

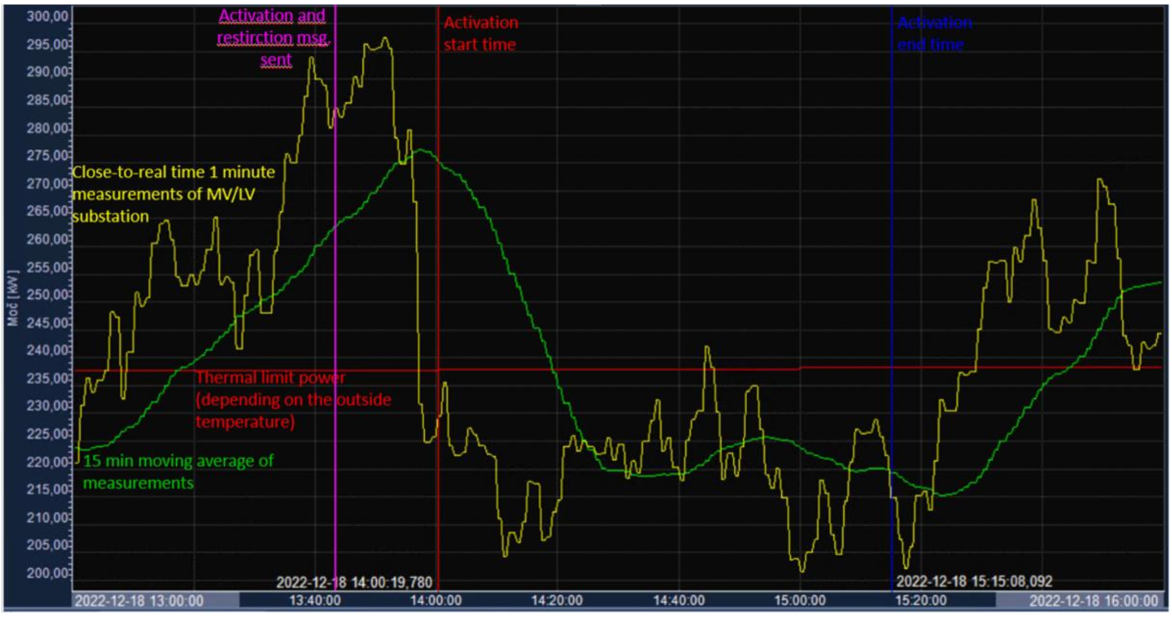

Figure 4-7 - Sample activation diagram

Activation during the first two years was manual, using the phone call. With an intention to automatize the overall process, the third year of demonstration used automatic activation. The implementation is made to fulfil the interoperability requirements and CIM is used as a semantic data model for this purpose (European Style Market Profile - ESMP). The activation signal is a CIM XML document (ActivationMarketDocument), while the activation is confirmed with a CIM Acknowledgement document. Messages are exchanged using MQTT protocol.

4.1.2 TP Železno (DSO Elektro Celje) - Congestion management

The MV/LV substation TP Železno is supplying approximately 70 households with electricity. A total of 14 consumers with installed household heat pumps have been identified within this substation area. The project aims and pilot have been communicated to 14 consumers, with 7 consumers agreeing to participate and signing a cooperation agreement. Figure 4-8 shows the aerial view of the demonstration site.

The Demo location was established in October 2021, with the "first season" of the Congestion management service starting in December.

There were 6 different types and producers of heat pumps among these 7 households. Each heat pump has been equipped with a smart controller and included into the GEN-I VPP. Similarly with the first demo site, smart meter data (power, phase currents, phase voltages) have been collected from the smart metering utilizing additional IoT devices. The collected data is sent to the GEN-I backend database.

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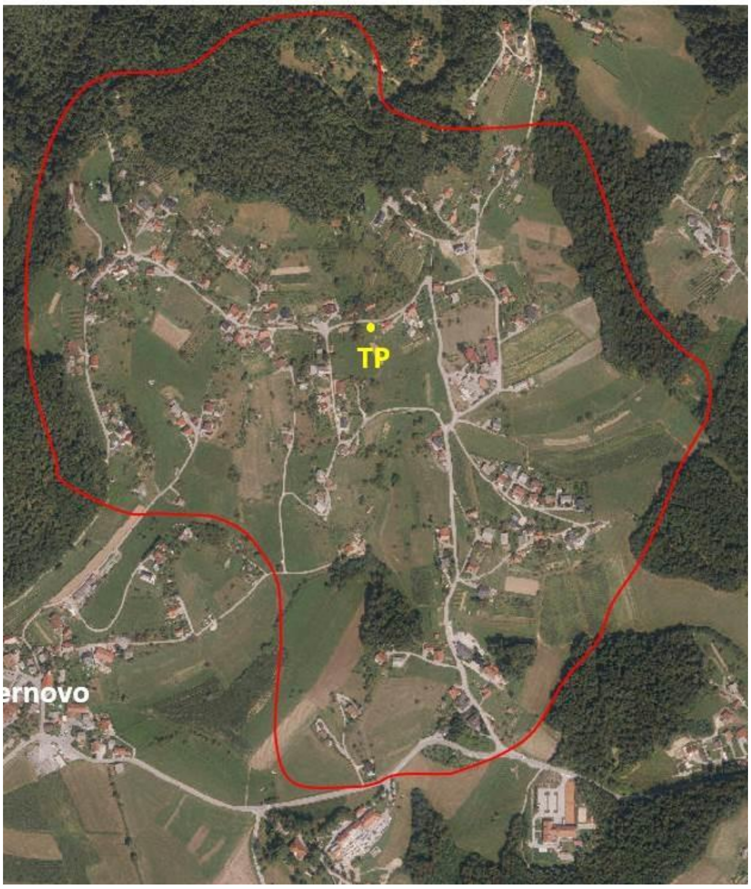

Figure 4-8 - Aerial view of TP Železno area (Source: Elektro Celje, d.d.)

Figure 4-9 presents additional equipment used to upgrade existing heat pumps to become a flexibility asset, that can be controlled automatically. Communication and data exchange is done using the same concept and infrastructure presented in Figure 4-5.

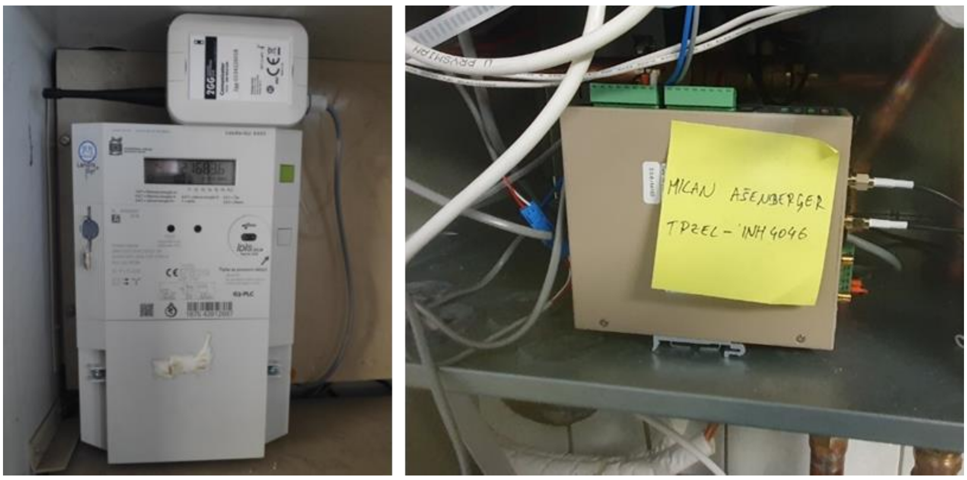

Figure 4-9 - (Left) The main meter with an IoT device, (Right) a controller installed inside a heat pump (Source: GEN-I d.o.o.)

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Figure 4-10 - GEN-I Grafana dashboard for TP Železno (Source: GEN-I d.o.o.)

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Data storage and visualization tool are leveraged from the first demo site. Such a system allows the monitoring of heat pumps and their availability of offer flexibility. With such a set of data received in real time, the optimal plan for the heat pump activation is determined.

4.1.3 TP Srakovlje (DSO Elektro Gorenjska) - Voltage control

The MV/LV substation TP Srakovlje is supplying around 25 households with electricity. A total number of 7 consumers with a household installed PV plant have been detected. Six of them are currently GEN-I customers and have agreed to participate in this demonstration. Figure 4-11 shows a geographical view of the demo site.

Legend

SE without battery system

SE with battery system

MV/LV transformer substation

Figure 4-11 - Aerial view of TP Srakovlje area (Source: GEN-I d.o.o.)

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For the voltage control demonstration purposes, three of the existing PV plants (circled in blue in Figure 4-11) were upgraded with a battery storage unit. The configuration of the storage unit is 5 kW/12 kWh. Voltage control uses the “Volt-Watt” method, charging the batteries when solar production is high and consequently maintaining the voltage within the requested limits (up to some point).

Figure 4-12 - A PV plant upgraded with a hybrid inverter and a battery storage unit

For the voltage control demonstration purposes, three of the existing PV plants (circled in blue in Figure 4-11) were upgraded with a battery storage unit (shown in Figure 4-12).

Flexibility assets for this demo site (all 6 PV plants and 3 battery storage units) are included into the GEN-I VPP portfolio, using the same approach as for the first two demo sites. Data acquisition and transfer to the GEN-I backend database is completely aligned with Figure 4-5. Therefore, it is the same ICT architecture for data acquisition and activation of flexibility assets (heat pumps, PVs and batteries).

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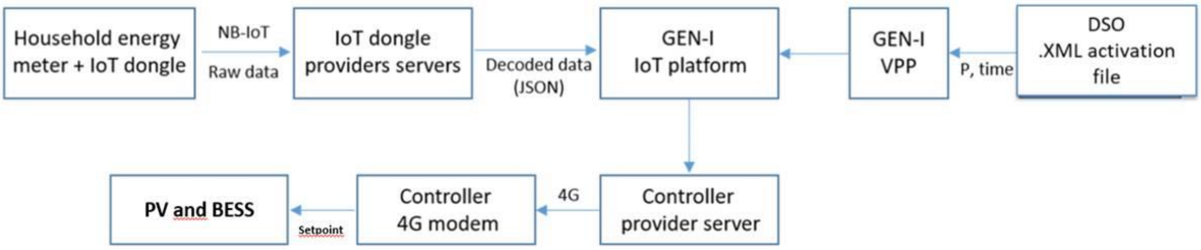

Figure 4-13 - Communication chain from household at TP Srakovlje to GEN-I backend (Source: GEN-I d.o.o.)

For each household a visualization of the captured data has been done in Grafana. The Grafana dashboard enables insight into real-time data including the production of each PV plant, state of charge (SoC) of each battery and values of charging/discharging. By monitoring voltages at each household and the LV substation, the required voltage change can be calculated. This voltage reduction/increase has been further achieved through the flexibility service activation (control of flexibility assets).

An example activation of batteries for the voltage control service has been presented in Figure 4-14. The dotted red vertical lines denote the start and end of service activation. It can be observed that very fast activation of battery storage for 4 kW decreases voltage by approximately 5V. The result of each activation can be observed through the Grafana dashboard.

Figure 4-14 Example activation of voltage control service

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4.2 Demonstration of services and products in SLO Demo

To address the needs of distribution grid in a market-based way the SLO demo aims to test non-frequency services – e.g., voltage control and congestion management through active power management. The flexibility assets, located at the households, used in this demo include:

- Heat pumps, switching on and off;
- Battery storage, with the control of charging/discharging power;
- PV production, with the control of produced active power.

The aggregator manages a portfolio of several households in the congested grid areas where heat pumps are already installed. Temporarily switching off heat pumps can prevent the transformer substation from overheating and line congestion. The aggregator also manages several household-sized PV power plants with battery energy storage units to solve the voltage problems in the LV network. When voltage control is needed, active power curtailment will be activated via an inverter. The excess energy will be used to charge the battery systems and the stored energy could be used later in the day. In the process of acquiring participating customers motivational factors such as financial benefits and guarantee of minimal impact on comfort and the absence of risks were used.

The flexibility products have been designed to meet the needs of the respective LV grid areas, defining specific time periods and seasonality. For the congestion management service, delivery is contracted from September to March of three consecutive winters. Furthermore, the flexibility service activations are limited to day-time hours from 6:00-22:00.

Congestion management service delivery was elevated from the manual to automatic activation during the demonstration period. Using the same data model (CIM ESMP) for the activation signal, as the one used by the TSO for the balancing market, makes the integration of flexibility assets into existing aggregator's VPP easier. The DSO sends an activation signal as a CIM XML file, which is directly read by the GEN-I VPP and allows quick response time. The dashboards for the activation monitoring at the two demo sites, where congestion management service is demonstrated, are presented in Figure 4-15 and Figure 4-16, respectively.

Conclusions drawn from these three demonstration sites are the following:

- Flexibility services are an effective tool for the distribution grid to tackle with operational issues and physical limitations. However, it is a necessary condition to have available flexibility assets and engaged active consumers that participate, who must clearly see the benefits of this engagement.
- Flexibility service usage requires LV grid observability to detect needs for flexibility and determine appropriate time and location for the activation of flexibility resources.

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- Aggregation of flexibility resources in a large number requires IT integration for remote supervision and control of flexibility assets and automatic activation of flexibility services.
- Integration should be implemented using standard interfaces (communication protocols and data models). In such a manner, inclusion of new assets in the aggregator's portfolio and offering services at the different markets is simplified.

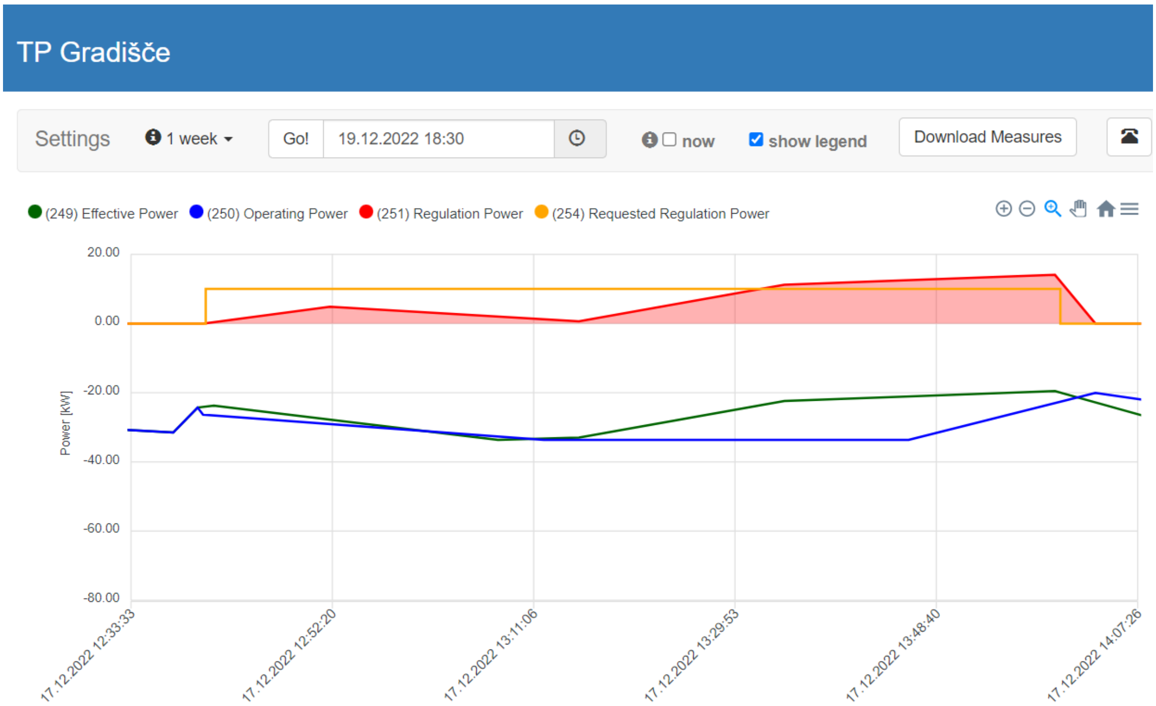

Figure 4-15 - TP Gradišče: Activation signal and response in the GEN-I VPP (Source: GEN-I d.o.o.)

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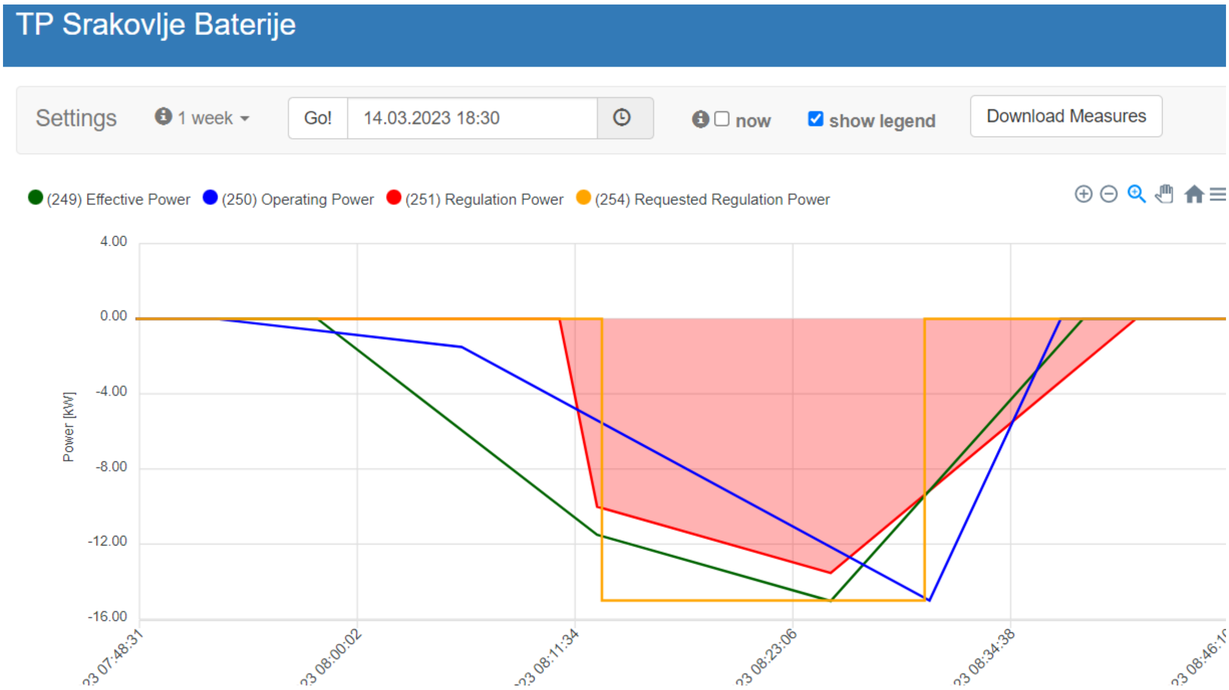

Figure 4-16 - TP Srakovlje: Activation signal and response in the GEN-I VPP (Source: GEN-I d.o.o.)

Beside these three physical demonstration sites, the Slovenian pilot includes a demonstration of the local flexibility market and IT platform for the purchase and activation of flexibility services for DSO needs. This demonstration is part of the demo IT architecture and is explained in Section 4.3.

4.3 IT architecture

Since there was no market platform for DSOs in Slovenia, the existing web portal 'mojelektro.si' has been upgraded to enable trading with the flexibility. The web portal is part of the Uniform system access to metering data – national metering data hub (SEDMp). Through this web portal, consumers from the whole of Slovenia have the opportunity to monitor their energy consumption or production from their own metering points, regardless that there are five DSOs in Slovenia. Each DSO has independent 'metering centre' for the data collection from the smart meters, but they are all connected with the web portal 'mojelektro.si'. This portal has been upgraded with the flexibility functionalities. Besides B2C portal 'mojelektro.si', SEDMp has a Business user Portal (central electro-energy portal CEEPS) which is used for sharing metering data to Business subjects such as TSOs, energy suppliers and aggregators. CEEPS was also upgraded in such a way, that aggregators can apply on tenders and view settlement data for activations as well. The authorization management function enables customers to grant the access to their data to third parties (suppliers, aggregators, etc.) through the B2C web access.

The described IT architecture (Figure 4-17) is already in operation in Elektro Ljubljana (DSO). The process of flexibility procurement includes different systems. The two most important systems are the flexibility

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procurement system and the flexibility management system (FMS). For external stakeholders, the SEDMp system with 'mojelektro.si' portal and CEEPS web portal enable access to participate in flexibility services (Figure 4-18). All systems exchange messages through Message Queuing Telemetry Transport (MQTT) and Message queuing system. The last one is responsible for message conversion between MQTT and Apache Kafka, which forward converted messages into Kafka broker. Some messages for aggregators and TSOs must be converted into MQTT, since existing Message Queuing systems at aggregator's side supports MQTT messages. Figure 4-17 illustrates systems and information exchange with Message Queuing (MQ) topic names on brokers.

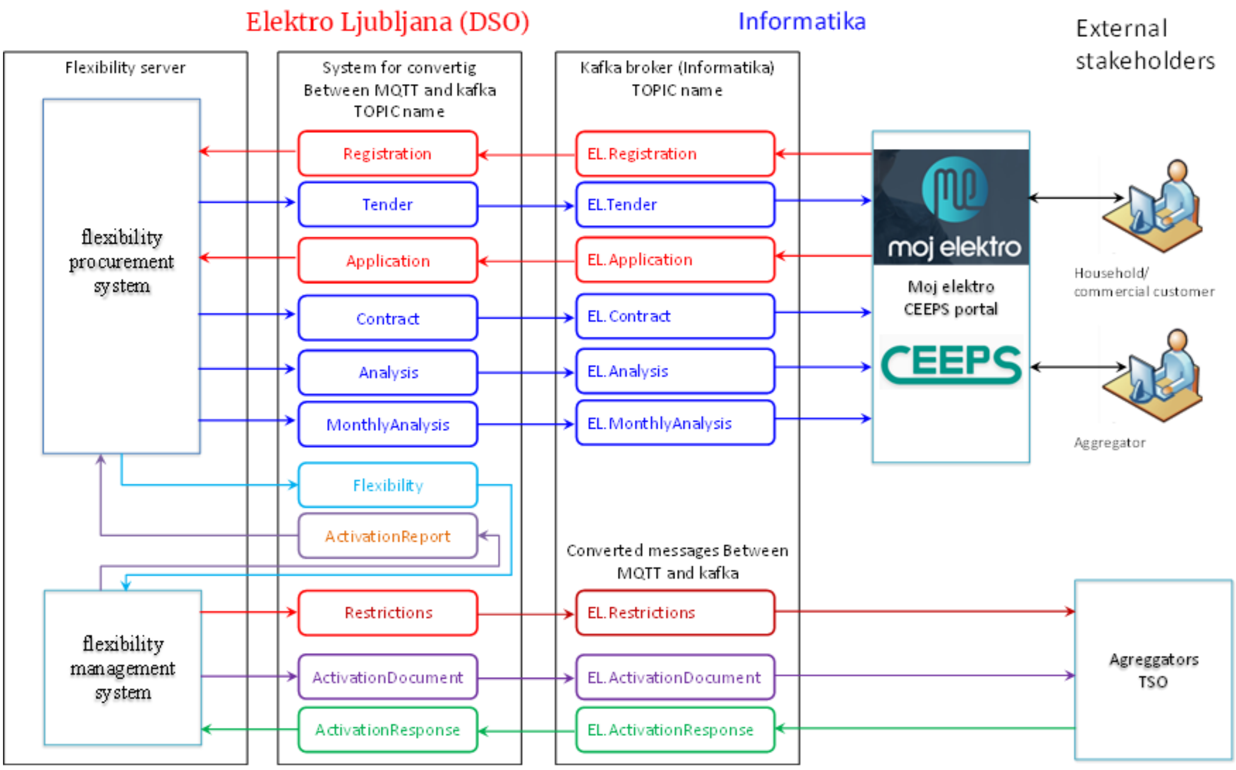

Figure 4-17 – IT architecture of the local flexibility platform used in the Slovenian demo

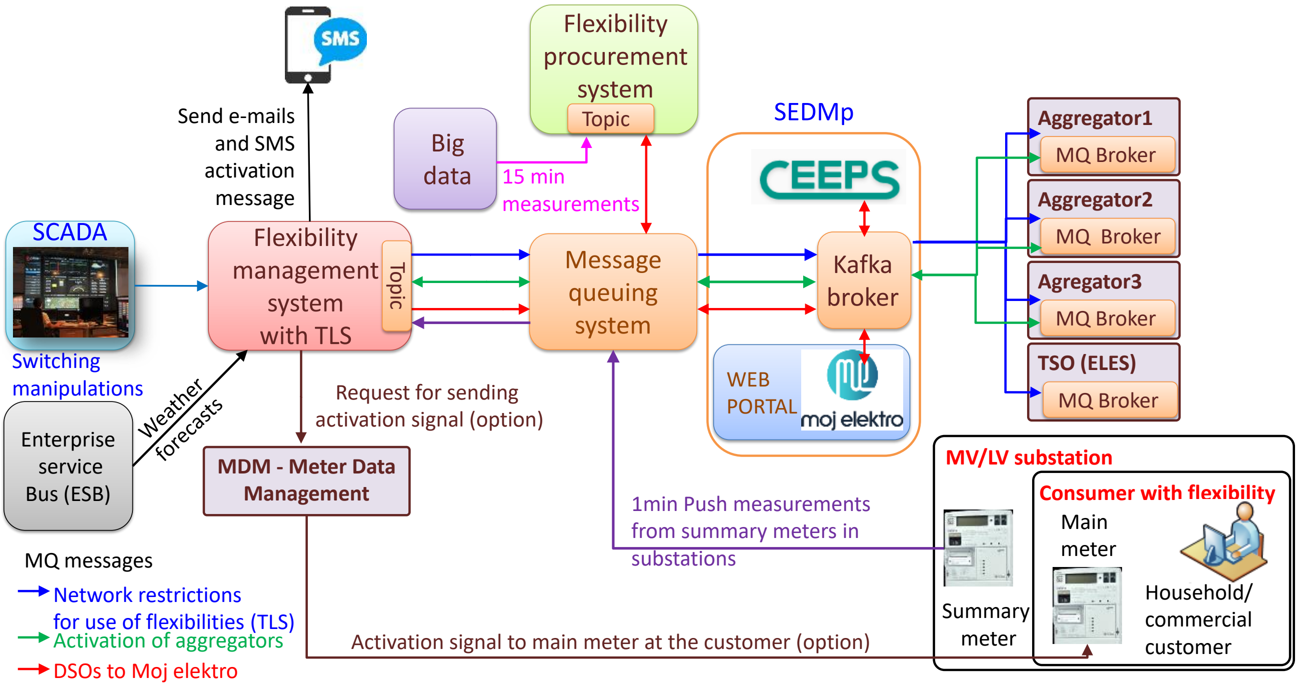

Figure 4-18 – Access of DSO IT/OT systems and external systems to the flexibility procurement (Demo site in Slovenia)

4.3.1 Flexibility procurement system

This system is needed for flexibility register, inserting new tenders for flexibility in the distribution grid, collection of the consumers/aggregators bids, making auctions and contracts, and at the end making calculations of activations with reporting settlement data.

4.3.2 Flexibility management system (FMS)

For monitoring close-to real time consumption of MV/LV substations smart meters were installed to push metering data into Mosquitto MQTT broker. Since SCADA don't support MQTT client we established Flexibility management system which is further linked to the SCADA system. This system monitors the consumption of MV/LV substations and in case of overload it sends activation messages to the aggregator.

4.3.3 Moj elektro and CEEPS portals

The upgraded 'Moj elektro' portal is used for consumers (owner of measurement point) to register flexibility on their metering point. They can choose if they offer flexibility with or without an aggregator. When the consumer registers flexibility, the MQ message *'Registration'* is sent to topic for adequate DSO. The message

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contains information of the metering point (ID and postal address), name and surname of the consumer, email, mobile number, consensus for SMS messaging for new tenders, information about selected aggregator, flexible power and topology of connected point (main HV/MV substation, MV feeder, MV/LV substation).

The DSO publishes the tender on the platform, related to the grid area where operation issues exist (e.g., congestion, overload, voltage profile outside limits). Information about the tender DSO sends to Moj-elektro and CEEPS by 'Tender' MQ message. The message includes the following information: link to the terms and conditions, due date, ID and name of the tender, total needed flexibility power, minimal flexible power that consumer can offer, maximal price for flexible energy and area of the tender (ID of main HV/MV substation or ID of MV feeder or ID of MV/LV substation). At the same time the Flexibility procurement system sends an SMS and an e-mail to the consumers which are located in tender area (flexibility products for DSO require location info) and have already registered their flexibility, so that they can insert their bids. Consumers have to login on mojelektro.si to insert the bid.

Consumers can register their flexibility after the tender, but only those who are in the tender area can submit an offer. If the consumer selected aggregator in the flexibility registration, then an aggregator will insert bid for authorised measurement places in CEEPS portal. With inserting the bid in the name of consumer, the aggregator confirms that it has signed an agreement or a contract with the consumer for providing flexibility services on measuring place. Each measuring place can only have one aggregator for DSO product. Inserted bids of consumers/aggregators are transferred to DSO's flexibility procurement system by Application MQ message. In the message there is tender ID, flexible power and measurement place ID.

Once a day DSO's flexibility procurement system makes a price comparison and consumers or aggregators with high prices are notified with e-mail or SMS, so they can lower their price. After the due date, the final auction is made, and all bidders are informed if their bid was selected or not. The DSO sends contracts to consumers or aggregators which were successful on auction. By signing a contract, consumers or aggregators became flexible service provider (FSP). Signed contracts of FSP are recorded in the flexibility procurement system. Then the flexibility procurement system sends Contract MQ message to mojelektro portal. In this message there are information of signed contact such as contract ID, link to the terms and conditions, signed date, contract start and end date, flexible power, and measurement place ID or aggregator ID. This information is then also shown on mojelektro.si. After the signed contract is entered in the flexibility procurement system, it also sends a Flexibility MQ message to the flexibility management system. This message contains contracts information: -connection point (main HV/MV substation, MV feeder, MV/LV substation)

-ID and name of the contract

-Start and end date of the contact

-Number of maximum daily activations

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-Max duration of single activation

-Daily schedule of activations for different days

-Flexible power in W

-Name and surname of consumer

-E-mail for sending activation messages

-SMS Messages status with GSM number

With the connection point information, the flexibility management system groups FSPs by three layers: HV/MW substation, MV feeder and MV/LV substation.

Before the start date of the contract, the DSO checks if the consumers have smart meter, which enables reading 15 min measurements, and if necessary, replace the billing meter. If the consumer wants their appliances (heating pumps) to receive physical contract on activation, the DSO enables that activation signal is send by relay output on billing meter. But in the SL demo all consumers offered their flexibility over an aggregator, which installed a controller for turning off the heat pump.

At activation, the DSO's flexibility management system sends the activation MQ message *Activation*. The message is the same as in mFRR for TSO. In the activation messages there is the ID of the DSO as sender, the ID of the aggregator as receiver, the ID of the contract (it determines location of the grid), the time of message, the start/end time of activation and the requested power. The aggregator then sends a response message in which the received information of activation is included.

After activation, the flexibility management system sends the MQ message '*ActivationReport*' to the flexibility procurement system with the following information: activated contract ID, activation ID, start/end time of activation and requested power.

4.4 Demonstration results

The flexibility procurement system makes the calculation of activated energy based on information from the ActivationReport and 15 min measurements from metering points where flexibility was activated. The flexibility procurement system sends '*Analysis'* MQ message with the following information: baseline value, start/end time of activation, contract ID, activation ID, the amount of the award in EUR and activated energy. This information is then shown on Moj elektro (for consumers) or on CEEPS portal (for aggregators). At the end of the month, the DSO's flexibility procurement system sends '*MonthlyReport'* MQ message with summary data for the whole month (number of activations, total amount value and total quantity of energy).

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The demonstration analyses for these three demo sites of the Slovenian demonstrator are given in the following subsections.

4.4.1 TP Gradišče (DSO Elektro Ljubljana) - Congestion management

The results for the congestion management service at the location TP Gradišče have been acquired in the three seasons. In the second season, an existing flexibility portfolio has been extended with new consumers with heat pumps. With additional HPs we were able to provide more flexibility, thus the success rate had a significant growth in the second and third year. **Error! Reference source not found.** shows the success rate of activation during the demonstration period. The overall number of activations is presented in Table 4-2.

From the results we observe that the majority of activations occurred during the weekends. The ratio of activation between weekdays and weekend increased even more in the second year. Whereas the ratio was lower in the third year, 30% more activations during the weekends.

Table 4-1 – TP Gradišče: Success rate of the Congestion management activations from 2020 to 2023

	2020/2021	2021/2022	2022/2023
Succes rate	43%	79%	85%
No. of participating HPs	12	17	17
avg. no. of activated HPs per activation	9	15	15
No. of all activations	33	24	39
No. of successful activations	15	19	33

Table 4-2 – TP Gradišče: Number of activations

No. Activations	First year	Second year	Third year	Total
Weekdays	11	6	16	**33**
Weekends	22	18	23	**63**
			Grand total	**96**

The distribution of activation during a day for weekends in all three seasons is given in Table 4-3. The number of activations per hour during weekends is graphically presented in the chart given in Figure 4-19. Activations are obviously most common during weekends between 12:00 and 13:00 and between 18:00 and 20:00. During

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the weekends there were two slots of activations, the first slot was around noon (lunch time) and the second slot was in the late afternoon or evening (when HPs were working at higher rate).

A similar analysis has been conducted for the weekdays and the results are presented in Table 4-4 and Figure 4-19. On weekdays the activations mostly occurred in the late afternoons and evenings, when the HPs were working at a higher rate. Among the years there was not a lot of change in spread during the hours.

Table 4-3 – Number of activations per hour during weekends

Hour	First year	Second year	Third year
10			1
11	2	2	3
12	2	1	5
13	6		1
14	1		4
15			1
16	1		1
17		2	
18	2	4	3
19	2	5	2
20	5	4	4
21	1		

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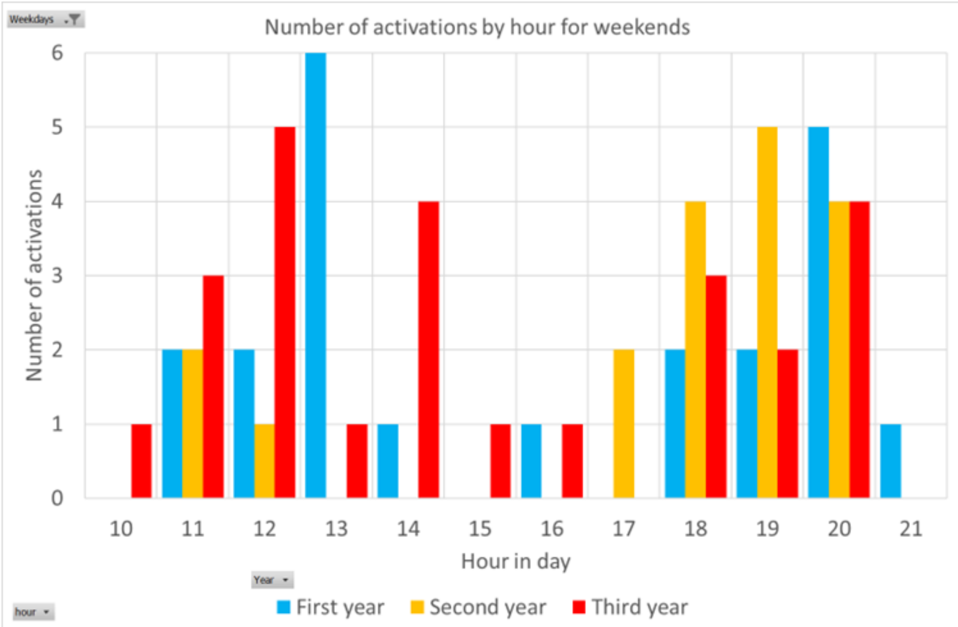

Figure 4-19 – TP Gradišče: Number of activations by hour for weekends (Source: Elektro Ljubljana)

Table 4-4 – Number of activations per hour during weekdays

Hour	First year	Second year	Third year
17	1	1	
18	3	1	3
19	4	3	4
20	2	1	5
21	1		2

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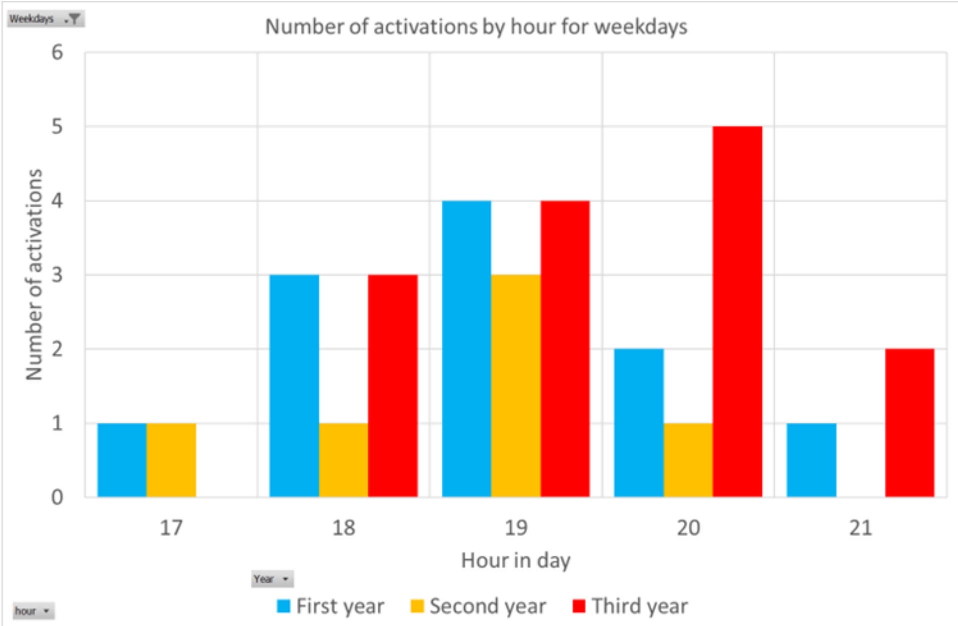

Figure 4-20 – TP Gradišče: Number of activations by hour for weekdays (Source: Elektro Ljubljana)

The amount of requested flexibility for each activation is analysed and presented in Table 4-5. It can be observed that the most frequent values of requested power were 10 kW and 20 kW. The need for higher requested power was lowering by the end of each season, which is logical, since the outdoor temperature was rising and consumers used their HPs less.

Table 4-5 – TP Gradišče: Requested power through the activations

Requested power [kW]	No. Of occurences	Share
<10	9	9%
10	27	28%
10,1 < 14,99	8	8%
15	15	16%
15,1 < 19,99	11	11%
20	26	27%
Grand total	96	100%

The relation between requested and delivered flexibility energy can be observed in Table 4-6 and Figure 4-21, respectively. As seen from the data, through the years, the highest request for energy was in January every year, since that is the peak of heating season. The values of requested and delivered energy were aligned the most in the second year of activations. With significant shortage of delivered energy in the third year.

Table 4-6 – Delivered and requested flexibility energy during the demonstration period

Month	Delivered energy [kWh]	Requested energy [kWh]
nov 20	41	90
dec 20	122	174
jan 21	232	224
feb 21	24	39
dec 21	109	60
jan 22	199	136
feb 22	111	106
mar 22	84	74
dec 22	176	176
jan 23	97	263
feb 23	114	189
mar 23	69	69
Total Energy [kWh]	1379	1600

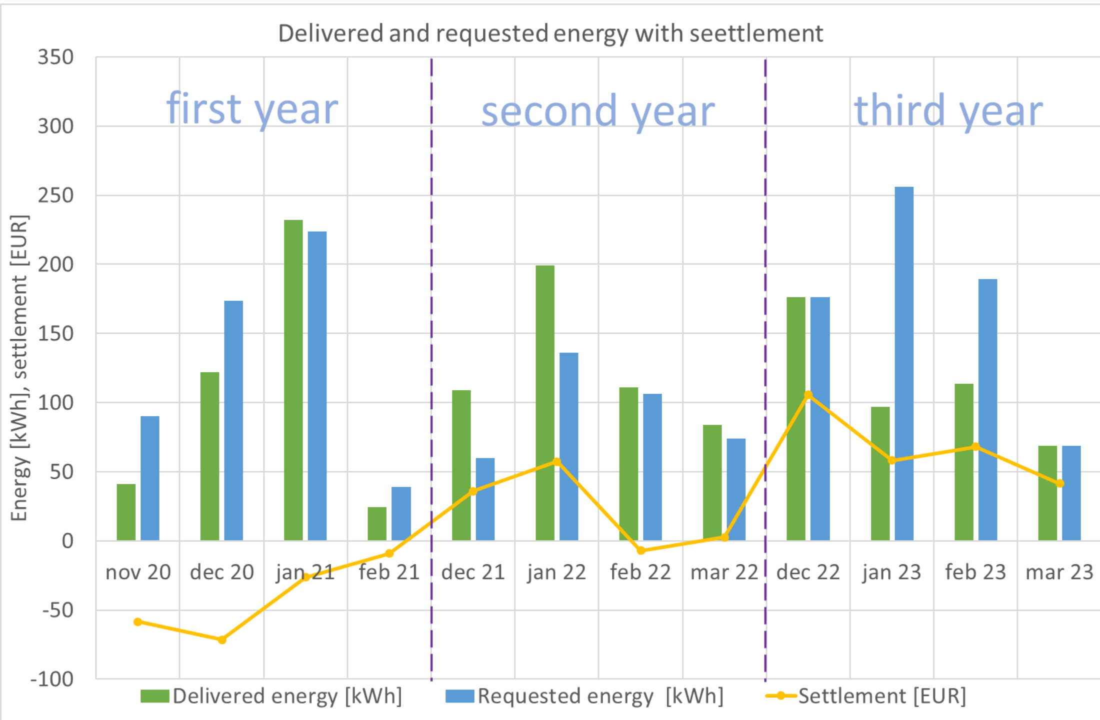

Figure 4-21 - TP Gradišče: Requested and delivered energy through the years (Source: Elektro Ljubljana)

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In the third year, we changed the methodology for calculating baseline and activated energy. In the first two years, the aggregator predicted the baseline. Activated energy was calculated as the difference between aggregated active power and the corrected baseline. Since the actual consumption of customers with flexibly deviate from the predicted baseline, the baseline was corrected based on the comparison of the average consumption and the predicted aggregator's baseline in the last four full 15-minute intervals before activation. In the first two years, there was penalization if reduced power in any 15-minute period was lower than 75% of requested power. Penalization was double the required energy value.

In the last year, we changed the methodology of the baseline. Baseline was defined as power in the last 15-minute period before the activation announcement, and it was constant the whole time of activation. Figure 4-22 shows a graph of baseline methodology in the last year. The blue line presents the aggregated measured power of all flexible units that the aggregator is offering on the substation. At 18:45, DSO sent an activation message to the aggregator for activation from 19:00 to 20:15 with a requested power of 30 kW. Before the activation announcement, the summed power of all flexible units was 50 kW, and that is the baseline. Since flexible units have a 15-minute response time, the first period lasted from 19:00 to 19:15. Activated energy in the first period is yellow. If power is higher than baseline, like in the 3rd period, the calculated energy is 0, and the aggregator is not penalized with negative energy.

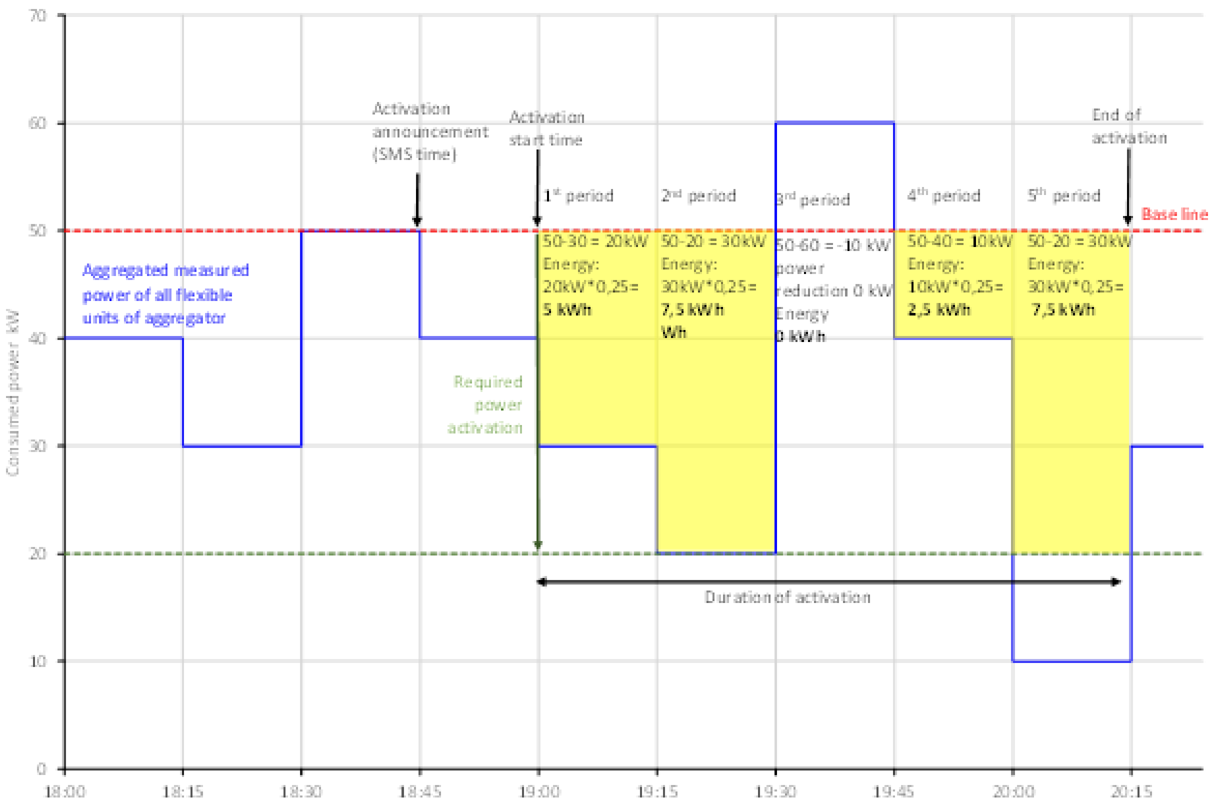

Figure 4-22-- Baseline methodology in the third year

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4.4.2 TP Železno (DSO Elektro Celje) - Congestion management

The second demo site TP Železno also demonstrates the flexibility service "Congestion management", leveraging flexibility of heat pumps at the households. We were able to run this demo location for only one heating season. Despite the limited number of household customers with a HP, we were able to acquire 7 customers and add their HPs into the pool of units.

Table 4-7 provides the success rate of the activation at this demo site, for the one season. During weekdays there were 17 activations and 2 additional activations were during weekends. The success rate of these activation is 47%, which is a similar success to the first year of demonstration in the demo site TP Gradišče. From Figure 4-23 it can be observed that more than half of activations occurred in the evening hours. Another peak is observed at 8:00 in the morning.

Table 4-7 – TP Železno: Success rate of the Congestion management activations in the 2022/2023 season

	2022/2023
No. of participating HPs	7
Avg. no of activated HPs/activation	5
No. of all activations	20
No. of succesful activations	10
Success rate	50%

Table 4-8 – TP Železno: Delivered and requested flexibility energy during the demonstration period

Month	Delivered energy [kWh]	Requested energy [kWh]
apr 22	1,3	10
jun 22	0,0	3
sep 22	11,6	10
okt 22	12,7	9
nov 22	1,3	10
dec 22	22,5	10
feb 23	13,3	12,5
mar 23	21,6	12,5
apr 23	11,1	6,3
Total Energy [kWh]	95	83

The relation between requested and delivered flexibility energy can be observed in Table 4-8. As seen from the data, through the years, the highest request for energy was in December 22, in the peak of heating season, and additionally in March 23, since the temperatures were low in the evenings and the HPs were in use.

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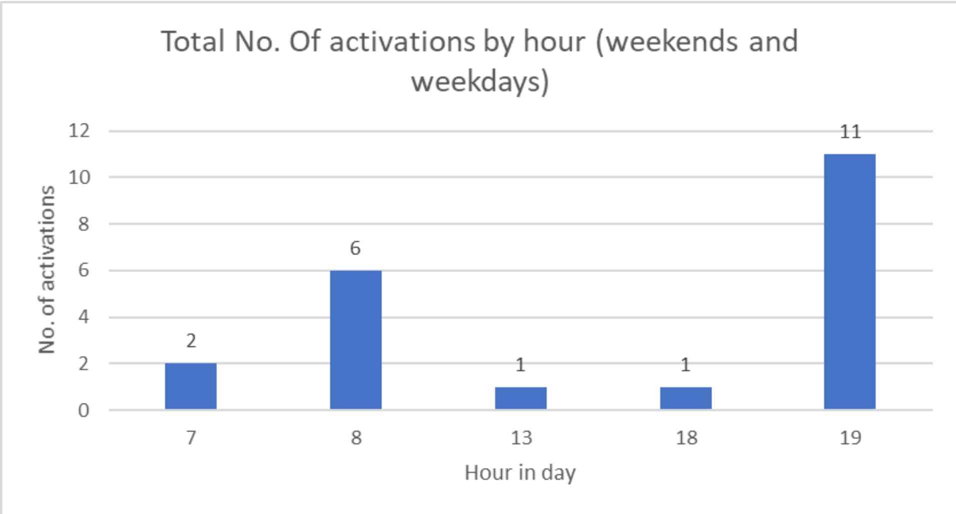

Figure 4-23 - TP Železno: Number of activations by hour for weekends and weekdays

4.4.3 TP Srakovlje (DSO Elektro Gorenjska) - Voltage control

Activities on the Srakovlje Demo location are predicted from May 2023 onwards, when the main PV production season starts.

4.5 Conclusions

The Slovenian pilot demonstrated two types of flexibility services in the distribution grid (congestion management and voltage control) at three pilot geographical locations. The flexibility assets that have been used are heat pumps, batteries and PV. The pilot TP Gradišče lasted three seasons and provided the most detailed insights into the use of flexibility services for DSO. In addition, a traffic light system was implemented to inform flexibility service providers and TSO about constraints in the distribution network with regard to activating flexibility assets for frequency ancillary services. At the end of the demonstration, we came to the following general conclusions:

- Congestion management is a flexibility service that can be used effectively in the distribution grid. In particular, switching off heat pumps reduces the overload on a distribution transformer. However, the number of heat pumps (consumers) in the aggregator's portfolio has a strong influence on the success of activation. During the demonstration, the number of participating consumers increased, making this service more effective.
- Observability of the grid is necessary for adequate activation of the flexibility product. In the low-voltage grid, stochasticity is particularly pronounced and a good prediction of the grid condition is required. In this way, false activations are avoided.
- Automating the whole process of activating flexibility services increases the activation success rate.

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- Interoperability, common data modelling and harmonisation of flexibility products facilitate integration between systems. For example, the same activation signal is used for the TSOs' balancing market as for the DSOs' local flexibility market.
- The effective use of batteries and the limitation of PV generation have proven to be effective for voltage regulation in the distribution grid. These flexibility assets are included in the VPPs offered to DSO under market conditions.
- A simple TLS (Traffic Light System) can be implemented to inform the market (TSO, aggregator), that some distribution grid area has constraints in the use of flexibility of the consumers connected to that grid area. In Slovenian demo, new CIM profile was develop and implemented to exchange TLS message in standardised and interoperable way (described in OneNet deliverable D5.6).
- Use communication platform (in this case OneNet system) is an effective tool to publish data about flexibility market and potential European wide and open new business opportunities (e.g. for aggregators and flexibility service providers). Within Slovenian demo use case, flexibility market results are provided through OneNet system for three seasons.

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5 Hungarian demo (T10.4.4)

5.1 Demo background – locations, stakeholders, and schedule

The motivation behind the Hungarian demo area selection is to demonstrate the business use cases that stem from the issues caused by the high penetration of solar photovoltaic generation on the MV distribution network. Regarding the two BUCs, both voltage limitation and transformer overloading management have been demonstrated as it has been outlined in Deliverable 2.3 [5].

The two distinct grid areas as demonstration sites have been according to the demonstration needs of the BUCs.

5.1.1 General description of the demo area selection process and network topology

The Hungarian DSOs operate both cables and overhead lines (Ohl) at MV level. The specialty of most DSOs is that the ratio between Ohl/Cable is ~80%. The structure of the Ohl lines follows the arc schema, i.e., there is a line located between two HV/MV substation which has an open point, the lines are operated in a radial manner. The general figure below shows this structure.

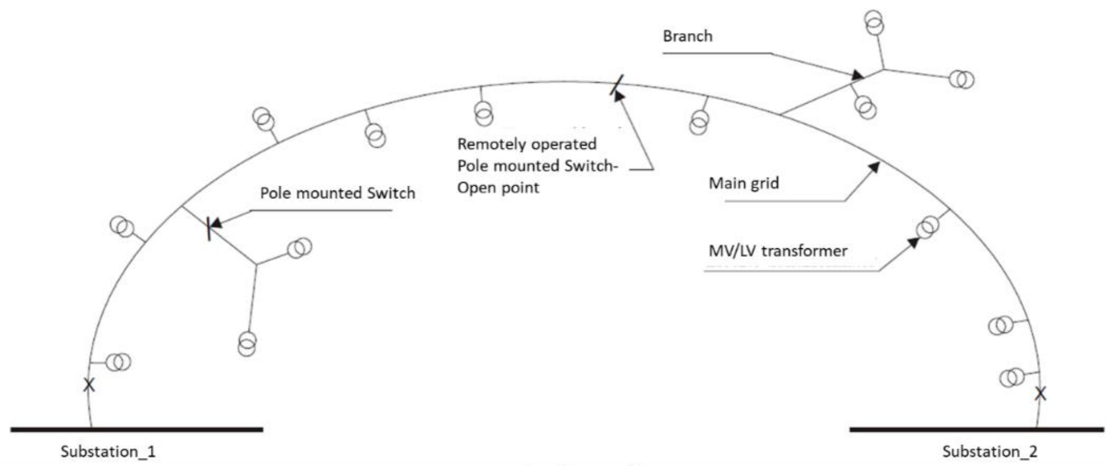

Figure 5-1 - MV overhead line structure

The average length of the above-mentioned Ohl feeders exceeds 15-20 km, this feature implies that connected DERs (e.g., PV plants) can increase the voltage, mostly if they are connected to the end of the line (close to the open point). The generator connection guideline of DSOs prescribes load flow calculation, whether the new PV will cause Δ2% voltage increase or not. A lot of Ohls are already „saturated" due to the PV proliferation. Besides voltage increases the PVs can also cause HV/MV transformer overloading according to load flow calculation, this is the other reason for the „saturation" PV plants of an HV/MV substation supply area.

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The above-mentioned phenomenon limits the connection of new renewables, in other words, the penetration of PV power plants is reaching its limit within the DSO's networks due to potential transformer overloading and out-of-range voltage increase. There are more solutions to connect additional DERs to the network, one of them is the flexibility provision (of course the ANM, Active Network Management can also be a way to increase the hosting capacity). The Hungarian Network code allows DSOs to use classical flexibility services, non-market-based redispatch, and so-called flexible connections. Flexible connection means that instead of the reinforcement of the grid, DSOs can allow new customers to connect to the network provided that the customer agrees to curtail production when the network is close to capacity limits. The non-market-based redispatch can be the last resort, i.e., the DSO has a right to curtail the production of a generator (in case of renewables it cannot exceed 5% of the yearly production).

In order to demonstrate the BUCs, two demo areas have been selected within the Hungarian consortium. The two demo areas represent a section of the two consortium member DSOs' MV networks, namely E.ON's and MVM's. Both demo areas are located in southern Hungary, where the geography and the sunshine hours are in favour of PV generation. The two demo areas are two HV/MV substation supply areas, namely:

- Demo area of Siklós (E.ON EDE)
- Demo area of Békés (MVM DÉMÁSZ)

The locations are indicated on the following figures.

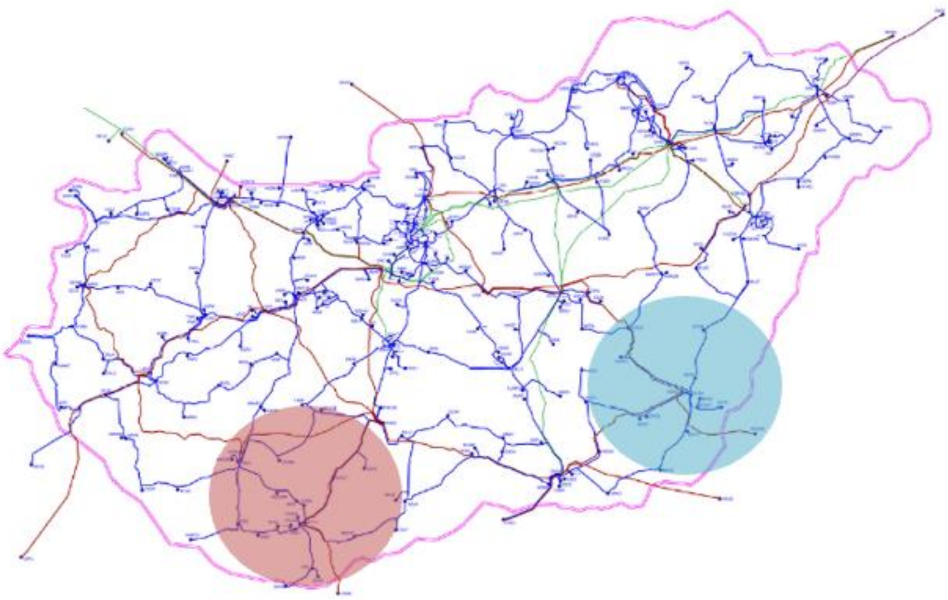

Figure 5-2 – Location of the two demo areas in Hungary (Red zone = E.ON; Blue Zone = MVM)

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Figure 5-3 – Demo area of Siklós (E.ON EDE)

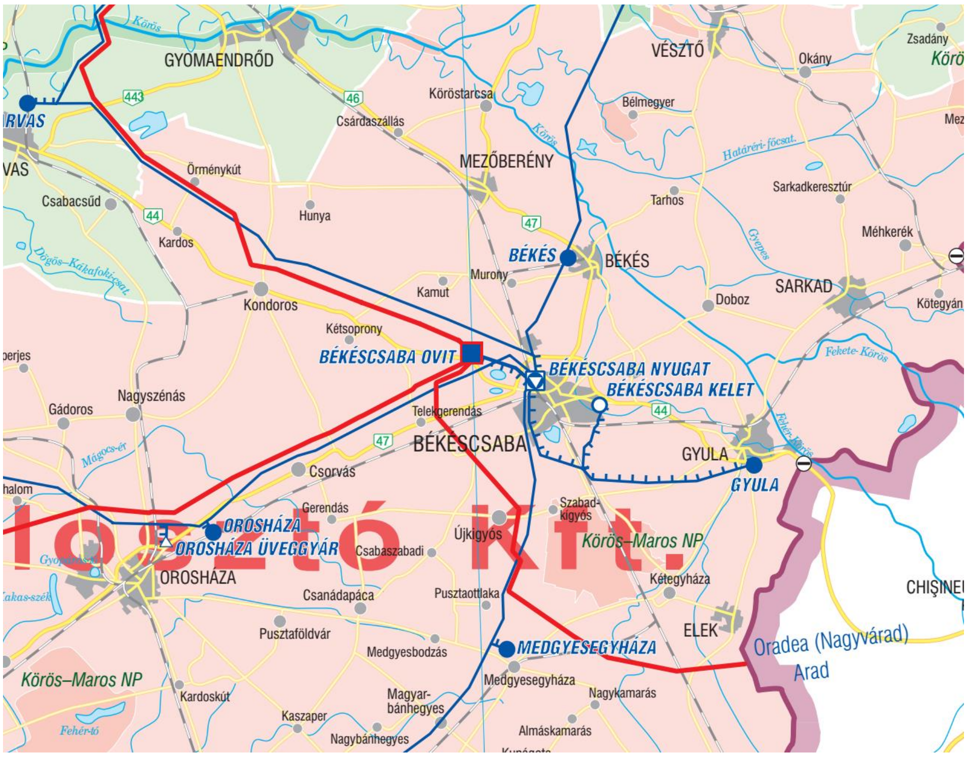

Figure 5-4 – Demo area of Békés (MVM)

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5.1.1.1 E.ON demo area

The pilot demo site of E.ON consists of one HV/MV substation supply area. We have selected one substation in the southern part of Hungary. The reason behind this specific site was the saturated network and events in the past that caused a significant voltage increase (two lines were interconnected, i.e., the open point was closed due to planned maintenance).

The following pictures inform about the site, the location of the substation, the MV Ohl lines, and the connected PV plants.

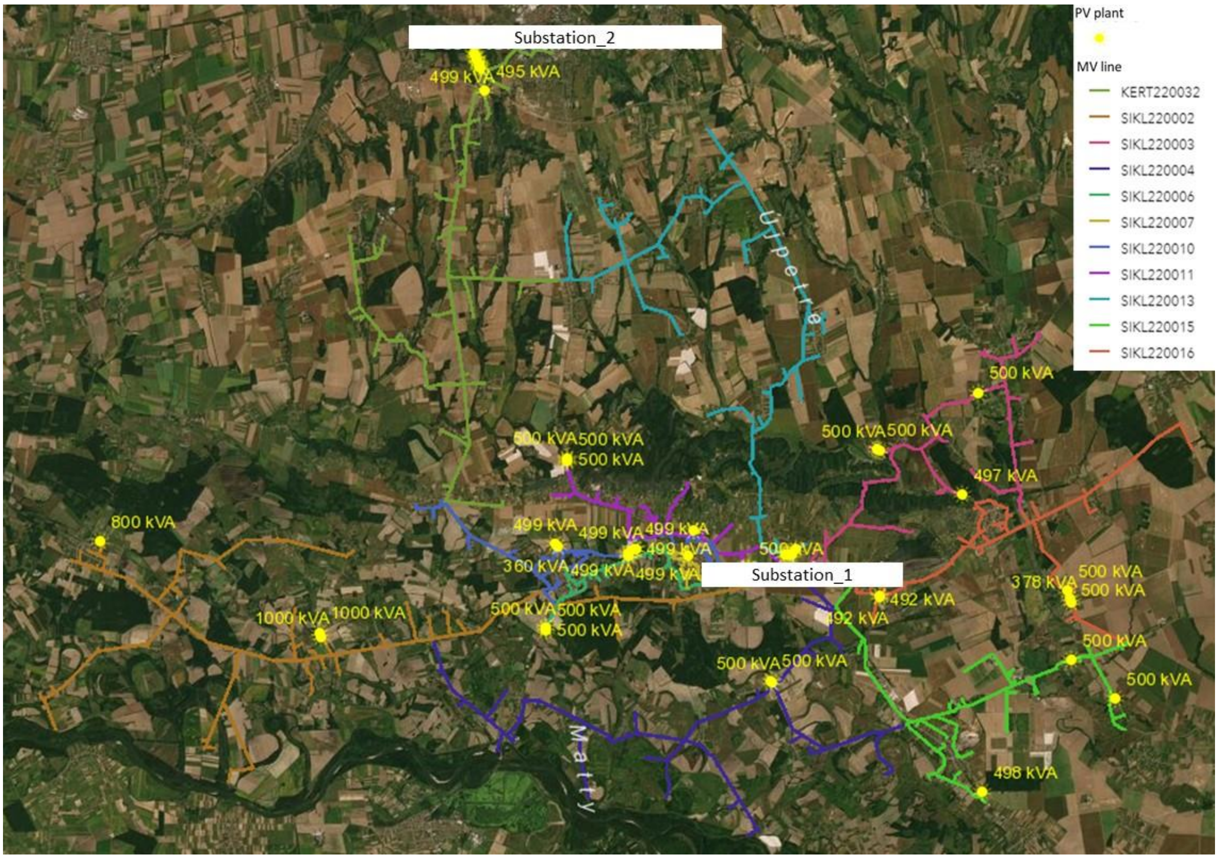

Figure 5-5 – Siklós substation with its supply area and PV generators marked with yellow dots

To the original selection another line was added which – in normal disposition- is supplied by Substation_2, this line was connected to another line (with closing the open point) which is supplied by Substation_1, this situation caused a severe voltage increase. Of course, this condition can rarely occur, usually once or twice a year, but if we would like to increase the hosting capacity of the line it could occur more times, not only in this special disposition but in normal disposition as well. Normally the DSO prohibits this to occur without flexibility. If it is in order to ensure normal operation, the effect of DER hosting capacity increment can be mitigated and handled with DSO level flexibility services.

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The supply area of Substation_1, with the connected PV plants is shown on the picture below:

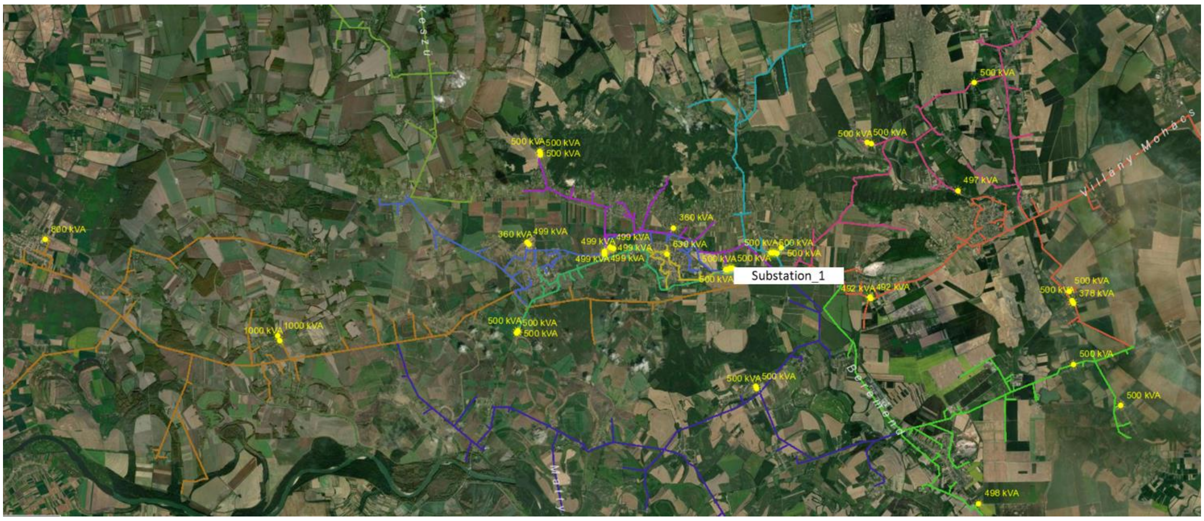

Figure 5-6 – Siklós supply area of Substation_1 with its connected PV plants

The left upper corner of the picture shows the two already mentioned lines, with green and blue colour.

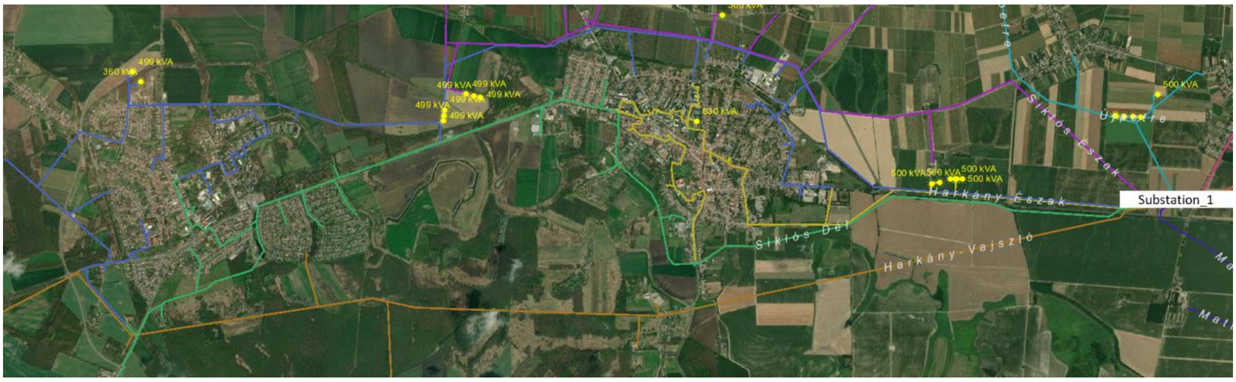

Figure 5-7 – Blue line of Substation_1 (Siklós)

The blue hosts 5 PV plants with a sum of 2,4MW. The green one hosts 11 PV plants with a sum of 11 MW, supplied from Substation 2.

The PV plants on each line did not cause serious voltage increase (only within the allowed voltage band), but in case of network contingency, i.e., planned maintenance (closed open point), the voltage exceeded the allowed level. The Voltage Control Use case refers to this special situation which nowadays can occur, but this kind of phenomenon can occur in normal disposition also when we would like to increase the number of the connected PV plants to the MV Ohl.

The number of connected PVs with MV grid connection exceed 25 generators, the connected production capacity is about 26MW. This power level exceeds the transformer capacity (25MVA). On each MV line there are PV plants, the tables below show the MV branch lines and sum of max load on the lines.

Figure 5-8 – Green line of Substation_21 (Siklós)

Table 5-1 – MV feeder lines connecting to the Siklós substation

MV line	No of PVs	Sum of Power
Line_1	3	1635
Line_2	4	1988
Line_3	2	990
Line_4	5	2900
Line_5	7	3994
Line_6	6	2936
Line_7	9	4352
Line_8	6	2994
Line_9	4	1704
Line_10	6	2455
	52	**25948**

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The table below lists the power of each PV plant. It is worth mentioning that the statistical mode of generation power is around 499kVA due to the given legal/regulatory measures in the past (500 kVA category limit).

Table 5-2 –MV connection PV plants to the Siklós substation

Nr.	Nominal power of PV (kVA)	Nr.	Nominal power of PV (kVA)
1	1000	**27**	499
2	499	**28**	499
3	495	**29**	499
4	499	**30**	499
5	499	**31**	492
6	637	**32**	492
7	493.85	**33**	499
8	493.85	**34**	499
9	499	**35**	499
10	499	**36**	498
11	495	**37**	499
12	495	**38**	499
13	499	**39**	499
14	499	**40**	499
15	499	**41**	499
16	499	**42**	499
17	499	**43**	499
18	499	**44**	498.8
19	498	**45**	498.8
20	498	**46**	95
21	499	**47**	499
22	499	**48**	499
23	378	**49**	580
24	486	**50**	910
25	360	**51**	496
26	360	**52**	225

Our goal is to use these PV plants as flexibility providers. These can be both market or non-market based, it depends on the liquidity of the market and the intention of the PV plant operators. If there is not enough market offer, then the DSO has to use the non-market-based flexibility, namely non-market redispatch (as opposed to market-based TSO redispatch, schedule modification, and other, balancing market related services). Nonetheless, this type of flexibility also has a definite pricing scheme (based on day-ahead market prices and feed-in-tariff) which is set by the Distribution Network Code.

As the governing pricing rule is universal for all FSPs, then, in case of the non-market-based activations the differentiation between the available non-market-based flexibility resources from a selection point of view will be the so-called (grid impact) sensitivity factor. Of course, this factor will have also a role in market-based flexibility provision, but in that case, generally the market-based bid price differences have a defining impact on the merit order list contrary to non-market-based flexibility. The non-market-based flexibility resources are also part of the single Merit Order List.

5.1.1.2 MVM Demo area – Békés

Figure 5-9 – Routes of MV feeders in Békés area. Total length is 292 km

Due to increased penetration of intermittent renewable energy sources, this grid part in the selected demo area operates very close to its capacity. Congestion occurs when transmission networks fail to transfer power based on the load demand. Congestion may occur due to the following reasons:

- generator outages,
- transmission line outages,
- changes in energy demand,
- uncoordinated transactions,
- infeasibility in existing and new contracts,
- congestion that may damage the systems equipment.

In our case, congestion management practically includes temporary performance limitation of connected PVs and in case of grid maintenance, the limitation of consumers.

The proliferation of PV plants in the supply area of the HV/MV substation (see the picture below) necessitates flexibility use in the future (hosting capacity increase with help of flexibility) which prohibits the HV/MV transformer overloading (CM).

The grid topology of the Békés demo area can be seen on the map snapshot shown in Figure 5-9.

Figure 5-10 – MV/LV transformer locations in the Békés area

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Table 5-3 – MV connected PV plants in the Békés substation feeding area

Power in kVA	Type of DER	Nr.
500	PV	1
500	PV	2
500	PV	3
500	PV	4
500	PV	5
500	PV	6
500	PV	7
500	PV	8
500	PV	9
500	PV	10
500	PV	11
500	PV	12
500	PV	13
500	PV	14
500	PV	15
500	PV	16
500	PV	17
500	PV	18
500	PV	19
500	PV	20
500	PV	21
500	PV	22
500	PV	23
500	PV	24
500	PV	25
500	PV	26

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5.1.2 Scheduling of HU demonstrations

The demonstration is carried out via simulations that are based on historical data. The simulations are run for both demo areas and both business use cases.

The historical data contains the hourly measurements of the given HV/MV substation of the area measurements of PV plants tied to the MV network, and standard load profiles (SLP) with the yearly consumption data. The dataset covers two separate years of the two demo areas, respectively.

The schedule of the demonstration simulations can be seen in the following table.

Table 5-4 – Scheduling of the business use cases and demo areas

		ONENET demonstration - simulation schedule																								
		Year	2020												2021											
Business use-case	Demo area	Month of year	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
MV feeder voltage control (EACL-HU-01)	E.ON EDE																									
MV feeder voltage control (EACL-HU-01)	MVM																									
HV/MV transformer overload (EACL-HU-02)	E.ON EDE																									
HV/MV transformer overload (EACL-HU-02)	MVM																									

5.1.3 Demo participants

The market participants in the simulation scenarios consist of the selection of the generators connected to the MV network of each demo area. The market, and therefore the participants of the demo, are simulated. They are based on real historically accurate data, such as the topology of the MV grid connection; type of generation (e.g., PV, gas engine, battery), and nameplate values (max. gen power). The type and number of bidding participants of the market are selected for each business use-case and demo area, depending on the demonstration goals.

The assets that can be assigned to simulation scenarios for demo areas respectively are as follows:

E-.On EDE demo area available FSPs

- 52 PV power plants

MVM demo area available FSPs

- 26 PV power plants

5.2 Demonstration of services and products of HU Demo

The Hungarian demonstration is focused on two BUCs, namely: mitigation of HV/MV transformer overload and overvoltage on MV lines. Due to the delayed deployment of the Hungarian Flexibility Platform, four extensions developed for the Hungarian flexibility platforms are demonstrated in their full technical scope via simulations. The demonstration has been thus carried out using the real network topology of the demo areas and historical market and weather data.

5.2.1 Functional extension demonstration

In this section, the flexibility market simulation method and the functional extensions are elaborated.

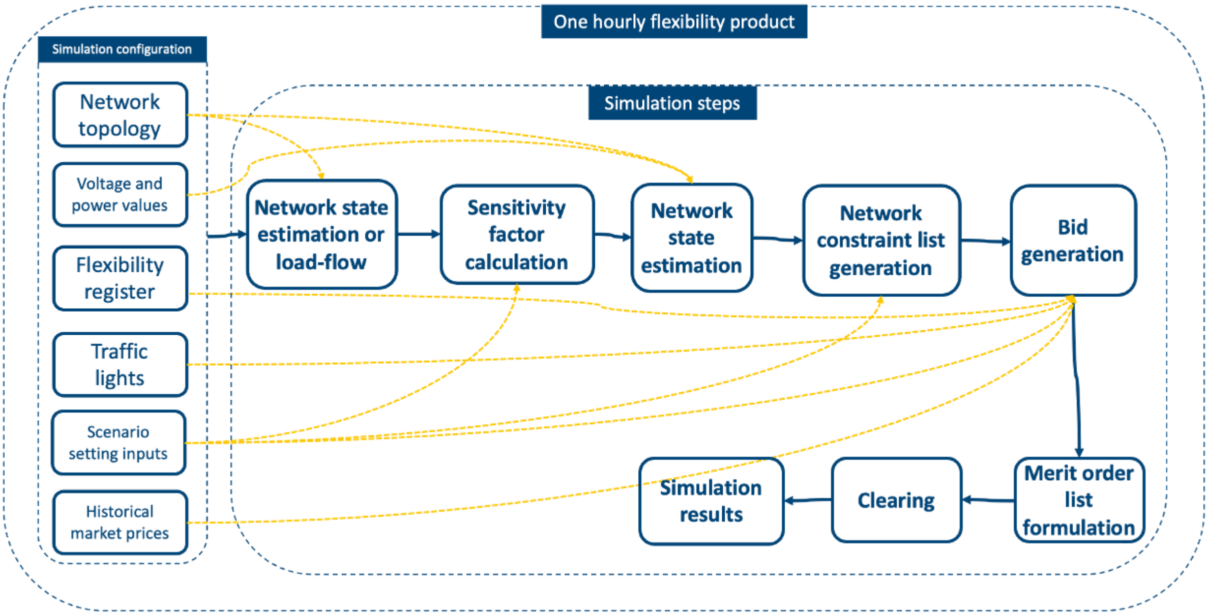

Figure 5-11 – The simulation flowchart of HU flexibility demonstrator (yellow lines indicate data flow)

The simulation steps are depicted on the flow chart in Figure 5-11, and the configurations and steps are elaborated on in the subsequent text.

- Network topology: contains the network topology of the chosen demo area.
- Voltage and power values: historical voltage and power values over a given period for
    - generators
    - loads
    - grouped loads
    - SLP (standard load profile) loads
    - transformer power/current/voltage measurements
    - busbar power/current/voltage measurements
    - feeder power/current/voltage measurements
- Flexibility register: contains the FSP prequalified and their properties for market participation.
- Traffic lights: contains restrictions for FSPs provided by the TSO traffic light
- Scenario setting inputs: contains the following configuration data for the simulation
    - simulation period selection

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- network calculation method: state estimation or load flow
- threshold percentages for overvoltage and overload

- Historical market prices: day-ahead electricity market prices and gas market prices are used for the FSP's bid generation

The simulation is carried out in following steps:

- simulation configuration: gathering input data and checking validity
- network state estimation or load-flow: running state estimation or load-flow network calculation of the given demonstration topology and measurements, the output of this step is the base of the sensitivity factor calculation
- sensitivity factor calculation: calculates the sensitivity factor for each FSP
- network constraint list generation: creates the list of network elements that are constrained. Outputs the list of overloaded transformers and lines with overvoltage.
- bid generation: generates bids for the selected FSP during simulation configuration
- network state estimation: running state estimation of the given demonstration topology and measurements, the output of this step is the power and voltage levels on the selected demo area network
- network constraint list generation: using the voltage and power levels of the network sate estimation and the range limits from the configuration outputs the lines with overvoltage and overloaded transformers
- bid generation: using the prequalified FSPs and historical market prices in order to generate bids for the selected FSPs
- merit order list formulation: using the generated FSP bids and previously generated sensitivity factors a merit order list is set up based on the prices and impact on the congestion(s)
- clearing: based on the merit order list clearing is carried out and the result is checked if the congestion is resolved.
- Simulation results: the selected FSPs and bids are output into an SQL database

Data for simulation was extracted from the two DSOs' SCADA systems and enterprise management systems. The data serves as input for the simulation as well as the configurations set by the given scenario.

In order to gain a comprehensive experience and conclusions from the simulation process, several simulations have been carried out as scenarios.

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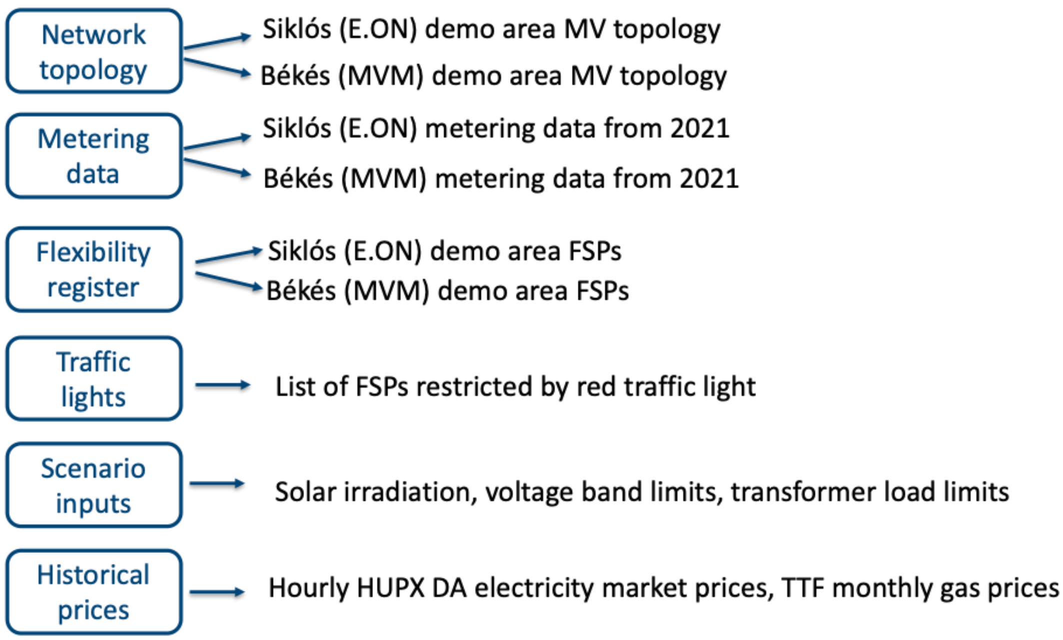

Figure 5-12 – HU demonstration's scenario configurations

Two of the involved DSOs' demo networks have been used for simulation, including the network topology, available metering data (voltage, current, active and reactive power) and FSPs registered to the flexibility register (solar power plants), respectively.

In order to tune the simulations voltage bands and transformer load limits can be set.

For simulation of the FSP bidding a so called "bid generator" has been developed and implemented that is elaborated in 5.2.3. In order to run the bid generator a solar irradiation rate (a number between 0 and 1) is introduced that is used for the solar powerplant's generation forecast. Historical day-ahead marker prices and monthly TTF gas prices are used for bid pricing.

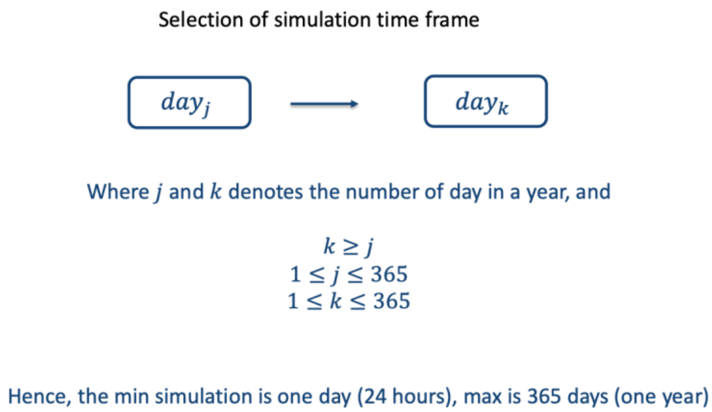

Figure 5-13 – Simulation time frame

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The minimum simulation period is one day. The number of days can be set in the range of 1 to 365 as can be seen in Figure 5-13.

In order to test and put the features to the limit, a use-case scenario list is created that is depicted in **Error! Reference source not found.**. The principle is to demonstrate the functional extension in various situations, where each scenario has one input changed all the others are ceteris paribus.

Use-case scenario list:

- Two demo areas - **Siklós (E.ON) or Békés (MVM)**
    - Historical power and voltage values — **2 x**
- BUCs - **MV feeder voltage control or HV/MV transformer overload**
    - BUCs tested respectively and combined — **3 x**
    - One congestion instance or multiple (2-3) — **2 x**
- FSP bid generation
    - Market prices (electricity and gas) from 2020 or 2021 — **2 x**

≈ 24 scenarios

Figure 5-14 – Use-case scenario list

5.2.2 TSO-DSO communication

5.2.2.1 The root cause for establishing clear and straightforward communication between TSO and DSO

The reason for establishing communication between the DSOs and TSO stems from the conflict of interest of certain assets.

Table 5-5 – Network issue matrix

	DSO down	**DSO up**
TSO down	**no issue**	**no issue**
TSO up	**generated issue** Firstly the market-based DSO flexibility market caused down-regulation does not generate any issues, since first-come-first-served rule applies for the balancing and flexibility markets. Secondly, the issue is generated by the non-market based redispatch.	**no issue**

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Issues can be induced between TSO and DSO as the direction of asset dispatch is opposing, in other words there can be a conflict of interest between the frequency of non-frequency based dispatches of an asset.

In the 2x2 Table 5-5 above, the TSO aFRR and mFRR up & down dispatches and DSO flexibility up & down dispatches are indicated. The generated issues are in the intersections of the various dispatch scenarios, if there are any. In the case of market-based regulation, the following problems do not occur, but only in the case of redispatch, i.e., non-market-based DSO side down-regulation. Thus, in the case of security of supply and supply quality issues can be caused, the priority of asset dispatch in the case of competing uses should be examined.

5.2.2.2 Definition of the traffic light signals for TSO and DSO

Colour definitions:

- **Red:** Certain issue or problem in operations
- **Yellow colour definition:** Forecasted issue
- **Green:** No sign of issue

The traffic lights below indicate the status of the DA procurement of flexibility for aFRR and mFRR services.

Table 5-6 – Traffic light definitions - TSO

TSO		
Red	Yellow	Green
Insufficient daily capacity procurement	Expected insufficient daily capacity procurement	Sufficient capacity procured through

The traffic lights indicate the status of the DA network and asset forecast of the DSO.

Table 5-7 – Traffic light definitions - DSO

DSO		
Red	Yellow	Green
Based on D-1 forecast, the DSO should carry out redispatch in a given area because of transformer overload or network congestion	The asset or unit is an accredited BSP by the TSO and also has a bid submitted on the DSO flexibility market.	Based on D-1 forecast, there will be no issue on the network

It is important to define the granularity of the traffic light system represented in the network.

The TSO traffic light indicates the status of the whole TSO control area.

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The DSO traffic light indicates the status of a given network area or element (e.g., a transformer). Also, the DSO breaks down the network issue to network assets (generators and loads) and assigns them a sensitivity factor that indicates the degree that the network issue can be resolved by.

This leads to the following: the traffic light logic should be applied at asset (or unit) level, thus the physical network can be sufficiently represented.

5.2.2.3 Definition of traffic light intersections

In the following table the intersections of the TSO and TSO traffic lights are introduced and defined. In the intersections the action to be taken is defined.

Table 5-8 – Definition of traffic light intersections

		TSO		
		Red	Yellow	Green
DSO	Red	**the DSO is prohibited to redispatch the unit that is not based on renewable energy sources and are accredited BSPs.**	**the DSO will apply redispatch to the asset or unit**	**the DSO will apply redispatch to the asset or unit**
	Yellow	**the DSO is prohibited to redispatch the unit that is not based on renewable energy sources and are accredited BSPs.**	The asset or unit is an accredited BSP by the TSO and has a winning bid on the DSO flexibility market **no action to be taken**	The asset or unit is an accredited BSP by the TSO and has a winning bid on the DSO flexibility market **no action to be taken**
	Green	**the DSO is prohibited to redispatch the unit that is not based on renewable energy sources and are accredited BSPs.**	Expected insufficient daily capacity procurement **no action to be taken**	**no action to be taken**

5.2.2.4 TSO-DSO data exchange model

According to the introduced traffic light conception, a blacklist is sent from the TSO to the DSO on a daily basis if there is an insufficient daily capacity procurement of aFRR or mFRR services. The blacklist contains the assets and units that are prohibited of redispatch by the DSO. Since as of now only the TSO red light has the actionable function, it is the only communication between the TSO and DSO that takes place.

The data exchange is carried out in two steps between the TSO and DSO:

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1. The TSO shall send to the DSOs, at least on a monthly basis, a list of power plants that are connected to the DSO network, are not based on renewable energy sources and are accredited BSPs.
   - The monthly data exchange shall contain the following information:
     - plant name
     - plant location
     - POD
     - primary energy source
     - Connection voltage level
     - dispatch zone
     - Plant unit ID
   - The Flexibility Register (FR) is updated based on the attached excel.
   - Based on the POD identifier, the asset should be updated in the FR
2. The TSO shall send to the DSOs, on a case-by-case basis (in case a daily capacity procurement procedure closes with a deficit), after the closure of the daily capacity procurement procedures, a list of the dispatched BSP units that have submitted valid, accepted offers in a capacity procurement procedure for the settlement periods affected by the deficit.
   - The daily data exchange shall contain the following information:
     - start of period
     - end of period
     - Plant unit ID
   - The daily blacklist contains the dispatched units for which it is forbidden to generate redispatch bids for conventional rotating machine assets. If a market bid has been received for the asset, it can still be used.

Monthly data exchange: on the first working day of each month, TSO sends the master data by email by 9:00 am.

Daily data exchange: TSO sends the list of participants already committed in the tender by 9:30 a.m. on days on which the capacity tender has failed. Consequently, it is not guaranteed that data exchange will take place every day.

Data exchange between TSO and DSOs is carried out manually. The interface format is an excel file, which is manually uploaded by the market operator to the flexibility platform.

5.2.3 Bid generation

This section elaborates on the method of bid generation for the simulations.

5.2.3.1 Bid types

Each market participant makes an offer for maximum and minimum power generation or consumption. In the case of energy generation, we use the terms P_{max}^{+} and P_{min}^{+} and in the case of energy consumption, we use the terms P_{max}^{-} and P_{min}^{-}.

- If a P_{max}^{+} offer is accepted, the actor cannot inject more energy into the network than q_{offer}.
- If a P_{min}^{+} offer is accepted, the actor must inject at least q_{offer} energy into the network.
- If a P_{max}^{-} offer is accepted, the actor cannot withdraw more energy from the network than q_{offer}.
- If a P_{min}^{-} offer is accepted, the actor must withdraw q_{offer} at least energy from the network.

Each market actor must make an offer for each hour on the next day and each offer has to cover 100% of their possible power generation or consumption, divided into powerbands. Each powerband can have different price if the prices form a monotonous, ascending set. Actors that can generate and consume must make offer for generation and consumption.

An algorithm for each type of market participant has been developed that predicts possible bids on the flexibility market. We use certain simplifications to keep the algorithm as general as possible.

The algorithm inputs in all cases consist of wholesale and retail energy prices (electricity, gas, heat) and asset specific parameters. Energy prices in all cases are estimated based on available data from previous time periods. The goal of the algorithm to determine the possible power restrictions and prices for each asset.

5.2.3.2 Photovoltaic generators

Photovoltaic (PV) generators can be divided into two groups:

- household-size PV generators (<50 kVA)
- solar farms (usually between 500 kVA and a couple 10 MVA)

While solar farms sell energy on the DAM, household-size PV generators can only sell energy through the Universal Service Provider (USP) for commercial price of electricity, with net metering.

PV generators can make P_{max}^{+} offers on the flexibility market. The offers are created based on the weather forecast and irradiation data available for the given day.

5.2.3.3 Solar farms

Solar farms sell energy on the spot market, on day-ahead timeframe (DAM).

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The flexibility powerband between the maximal allowed power injection (based on contract) and the estimated maximal generation is offered 0 EUR/MWh. Between the estimated maximal generation and no generation, the actor set flexibility powerbands and for each powerband a different price.

Household-size PV generators

Unlike solar farms, these generators sell energy directly to their USP. The price of the sold electricity is determined by the actual commercial electricity price. Since the price is fixed, the offers of these PVs contain small powerbands with the same price (so the algorithm can choose the best possible limit).

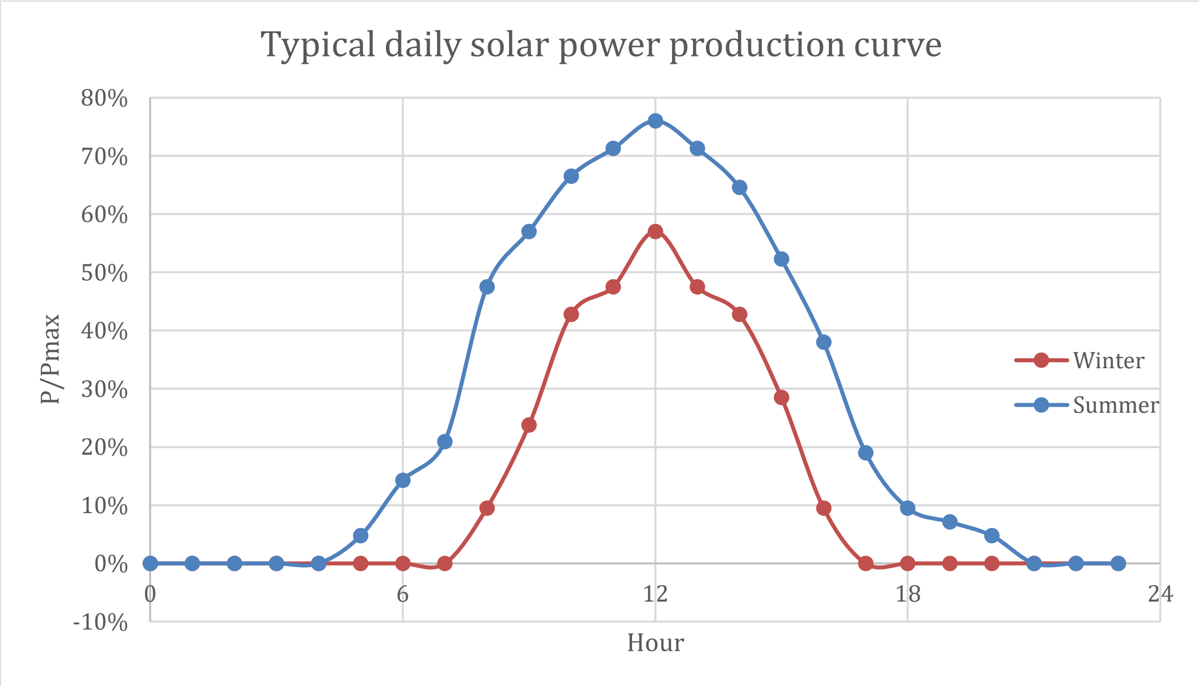

Figure 5-15 - Typical daily solar power production curve (winter – red, summer – blue)

5.2.3.3.1 Algorithm

Inputs

Hourly solar irradiation data: $\eta_{irradiation}[h]$. To measure the effectiveness of PV generation, the Global Solar Atlas used $\left[\frac{kWh}{kWp}\right]$ unit. In general, the PV potential does not vary within a country. $\eta_{irradiation}[h]$ can take values from 0 to 1.

Since the DAM prices are not available for the exact day, $p_{DAM}^{HUPX}[h]$ are estimated based on the previous day's prices.

P_{nom} is the PV's nominal power and $P_{max}[h]$ indicates the hourly maximum possible power output for that generator based on weather data. The difference between P_{nom} and $P_{max}[h]$ will be offered free of charge.

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The powerbands are defined by $k_1, k_2 \dots k_n$, where $k_1 = 100\%$ and the first band's upper and lower limit is k_1 and k_2 respectively. The first band, which can be offered for free, can be precisely calculated from solar irradiation data, the rest of the bands are randomly generated.

Calculations

1) First the maximal power output for the hour is calculated based on weather forecast.

$$P_{max}^{+}[h] = P_{nom} \cdot \eta_{irradiation}[h]$$

2) The powerbands are set for each PV generator

   Band 1: $P_{nom}[h] - P_{max}^{+}[h] \cdot k_1^{+}$

   Band 2: $P_{max}^{+}[h] \cdot k_1^{+} - P_{max}^{+}[h] \cdot k_2^{+}$

   ...

   Band n: $P_{max}^{+}[h] \cdot k_{n-1}^{+} - P_{max}^{+}[h] \cdot k_n^{+}$

3) Pricing for the bands is calculated based on the estimated DAM price

$$p_1[h] = 0$$

$$p_n[h] = p_{DAM}^{HUPX}[h] \cdot \left(1 + 0{,}05\,(n-1)\right), \qquad n \neq 1$$

For household-size PV generators the price of each band is equal and calculated using the household electricity price for the given month.

Example for PV

Table 5-9 – Flexibility offer – power bands example for PV

P_{nom}	20	[MW]	**From**	**To**	**Price [Euro/MW/h]**
$\eta_{irradiation}$	80%		20.00	16.00	0.00
P_{max}	16	[MW]	16.00	8.80	460.00
P_{min}	0	[MW]	8.80	4.80	483.00
$p_{DAM,est}^{HUPX}$	460	[Euro/MWh]	4.80	0.00	506.00
Bands:					
k_1	100%				
k_2	55%				
k_3	30%				

5.2.3.4 Energy Storage System

Energy Storage Systems (ESS) buy and sell energy on the DAM. Actors of this type must make and offer for both generation and consumption for each hour. Two possible scenarios are: $(P_{max}^{+}; P_{min}^{-})$, when the DSO wants to increase overall consumption and $(P_{min}^{+}; P_{max}^{-})$, when the DSO wants to increase overall generation.

It is complicated to make an offer for a period of 24 hours in the case of ESSs, since the possible energy injection or withdrawal depends on its current State of Charge (SoC). To avoid offers which cannot be fulfilled, we create offers for ESSs, which take SoC at the start of the day in account.

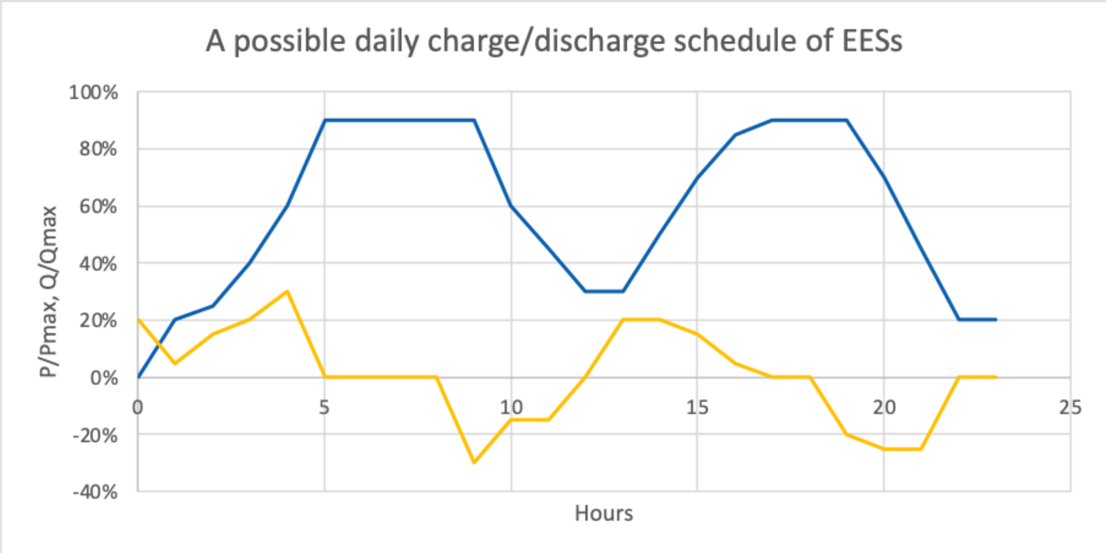

Figure 5-16- EESs discharge schedule (SoC – blue, Charge/Discharge – red)

5.2.3.4.1 Algorithm

Inputs

- Like PV generators, previous DAM prices are used to estimate the price of electricity in each hour
- The nominal power P_{nom}, total capacity Q_{max} of the energy storage. $X/X_{max}A$
- Planned state of charge in the beginning of the day $SoC\ [d]$.
- The powerbands are defined by $k_1, k_2 \dots k_n$ and $k_1 = 100\%$ and the first band's upper and lower limit is k_1 and k_2 respectively.

Calculations

Case I: Setting minimal withdrawal and limiting

1) Calculate the hourly maximum power for consumption:
$$P^{+}_{max}[h] = \frac{P_{nom} \cdot SoC[d]}{24}$$
2) Calculate the hourly minimum power for generation:
$$P^{-}_{min}[h] = \frac{P_{nom} - P^{+}_{max}\ [h] \cdot 24}{24}$$
3) Powerbands are calculated based 2) and 3)

Band 1: $P^{+}_{\max}[h] \cdot k^{+}_{1} - P^{+}_{\max}[h] \cdot k^{+}_{2}$

Band 2: $P^{+}_{\max}[h] \cdot k^{+}_{2} - P^{+}_{\max}[h] \cdot k^{+}_{3}$

…

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Band n: $P_{max}^{+}[h] \cdot k_n^{+} - 0$

Band $(n+1)$: $0 - P_{min}^{-}[h] \cdot k_1^{-}$

Band $(n+2)$: $P_{min}^{-}[h] \cdot k_1^{-} - P_{min}^{-}[h] \cdot k_2^{-}$

…

Band $2n$: $P_{min}^{-}[h] \cdot k_{n-1}^{-} - P_{min}^{-}[h] \cdot k_n^{-}$

4) Pricing of the bands are calculated based on the estimated DAM price.

$$p_1[h] = 0$$

$$p_n[h] = p_{DAM}^{HUPX}[h] \cdot \big(1 + 0{,}05\,(n-1)\big), \qquad n \neq 1$$

Case II: injection Limiting withdrawal and setting minimal injection

1) Calculate minimal power for consumption:

$$P_{max}^{-}[h] = \frac{P_{nom} - P_{nom} \cdot SoC[d]}{24}$$

2) Calculate maximal power for generation:

$$P_{min}^{+}[h] = \frac{P_{nom} - P_{max}^{-}[h] \cdot 24}{24}$$

3) Calculate the powerbands:

Band 1: $P_{\mathrm{max}}^{-}[h] \cdot k_1^{-} - P_{\mathrm{max}}^{-}[h] \cdot k_2^{-}$

Band 2: $P_{\mathrm{max}}^{-}[h] \cdot k_2^{-} - P_{\mathrm{max}}^{-}[h] \cdot k_3^{-}$

…

Band n: $P_{max}^{-}[h] \cdot k_n^{-} - 0$

Band $(n+1)$: $0 - P_{min}^{+}[h] \cdot k_1^{+}$

Band $(n+2)$: $P_{min}^{+}[h] \cdot k_1^{+} - P_{min}^{+}[h] \cdot k_2^{+}$

…

Band $2n$: $P_{min}^{+}[h] \cdot k_{n-1}^{+} - P_{min}^{+}[h] \cdot k_n^{+}$

4) Calculating powerband prices

$$p_1[h] = 0$$

$$p_n[h] = p_{DAM}^{HUPX}[h] \cdot \big(1 + 0{,}05\,(n-1)\big), \qquad n \neq 1$$

Example for ESS

Table 5-10 – Flexibility offer – power bands example for ESS

			Case I.			
			From	**To**	**Price [Euro/MW/h]**	
$P_{nominal}$	20	[MW]	20,00	0,50	0,00	P_{max}^{+}
SoC	60%		0,50	0,28	460,00	
$+P_{max}$	12	[MW]	0,28	0,25	483,00	
$-P_{min}$	8	[MW]				
			0,25	0,00	506,00	P_{min}^{-}

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			0,00	-0,10	529,00	
$-P_{max}$	8	[MW]	-0,10	-0,18	552,00	
$+P_{min}$	12	[MW]	-0,18	-8,00	575,00	
p_{HUPX}	460	[Euro/MWh]				
			Case II.			
			From	**To**	**Price [Euro/MW/h]**	
			-20,00	-0,33	0,00	
			-0,33	-0,18	460,00	P_{max}^{-}
			-0,18	0,10	483,00	
			0,10	0,00	506,00	
Bands:						
k_1	100%		0,00	0,15	529,00	
k_2	55%		0,15	0,28	552,00	P_{min}^{+}
k_3	30%		0,28	12,00	575,00	

5.2.3.5 Demand-side management

Demand-side Management (DSM) assets such as household boilers (electric water heaters) are influenced by the distribution operator to optimize generation and consumption. In Hungary household boilers are dispatchable, and so are available for this purpose.

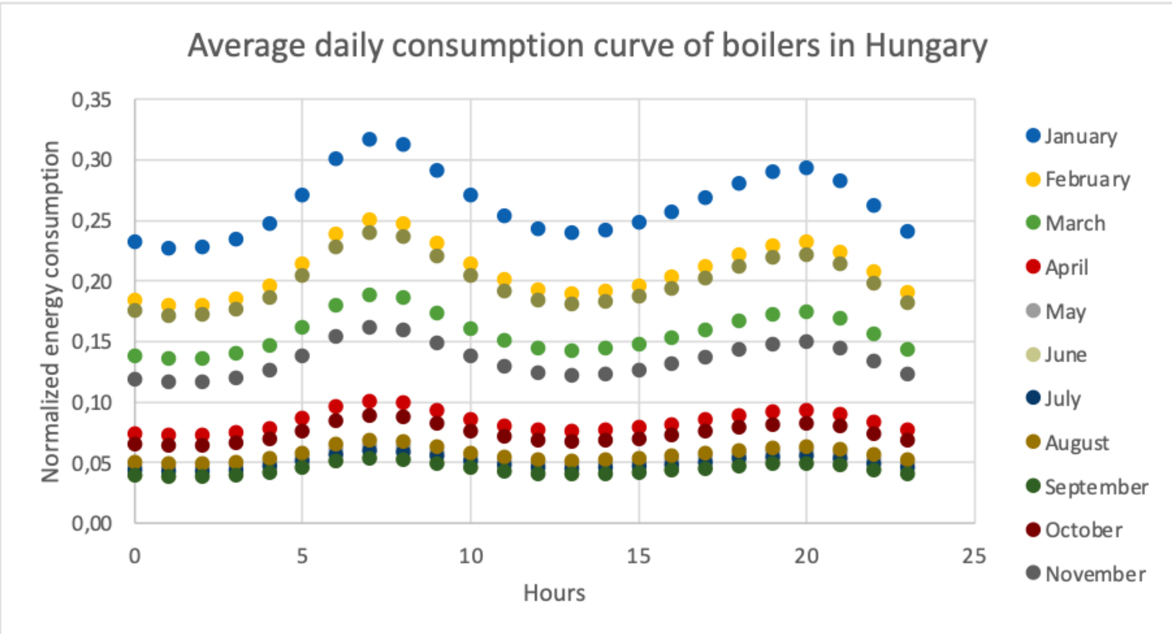

Figure 5-17 - Average daily consumption curve of boilers in Hungary each month

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We model boilers with an average consumption model. m is the number of household members for each household with DSM asset. For a single person we count with 2.5 kWh electricity consumption to cover the daily warm water needs. Additionally, we count with 1.3 kWh loss.

Water heaters can be regulated (by ripple control) by the DSO free of charge, as long as the DSO fulfils the commitments of the special tariff. Due to the time-of-use tariff DSOs are obligated to provide voltage for at least five hours but only for a maximum of six hours at these connection points during off peak periods (22:00-6:00). Therefore P^{+}_{min} offers cannot be accepted for every hour of the off-peak period but only for 6 of them.

5.2.3.5.1 Algorithm

Inputs

- Price of the special tariff for DSM assets, $p^{Cont}[h]$.
- Nominal power of each boiler, P_{nom}. Most residential boilers in Hungary have a rated power of 1,2 kW, 1,5 kW or 1,8 kW so we chose a default P_{nom} of 1,5 kW for DSM assets.
- The number of boilers b.
- The powerbands are defined by $k_1, k_2 \dots k_n$ and $k_1 = 100\%$ and the first band's upper and lower limit is k_1 and k_2 respectively.

Calculations

Case I: Setting maximal withdrawal

1) Calculate the maximal power output for each hour:

$$P^{-}_{max}[h] = P_{nom} \cdot b$$

2) Calculate powerbands for each hour:

Band 1: $P^{-}_{\max}[h] \cdot k^{-}_1 - P^{-}_{\max}[h] \cdot k^{-}_2$

Band 2: $P^{-}_{\max}[h] \cdot k^{-}_2 - P^{-}_{\max}[h] \cdot k^{-}_3$

…

Band n: $P^{-}_{max}[h] \cdot k^{-}_n - 0$

3) Price of each band is equal and set to 0. (This is due to the contract between consumer and DSO for special tariff assets)

Case II: Setting minimal withdrawal

1) Calculate the maximal power output for each hour:

$$P^{-}_{min}[h] = P_{nom} \cdot k$$

2) Calculate powerbands for each hour:

Band 1: $P_{\min}^{-}[h] \cdot k_1^{-} - P_{\min}^{-}[h] \cdot k_2^{-}$

Band 2: $P_{\min}^{-}[h] \cdot k_2^{-} - P_{\min}^{-}[h] \cdot k_3^{-}$

…

Band n: $P_{min}^{-}[h] \cdot k_n^{-} - 0$

3) Price of each band is equal and set to 0. (This is due to the contract between consumer and DSO for special tariff assets)

Table 5-11 – Flexibility offer – power bands example for water heater DSM

P_{nom}	0,2	[MW]				
b	100	[pcs]	**Case I.: P_{max}^{-}**			
			From	**To**	**Price [Euro/MW/h]**	
P_{nom}^{agg}	20	[MW]	-20.00	-15.00	0.00	
$p_{contract}$	0	[Euro/MWh]	-15.00	-10.00	0.00	
			-10.00	-5.00	0.00	
Bands:			-5.00	0.00	0.00	
k_1	100%					
k_2	75%		**Case II.: P_{min}^{-}**			
k_3	50%		**From**	**To**	**Price [Euro/MW/h]**	
k_4	25%		0.00	-5.00	0.00	
			-5.00	-10.00	0.00	
			-10.00	-15.00	0.00	
			-15.00	-20.00	0.00	

5.2.3.6 Combined Heat and Power Generation

Combined Heat and Power (CHP) use fossil gas to generate electricity and heat at the same time. They sell energy on the DAM. Unlike PV generators, the CHP generators' power output can be given accurately for every hour. They have a minimal working time ($N\ hours/day$, where N depends on the asset's nominal power) and a minimal working condition (at least 40% of the nominal power). Distribution system size CHP generator's rated power ranges between 400 kW and 6 MW.

5.2.3.6.1 Algorithm

Inputs

- CHP maximum power output $\boldsymbol{P_{max}}$.
- Number of powerbands $\boldsymbol{n}$.
- Hourly estimated DAM prices $p_{DAM}^{HUPX}[h]$.

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- Monthly gas price p_{TTF} estimated based on data from *CEEGEX*.
- Heat price p_{heat} is estimated based on p_{TTF}.

Calculations

1) Calculate p_{heat}.

$$p_{heat} = 1{,}1 * p_{TTF}$$

2) Setting the threshold for power output. The price of P_{min} is set extremely high.

$$P_{min} = P_{max} \cdot 0{,}4$$

$$p_{min} = 9999.9$$

3) Calculate the prices of each powerband above the threshold (n equal band):
   - $P_1[h] = P_{max} - \frac{(P_{max}-P_{min})}{n}$
     $$p_1 = (P_1 * p_{DAM}^{HUPX}[h]) - (3P_1 * p_{TTF}[monthly]) + (1{,}5P_1 * p_{heat}[monthly])$$
   - $P_2[h] = P_{max} - 2\frac{(P_{max}-P_{min})}{n}$
     $$p_2 = (P_2 * p_{DAM}^{HUPX}[h]) - (3P_2 * p_{TTF}[monhtly]) + (1{,}5P_2 * p_{heat}[monhtly])$$

   …

   - $P_n[h] = P_{max} - n\frac{(P_{max}-P_{min})}{n}$
     $$p_n = (P_n * p_{DAM}^{HUPX}[h]) - (3P_n * p_{TTF}[monhtly]) + (1{,}5P_n * p_{heat}[monhtly])$$

5.2.4 Prequalification (accreditation) process

Current situation in Hungarian legislation: While implementing the Clean Energy Package, the main goal of the Regulator was to focus on the high-level legal framework, so the regulation as of today gives rather just an enabling possibility framework than an exact solution.

The Hungarian Act on Electricity defines DSO flexibility, making a clear difference to the TSO's ancillary services. DSO flexibility may include redispatch, non-frequency ancillary services or any congestion management services. The main message of regulation is to focus on the market: DSOs should procure the needed flexibility on the market in a transparent way and for market-based prices. While doing this, the DSO should observe the requirement of equal treatment, the network development plan and the principle of lowest cost.

In order to ensure the application of the above-mentioned principles, DSOs should implement a detailed procurement process in the DSO Code based on rules set out in the Electricity Act. Such procurement can be performed by a single DSO or in cooperation with other DSOs as well. Specifications shall include the type of necessary product or service, length of the contract and the technical criteria. The Electricity Act only mentions the website as the tool of tender, but the DSO Code refers to "any other DSO tool" as well referring to the platform itself.

Legislation defines the potential flexibility providers as well. Any electricity producer, storage or demand-side response facility could provide flexibility services if they meet all the criteria laid down in the DSO Code. The minimum legal requirements include description of the necessary flexibility services and the standardised product, furthermore establishment of an accreditation procedure.

The legislation gives priority to market-based solutions, but for the time being, there is no flexibility market in Hungary and DSOs need a tool to ease the problems generally caused by renewable generators. For that reason, the Regulator can give an exemption and also allow a non-market-based procedure (Redispatch). If the DSO uses this tool, it shall pay compensation. If the DSO is willing to pay, such a request cannot be refused by the facility. The level of compensation is the price equal to the hourly price settled at the Hungarian Energy Exchange for the same hours as the hours affected by the restriction. This compensation is an eligible cost for the DSO as well.

Besides classical flexibility services and non-market-based redispatch, there is one more tool DSOs may use, namely flexible connection (or non-guaranteed connection). It means that instead of the reinforcement of the grid, DSOs can allow new customers to connect to the network provided that the customer agrees to being constrained off when the network is close to capacity limits. This may reduce the cost of connecting to the network and also the time to connect as grid reinforcement works are not required. The conditions of flexible connection should be laid down clearly by previously determining the technical criteria of the possible constraint. The customer having a flexible connection can decide anytime to switch to a normal connection if they are ready to pay the normal connection fee to the DSO. It is also important that having a flexible connection does not exclude the customer from participating in the flexibility service market or being used for non-market-based redispatch.

Beyond the regulatory framework provided for by the Electricity Act, details are to be elaborated by DSOs in the DSO Code. This work is still ongoing. There are currently some important principles regarding procurement, accreditation, and TSO-DSO cooperation. We have also set a timeframe for accreditation (pre-qualification), it should be renewed every 3 years by the producer or the facility. The DSO's need has a priority over the TSO's requirement, but at the same time, the DSO should primarily use those facilities which do not participate in the TSO market. However, flexibility service providers can be used in both markets at the same time if it is doable technically. Data exchange is prescribed not only between system operators but towards FSPs and balancing responsible parties as well.

According to the description above, the DSO can use three types of flexibility: non-guaranteed connection (flexible connection), market-based flexibility and non-market-based flexibility (Redispatch). A lot of already connected PVs can be considered as a non-guaranteed connection. The accreditation process has to handle all types of above-mentioned tools, furthermore the process has to care about the type of products as well.

In order to understand the accreditation process – besides the above-mentioned tool- it is worth depicting the products which are also an important part of accreditation.

The goal is setting a limit to the FMP, i.e., do not produce more than X, do not consume more than Y (Limit type products), or consume at least Z, or produce at least W (Must Run type products). All of these can provide the Capacity limit type of service, but they are different products. They can also be placed in the classic up/down control terminological coordinate system. Do not produce more than X or consume at least Z products embody the Down direction, while do not consume more than Y or produce at least W products embody the Up direction.

Figure 5-18 below describes the type of products which are so called capacity limit products.

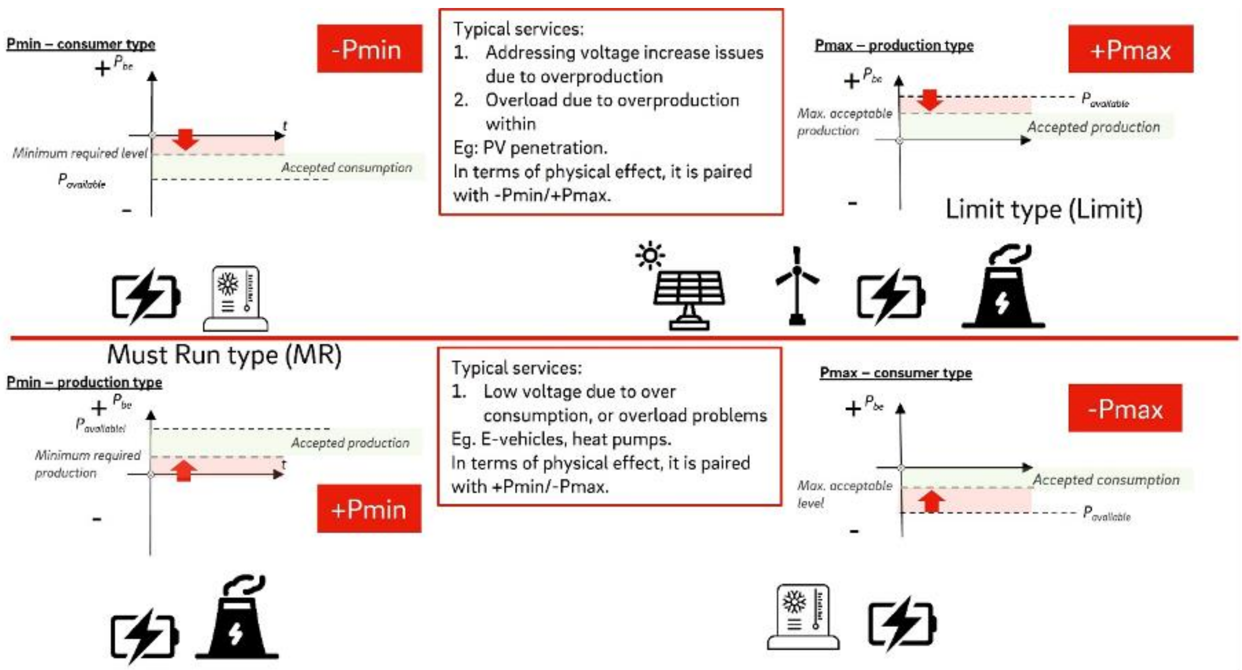

Figure 5-18 - Visualization of capacity limit products

The goal is setting a limit to the FMP, i.e. do not produce more than X, do not consume more than Y (Limit type products), or consume at least Z, or produce at least W (Must Run type products). All of these can provide the Capacity limit type of service, but they are different products. They can also be placed in the classic up/down control terminological coordinate system. Do not produce more than X or consume at least Z products embody the Down direction, while do not consume more than Y or produce at least W products embody the Up direction.

The pictograms on the figure above show which types of devices are capable of providing the given product. All kinds of producers can provide +Pmax, while +Pmin products cannot be provided by renewables. -Pmax can be provided by consumers when they reduce their consumption, while -Pmin can be provided by consumers

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when they increase their consumption. Note that the battery storage can provide services with products in all four quarters.

The accreditation process according to the description above has to consider both the type of flexibility provision (non-guaranteed connection / market based / non-market based or in other words Redispatch) and type of products.

In the initial step, the DSO examines the available contracts and the technical and economic framework of the contract to be concluded. Since four types of products have been defined, it is necessary to decide whether it is a producer or a consumer type.

The branch on the left of the first part of

Figure 5-19 - Prequalification process

examines the types of production. It is important whether the entity knows other types of products in addition to +Pmax (+Pmin, which, for example, a storage or gas engine can also know). If only the entity knows a +Pmax product, it means that it must be prequalified for the so-called Redispatch discussed in the introduction. If the entity wants to appear as a market participant, it will be decided during the auction anyway, the prequalification entitles it to submit a +Pmax market offer. Those who do not want to submit a market offer can potentially still be redispatches. PV power plants can be typical players.

The other branch of the left examines whether the actor can provide a +Pmin product and wants to be this market actor. If you don't want to be a market player, you will still have the +Pmax extension option. If the entity wants to be a market player and can provide a +Pmin product, it will also be accredited for that. Typical players can be storage and gas engines.

The branch on the right examines consumer-type service providers. The first question to be decided is whether it has a guaranteed connection. If not, you must ask how the entity wants to be a market participant. If not, then the process ends, since neither the entity's contract entitles me to examine its capabilities, nor the market opportunity. After these decisions, it is worth examining what the non-guaranteed contract entitles the DSO to. We also ask him how he wants to be a market player. After that, the two types of products can be accredited, either for one (-Pmin), or for the other (-Pmax), or for both. -Pmax covers the classic DSR, where consumption is restrained by the entity, while -Pmin is a must run type product, we ask you to consume more than X.

After that, the DSO checks for the given entity whether it can execute the activation instruction to be sent. Since D-1 is the operating time frame (the auction closes by 11 a.m. and the activation instruction is sent out), the entity has, in principle, 13 hours to incorporate the instruction into its operational framework. Of course, in the case of a PV, several times may be available. However, D-Day starts at midnight.

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The final phase of the process examines whether the given entity is capable of this continuous regulation. This is necessary because in the case of previously connected PVs, there may be those who cannot control it continuously, it is only possible to set a state of 0 or 1 with a circuit breaker.

In this phase, the DSO can draw the entity's attention to what it will do if it cannot be controlled continuously, and at the end of the process, it will be recorded whether it is capable of continuous power control, or whether it has a guaranteed or non-guaranteed connection. All of this must be included in the so-called flexibility register. The flexibility platform takes into account the register data, e.g., in the case of an entity with a non-guaranteed connection, we will use them first during clearing. While an entity with 0-1 control capability is also important information, as it is necessary to communicate with them about the deployment.

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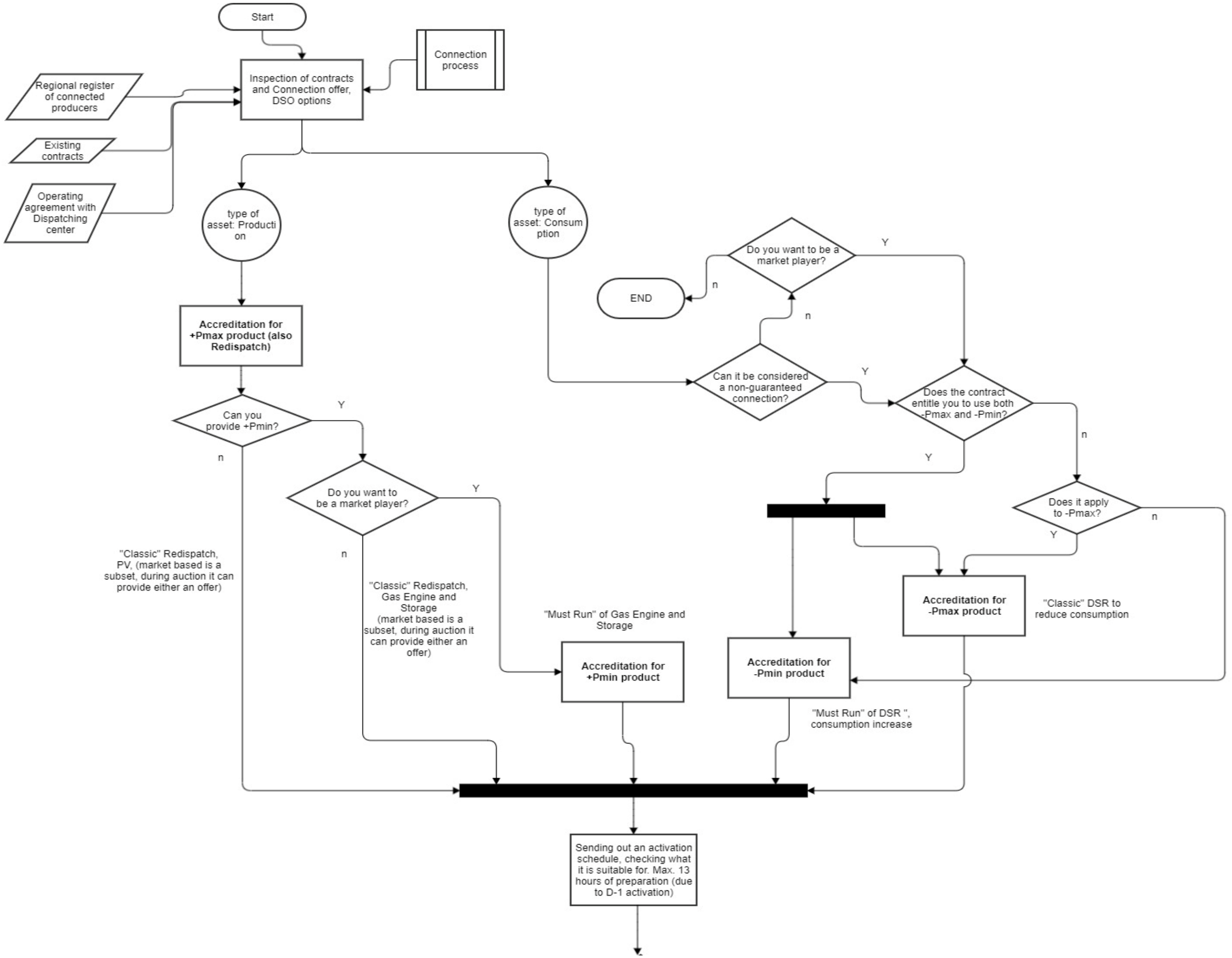
Start
Connection process
Regional register of connected producers
Inspection of contracts and Connection offer, DSO options
Existing contracts
Operating agreement with Dispatching center
type of asset: Production
type of asset: Consumption
Do you want to be a market player?
Y
n
END
n
Accreditation for +Pmax product (also Redispatch)
Can it be considered a non-guaranteed connection?
Y
Does the contract entitle you to use both -Pmax and -Pmin?
Can you provide +Pmin?
Y
n
n
Y
Do you want to be a market player?
Y
Does it apply to -Pmax?
n
Y
"Classic" Redispatch, PV, (market based is a subset, during auction it can provide either an offer)
n
"Classic" Redispatch, Gas Engine and Storage (market based is a subset, during auction it can provide either an offer)
Accreditation for -Pmax product
"Classic" DSR to reduce consumption
"Must Run" of Gas Engine and Storage
Accreditation for +Pmin product
Accreditation for -Pmin product
"Must Run" of DSR ", consumption increase
Sending out an activation schedule, checking what it is suitable for. Max. 13 hours of preparation (due to D-1 activation)

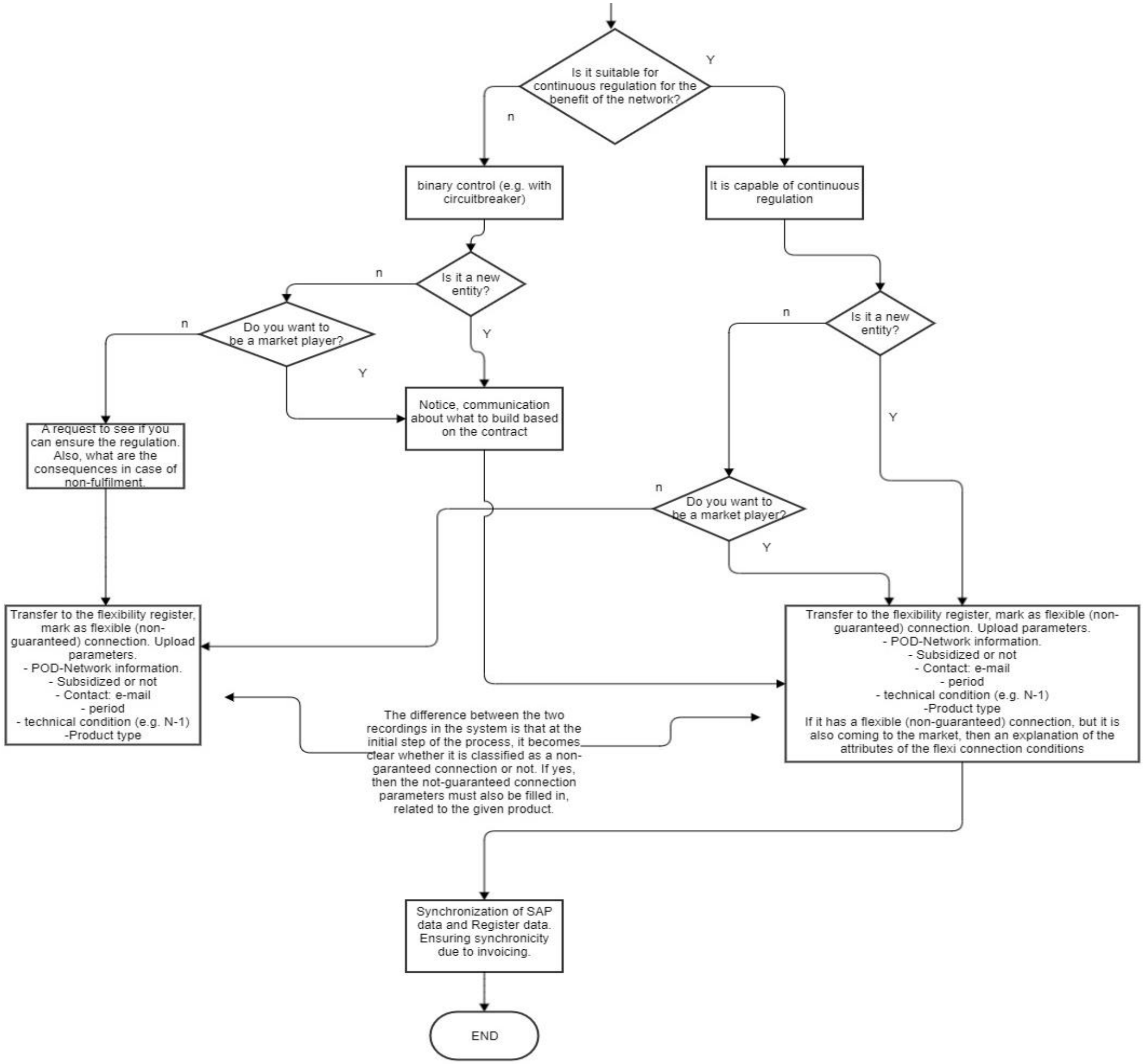

Figure 5-19 - Prequalification process

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5.3 IT architecture

The extensions developed within the OneNet project are utilized in three IT systems:

- Simulation platform:
  - Developed for demonstrating the functional extensions on the demo areas.
- E.ON EDE platform:
  - A newly developed platform of E.ON that contains the functional extensions.
- MVM DÉMÁSZ platform
  - An existing operator platform is extended with flexibility market functionalities and the functional extensions. The solution is not introduced in detail since it is an existing grid operator platform.

5.3.1 Simulation platform

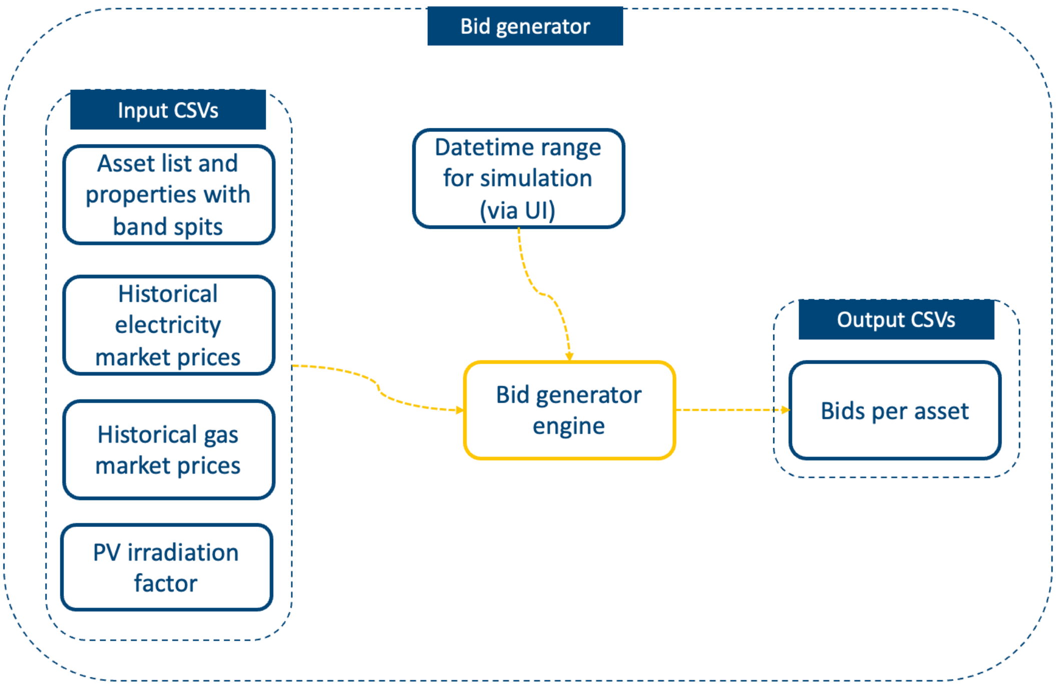

Figure 5-20 – Bid generator process diagram

The simulation platform is deployed to two virtual private servers (in MS Azure service):

- One Linux server that carries out the simulation.
- One Windows server that is purposed as an operations server (for data input and output and visualization)

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The simulation server has two separate services, namely bid generator and the flexibility market simulator. The bid generator can be run separately in order to generate bids for the simulation while simulating customer's behaviour. The process of bid generation is depicted in Figure 5-20.

The flexibility market simulator's process is depicted in Figure 5-21, the simulator consists of several modules:

- Grid sensitivity factor calculator: calculates the sensitivity factor matrix for the demo area network
- merit order list formulation: given the assets' bids (submitted with prices) and the sensitivity factor matrix a merit order list is formulated for each network congestion
- clearing: the market is cleared, results are generated into an SQL database

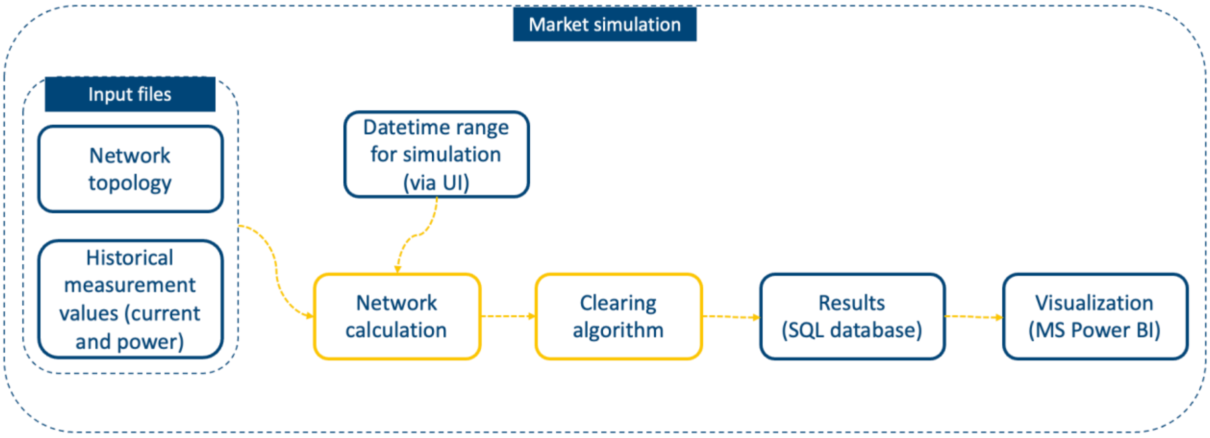

Figure 5-21 – Market simulation flow of the Hungarian Demo

The simulation platform is deployed onto two virtual servers on the Microsoft Azure platform.

5.3.2 E.ON's FlexON platform

The functional extensions are implemented on E.ON's FlexON flexibility platform. The IT architecture of the platform is elaborated in this section.

The core component is the Flexibility platform that runs in MS Azure Kubernetes system.

Flexibility platform staging:

- AzureSQL based FlexON platform staging database: contains data for numerous sources to feed into the platform, such as:
  - network topology: the distribution system network topology
  - SCADA measurements: measurements from DSO substations (mainly HV/MV substations)
  - Remote metering data: metering data from smart meters

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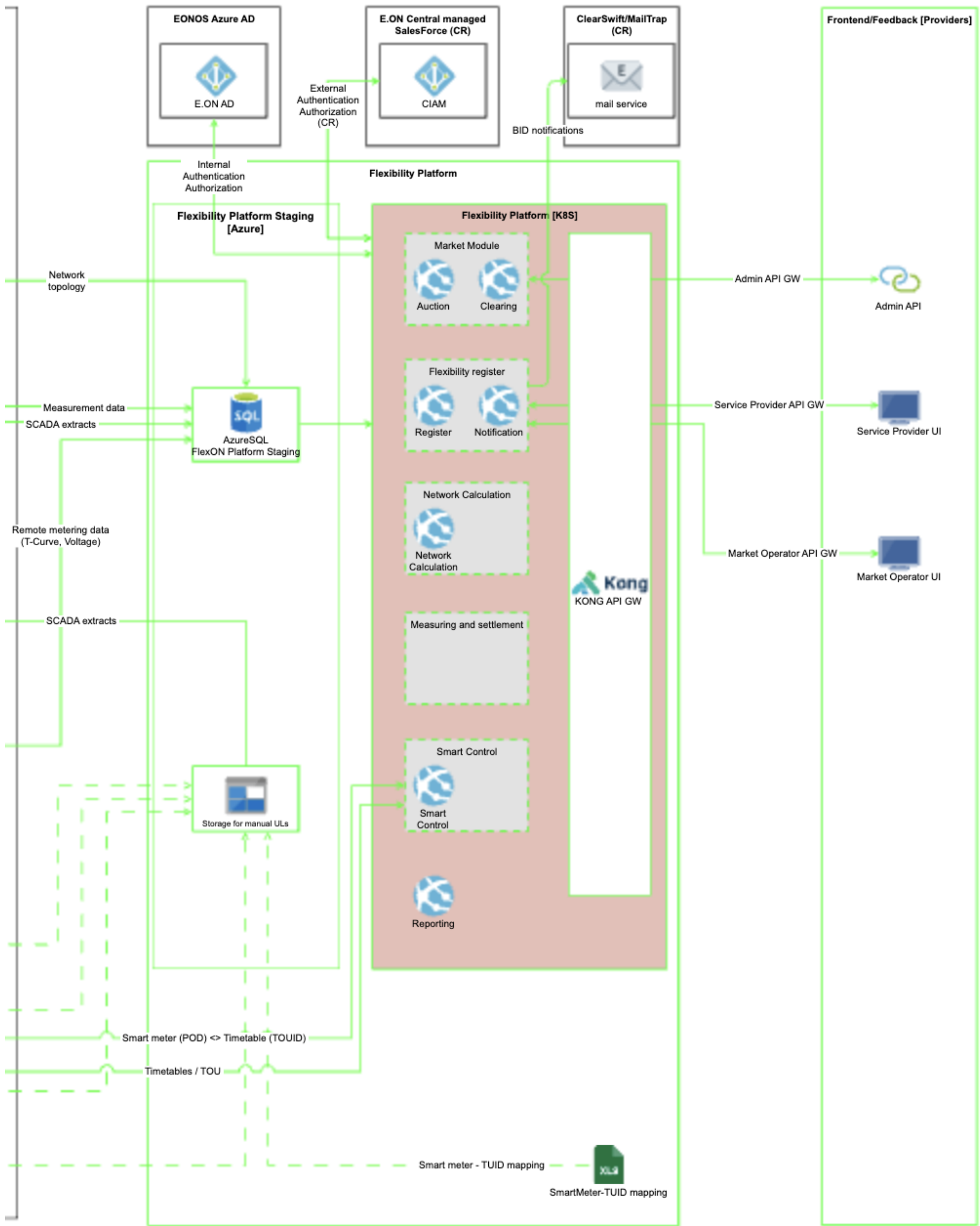

Figure 5-22 – FlexON Flexibility platform

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- Storage for manual uploads: an Azure Blob (Binary Large Object) Storage that serves as an input for manual file uploads to the platform
    - GIS-SCADA mapping: XLS file for mapping SCADA elements with GIS data
    - Factory preparations
    - SCADA extract: contains the SCADA static data in order to map into the network calculations
    - Substation topology: contains the substation topologies in order to map into the network calculations
    - TOUID description: Predefined ON/OFF schedule for smart meters
    - Smart meter TOUID mapping: contains relation information between smart meters and on/off schedules

Data that is needed for the flexibility platform operations is scattered in numerous systems or subsystems, hence ETL (extract, transform, load) processes are necessary to extract data from highly distributed sources, transform it through manipulation, parsing, and formatting, and load it into staging databases. Also, enterprise service bus (ESB) provides API-based connectivity to other systems of the DSO with real-time integration.

The network topology data is polled from the GIS and staged via MuleSoft ESB before loading into the FlexON Platform's SWL database.

The flexibility platform itself consists of modules that are defined as functional and business logic groups.

The platform is based on a microservice architecture that runs in ESP Kubernetes runtime environment, which is an E.ON Central IT managed platform. The communications between the microservices are event-based and managed by Confluent Kafka which is a distributed event streaming platform.

The interaction with the users is carried out as follows:

The KONG component serves as a gateway between the internal APIs and the public internet.

Admin API GW: admin API gateway for admin level calls. Admin has access to see the results of the market clearing, network calculations, submitted bids, uploading TSO traffic light lists. As standard operational procedure Swagger UI is used to visualize and interact with the API.

Service Provider API: connects with a web client that serves as a UI for FSPs for bid submissions, clearing results, etc.

MailTrap / Clearswift: email service for sending out results and auction related emails for FSPs.

Azure AD: authentication and authorization provider for E.ON internal users.

SalesForce CIAM: SalesForce based central identity management component for external user / customer authentication and authorization.

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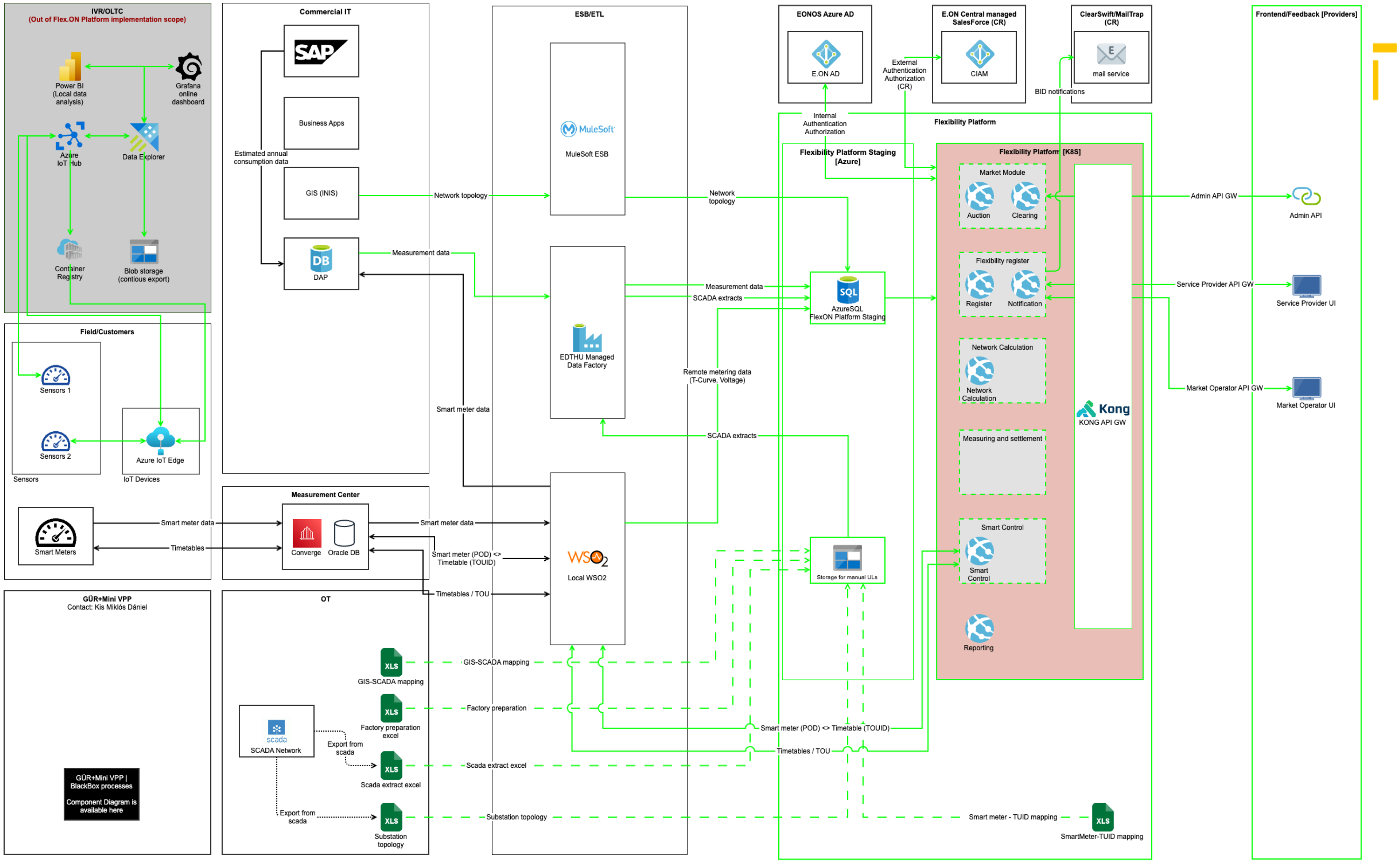

Figure 5-23 – Overview of FlexON Flexibility platform embedded and interfaced with the DSO's IT systems

One extra feature in this is that DSM loads (mainly domestic water heaters) that are currently scheduled by the DSO can be channelled into the platform via zero-cost bids. If the bids are accepted timetables are sent to the smart meters via Staging DB and BLOB storage, the communication is staged with a Local WSO2 between the BLOB storage and Measurement Centre.

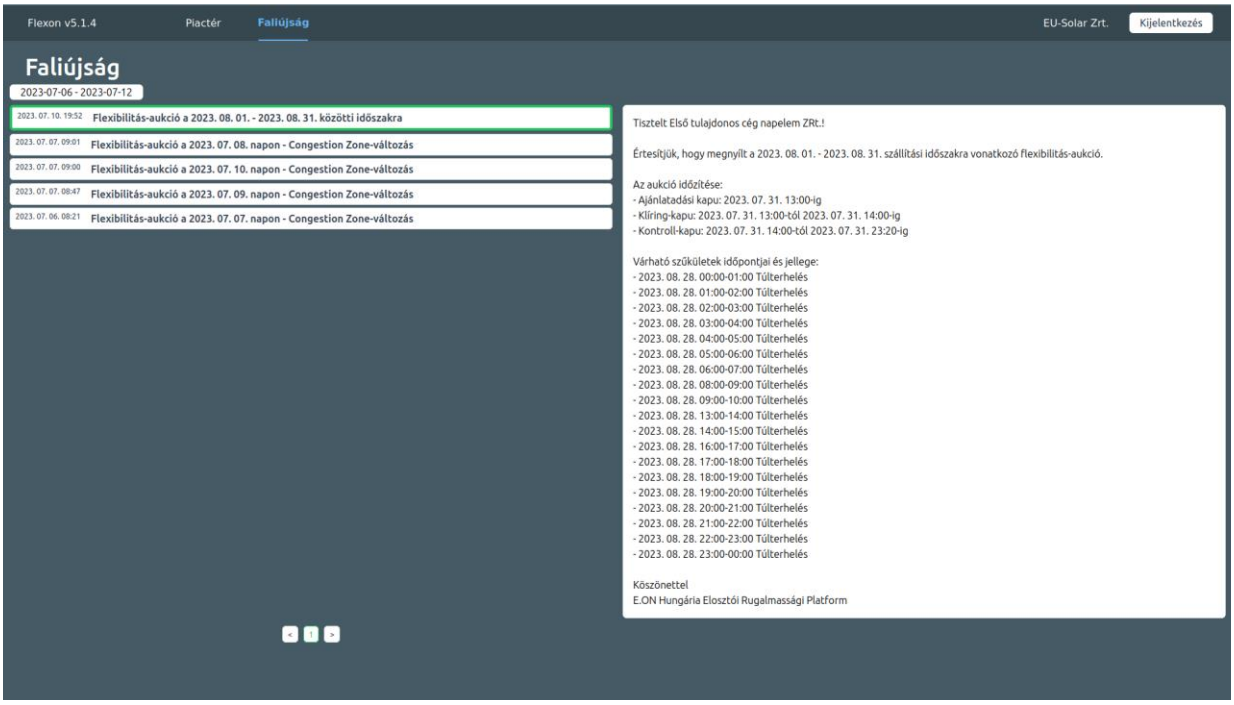

Figure 5-24 – FlexON Flexibility platform UI interface for FSP's example – Updates UI

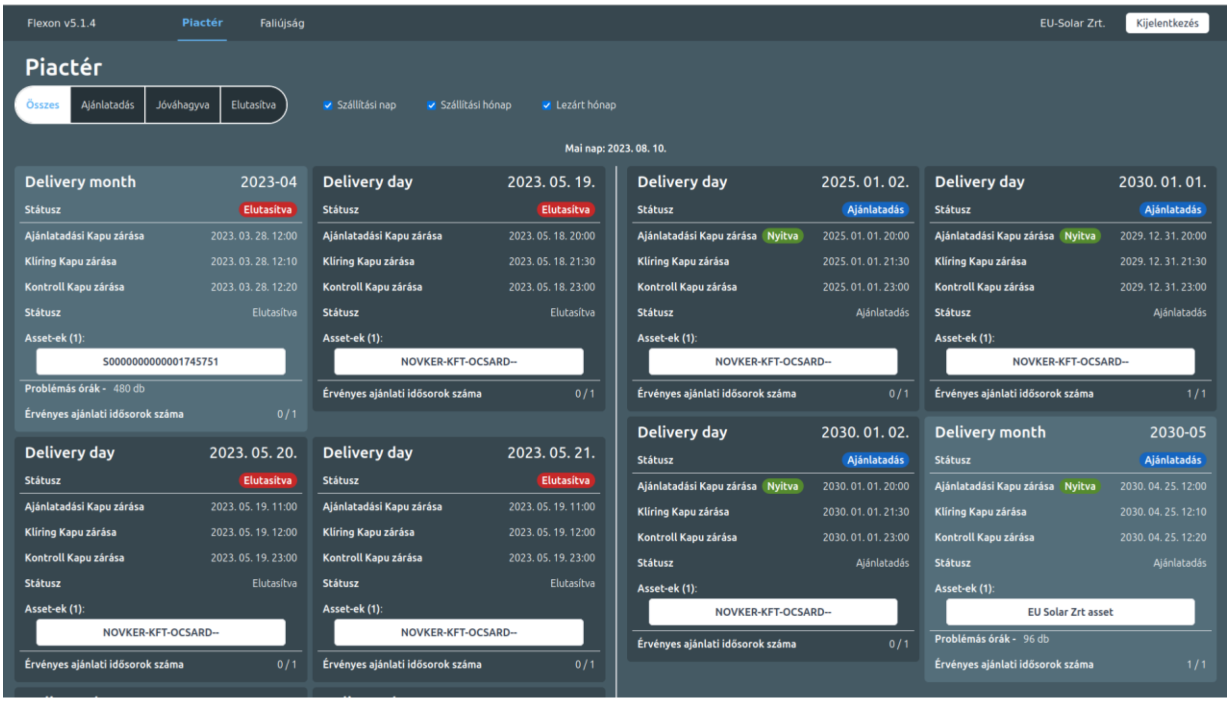

Figure 5-25 – FlexON Flexibility platform UI interface for FSP's example – Marketplace UI

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5.3.3 OneNet Connector

In the Hungarian demo, the OneNet Connector's integration is primarily facilitated through a GUI channel. This approach is designed to streamline the process, making it more user-friendly and efficient.

The OneNet system not only simplifies information exchange across different countries but also offers a platform to share insights about local markets. This shared knowledge paves the way for potential future participants, allowing them to navigate and enter the market with increased confidence and understanding.

The Hungarian demo emphasizes a key use case for the OneNet Connector: leveraging communication platforms, in this instance, the OneNet system, as a potent tool to disseminate data on a European scale about local flexibility markets. This widespread dissemination of data can unlock new business avenues, especially for aggregators and flexibility service providers. By providing them with a comprehensive overview of market dynamics and potential, they are better positioned to strategize and capitalize on emerging opportunities.

The data is systematically organized and presented in an XLSX and CSV format.

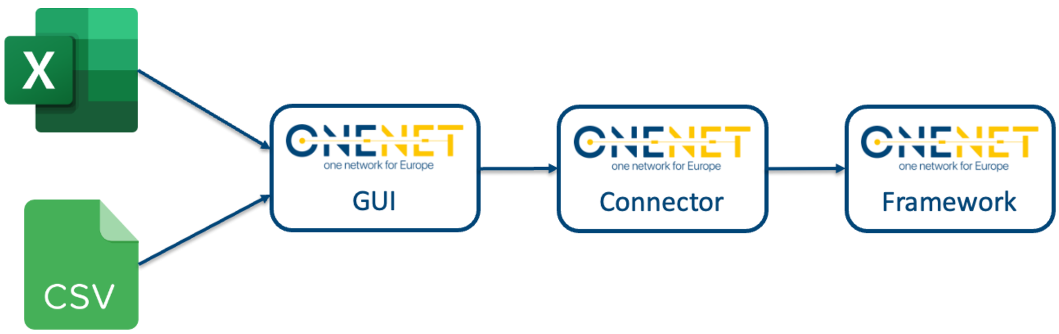

Figure 5-26 – OneNet Connector integration

As the energy landscape continues to evolve, the potential for more automated and integrated solutions, like machine-to-machine (M2M) integrations, becomes increasingly evident. In such scenarios, REST API services could be employed to enhance the registration process within the service catalogue of the OneNet Platform, ensuring a more interconnected and automated energy ecosystem.

5.4 Demonstration results

The demonstration of the functional extensions was carried out as a simulation on the topology of the demo areas. In this section a simulation of a flexibility auction is introduced including the process and result of a simulation.

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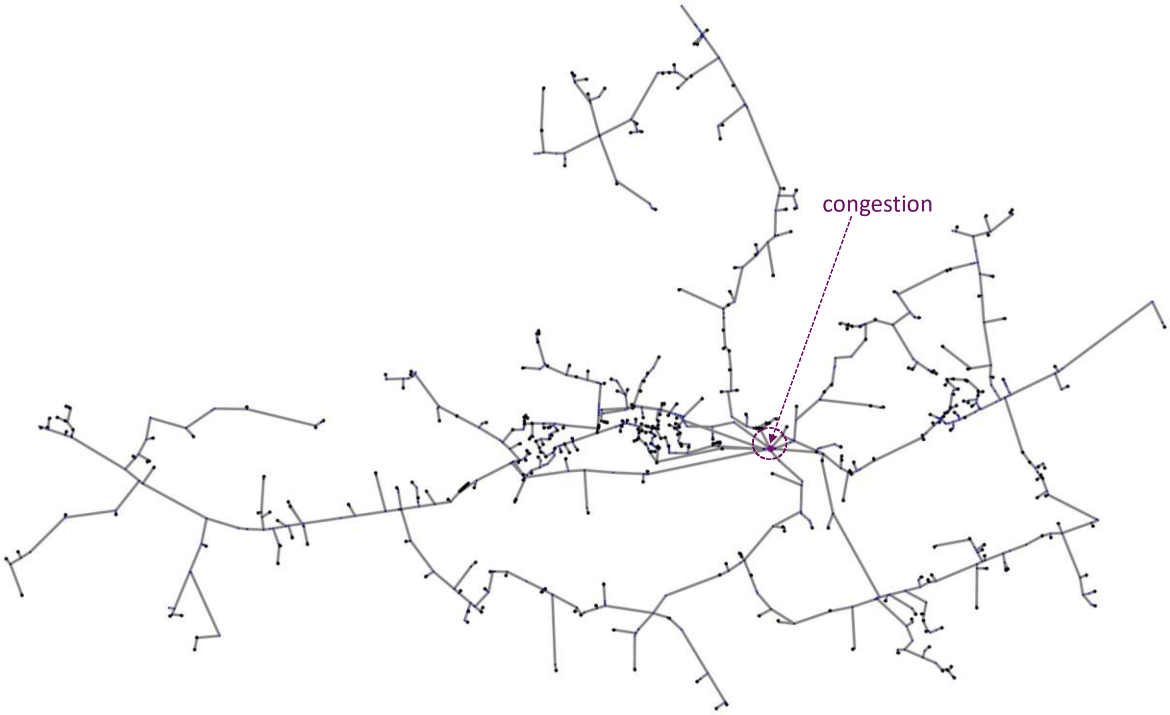

Figure 5-27 – Topology of the Siklós demo area included in the simulation (indicating transformer overload)

The calculation yielded one congestion on the one given MV/HV transformer where the absolute value of max power-flow on the transformer was 8193.1 kW and the calculated flow was 11265.71 kW, hence an overloaded transformer was created for the simulation.


```
{
      "trafo-id": 10000,
      "flow-kw": 11265.71,
      "is-active-congestion": "True",
      "min-flow-kw": -8193.1,
      "max-flow-kw": 8193.1
    },
```


In **Error! Reference source not found.** an excerpt of the sensitivity factor matrix can be seen which contains all of the factors between the HV/MV transformer and buses of Assets and residential prosumers/consumers.

Table 5-12 – Sensitivity Factors between the MV/HV transformer and MV buses

Transformer ID: 10000							
Bus ID	Sensitivity factor	Bus ID	Sensitivity factor	Bus ID	Sensitivity factor	Bus ID	Sensitivity factor
99	1	497	1	940	1	1722	1
108	1	502	1	973	1	1733	1
117	1	562	1	1110	1	1765	1

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165	1	578	1	1119	1	1800	1
166	1	611	1	1157	1	1823	1
169	1	632	1	1264	1	1867	1
171	1	653	1	1326	1	1903	1
222	1	662	1	1373	1	1923	1
249	1	669	1	1391	1	1958	1
329	1	790	1	1404	1	2111	1
349	1	803	1	1414	1	2168	1
352	1	806	1	1424	1	2173	1
356	1	855	1	1464	1	2186	1
371	1	871	1	1522	1	2286	1
398	1	906	1	1617	1	2319	1
472	1						

Bids considering the DAM prices has been generated for each PV Asset. The bids contain multiple steps with separate pricing as it can be seen in Figure 5-28.

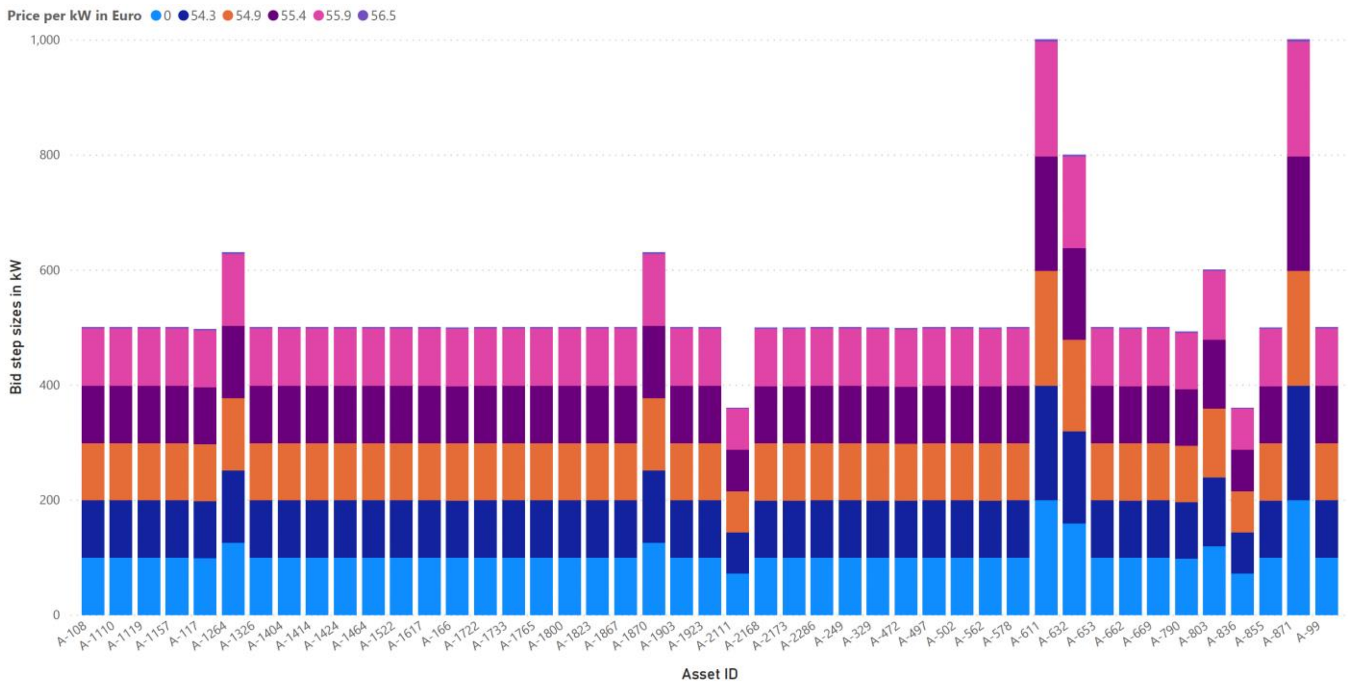

Figure 5-28 – Generated bids (priced by steps)

After clearing the results of bid activation can be seen in Figure 5-29.

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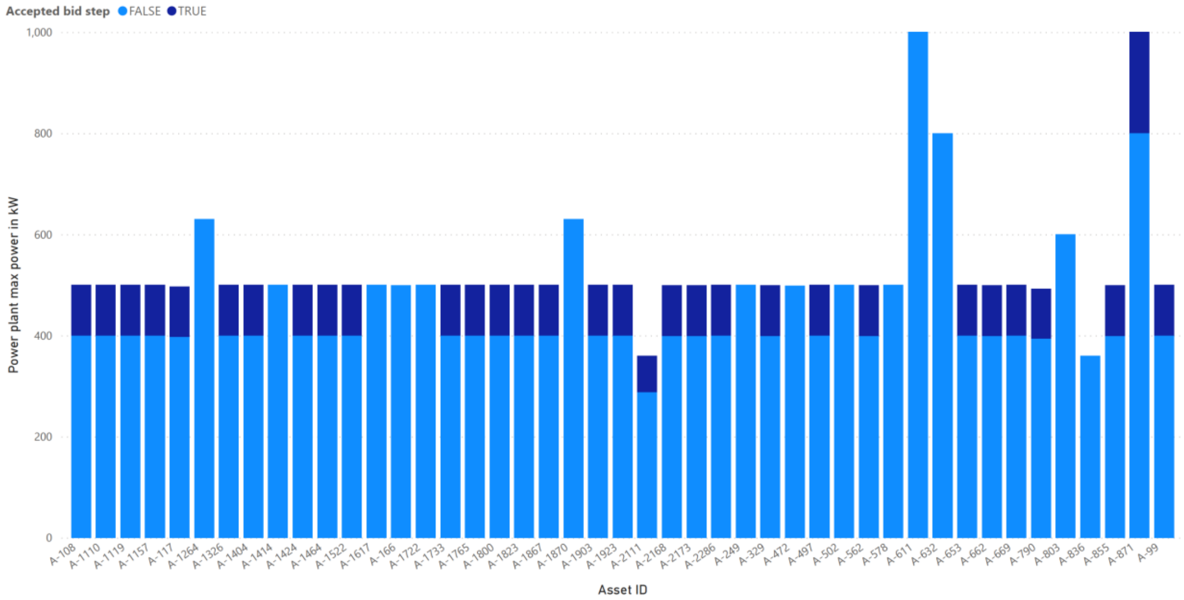

Figure 5-29 – Accepted bids

5.5 Conclusions

The Hungarian demonstration, as part of the OneNet project, embarked on a comprehensive journey to explore the potential of flexibility markets in the context of the evolving energy landscape. The demonstration was strategically situated in areas that provided a diverse range of network topologies and challenges, ensuring a robust testing environment for the developed solutions. The selection process for the demonstration areas was thorough, ensuring that the chosen locations provided a representative snapshot of the challenges and opportunities inherent in the Hungarian energy system. This careful selection process was crucial in ensuring that the demonstration results were both relevant and scalable to broader contexts. A key aspect of the demonstration was the functional extension demonstration, which showcased the potential of flexibility markets in addressing grid challenges. Through this, the Hungarian demo highlighted the importance of effective TSO-DSO communication, emphasizing the need for smooth information exchange to ensure grid stability and efficiency.

The bid generation process, another significant component of the demonstration, underscored the importance of a well-structured and transparent mechanism for the simulation of flexibility procurement. The demonstration showed that a well-implemented bid generation process could be essential in ensuring that flexibility resources are harnessed optimally, benefiting both the grid and the market participants.

The prequalification (accreditation) process was another area of focus. The demonstration highlighted the importance of a robust and transparent prequalification mechanism to ensure that only credible and capable flexibility providers participate in the market. This is crucial to maintain the integrity and reliability of the flexibility market.

From an IT perspective, the demonstration used advanced platforms and tools. The simulation platform played a crucial role in modelling various scenarios and understanding their implications. The E.ON's FlexON platform, on the other hand, provided a solid foundation for the demonstration, ensuring that the various components of the demonstration were seamlessly integrated. The integration with the OneNet Connector realised through a GUI channel, showed the adaptability and scalability of the solutions developed during the demonstration.

Lessons learned from the demonstration are manifold. Firstly, the importance of a well-defined and transparent process, be it for bid generation or prequalification, is clear. Such processes are essential in ensuring the credibility and reliability of the flexibility market. Secondly, effective TSO-DSO communication is vital in ensuring grid stability. The demonstration highlighted the need for platforms and tools that facilitate smooth information exchange between these entities. Lastly, the demonstration emphasized the importance of adaptability. As the energy landscape evolves, solutions need to be adaptable and scalable to address emerging challenges and harness new opportunities.

In conclusion, the Hungarian demonstration has provided valuable insights into the DSO flexibility markets. The lessons learned from the demonstration will undoubtedly be instrumental in shaping the future direction of the OneNet project and the broader European flexibility markets and regulations.

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6 Conclusions

This deliverable document encapsulates the collaborative spirit and innovative drive of the eastern cluster demonstrators, all converging to address the pressing challenges and opportunities within the energy sector. This document, while comprehensive, is a mosaic of diverse methodologies, strategies, and solutions, each tailored to the unique energy landscape of its region.

While the shift towards sustainable energy is commendable, it has brought to the fore operational challenges that demand innovative solutions. Voltage management, grid congestion, and the seamless integration of renewable sources have become paramount in the demonstration phase. Adaptive grid management solutions, such as the network traffic light scheme, have proven their benefits in addressing these challenges, offering a more responsive and efficient energy market. Modern energy solutions, from EV charging infrastructures to platforms for non-frequency services, have been at the forefront of demonstrations. These initiatives not only address current challenges but also lay a robust foundation for future advancements in the sector. The integration of resources across various voltage networks, aimed at supporting both DSO and TSO operations, has been a significant theme. This integration, coupled with the role of aggregators and the establishment of comprehensive visibility into the distribution network, underscores the strategic approach adopted across the demonstrators.

Besides real-word testing, simulations have played a pivotal role in bridging the gap between theoretical solutions and their practical applications, especially for possible emerging grid issues in the future. These controlled environments have facilitated rigorous testing, validation, and optimization of solutions, ensuring their efficacy in real-world scenarios. The emphasis on functional extensions, combined with these simulation environments, showcases a blend of innovation and pragmatism.

The document also sheds light on the importance of collaboration and coordination. The seamless interaction between TSOs and DSOs, facilitated by real-time information exchange and structured processes, is a testament to the unified approach adopted in the OneNet project. This synergy ensures that the grid remains stable, efficient, and responsive to the ever-evolving demands placed upon it. Furthermore, the integration with the OneNet platform has emerged as a central theme. This integration signifies the collective vision of a harmonized energy management approach across Europe. It ensures that the strategies, methodologies, and solutions developed are part of a larger, cohesive framework aimed at optimizing the continent's energy ecosystem.

The collective efforts, insights, and lessons from these demonstrations are set to guide Europe towards a more integrated, resilient, and efficient energy future, setting a benchmark for others to follow. As we move forward, the findings of this document will serve as a beacon, illuminating the path towards a sustainable and efficient energy ecosystem for Europe

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