Evaluation of Demonstration Results in Greece and Cyprus

D8.4

Authors:

Charalambos Charalambous (UCY)	Vladan Ristic (EnergoInfo)
Kyriakos Kyriakou (UCY)	Nenad Sijakovic (EnergoInfo)
Markos Asprou(UCY)	Aleksandar Terzic-(Energoinfo)
Lenos Hadjidemetriou (UCY)	Emmanouil Zoulias (UoA)
Therapontos Fivos (EAC)	Dimitra Makrygiorgou (IPTO)
Michalis Michael (TSOC)	Christos Christodoulou (HEDNO)
Rogiros Tapakis (TSOC)	

Responsible Partner	University of Cyprus
Checked by WP leader	Emmanouil Zoulias (UoA), 11.03.2023
Verified by the appointed Reviewers	Beatriz Alonso Santos (IDAE), 18.02.2024 Madalena Lacerda (E-REDES), 20.03.2024
Approved by Project Coordinator	Padraic McKeever (Fraunhofer), 29.03.2024

Dissemination Level	Public

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 957739

Issue Record

Planned delivery date	31.03.2024
Actual date of delivery	29.03.2024

Version	Date	Author(s)	Notes
0.1	15/01/2024	Markos Asprou-UCY Lenos Hadjidemetriou-UCY	Initial outline of the deliverable
0.2	08/02/2024	Charalambos Charalambous - UCY Kyriakos Kyriakou - UCY Markos Asprou-UCY Lenos Hadjidemetriou-UCY Therapontos Fivos – EAC Michalis Michael – TSOC Rogiros Tapakis – TSOC Emmanouil Zoulias-UoA Nenad Sijakovic-EnergoInfo Aleksandar Terzic-Energoinfo Dimitra Makrygiorgou –IPTO Christos Christodoulou – HEDNO	Draft creation for internal review
0.3	12/03/2024	Markos Asprou – UCY Lenos Hadjidemetriou – UCY	Updated version to be submitted for internal review
0.4	28/03/2024	Markos Asprou-UCY Lenos Hadjidemetriou-UCY Vladan Ristic - Energoinfo	Updated version based on reviewer comments
1.0	28/03/2024	Markos Asprou Lenos Hadjidemetriou	Final version submitted to Project Coordinator

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 standardized 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.

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

List of Figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

List of Tables

List of Abbreviations and Acronyms

Acronym	Meaning
ABCM-D	Active Balancing Congestion Management-DSO
ABCM-T	Active Balancing Congestion Management-TSO
API	Application Programming Interface
BSP	Balancing Service Provider
BUC	Business Use Cases
DER	Distributed Energy Resources
DSO	Distribution System Operator
EAC	Electricity Authority of Cyprus
FCR	Frequency Containment Reserve
FSP	Flexibility Service Provider
GUI	Graphical User Interface
HiL	Hardware in the Loop
HV	High Voltage
ID	Identification number
KPI	Key Performance Indicator
LV	Low Voltage
MAPE	Mean Absolute Percentage Error
MV	Medium Voltage
OHL	Overhead (Power) Line
PB	Phase Balancing
PF	Power Factor
PMU	Phasor Measurement Unit
PoI	Point of Interest
PV	Photovoltaic
RES	Renewable Energy Sources
RSC	Regional Security Center
RTS	Real Time Simulator
SCADA	Supervisory Control and Data Acquisition
SPP	Solar Power Plant
SUC	System Use Cases
TSO	Transmission System Operator
WPP	Wind Power Plant

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Executive Summary

This deliverable presents the demonstration and evaluation activities performed in the Southern cluster demos that are implemented in Greece and Cyprus as well as the evaluation of the results obtained through the operation of the demos. The two demos focus on the implementation of innovative solutions to address the current and future challenges encountered by the Cypriot and Greek power grid in coping with the high penetration of Renewable Energy Sources (RES). In order to evaluate the performance of the different innovative solutions that were developed in the two demos a Key Performance Indicators (KPI)-based approach is followed. The document describes in detail how the KPIs are calculated and provides their respective values for both Cyprus and Greek demo systems along with a discussion about the obtained results. In this executive summary the description of both demos, their respective evaluation framework and the results for each KPI category are summarized.

Cypriot Demonstration

The Cypriot demonstration illustrates the effective collaboration among power system stakeholders using the OneNet system, aiming to empower prosumers to provide power flexibility services and enhance RES integration while ensuring grid stability. Several challenges that arise from the islanded nature of the system and the localized congestion due to concentrated photovoltaics, PVs, are addressed through the demo activities, showcasing (1) the cooperation among TSO, DSO, and Market Operator, (2) the participation of the Flexibility Service Providers (FSPs) to an innovative electricity market framework developed for the demo purposes, and (3) the effective monitoring, control and management of the transmission and distribution grid. The latter is enabled through the Active Balancing and Congestion Management (ABCM) platform, developed under Task 8.3.

The Cypriot demo utilized a comprehensive set of KPIs to assess the effectiveness of developed solutions and market operations. These KPIs covered various aspects including frequency stability, voltage regulation, energy losses, and market participation. Furthermore, KPIs related to the System Use Cases (SUCs) of the Cypriot demo, such as grid monitoring, prequalification (in order to ensure overloading) valuation of the FSP response, are devised and evaluated. For system operations, KPIs such as Rate of Change of Frequency (ROCOF) improvement and improvement of frequency nadir evaluated the impact of RES on frequency support during disturbances. Additionally, indicators like overloading and improvement on voltage limits violations measured improvements in grid reliability and stability. Market-related KPIs focused on the participation of Distributed Energy Resources (DERs) and Flexibility Service Providers (FSPs) to the market, assessing factors like the number of participants, volume of service offers, and transaction volumes.

Within the validation phase (refinement, communication, integration, debugging and improvement) of the developed platforms, the following four SUCs were used: real-time monitoring of the grid (SUC1),

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

prequalification of the location-based limit of each market product (SUC1), evaluation of the FSPs response (SUC3) and coordination of distributed flexible resources (SUC4).

The three SUCs modules of the OneNet Cypriot demo focusing on grid monitoring, pre-qualification of transformer limits, and evaluation of FSPs responses are demonstrated and evaluated successfully. The real-time grid monitoring observes both transmission and distribution grids using state-of-the-art technologies like Phasor Measurement Units (PMUs) (for the transmission grid) and smart metering and SCADA measurements (for the distribution grid). Evaluation of the monitoring schemes for both grids shows high accuracy, with low voltage magnitude and angle errors, ensuring reliable real-time monitoring. Regarding the prequalification limit SUC that determines transformer capacities to ensure grid reliability during FSP participation in the Frequency Containment Reserve market, the related KPI indicates high accuracy of the prequalified limits, crucial for smooth grid operation. In addition, the assessment of the third SUC, related to the evaluation of FSP response indicate accurate responses from FSPs located in both MV and LV distribution grids for various coordination services.

Two operational scenarios are also demonstrated and evaluated in the Cypriot demo. The first scenario is related to the frequency balancing using KPIs related to the Rate of Change of Frequency (ROCOF) and frequency nadir. The results show that flexible RES providing frequency containment reserve services significantly improve ROCOF and frequency nadir, enhancing in this way the system stability. The inclusion of virtual inertia further improves these metrics. The second operational scenario is related to the congestion management of the grid, which basically constitutes the background for the fourth SUC of the Cypriot demo that deals with the coordination of the distributed flexible resources. Two main use cases are presented for this scenario namely, the active/reactive power coordination in medium voltage, MV, distribution grids and phase balancing in low voltage, LV, grids. Results show successful congestion relief and improved grid efficiency through the sophisticated coordination of the services provided by the FSPs. The KPIs that were related to this scenario confirms improvements in thermal loading, energy losses, and loading asymmetries. This evaluation verifies the effectiveness of SUC4 in managing grid congestion and enhancing power quality.

The demonstration and evaluation activities of the Cypriot demo also focuses to the operation of two different markets for ancillary services in the electricity grid, the Intra-Day TSO Frequency Containment Reserve market and the Near Real-Time DSO Ancillary Services. The two market frameworks facilitate collaboration among stakeholders in the electricity market, enabling effective data exchange between TSOs, DSOs, market operators, and FSPs or prosumers. This integration is achieved through the OneNet system, which facilitates standardized data exchange. The demonstration of the two markets in the Cypriot demo includes four distinct steps: (1) the procurement of products by either the TSO or the DSO, (2) the submission of offers by the FSPs before the market closure (3) the clearing of the market, and (4) the dissemination of the results to the market participants (FSPs, TSO and DSO). The market results are evaluated based on various KPIs such as the number of participants, number of transactions, and volume of transactions. The demonstration cases indicate successful market clearing and utilization of market results in congestion management scenarios, highlighting the effectiveness of the framework, while the market liquidity and the provided flexibility is enhanced through the proposed market frameworks.

Greek Demonstration

The Greek Demo aims at enhancing the management of the energy grid in Crete and Peloponnese regions. The demo focuses on improving grid management through enhanced active power management and severe weather condition management for TSO-DSO coordination. In order to achieve this comprehensive data on network infrastructure, substations, and RES was gathered, emphasizing the importance of effective communication and coordination between project key stakeholders to mitigate risks. Two BUCs were identified:

- BUC 1: Enhanced Active Power Management for TSO-DSO coordination. This BUC was founded on improved identification of the available flexibility resources, focused primarily on the DSO voltage level, together with enhanced identification of the power system flexibility needs, focused on the TSO voltage level grid. Also, this BUC considered longer time horizon and wider geographical scope than respective methods for the same purpose that are commonly used today. That was achieved through the simultaneous market and grid simulations backed up by AI based calculation engines.
- BUC 2: Enhanced severe weather condition management and outage management for TSO, DSO and micro grid operator. This BUC focused on enhanced severe weather condition management with predictive maintenance algorithms, combined with enhanced storm and icing predictions in order to prevent the power system from running into dangerous topological or operational regimes.

Each of the identified BUCs came with the specific scenarios aimed at addressing grid challenges such as contingency identification, voltage control, and power regulation. These scenarios provided a framework for testing and validating the proposed solutions. The main enabler of the key activities of the Greek demo is the F-channel platform, a web-based application, serves as the backbone for the project, integrating weather forecasting, Artificial intelligence (AI) methods, and cloud calculation engines. It consists of two major modules: the Forecasting Module and the Coordination Module.

The Forecasting Module offers the capabilities for energy production forecasts, load flow simulations, and weather parameter forecasts, while the Coordination Module of the F-channel platform facilitates grid services for balancing and congestion management through interfaces for flexibility register and auctioning. Overall, the Greek Demo demonstrates significant advancements in grid management capabilities, with a focus on improving forecasting accuracy, grid observability, and existing techniques for the flexibility management in the systems. Effective collaboration and innovative technological solutions played a crucial role in achieving project objectives and ensuring the stability and reliability of the energy grids that decide to use the developed solution.

The evaluation of the Greek Demo's outcomes focuses on KPIs across three categories: market-based, scenario-based, and regional. In terms of market-based KPIs, the project exceeded expectations, with a total of 83 FSPs participating in the market and in the different operational scenarios of the demo, far surpassing the target of 20. Additionally, transactions on the energy market exceeded targets for both the number and volume of transactions, indicating active market engagement. In scenario-based evaluation, the project achieved 100% success in avoiding technical restrictions through accurate forecasting and preventive actions, demonstrating effective scenario management. Finally, in regional evaluation, the project successfully forecasted and mitigated cyber threats, achieving 100% success, and identified over 27,000 severe weather conditions, showcasing effective prediction capabilities. Overall, the Greek Demo project demonstrated significant success across all evaluated KPIs, highlighting its effectiveness in enhancing grid resilience and operational efficiency through strong market participation, proactive scenario management, and regional collaboration.

The evaluation results from both demos in the Southern cluster are very encouraging. In particular both demos indicate that the innovative solutions that were developed can contribute significantly to alleviating critical challenges associated to the future power systems, enhancing integration of RES and promoting the green transition of the Southern Europe.

1 Introduction

Within the framework of the OneNet project, the Southern cluster demonstrator is actively involved in implementing two pilots, located in Cyprus and Greece, respectively. These countries encounter a variety of challenges in the grid operation due to the increasing electricity demand and the high penetration of renewable energy resources. The main objective of these two pilots is to address the issues faced by Transmission System Operators (TSOs), Distribution System Operators (DSOs), market operators, market participants, and consumers in both countries.

In particular, the current power system in Cyprus is islanded, while despite the liberalisation of the electricity market, the Electricity Authority of Cyprus (EAC) retains significant control, with almost 100% of retail supply and over 90% of generation. Due to the electrification of the heating, cooling and transportation sector, the TSO has prepared a long-term projection for annual maximum generation from 2021 to 2028, anticipating a substantial increase of around 2000 GWh (almost 40%) compared to the current generation. Given Cyprus' isolated power system and heavy reliance on oil-powered plants, enhancing the flexibility of the country's power infrastructure is crucial to accommodate the anticipated demand increase. With an installed power generation capacity of around 1740 MW, predominantly provided by the EAC, Cyprus aims to achieve 23% Renewable Energy Source (RES) penetration in gross energy consumption by 2030. RES currently constitutes 17.2% of total electricity consumption, sourced from photovoltaic and wind systems. To increase RES penetration, strengthening the flexibility of Cyprus' power system is essential, since existing limitations in flexibility prevents the higher RES penetration. Addressing this involves measures such as the interconnection with Israel and Greece through EuroAsia Interconnector and operating the electricity market following a Net-Pool Market model. These actions are expected to enhance the flexibility of the Cyprus power network, minimizing the need to curtail RES and reinforcing market liquidity through novel ancillary services products.

In accordance with the current challenges in the Cyprus power system, the overall approach of the Cyprus demo was to create advanced tools for monitoring, control, and management of both the transmission and distribution grid. These tools have been seamlessly incorporated into the ABCM-T (transmission grid) and ABCM-D (distribution grid) platforms, which were concurrently developed under Task 8.3 [1]. Additionally, this task involved the formulation of a novel electricity market framework, facilitating the provision of ancillary services by FSPs situated at both the transmission and distribution grids. All tools and methodologies developed in Task 8.3 undergo rigorous testing, validation, and demonstration within the Cyprus demonstration framework. This framework encompasses the Cyprus digital twin power system, along with various Hardware in the Loop, HIL, setups facilitating integration with the real-time digital twin power system. Comprehensive testing, validation, and demonstration of the developed tools through 'dry-run' scenarios in the Cyprus demo simulation environment are also executed. The demonstration and evaluation results of the Cyprus demo are described in this deliverable, discussing the outcomes and their impact in the operation of the Cyprus power system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Greece faces several challenges in its current electricity system and market while simultaneously striving to achieve the goals outlined in the Clean Energy Package. Electricity market liberalization presents a significant barrier for the Greek energy system, as effective competition is not feasible in the electricity market, thereby limiting the benefits for consumers. Moreover, meeting the 2030 target for installed Renewable Energy Sources (RES) electricity units poses additional difficulties due to prevalent issues related to RES project implementation in Greece [2]. These issues encompass time-consuming licensing procedures, uncertainties surrounding the future of the special RES account, and inadequate electrical interconnections with RES-rich regions (i.e., islands). In addition to these challenges, new obstacles for renewables have arisen, necessitating significant improvements to the auction-based Feed-in-Premium (FiP) system, delays in the complete implementation of the Target Model and regional electricity market coupling, and the absence of a coherent regulatory framework for emerging RES technologies. Furthermore, enabling consumer participation in the energy system, both through their generation assets and load flexibility, remains unfeasible under current market rules [3].

In response to the aforementioned challenges in the Greek power system, the OneNet Greek demo has developed the "TSO-DSO Flexibility Channel" (F-Channel), a digital platform designed to showcase the establishment of a flexibility market featuring various common products for TSO and DSO coordination. Key technologies of this platform include a forecasting module ensuring predictability of highly volatile RES generation and demand, as well as a coordination module that leverages existing functionality and data from IPTO-HEDNO key systems, such as the control system and asset register. The Greek demo also facilitates the provision of grid services (both frequency and non-frequency) to address balancing and congestion management challenges. The developed F-Channel platform encompasses all stakeholders participating in existing or near-future markets in Greece, including prosumers and aggregators.

In the Southern cluster demo of OneNet the unique complexities of the power systems and the regulatory environments of the two countries were taken into consideration. In this attempt innovative digital platforms, new market frameworks, and enhanced collaborative frameworks between the key energy stakeholders were developed in both demos. The demos efforts are supported by the seamless exchange of information between the different key energy stakeholders through the OneNet system. This deliverable provides the demonstration and evaluation results of the two demos, indicating the impact of the developed solutions to the Cypriot and Greek power systems.

1.1 Task 8.4 - Evaluation of Results (of the Southern Cluster demos)

Task 8.4. deals with the assessment of the outcomes of the Cypriot and Greek demonstrations developed in Tasks 8.2 and 8.3. Specific Key Performance Indicators (KPIs) were decided for the two demos through the activities of Task 2.4 of the OneNet project. After the implementation of the two demos, these KPIs are computed in this task to indicate the benefits derived from the innovative platforms developed in the Southern cluster. More specifically, the activities of this task include (1) the evaluation of the SUCs that were developed in the two demos and are encompassed to the ABCM-D/T and F-channel platforms, (2) the volume of balancing/flexibility services provided during the experimental period through the new market frameworks that were proposed in the two demos, (3) the participation levels of various energy actors and end-customers in the scenarios, (4) the impact evaluation of the application of the two platforms to the system operation. The results from the KPI-based evaluation procedure that is followed in Task 8.4 are included in Deliverable 8.4.

1.2 Objectives of the Cypriot demonstration

The Cypriot demo aims to alleviate the barriers and challenges that are outlined above for the power system of Cyprus, contributing to the increase of the Cyprus power system flexibility in the upcoming years. Therefore, based on the features and characteristics of the Cyprus power system, the Cyprus demo objectives are:

- Optimization of the Renewable Energy Sources (RES) integration into the Cyprus electricity system. In particular, the Cyprus demo targets to the development and demonstration of an efficient collaboration framework that unites the TSO, the DSO, and the Market Operator. This collaborative framework includes a standardized data exchange framework for all the energy stakeholders, a new innovative market framework.
- Delivery of flexibility services within the electricity system by both FSPs located to the transmission and distribution system. To achieve this, the project empowers FSPs to actively engage in the process through an innovative market framework that includes a Frequency Containment Reserve (TSO level) and Congestion Management Market (DSO level). Furthermore, innovative tools for monitoring, control and manage the operation of both transmission and distribution systems are developed.

1.3 Objectives of the Greek demonstration

Greek demo aims to develop and demonstrate the platform known as the F-channel platform. This platform has been envisaged as the unified and unique tool that will make the functioning of the energy market in the future simple and reliable for all of the involved participants. In line with that, the demo's objectives are the:

- The development of a forecasting module of the F-channel platform for facilitating the integration of renewable sources into the grid. It relies upon using the high-resolution weather forecasts and accurate technical data on the grid to predict all relevant indicators regarding the system state well in advance. All the results that are acquired through the Forecasting Module are shown on the system georeferenced map.

- The development of a coordination module of the F-channel platform to enhance communication between the different participants in the energy market, may those be system operators, aggregators or independent flexibility service providers. For that target to be achieved, this module combined the user-friendly interface with the submodules following every major step in the bidding and auctioning process. In addition to this, this module enables the exchange of critical information among the users (such as operators).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

1.4 Outline of the Deliverable

This report encompasses various sections evaluating the results of the demonstrations carried out in Greece and Cyprus demos within the framework of the OneNet project. A brief introduction is presented in Section 1, offering an overview of the main challenges for the Cypriot and Greek power system also including the main activities of the two demos to overcome these challenges. Section 2, the Cyprus demo description, provides details regarding its overall structure, scenarios of Cyprus Demo along with the development and integration processes followed in the demo. Furthermore, the Cypriot Demo Evaluation is described in Section 3 by introducing the validation and evaluation framework that is followed in the Cypriot demo. The KPIs values that are related to the SUCs, to the two testing and validation scenarios, and to the electricity market operators are provided and discussed. Moreover, Section 4 provides a comprehensive overview of the Greek demo, covering its overall description, scenarios, and the development and integration processes. Additionally, the Greek demo evaluation, encompassing a validation and evaluation framework along with three distinct types of KPIs (Market-based, Scenario-based, and Regional) are described in Section 5. Finally, conclusions summarizing the key findings from the evaluation of both demos and insights of the achievements and overall effectiveness of the OneNet project in the southern cluster are outlined in Section 6.

1.5 How to Read this Document

For better understanding of this deliverable, it is important for the reader to read Deliverable 8.1 [4] that describes the requirements and specification of the pilots in Greece and Cyprus. Further it will be helpful to read Deliverable 8.2 [5] that provides insights regarding the development and integration of the F-channel platform in the Greek demo, as well as Deliverable 8.3 [1] that discusses the activities of the Cypriot demo regarding the development of the Active Balancing Congestion Management (ABCM) platform, the innovative market framework, and the different SUCs of the Cypriot demo. Furthermore, the reader can find more details regarding BUCs of the Cypriot and Greek demo in Deliverable 5.1 [6] and regarding SUCs in Deliverable 2.3 [7], while details about the developed electricity market framework in the two demos can also be found Deliverable 3.4 [8]. Regarding the evaluation framework, although the KPIs for the two demos are also provided in this deliverable the reader can find the KPIs of the Cyprus and Greek demo in Deliverable 2.4 [9], while the values of the KPIs for the two demos are included in Deliverable 11.1 [10].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

2 Cyprus Demo Description

2.1 Overall description

The Cyprus demonstration aims to showcase the effective collaboration among various power system stakeholders, leveraging the OneNet system. Its goals include empowering prosumers to offer power flexibility services and increasing the integration of Renewable Energy Sources (RES) while maintaining grid stability. Challenges arise from the islanded nature of the system, compounded by localized congestion due to concentrated PV installations. To tackle these issues, the demo highlights cooperation among the Transmission System Operator (TSO), Distribution System Operator (DSO), and future Market Operator. The demo activities require the active participation of both the TSO and DSO, providing essential data and historical information.

The architecture of the demo, as depicted in Figure 1, emphasizes platforms such as Active Balancing and Congestion Management, developed under Task 8.3 of the OneNet project. These platforms facilitate coordination among stakeholders and flexibility service providers like aggregators and prosumers. The seamless exchange of information facilitated by the OneNet system is crucial in this undertaking. Additionally, a simulated market is incorporated to emulate operational conditions. The demonstration is realized in a controlled hardware-in-the-loop (HiL) environment, enabling the testing of various scenarios of the demo.

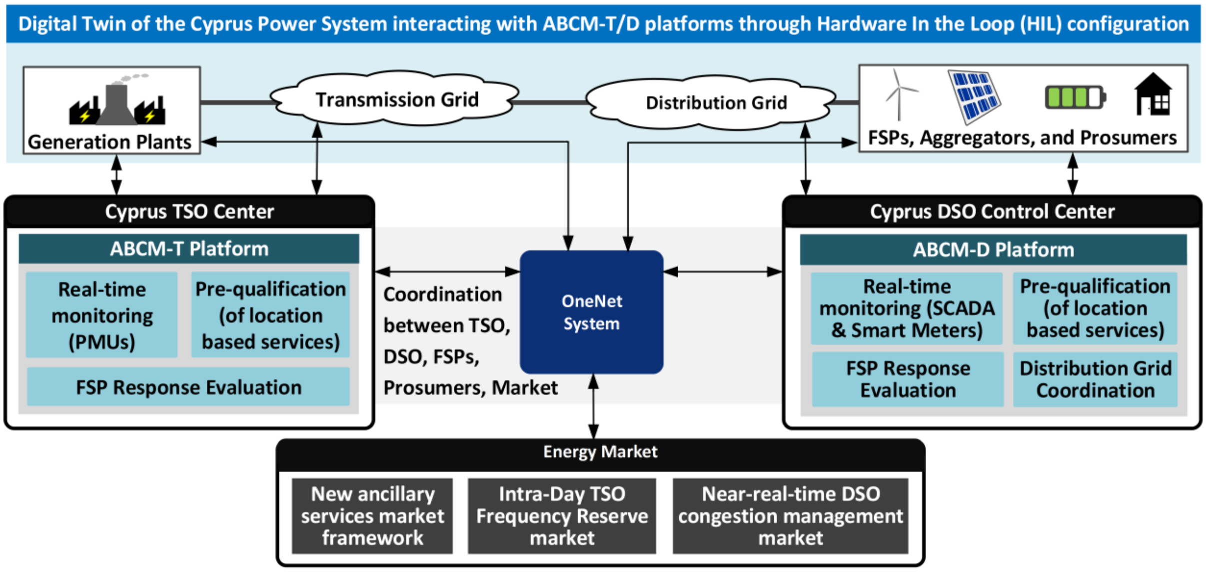


Figure 1: Cyprus demo general architecture

Two main Business Use Cases (BUCs) have been identified for the ABCM platforms and the Cyprus demonstration as shown in Table 1. The first BUC focuses on enhancing the active power flexibility of the power system while the second BUC targets on reactive power and power quality flexibilities.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

BUCs Name	BUCs Description
BUC 1	Active Power Flexibility
BUC 2	Reactive power flexibility and power quality

Table 1: Business Use Cases

Alongside, four System Use Cases (SUCs) have been identified for the Cyprus demo and are included in ABCM-T and ABCM-D platforms. These four SUCs are listed at in Table 2.

SUCs Name	SUCs Description
SUC 1	Real-time monitoring of the grid
SUC 2	Prequalification of the location-based limit of each market product
SUC 3	Evaluation of the FSPs response
SUC 4	Coordination of distributed flexible resources

Table 2: System Use Cases

2.2 Scenarios of Cyprus Demo

In the Cyprus demo, two main scenarios are considered to showcase the impact of the solutions developed in the demo. These scenarios are directly related to the BUCs of the demo that were discussed earlier in Section 2.1. The first scenario dealt with getting FSPs involved to provide frequency support in case of a frequency event, while the second scenario focused on handling local congestion and power quality issues in the distribution grid through the engagement of FSPs located at the distribution feeders that face congestion problems as described below.

Scenario 1-Frequency balancing: The scenario of frequency balancing for the grid deals with the issue of power generation loss following a grid fault. This loss disrupts the balance between generation and demand, leading to a significant disturbance in frequency that can affect the stability of the system. To address this, flexible resources such as FSPs and prosumers, who have been granted participation in frequency balancing through the TSO market, are automatically activated to offer support and help to restore frequency equilibrium. It's worth noting that bids from FSPs located in the distribution grid and participating in this scenario were submitted via the Intra-Day DSO market. Additionally, prequalification limits (determined by the prequalification scheme) for the transformer connected between HV/MV interfaces are transmitted to the TSO market. Thus, FSPs operating at the distribution level and participating in the TSO market must meet prequalification criteria set by the DSO for their awarded activation products. Following the provision of services by participating FSPs, the TSO and DSO carry out online assessments of the FSPs' response to ensure proper functioning, and an evaluation report is then shared with the energy market.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Scenario 2-Congestion management: The congestion management scenario within the distribution grid deals with issues such as line overloading and power quality by activating flexibility services from local distributed resources. This involves authorized FSPs in the distribution feeder. Unlike frequency balancing, flexibility resources are utilized through the ABCM-D platform when feeder congestion occurs. The DSO submits offers to the local DSO market, and FSPs submit availability bids. Once the local DSO market clears for procured products, approved bids are communicated to FSPs. When congestion arises and the ABCM-D platform detects violations via real-time monitoring, coordination signals are dispatched to the market-approved FSPs to alleviate congestion. The ABCM-D platform assesses FSPs' responses, and the DSO issues an evaluation report to the local DSO market.

From these two main scenarios, various KPIs were defined to evaluate the performance of the different solutions developed in the Cypriot demo and quantifying the impact of the Cypriot demo to the grid operation. These KPIs are analysed in this deliverable in the subsequent sections.

2.3 Development and integration

2.3.1 ABCM-T/D platforms development and SUCs integration

In the development and integration process of the ABCM-T and ABCM-D platforms, as detailed in Deliverable 8.3 [1], significant effect has been made to align with functional requirements and architectural frameworks specified in Sections 4.2 and 4.3 of [1] respectively. Initially, the software development initiated with configuring backend infrastructure using the FIWARE platform, encompassing elements such as the context broker (ORION), database interface (QuantumLeap), and time-series database. Integration with the digital twin was facilitated through middleware development, including Python-based IoT agents for data exchange. Moreover, commercial phasor data concentrators from SEL [11] were employed to consolidate measurements from physical and virtual Phasor Measurement Units (PMUs), a critical aspect for real-time monitoring and analysis.

Subsequently, SUCs (see Table 2) were developed and seamlessly integrated into the ABCM-T/D platforms, as detailed in [1]. This integration was achieved through the establishment of standardized APIs, enabling the retrieval of last-values and historical data for real-time processing, post-event analysis and online coordination purposes. Each SUC was furnished with appropriate interfaces, empowering users to monitor transmission and distribution grids in real-time, pre-qualify ancillary service capacities, automate distribution grid operations, and assess the responses of Flexible Service Providers (FSPs).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

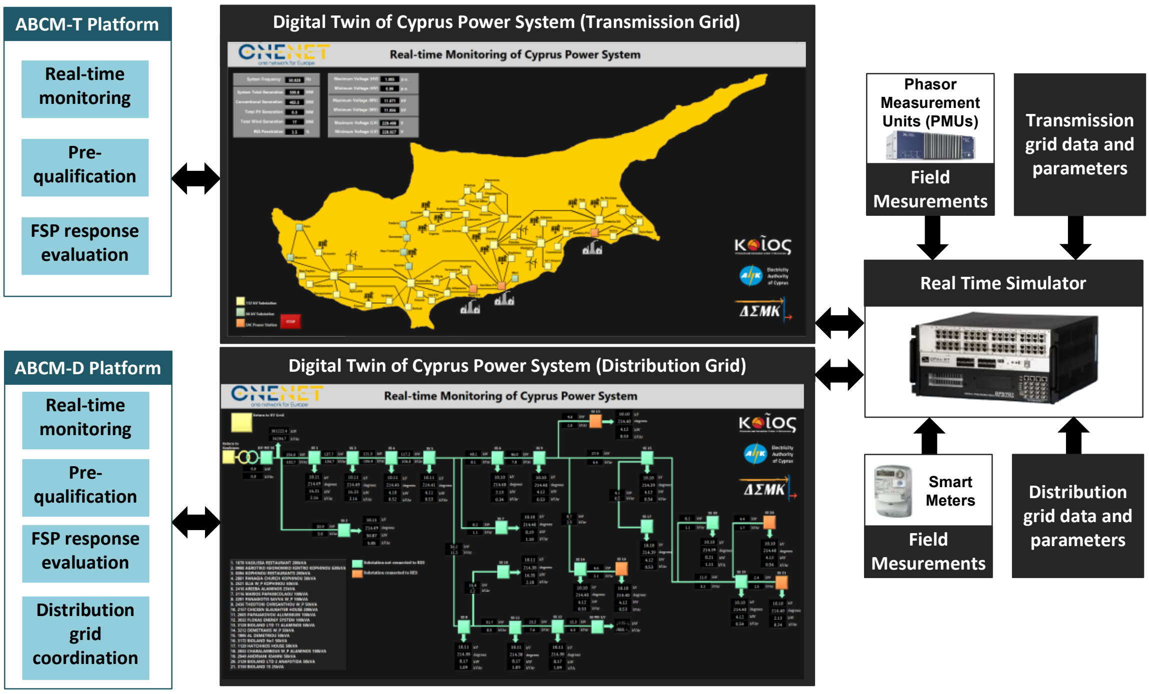


Figure 2: Development of the ABCM-T and ABCM-D platforms, where the SUCs have been incorporated and integration with the Cyprus power system digital twin through a control-HIL configuration.

2.3.1.1 Integration with Cyprus grid digital twin for validation and evaluation

Following platform development and SUC integration, the focus shifted towards the integration between the ABCM-T/D platforms with the Cyprus power system digital twin for validation and evaluation purposes. The Cyprus power system digital twin, including the entire transmission grid and part of the distribution grid has been developed through a high-fidelity simulation model enhanced with field measurements that is able to be executed in a Real-Time Simulator (RTS), as illustrated in Figure 2. The digital twin enables a very realistic and online replication of the actual power grid operation while allowing a non-invasive framework for demonstrating the Cyprus demo solutions.

The integration between the digital twin and ABCM-T/D platforms has been facilitated through a periodic and seamless data exchange approach, fostering a Control-Hardware in the Loop (HIL) framework for validating and demonstrating all the solutions developed for the Cyprus demo. The validation and evaluation of the SUCs and scenarios of the Cyprus demo through the real-time digital twin is presented in detail in Section 3 of this document.

2.3.1.2 Integration with an actual prosumer for validation

Another important activity for validating and evaluating the Cyprus Demo results considers the integration of an actual residential prosumer in the whole demonstration process. This was achieved through the OneNet

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Open Call procedure, which enables the involvement of a third-party company, Wise Wire Energy Solution Limited (WiseWire) for facilitating the engagement of an actual prosumer through the OneNet – ActiveProsumer cascading project [12]. The integration of the actual prosumer was particularly important for demonstrating the effectiveness of SUC4 related to the distribution grid coordination using FSPs and prosumers.

The actual prosumer integration, as demonstrated in Figure 3, has been achieved through the WiseWire Cloud that enables the bidirectional data exchange with the prosumers' smart meter and photovoltaic/storage inverters. The integration process has been facilitated through the development of two dedicated middleware: (a) Middleware A – responsible for integrating the residential building operation in the digital twin to accurately replicating the energy consumption and generation; and (b) Middleware B – dedicated for enabling the coordination of the residential building operation according to the active and reactive power control set-points generated by the real-time monitoring (SUC1) and distribution grid coordination (SUC4) tools of the ABCM-D platform. Through the two middleware, the Cyprus power system digital twin, the ABCM-D platform (equipped with SUC1 and SUC4), and the actual prosumer building were integrated in a real-time HIL configuration allowing an innovative demonstration framework where the ABCM-D platform is able to control the energy performance and grid interaction of an actual building and of various virtual buildings (emulated within the digital twin) while the actual building response is replicated within the digital twin to investigate the grid-level impact of the OneNet solution. This demonstration framework is useful for evaluating the results considering the congestion management scenario (Section 0) while evaluation results with the actual prosumer in the loop have already demonstrated in D8.3 [1].

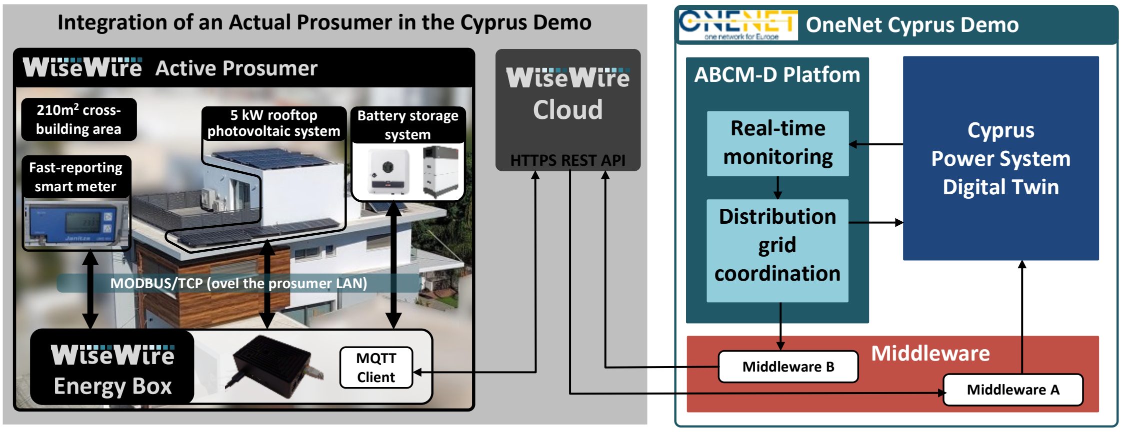


Figure 3: Integration of an actual prosumer in the Cyprus demo for demonstrating congestion management scenarios.

2.3.2 Ancillary services market development and integration

The OneNet project aims to enhance grid operational capabilities and increase RES penetration through seamless coordination among TSO, DSO, FSPs, and prosumers. Active participation and support from FSPs and prosumers, including the provision of ancillary services, are crucial for achieving these objectives. In response, a

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

new ancillary services market framework has been developed within the Cyprus demo of the project, enabling FSPs of varying scales to offer ancillary services, thus enhancing economic benefits and improving congestion management capabilities and grid stability. This framework operates within the existing broader electricity market structure, as presented in Figure 4.

The existing *Energy* market encompasses day-ahead, intra-day, and near-real-time markets, operated by the Global TSO Market. The day-ahead market focuses on energy balancing between prosumers and retailers, with the Global TSO Market finalizing energy production and consumption quantities at optimal prices to maximize Social Welfare (SW) and implementing energy balancing according to initial energy clearance in intra-day and near-real-time levels.

The new *Ancillary Services* market encompasses intra-day and near-real-time markets overseen by the Global TSO Market and the Local DSO Market, respectively. The new market framework developed within the OneNet project, as presented in Figure 4, aims to revolutionize ancillary services coordination, addressing the evolving needs of modern power grids. With a focus on seamless collaboration between TSO, DSO, and FSPs this framework facilitates efficient grid operation while maximizing the integration of RES. By enabling active participation from FSPs and TSO/DSO procuring of ancillary services, such as frequency regulation and congestion management, the framework enhances grid reliability and stability while economically benefiting all stakeholders.

The innovative framework designed to revolutionize ancillary services coordination in modern power grids consists of these two new Ancillary Services markets:

- ***The Intra-Day TSO FCR Ancillary Services Market (ID-TSO-FCR)*** focuses on supporting transmission grid stability by facilitating the provision of Frequency Containment Reserve (FCR) services. In this phase, a clearing process takes place to ensure the availability of FCR services for maintaining transmission grid stability in case of power disturbances. Offers for FCR service, including volume and price, originate from the ID-DSO-AS market, where FSPs connected at the distribution grid can place their offers. At the same market (ID-DSO-AS), the DSO provides the pre-qualification location-based limits to ensure that the provision of such FCR services will not cause any over-loading violation. Then both offers and pre-qualification limits are forwarded from ID-DSO-AS to the ID-TSO-FCR market. In the latter market, FSPs operating solely at the transmission level can directly submit generation offers for provisioning FCR. At the same time, the TSO determines the required FCR needs in terms of total MW/Hz to ensure system frequency stability and submits this demand bid with a corresponding price to the market. The generation offers, and demand bids and the pre-qualification limits, are communicated via the OneNet system to the market operator, the Global TSO Market, which conducts market clearing and settlement.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

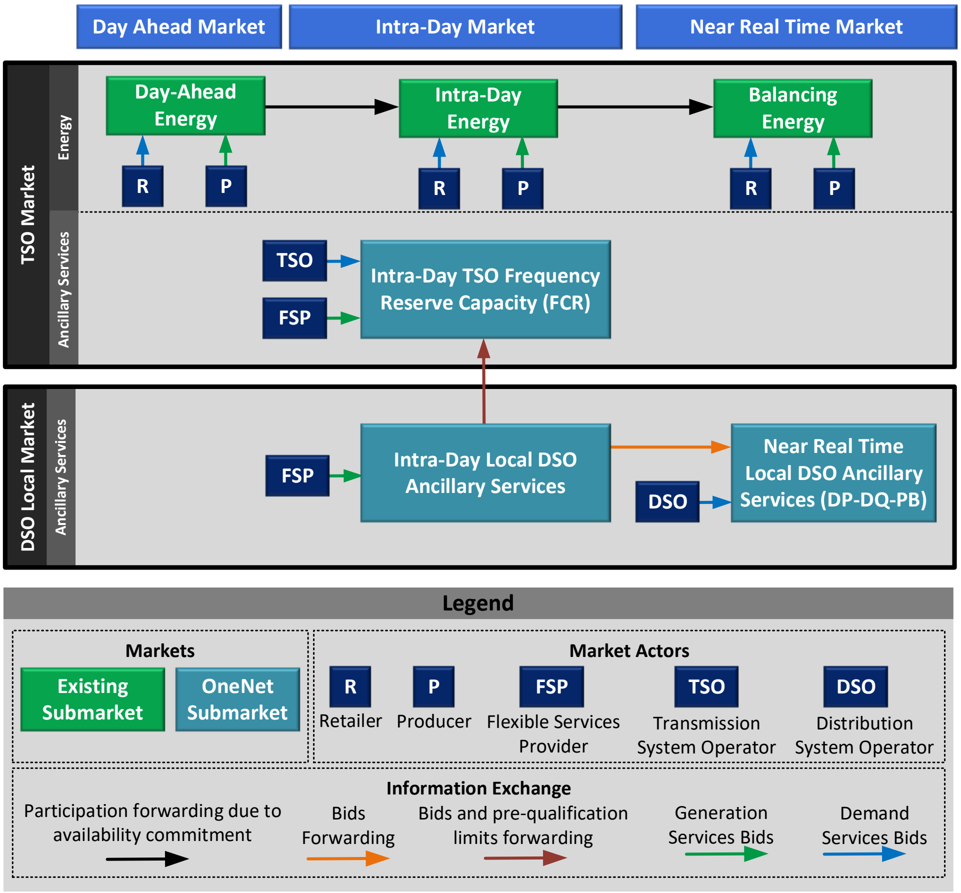


Figure 4: Energy market framework for the Cyprus demo.

- ***The Near Real-Time Local DSO Ancillary Services Market (NRT-DSO-AS)*** is designed to manage local grid congestion and enhance reliability and stability, enabling flexible service provision at the distribution substation level. This market handles near-real-time clearing for services dedicated to supporting the local grid, addressing congestion management needs at each substation. Ancillary Services (AS) involved include active power flexibility (ΔP), reactive power flexibility (ΔQ), and phase balancing (PB) to mitigate phase asymmetries within loading conditions. FSPs and prosumers connected to distribution grids place generation offers in the ID-DSO-AS market indicating their location, with only those directly linked to specific substations considered for clearing scenarios requiring congestion management. The services for congestion management are forwarded to NRT-DSO-AS market for the clearing process. On the other hand, the DSO calculates ancillary service needs at each substation to manage anticipated overloading conditions, including demands for ΔP and ΔQ to maintain operational limits. If intense asymmetries exist, the DSO can request for PB services as well to balance loading conditions, enhancing grid capacity utilization. Demand bids for ancillary services are transmitted to the NRT-DSO-AS market via the OneNet system, where the Local DSO Market operator conducts market clearing separately for each substation. The NRT-DSO-AS market operates on an hourly basis, with the Local DSO Market operator clearing market results and communicating them to participants (DSO, FSPs/prosumers) through the OneNet system, ensuring efficient RES integration while upholding grid stability and efficiency. These markets are pivotal in ensuring the seamless integration of RES while maintaining grid stability and efficiency.

Both markets play vital roles in the overarching objective of improving grid operational capabilities and optimizing RES integration. Additionally, they are closely linked to the ***Intra-Day Local DSO Ancillary Services Market (ID-DSO-AS)***, responsible for the submission of services offered by FSPs connected at the local substation level, allowing them to contribute to both transmission and distribution grid needs. FSPs at this level possess the capability to address requirements from both the Intra-Day TSO FCR market, such as active power FCR during frequency disturbances, and the Near Real-Time Local DSO Ancillary Services market, covering ΔP, ΔQ, and PB. Through the OneNet system, FSPs submit their service offerings for the upcoming 3-hour interval, utilized by both the Intra-Day TSO FCR clearing (occurring every 3 hours) and the hourly Near Real-Time Local DSO ancillary services clearing. Participants can present their offers up to 15 minutes before the start of the intended 3-hour period. Moreover, at this market level, operators calculate pre-qualification limits for available capacity for ancillary services at each substation using the pre-qualification tool. These limits are transmitted through the OneNet system from the Intra-Day Local DSO Ancillary Services market to the Intra-Day TSO FCR market to ensure that the clearing process avoids conflicting decisions (e.g., decisions by TSO market that can cause problems to the distribution grid).

The ancillary services market is facilitated through various interface tools developed within the OneNet project for different market participants, as already presented in Section 5 of [1]. For example, the interface tools developed for the ID-TSO-FCR market are depicted in Figure 5. Each FSP uses the interface/tool of Figure 5(a) to submit its upward and downward generation capacity in MW/Hz and corresponding price for each service, covering a 3-hour timeframe with 1-hour resolution. Figure 5(b) displays the interface tool for TSO Market participants, where the TSO submits the demand bids in MW/Hz along with the respective price for a 3-hour timeframe. Finally, the Global Market operator uses the tool in Figure 5(c) to access FSPs' generation offers and TSO demand bids, facilitating the market clearing process.

Similar market participation tools and interfaces, as the ones demonstrated in Figure 5 for the ID-TSO-FCR market, have been implemented for the NRT-DSO-AS market as well, with the difference being that NRT-DSO-AS operates and clears on an hourly basis. In this market, the demand participant tool is submitted by the DSO, and the market clearing is executed by the DSO market operator. The market clearing is executed separately (for each substation) for each hour slot, utilizing an optimization algorithm. The optimization algorithm for the clearing process is similar in both the ID-TSO-FCR and the NRT-DSO-AS markets, as explained in [1], although some minor modifications are considered for each particular market. The market clearing algorithm is designed as a linear programming optimization formulation with an objective function to maximize Social Welfare (SW) while considering all technical constraints. The technical constraints involve the maximum volume of FSPs

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

generation offers and operator's demand bids while incorporating services generation-demand balancing [13]-[14]. In addition, in ID-TSO-FCR market, the pre-qualification limits have been incorporated as constraint as well to restrict the awarding of FCR in a substation that may be over-loaded when the provision of the specific services is needed. The developed clearing algorithm seeks to award ancillary services to the FSPs with the lower cost until the procured TSO or DSO demands are satisfied.

FSP Market Participation Tool (Intra-Day Ancillary Services)

Flexible Services Providers (FSP)

FSPs can use this tool for placing the generation offers for availability into the ancillary service market

Day-Ahead Energy Market

Select Date / Time: 16-Aug-2023 07:00

FSP Identification Number: FSP-007

Placing Bids | Market Results

Market Player ID: FSP-007
Primary Substation: KOKKI-18
Secondary Substation: -

FCR TSO Ancillary Services Market | DP & DQ & PB Local DSO Ancillary Services Market

Frequency Containment Reserve (FCR)

Time	Upward Generation Capacity (MW/Hz)	Upward Generation Price (€/MW/Hz)	Downward Generation Capacity (MW/Hz)	Downward Generation Price (€/MW/Hz)
07:00	10	9	7	5
08:00	10	9	7	5
09:00	10	9	7	5

Place Generation Offers to Intra Day Ancillary Service Market

(a)

TSO Market Participation Tool (Intra-Day Ancillary Services)

Transmission System Operator (TSO)

TSO can use this tool for placing the demand bids for availability into the ancillary service market

Intra-Day Ancillary Services Market

Select Date/Time: 13-Jun-2023 20:00

TSO Identification Number FSP No.: TSO_Dem

Placing Bids | Market Results (Raw Data)

Market Player ID: TSO_Dem

FCR TSO Ancillary Services Market

Frequency Containment Reserve (FCR)

Time	Demand Capacity (MW)	Demand Bid Price (€/MWh)
20:00	100	15
21:00	120	15
22:00	80	15

Place Demand Bids to Day Ahead Energy Market

(b)

Global TSO Market Tool

Day-Ahead Energy Market | Intra-Day Ancillary Services Market (FCR)

Market Operator can use this Tool for Clearing the Global TSO Market

Intra-Day Ancillary Services (FCR) Market

Select Date/Time: 01-Feb-2023 00:00

Market Operator Identification Number FSP No.: FSP-001

Market Clearing | Market Results

1. Load Demand Bids | 2. Load Generation Offers | Clearing... | 4. Send Market Results

Frequency Containment Reserve (FCR)

Time	Demand Capacity (MW)	Demand Bid Price (€/MWh)
00:00	0	0
01:00	0	0
02:00	0	0

(c)

Figure 5: Developed tools for Intra-day TSO FCR Ancillary Services Market: (a) FSP, (b) TSO Market Participation, (c) Global TSO Market Operator

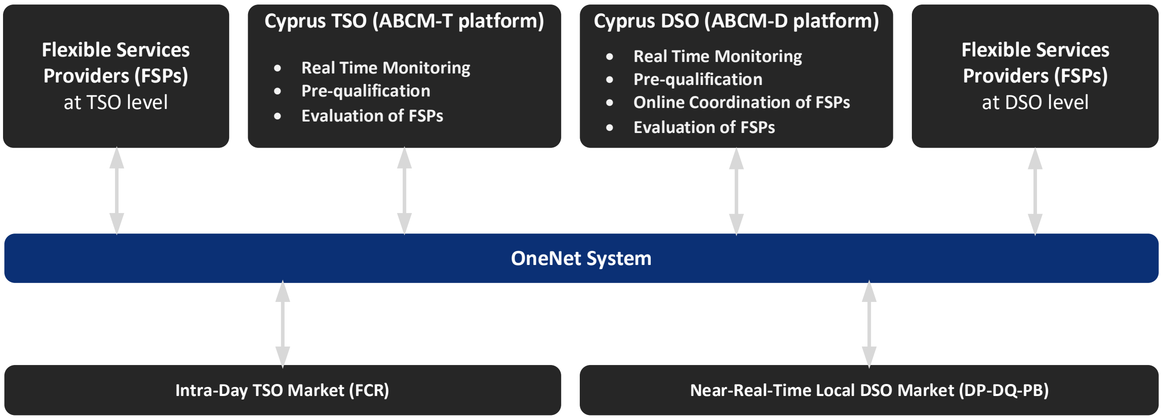


Figure 6: Integration of the new ancillary services market of the Cyprus demo with the ABCM-T and ABCM-D platforms through the OneNet System.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

The entire market framework with all the market participation tools and clearing interfaces, as described above, have been developed and then integrated through the OneNet System allowing a secure and seamless data exchange between all the market participants, as illustrated in Figure 6. The OneNet System facilitates effective collaboration among various entities within the electricity infrastructure, including TSOs, DSOs, market operators, and FSPs. By providing standardized data exchange capabilities, the system enables seamless interaction between different platforms such as ABCM-T, ABCM-D, FSPs, and market operator platforms. The ABCM-T/D platforms equip operators with tools for monitoring and managing both transmission and distribution grids, ensuring efficient and stable operation. Through APIs developed for communication with the OneNet system, different entities can exchange vital information, such as product procurement, bid placements, market clearing results, and prequalification limits. This integration allows for coordinated actions and improved decision-making processes across the electricity and ancillary services market in order to enhance grid reliability and stability while optimizing resources utilization towards a more sustainable energy future. More information about the new ancillary services market framework and its integration through the OneNet system can be found in Section 5 of [1].

3 Cypriot demo evaluation

3.1 Validation and evaluation framework

The design (D8.1) [4] and development (D8.3) [1] of the Cypriot demo followed the validation, and evaluation phase. In this phase the validation (refinement, communication, integration, debugging and improvement) of the developed platforms (SUCs) and the market operation was performed by using a KPI-based approach. In the Cyprus demonstration, we have identified 17 Key Performance Indicators (KPIs) to assess the effectiveness of the solutions developed. Some of the KPIs are computed based on the two scenarios (described above) within the Cyprus transmission and distribution system, while some others are related to the market operation and the SUC performance. The KPIs along with a brief description and the category that each KPI is related to are shown in Table 3.

Table 3. List of KPIs

Number	ID	Name	Description	Category
1.	KPI_N14	Rate of Change of Frequency Improvement	Measurement of frequency stability improvement	Scenario 1
2.	KPI_N15	Improvement of Frequency Nadir	Assessment of the enhancement in the lowest frequency point during operation	Scenario 1
3.	KPI_N16	Overloading	Evaluation of system overloading instances	Scenario 2
4.	KPI_N17	Improvement on Voltage Limits Violations	Measurement of improvements in violations of voltage limits	Scenario 2
5.	KPI_N18	Reduction of Energy Losses	Calculation of energy loss reduction across the system	Scenario 2
6.	KPI_N19	Reduction of Loading Asymmetries	Assessment of the decrease in loading imbalances within the system	Scenario 2
7.	KPI_N20	Power Factor Improvement	Evaluation of enhancements in power factor	Scenario 2
8.	KPI_H19A	Number of DER available for BSPs	Count of available Distributed Energy Resources for Balancing Service Providers	Market
9.	KPI_H18A	Volume of Balancing Service Offers for UP reserves	Measurement of service offers volume for Upward Primary Reserves	Market
10.	KPI_N21	Voltage Magnitude and Angle Error	Assessment of errors in voltage magnitude and angle	SUC -Monitoring
11.	KPI_N22	Calculated Limits Deviation	Measurement of deviations from calculated limits	SUC - Prequalification
12.	KPI_H23E	Deviation of the FSP response compared to the awarded bid	Evaluation of Frequency Service Provider (FSP) response deviations from awarded bids	SUC - Evaluation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

13.	KPI_H01	Number of FSPs	Count of Frequency Service Providers participating in the system	Market
14.	KPI_H07	Number of Transactions	Count of transactions within the system	Market
15.	KPI_H09A	Volume of Transactions – Received Bids (Availability)	Measurement of volume for received bid transactions (availability)	Market
16.	KPI_H09B	Volume of Transactions - Cleared Bids (Availability)	Measurement of volume for cleared bid transactions	Market
17.	KPI_H14A	Available Flexibility	Assessment of the system's available flexibility	Market

3.1.1 KPIs definition for SUCs

This section describes the KPIs that a related to the SUCs of the Cypriot demo [4], [9].

KPI_N21-Voltage magnitude and angle error (SUC1)

This indicator provides information about the estimation accuracy of the real-time monitoring scheme. It is calculated as the difference between the actual and the estimated voltage and angle (provided by the monitoring scheme). In the case of the Cyprus demo the monitoring scheme was applied to both transmission and distribution grid and was intended to provide the operating conditions of the grid through the processing of measurements. For the transmission grid both voltage magnitudes and voltage angles for all the buses were provided, while in the case of the distribution grid only the voltage magnitude was estimated since the angles do not deviate a lot from the reference bus. Therefore, this KPI can be calculated as,

$$V_{error} = \frac{1}{N}\frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{N}\left|V_{act}^{i,t} - V_{est}^{i,t}\right| \tag{1}$$

$$\theta_{error} = \frac{1}{N}\frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{N}\left|\theta_{act}^{i,t} - \theta_{est}^{i,t}\right| \tag{2}$$

where:

$V_{error}, \theta_{error}$: Estimation error of the voltage magnitude (p.u) and angle (degrees) respectively

N: Number of buses in the system.

$V_{act}^{i}, \theta_{act}^{i}$: Actual voltage magnitude (p.u) and voltage angle (degrees) respectively of the *i-th* bus.

$V_{est}^{i}, \theta_{est}^{i}$: Estimated voltage magnitude (p.u) and voltage angle (degrees) respectively of the *i-th* bus.

T, is the total number of time instances that the estimator is run.

N, is the total number of buses in the system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

KPI_N22-Calculated limits deviation (SUC2)

This indicator provides information about the calculation accuracy of the limits extracted from the prequalification tool. This tool provides the limits of the HV/MV interface in order to ensure that the transformer limits will not be violated in case where frequency support is provided by the DERs in the distribution grid. The prequalification tool provides the operational limits to the FCR market one hour before the clearing of the market. This KPI shows the accuracy of the prequalified limits in each hour by comparing the prequalified limits (that were provided one hour ago) with the actual limits of the transformer at each hour. Thus, this KPI is calculated as,

$$LD = max\left[\frac{|L_{act}(k) - L_{cal}(k)|}{L_{act}(k)}.100\right] \tag{3}$$

where:

LD: Maximum deviation (from all the calculated limits) of the calculated operational limits from the actual ones for a specific time interval (%)

$L_{act}(k)$: Actual operational limits of the HV/MV interface that the system has at the k^{th} hour (kA)

$L_{cal}(k)$: Calculated operational limits of the HV/MV interface extracted by the prequalification tool for the k^{th} hour.

KPI_H23E-Deviation of the FSP response compared to the awarded bid (SUC3)

This indicator assesses if the response of the FSPs corresponds to the awarded bids by the market. The indicator provides a percentage of how much each FSP response is in line with its market obligation. This KPI was calculated for the case of the FSPs located in the distribution grid that participated in the near real time DSO market for the provision of congestion management services (ΔP, ΔQ and PB coordination). For this KPI two indicators are used namely the maximum deviation of all the FSPs and the mean deviation of all the FSPs. The KPI can be calculated as,

$$\Delta P_{max} = \max_{k}\left(\frac{P_{FSPi}(k) - P^{*}(k)}{P^{*}(k)}\right) \cdot 100 \tag{4}$$

$$\Delta P_{mean} = \operatorname*{mean}_{k}\left(\frac{P_{FSPi}(k) - P^{*}(k)}{P^{*}(k)}\right) \cdot 100 \tag{5}$$

where:

$\Delta P_{max}, \Delta P_{mean}$: Maximum and mean value of the power deviation (ΔP) (kW or kVAr). The same formula is applied for reactive power as well to determine the ΔQ_{max} and ΔQ_{mean} indicators.

P^{*}, Q^{*}: Active (kW) and reactive (kVAr) power that an FSP should provide according to the awarded market bids. Any deviation from these values is recorded as deviation of the FSPs response.

$P_{FSPi}(k)$: Actual power provided by the FSP i

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

3.1.2 KPIs definition for Cypriot Demo Scenarios

This Section defines the KPIs that are related to the two evaluation scenarios of the Cypriot demo. It should be noted that since the KPIs are directly related to the operation of the system, they are also related to the SUC4 that has to do with the coordination of the distributed energy during operation.

KPI_N14-Rate of Change of Frequency Improvement (Scenario 1)

This indicator considers the maximum rate of frequency change (in Hz/s) after an intense frequency event in the Cyprus power system. This scenario demonstrated how the renewable energy resources (RES) can contribute to the frequency support of the system during a frequency disturbance. In this sense, two different RES penetration levels are considered for this KPIs, while for each RES penetration level, 2 cases are demonstrated. In the first case (case 1) the RES provide only droop support to the system while in the second case (case 2) the RES provide both droop and virtual inertia during an under-frequency event. The two cases were compared with the baseline case where the frequency support was provided only by the conventional generators. Thus, the ROCOF improvement in percent can be calculated as,

$$ROCOFI = \frac{ROCOF_{BaU} - ROCOF_{R\&I}}{ROCOF_{BaU}} \cdot 100 \tag{6}$$

where:

$ROCOFI$: Rate of Change of Frequency improvement (%)

$ROCOF_x$: for each scenario $x \in \{R\&I\ (RES\ support), BaU\ (baseline)\}$

$ROCOF_x = \max_k \left(\frac{f(k)-f(k-1)}{\Delta t}\right)$ (Hz/s)

KPI_N15-Improvement of Frequency Nadir (Scenario 1)

This indicator shows the improvement of the frequency nadir, which is the minimum point that the frequency reaches (in Hz) after an intense disturbance on system balancing. This KPI is also related to the frequency support of the system by RES during the disturbance. As in KPI_N14, two different RES penetration levels are considered, while for each RES penetration level 2 cases are demonstrated. In the first case (Case 1) the RES provide only droop support to the system while in the second case (Case 2) the RES provide both droop and virtual inertia during an under-frequency event. The two scenarios were compared with the baseline case where the frequency support was provided only by the conventional generators. The Frequency Nadir Improvement can be calculated as,

$$FNadirI = \frac{(f_n - FreqNadir_{BAU}) - (f_n - FreqNadir_{R\&I})}{f_n - FreqNadir_{R\&I}} \cdot 100 \tag{7}$$

where:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

$FNadirI:$ Improvement of Frequency Nadir (%)

$FreqNadir_x$ for each scenario $x \in \{R\&I\ (RES\ support), BaU\ (baseline)\}$

$FreqNadir_x = \min\,[f_x(k)]\ \ x \in \{R\&I, BAU\}$ (Hz)

f_n = ***nominal frequency (Hz)***

KPI_N16-Overloading (Scenario 2)

This indicator provides information for the maximum overloading conditions that occurs at the distribution grid with high penetration of RES in the system. Actually, the KPI shows the improvement in the maximum thermal loading (TL) status of a transformer/line, after the application of the innovative services provided by the flexible resources. The innovative solution provided by the FSPs is the coordination of the real and reactive power (P and Q) injection at each FSP node (ΔP and ΔQ coordination). The coordination signals are sent to the FSPs by the DSO. The KPI has been calculated in both MV and LV distribution grids, while in the case of the LV distribution, except from the (ΔP and ΔQ coordination) service the FSPs can provide phase balancing (PB) service as well. Furthermore, in the case of the LV distribution grid, two cases were investigated, (1) nominal power direction (no PV generation) and (2) reverse power direction (excess PV generation). The thermal loading improvement (TL_i) between the R&I (congestion management services) and the BAU (no FSP services) scenario can be calculated by,

$$TLI = \frac{|TL_{BAU} - TL_{R\&I}|}{TL_{BAU}}.100\ [\%] \qquad (8)$$

where the TL_x for each scenario $x \in \{R\&I, BaU\}$ is given by,

$TL_x = \frac{\max\,(S(k))}{S_n} \qquad x \in \{R\&I, BAU\}$

$S(k)$: apparent power of line/transformer at sample k.

S_n: rated apparent power of line/transformer.

KPI_N17- Improvement on voltage limits violations (Scenario 2)

This indicator provides information for the distribution grid's maximum over/under-voltage conditions in terms of intensity and duration. All the scenarios that run to the Cyprus demo did not exhibit any over and under voltage conditions during the steady state operation of the grid, therefore the improvement in terms of the voltage limit violation is zero for all the cases examined. It should be noted that The Maximum Upper and Lower Voltage Intensity improvement ($MUVVI_i$ and $MLVVI_i$) between the R&I and the BaU scenario are calculated according to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

$$MUVVI_i = \frac{MUVVI_{R\&I} - MUVVI_{BaU}}{MUVVI_{BaU}} \cdot 100[\%];\ MLVVI_i = \frac{MLVVI_{R\&I} - MLVVI_{BaU}}{MLVVI_{BaU}} \cdot 100\ [\%] \qquad (9)$$

where the maximum upper/lower voltage violation intensity *MUVVI*$_x$ and *MLVVI*$_x$ for each scenario $x \in \{R\&I, BaU\}$ is given by:

$$MUVVI_x = \max_j\left(\sum_k UVV_j(k) \cdot (V_j(k) - V_{max})T_s\right),$$

$$MLVVI_x = \max_j\left(\sum_k LVV_j(k) \cdot (V_{min} - V_j(k))T_s\right),$$

j ∈ $\{1, \ldots, N\}$ and represents all the voltage buses of the distribution grid under examination.

UVV_j and LVV_j represents upper and lower voltage violations respectively for bus j and defined as 0/1 as given by,

$$UVV_j = \begin{cases} 1, & V_j(k) > V_{max} \\ 0, & V_j(k) \leq V_{max} \end{cases} \quad \text{and} \quad LVV_j = \begin{cases} 1, & V_j(k) < V_{min} \\ 0, & V_j(k) \geq V_{min} \end{cases}$$

LVV: lower voltage violations, defined as 0/1 according to $LVV = \begin{cases} 1, & V(k) < V_{min} \\ 0, & V(k) \geq V_{min} \end{cases}$ and Bus j ∈ $\{1, \ldots, N\}$,

$V_j(k)$ are the voltage measurements at bus *j* at sample *k*,

V_{min} and V_{max} are the maximum and minimum voltage limits according to the grid regulations, and T_s is the sample time, time between 2 consecutives samplings.

KPI_N18-Reduction of energy losses (Scenario 2)

This indicator provides information for the energy losses of the distribution grid in the case that the ΔP, ΔQ and PB services are provided to the distribution. Since in the Cyprus demo 2 levels of distribution grid are considered (MV and LV), the KPI values were calculated for both grid levels as,

$$ELI = \frac{EL_{BaU} - EL_{R\&I}}{EL_{BaU}} \cdot 100 \quad [\%] \qquad (10)$$

where the energy losses *EL*$_x$ for each scenario $x \in \{R\&I, BaU\}$, the R&I corresponds to the scenario where ancillary services are provided by the FSPs while BaU is the scenario where no ancillary services are provided. The energy losses can be calculated as,

$$EL_x = \frac{Total\ Energy\ Losses_x}{Total\ Load\ Energy_x} \cdot 100 \quad [\%]$$

$Total\ Energy\ Losses_x$ represents the total energy losses in the part of the grid under investigation and is calculated by the difference between the input and the output energy for the *x* scenario (R&I or BaU). $Total\ Load\ Energy_x$ corresponds to the total load served by the grid under investigation during the x scenario (R&I or BaU).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

KPI_N19-Reduction of loading asymmetries (Scenario 2)

This indicator provides information about the loading asymmetry between the three phases (Current Phase Unbalanced Factor) at the substation level (either primary or secondary substation), before (BaU) and after (R&I) the provision of local flexibility services for power quality enhancement by the local FSPs. The reduction of loading asymmetries is measured according to the maximum and average Current Phase Unbalance Factor reduction ($MCPUF_r$ and $ACPUF_r$ respectively) between the R&I (with phase balancing services) and the BaU (no phase balancing services) scenario is calculated according to,

$$MCPUF_r = \frac{\max\limits_k(CPUF_{BaU}(k)) - \max\limits_k(CPUF_{R\&I}(k))}{\max\limits_k(CPUF_{BaU}(k))} \cdot 100 \quad [\%] \tag{11}$$

$$ACPUF_r = \frac{\underset{k}{\text{average}}(CPUF_{BaU}(k)) - \underset{k}{\text{average}}(CPUF_{R\&I}(k))}{\underset{k}{\text{average}}(CPUF_{BaU}(k))} \cdot 100 \quad [\%] \tag{12}$$

with the Current Phase Unbalanced Factor $CPUF_x$ for each scenario $x \in \{R\&I, BaU\}$ are given by,

$$CPUF_x(k) = \frac{|I^0(k)| + |I^N(k)|}{|I^P(k)|} \cdot 100 \quad [\%],$$

where:

$MCPUFR$: Maximum Current Phase Unbalance Factor Reduction (%)

$ACPUFR$: Average Current Phase Unbalance Factor Reduction (%)

$CPUF_x$: Current Phase Unbalanced Factor for scenario x

k: sample

I^0: is the zero-sequence component of the loading current at the substation

I^N: is the negative sequence component of the loading current at the substation

I^P: is the positive sequence component of the loading current at the substation

KPI_N20-Power factor improvement (Scenario 2)

This indicator shows the improvement of the power factor value in different nodes of the distribution grid. Actually, this KPI shows the improvement in the minimum power factor of a node, after the application of the ΔP and ΔQ coordination solution (provided by the FSPs) that it was developed in the Cypriot demo. The power factor improvement (PF_i) between the R&I (ΔP and ΔQ coordination) and the BaU (no coordination) scenario is given by,

$$PFI = \frac{PF_{R\&I} - PF_{BAU}}{PF_{BAU}} .100\ [\%] \tag{13}$$

where the PF_x for each scenario $x \in \{R\&I, BaU\}$ is given by

$$PF_x = \min\left[\frac{P(k)}{\sqrt{P(k)^2 + Q(k)^2}}\right] \quad x \in \{R\&I, BAU\} \tag{14}$$

with P representing the active power, Q the reactive power, and k the sample.

The power factor improvement was also examined in two operating conditions of the LV system namely, (1) nominal power direction (no PV generation), and (2) reverse power direction (excess PV generation), for two types of ancillary services ΔP and ΔQ coordination, and ΔP and ΔQ coordination and phase balancing. It should be mentioned that both services target congestion management and not the power factor correction, while a good power factor values should be close to unity.

3.1.3 KPIs definition for Market

This Section describes the KPIs related to the electricity market operation of the Cypriot demo.

KPI_H19A-Number of DER available for BSPs

This KPI indicates the number of DER (located at the distribution grid) that take part to the market for the provision of ancillary services to the grid. In the scenarios of the Cyprus demo, the DERs are available in two levels of the grid namely the MV and LV. The DERs participate in the market provide bids for ΔP and ΔQ coordination, and Phase Balancing (PB).

KPI-H18A-Volume of balancing service offers for UP reserves

This KPI shows the volume of balancing service offers for UP reserves submitted to the flexibility platform by BSPs from the distribution network. In particular, the KPI indicates the volume of active power that is available by the FSPs located at the distribution network for congestion management. In the Cypriot demo the market for the congestion management reserve is the Near real time DSO market which clears every hour the availability of FSPs.

KPI_H01 Number of FSPs

This KPI indicates the number of FSPs that participate in the market for the provision of ancillary services to the grid. In the scenarios of the Cypriot demo, the FSPs are available in the three levels of the grid namely the HV, MV, and LV. These FSPs participate in the market providing bids for frequency support, ΔP and ΔQ coordination, and phase balancing.

KPI_H07 Number of transactions

This indicator measures the number of transactions by measuring the number of offered and cleared bids for each product. In the case of the Cypriot demo three different scenarios are executed in the HV, MV, and LV. In the case of the transmission grid, a frequency containment reserve product is procured by the TSO while in the MV and LV congestion management services are procured. The number of transactions is analyzed for each grid separately.

KPI_H09A Volume of transactions – received bids (Availability) and KPI_H09B Volume of transactions-cleared bids (Availability)

These indicators measure the volume of received bids in kW (or kVAr) for a 3-hour period in the case of the scenarios examined in the HV, MV, and LV grid as well as the volume of cleared bids for the same scenarios. The service that is provided by the FSPs in the HV level is related to the FCR, while to the MV and LV level is related to the congestion management. In the case of the HV level the volume of received bids and the volume of cleared bids for a 3-hour period corresponds to the Global TSO market while for the MV and LV corresponds to the Near real time market.

KPI_H14A Available flexibility

This indicator assessed the available flexibility that can be provided by the FSPs that are located at the DSO level for congestion management services. This flexibility is calculated as,

$$Flexibility_{\%,t} = \frac{\sum P_{AvailableFlexibility,t}}{\sum P_{TotalinArea,t}} \cdot 100 \tag{15}$$

where:

$Flexibility_{\%}$: Percentage of available flexible power with respect to the total demand at a specific grid segment in reporting period (%), in the trading period t.

$\sum P_{AvailableFlexibility,t}$: Power in MW of available flexibility at a specific grid segment in reporting period (MW), in the trading period t.

$\sum P_{TotalinArea,t}$: Total power demand in MW at DEMO grid segment (MW) in the trading period t.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

3.2 Validation and evaluation of SUCs

The validation and demonstration of the 3 SUCs along with their related KPIs are discussed in this section. More specifically, the KPIs that are related to the grid monitoring, the pre-qualification of the limits, and the evaluation of the FSP response are discussed.

3.2.1 Accuracy of the real time monitoring of the grid (KPI_N21)

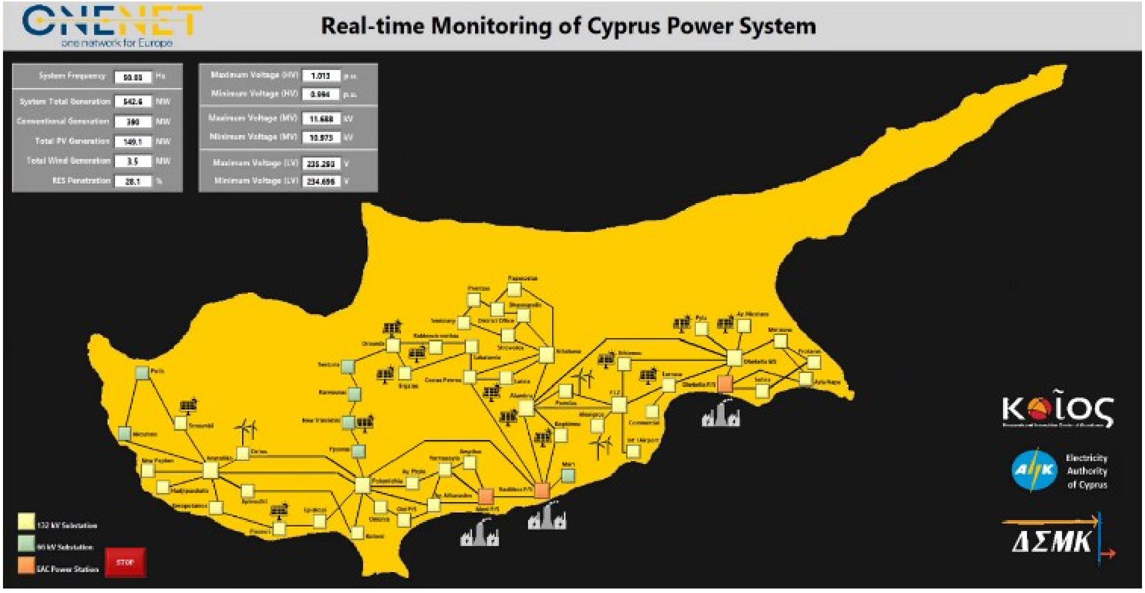
The SUC1 deals with the monitoring of the transmission and distribution grid. At the transmission level a state estimator based on Phasor Measurement Unit (PMU) measurements is developed and used for monitoring the Cyprus transmission grid. In particular, 18 PMUs are installed in the Cyprus transmission level, providing real time measurements to the developed PMU-based estimator. For evaluating the real time monitoring of the transmission grid the PMU based estimator run for 1 day with 1 second resolution, while the number of buses in the transmission grid is 58. The values for this KPI that are related to the monitoring of the transmission grid are shown in Table 4. As it is evident, the accuracy for the transmission grid monitoring scheme is very high since the voltage magnitude error is in the range of 10^{-4} and the angle error is 0.02 degrees. In the case of the distribution grid monitoring, the developed state estimator was based on conventional measurements and smart meters and the results presented in Table 4 are related to an MV distribution grid of 20 nodes. The monitoring scheme for the distribution grid was validated for 1 day with 1-minute measurements reporting rate. The average error of the developed monitoring scheme for the distribution grid is also very low (in the range of 10^{-3}), indicating the high accuracy of the developed monitoring scheme.

Table 4: Voltage magnitude and angle error

Scenario	V_{error} (p.u)	θ_{error} *(degrees)*
Transmission grid	$3.32\text{x}10^{-4}$	0.02
Distribution grid (MV)	$4.8\ \text{x}10^{-3}$	-

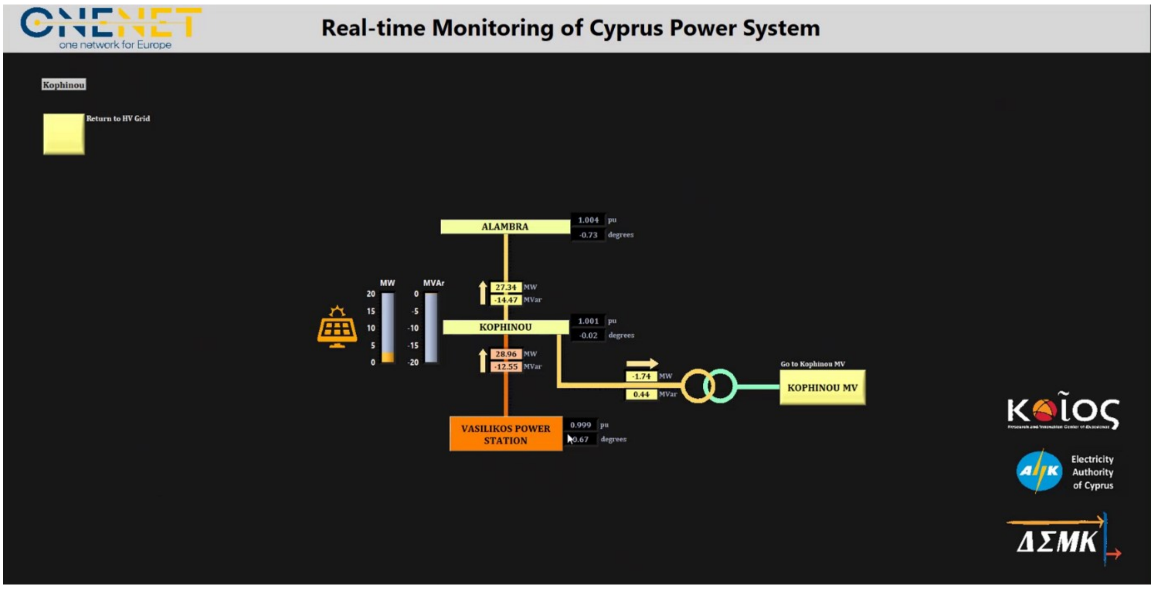
Figure 7 presents the dynamic real-time monitoring of the transmission level of the Cyprus demo. The monitor interface offers an online evaluation of the system providing valuable information such as the system frequency, total demand, conventional and renewable generation, and voltage limits. The user can also navigate to the high voltage substation and can monitor the states of this bus and the power flows flowing in or out of this bus.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739



System Frequency 50.00 Hz
System Total Generation 542.6 MW
Conventional Generation 390 MW
Total PV Generation 149.1 MW
Total Wind Generation 3.5 MW
RES Penetration 28.1 %
Maximum Voltage (HV) 1.013 p.u.
Minimum Voltage (HV) 0.994 p.u.
Maximum Voltage (MV) 11.688 kV
Minimum Voltage (MV) 10.973 kV
Maximum Voltage (LV) 235.293 V
Minimum Voltage (LV) 234.696 V

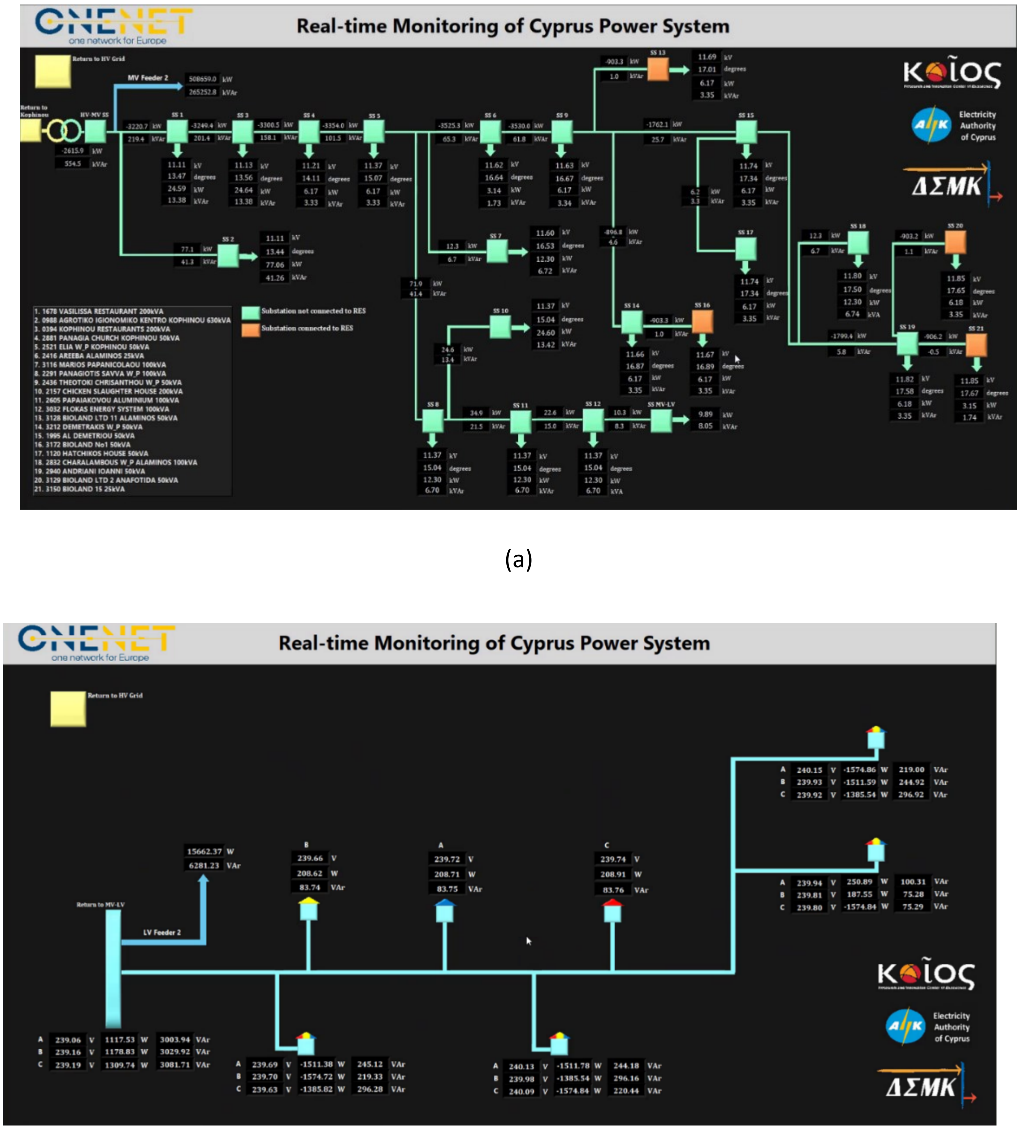
(a)



(b)

Figure 7: (a) Monitoring interface for the transmission grid and (b) monitoring of the HV-MV substation level

In Figure 8, the monitoring interface of the MV (Figure 8 (a)) and LV Cyprus distribution (Figure 8 (b)) grid is shown. In the MV interface the user can see the voltage magnitudes and angles of the nodes as well as the power flows and power injections. In the case of the LV monitoring interface the user can see the real and reactive power consumption of each end user as well as three phase voltage magnitude.



1. 1678 VASILISSA RESTAURANT 200kVA
2. 0988 AGROTIKO IGIONOMIKO KENTRO KOPHINOU 630kVA
3. 0394 KOPHINOU RESTAURANTS 200kVA
4. 2881 PANAGIA CHURCH KOPHINOU 50kVA
5. 2521 ELIA W_P KOPHINOU 50kVA
6. 2416 AREEBA ALAMINOS 25kVA
7. 3116 MARIOS PAPANICOLAOU 100kVA
8. 2291 PANAGIOTIS SAVVA W_P 100kVA
9. 2436 THEOTOKI CHRISANTHOU W_P 50kVA
10. 2157 CHICKEN SLAUGHTER HOUSE 200kVA
11. 2605 PAPAIAKOVOU ALUMINIUM 100kVA
12. 3032 FLOKAS ENERGY SYSTEM 100kVA
13. 3128 BIOLAND LTD 11 ALAMINOS 50kVA
14. 3212 DEMETRAKIS W_P 50kVA
15. 1995 AL DEMETRIOU 50kVA
16. 3172 BIOLAND No1 50kVA
17. 1120 HATCHIKOS HOUSE 50kVA
18. 2832 CHARALAMBOUS W_P ALAMINOS 100kVA
19. 2940 ANDRIANI IOANNI 50kVA
20. 3129 BIOLAND LTD 2 ANAFOTIDA 50kVA
21. 3150 BIOLAND 15 25kVA

🟩 Substation not connected to RES
🟧 Substation connected to RES

(a)

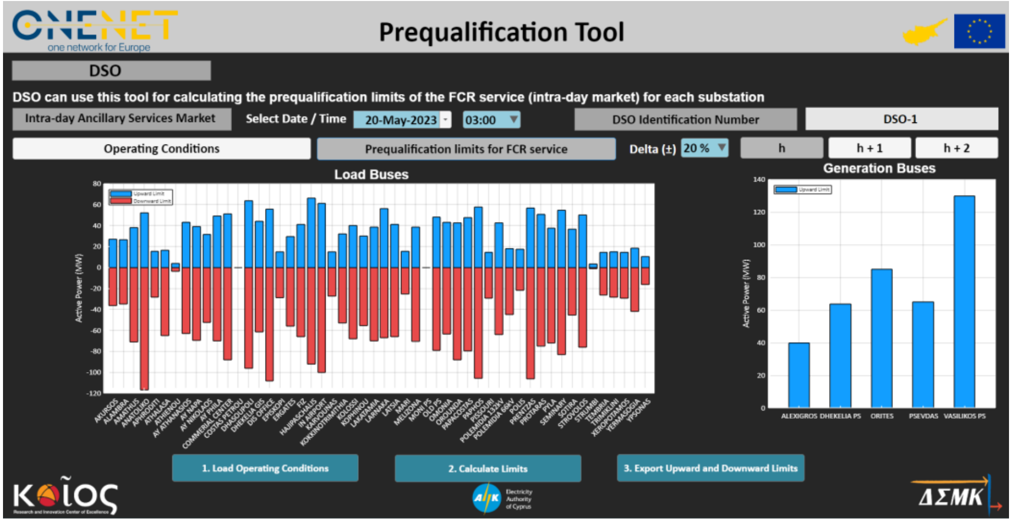
(b)

Figure 8: Monitoring interface for the distribution grid (a) MV feeder and (b) LV feeder

3.2.2 Prequalification limit accuracy (KPI_N22)

The prequalification scheme is crucial for ensuring the reliability of distribution grid operations when FSPs located at the distribution grid participate in the Intra-Day TSO Frequency Containment Reserve market. By analysing past data, the prequalification tool determines the capacity of each HV substation transformer, indicating the maximum power flow in both directions that each substation can handle without being overloaded. These limits are communicated to the market to ensure the smooth operation of the grid. The Graphical Interface (GI) tool, depicted in Figure 9, assists in this process, allowing users to monitor operations and share maximum and minimum limits with the market, thereby enabling FSPs in the distribution system to offer frequency support services without disruptions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739



Prequalification Tool

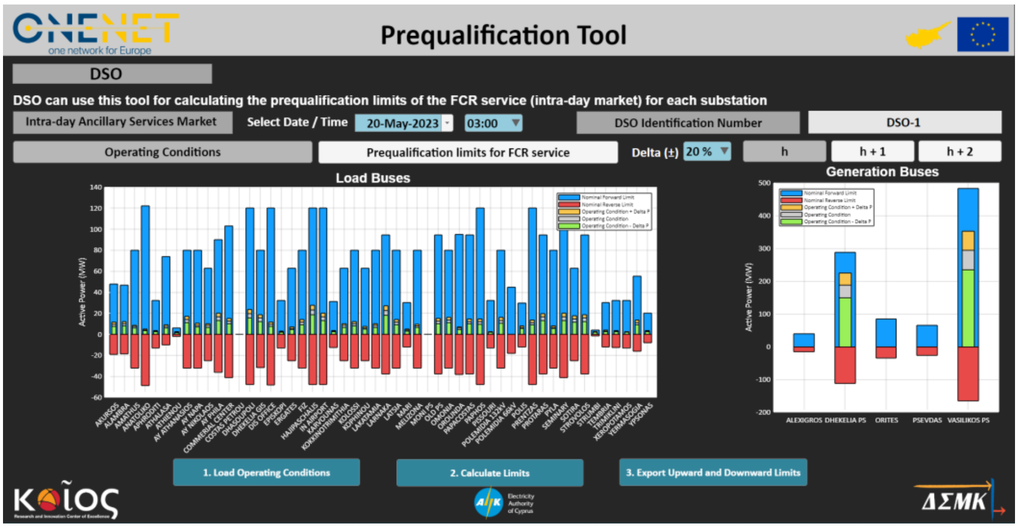
DSO

DSO can use this tool for calculating the prequalification limits of the FCR service (intra-day market) for each substation

Intra-day Ancillary Services Market | Select Date / Time: 20-May-2023, 03:00 | DSO Identification Number: DSO-1

Delta (±): 20 %

(a)



Prequalification Tool

DSO

DSO can use this tool for calculating the prequalification limits of the FCR service (intra-day market) for each substation

Intra-day Ancillary Services Market | Select Date / Time: 20-May-2023, 03:00 | DSO Identification Number: DSO-1

Delta (±): 20 %

(b)

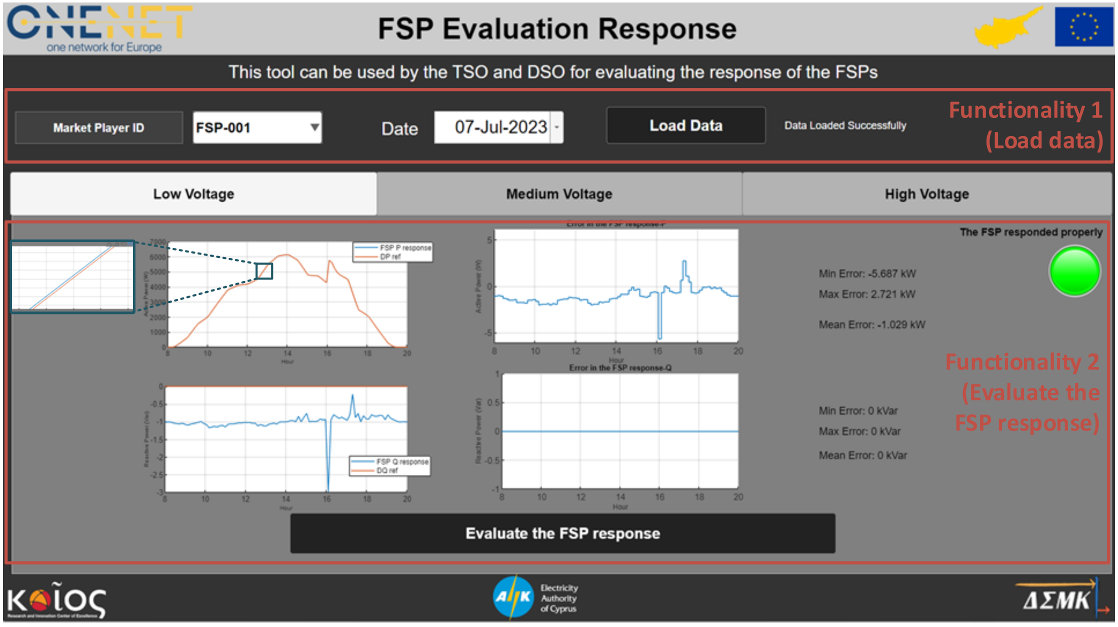
Figure 9: Graphical Interface of the Prequalification Tool: (a) Substations "Operating conditions", (b) "Prequalification limits for FCR service"

The KPI for the prequalification tool is the KPI_N22 "Calculated limits deviation". This KPI shows the accuracy of the limit calculations derived from the prequalification tool. The KPI was calculated based on the operating conditions of scenario 1 where at some point an under-frequency event occurs. Considering these operating conditions, the maximum **load deviation for a three-hours period was around 1.87%**. This shows that the limits provided by the prequalification tool is quite accurate, although they are calculated one hour before the market clearing.

3.2.3 Evaluation of FSP response (KPI_H23E)

The third SUC developed for the Cyprus demo focuses on evaluating the response of FSPs to market-cleared services, considering both automatic activations based on the grid conditions and manual activations by operators. This tool enables analysis by both TSOs and DSOs to extract insights for technical and administrative purposes, evaluating each FSP's capability to meet market and operator demands. Additionally, it facilitates the market operators to impose penalties in cases where FSPs fail to respond correctly. Developed using MATLAB's App Designer, the FSP evaluation tool features a graphical user interface (GUI), as shown in Figure 10. The evaluation of the FSP response can be done for all the FSPs located at the different voltage levels of the system. Furthermore, the tool provides an insight of how each FSP responds during an event indicating the minimum, maximum, and mean error that the FSP declines from the expected operation considering the market cleared values. In order to evaluate the performance of this tool the KPI_H23E namely, “deviation of the FSP response compared to the awarded bid” is used. The indicator provides a percentage of how much each FSP response is in line with its market obligation.

This KPI was calculated for the case of the FSPs located in the distribution grid (MV and LV) that participated in the near real time DSO market for the provision of congestion management services (ΔP, ΔQ and PB coordination). For this KPI two indicators are used namely the maximum deviation of all the FSPs and the mean deviation of all the FSPs. In the case of the LV grid both nominal and reverse power flow direction was assumed, where the FSPs provided only ΔP, ΔQ coordination or ΔP, ΔQ and PB coordination. The KPI values for all the



This tool can be used by the TSO and DSO for evaluating the response of the FSPs

Market Player ID: FSP-001

Date: 07-Jul-2023

Data Loaded Successfully

The FSP responded properly

Min Error: -5.687 kW
Max Error: 2.721 kW
Mean Error: -1.029 kW

Min Error: 0 kVar
Max Error: 0 kVar
Mean Error: 0 kVar

Figure 10: Interface of the FSP Evaluation tool response

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 957739

cases are shown in Table 5, where it is clearly depicted that the FSPs respond accurately to the coordination signal sent by the DSO for the provision of ancillary services.

Table 5: Deviation of the FSP response

Grid level	Scenario		ΔP_{max} (%)	ΔP_{mean} (%)
MV	ΔP and ΔQ coordination		0.04	0.01
LV	Nominal power direction	ΔP and ΔQ coordination	0.03	0.01
		ΔP, ΔQ and PB coordination	0.02	0.01
	Reverse power direction	ΔP and ΔQ coordination	0.04	0.02
		ΔP, ΔQ and PB coordination	0.04	0.02

3.3 Evaluation of scenarios

3.3.1 Frequency balancing

For evaluating the frequency balancing scenario, the KPIs related to the maximum rate of frequency (KPI_N14) in Hz/s and the frequency nadir (KPI_N15) in Hz are assessed under different FCR provisioning cases, when an intense power disturbance occurs (i.e., loss of 150 MW) due to the disconnection of 2 conventional generation units. It is noted that different cases regarding the penetration of flexible RES awarded for provisioning FCR services (e.g., 100 MW, 150 MW) have been examined, while the FCR type includes either droop only support or droop support combined with virtual inertia.

Rate of Change of Frequency (ROCOF) improvement (KPI_N14)

The ROCOF improvement (KPI_N14) under different cases are presented in and in Figure 11. As it is illustrated in all the cases, the KPI indicates that the FCR contribution by flexible RES for stability enhancement is vital for improving the ROCOF of the Cyprus system, indicating a ROCOF improvement between 15.52% and 23.73% compared to the BAU operation where the RESs do not provide FCR services. Furthermore, in cases where the capacity of RES providing FCR support is higher (higher FCR volume procured through the ancillary service market), the ROCOF improvement of the system is higher; thus the provision of frequency support services, such as droop and virtual inertia, by more resources can further enhance the frequency stability of the system.

Table 6: Rate of Change of Frequency Improvement

Cases		ROCOFI (%)
RES providing FCR	**Type of FCR**	
100 MW	Droop support by RES	15.52
	Droop and virtual inertia support by RES	18.04
150 MW	Droop support by RES	21.44
	Droop and virtual inertia support by RES	23.73

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

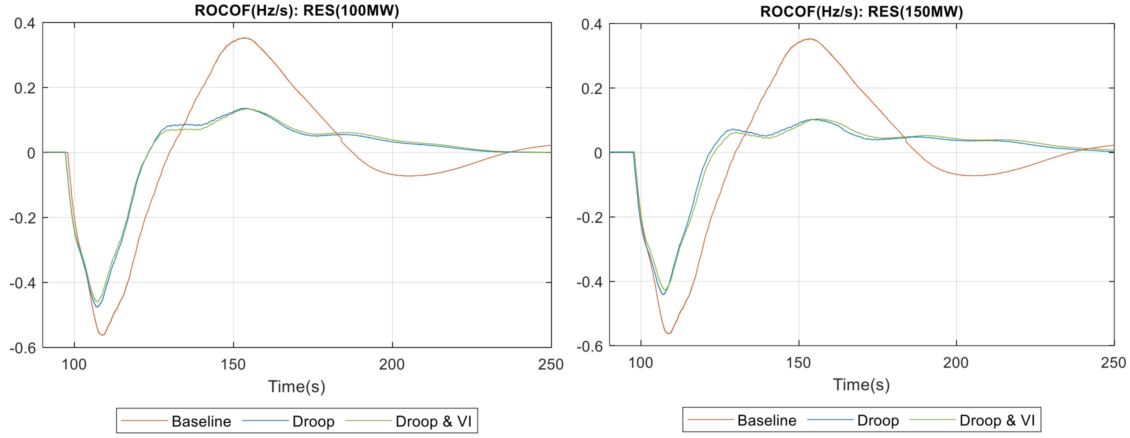


Figure 11: ROCOF of the Cyprus power system when no FCR is provision by RES-based resources (baseline) and when 100 MW (left) or 150 MW (right) of FCR is provisioned by flexible RES considering either droop only (droop) or droop combined with virtual inertia (Droop & VI) support.

In addition, in the cases where FCR is provided in the form of both droop and virtual inertia (compared to the case where only droop support is provided), a further improvement by 2-3% is achieved due to the virtual inertia support.

Frequency nadir improvement (FnadirI – KPI_N15)

The frequency nadir improvement (FnadirI – KPI_N15) is presented in Table 7, while the overall frequency response of the Cyprus power system is shown in Figure 12 under the different cases. The provision of FCR by 100-150 MW flexible RES can significantly increase the frequency nadir between 27.92% and 36.67%, enhancing the frequency stability of the power system. It is worth mentioning that 2.5-3% additional improvement can be achieved when the FCR product includes virtual inertia support as well compared to the case where only droop support is provided. The improvement of the frequency stability is also observable by the frequency responses of the Cyprus power system as presented in Figure 12, where the frequency deviation due to the intense power disturbances is significantly reduced with the increasing volume of FCR and it is further increasing when virtual inertia is provided as well. Furthermore, the frequency oscillations after the disturbance are damped faster with the provision of FCR demonstrating the crucial benefits in terms of frequency stability when flexible RES are able to participate in the ancillary services market for supporting the frequency.

Table 7: Frequency Nadir Improvement

Cases		FnadirI (%)
RES providing FCR	**Type of FCR**	
100 MW	Droop support by RES	27.92
	Droop and virtual inertia support by RES	30.83
150 MW	Droop support by RES	34.17
	Droop and virtual inertia support by RES	36.67

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

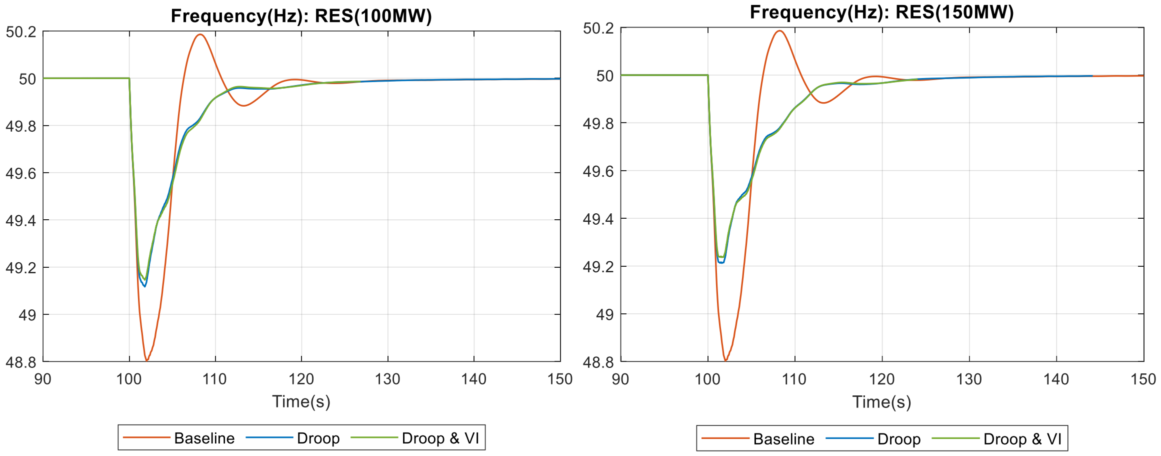


Figure 12: Frequency of the Cyprus power system when no FCR is provisioned by flexible RES (baseline) and when 100 MW (left) or 150 MW (right) of FCR is provisioned by flexible RES considering either droop only (droop) or droop combined with virtual inertia (Droop & VI) support.

3.3.2 Congestion management (evaluating the impact of SUC4)

This sub-section is focusing on demonstrating and evaluating the congestion management scenario of the Cypriot demo by introducing the SUC4 – "Coordination of distributed flexible resources" tool to real-time coordinate the distribution grid to relieve congestion, symmetrize loading conditions and improve efficiency.

3.3.2.1 Congestion management scenario demonstration

Two main demonstration use cases related to the congestion management scenario are presented below.

Active (ΔP) and reactive (ΔQ) power coordination to relieve congestion in a MV distribution grid

The demonstration of the SUC4 for relieving congestion in a MV distribution feeder of the Cyprus grid is presented in Figure 13, when FSPs are able to respond to active (ΔP) and reactive (ΔQ) control signals generated by the coordination tool of SUC4. The coordination tool is able to real-time monitoring the apparent power flow (S) of the Sub-Station (SS) (first sub-plot of Figure 13), and in case an over-loading violation is detected, total active (ΔP_{ref}) and reactive (ΔQ_{ref}) reference signals (fourth and fifth sub-plots of Figure 13) are generated by the coordination tool to relieve congestion with the minimum flexibility activation cost, as explained in Section 4.4.4 of [1]. It is noted that for ΔP activation the price is considered equal to the day-ahead clearing price for the corresponding time slot (e.g., 0.26€/kW for this example) for injecting additional active power and zero for absorbing active power, while for reactive power the activation price is (either injecting or absorbing power) is calculated as the 20% of the corresponding day-ahead energy price (e.g., 0.052€/kVar for this example). Then, the total active and reactive reference signals are properly allocated to the awarded FSPs by the *Near Real-Time Local DSO Ancillary Services Market* in order to respond accordingly and reduce the overall active P_{SS} and reactive

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

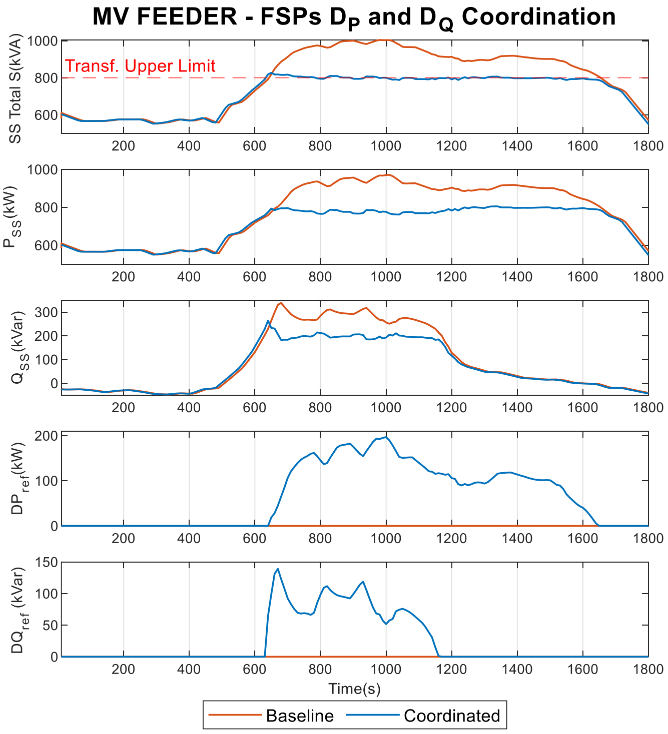


Figure 13. Overloading conditions at a MV distribution grid when (i) FSPs do not provide any congestion management services (baseline); and (ii) FSPs are able to track ΔP and ΔQ set-points according to the real-time coordination tool of SUC4.

Q_{SS} power flow at the substation level (second and third sub-plots of Figure 13). As a result, the apparent power (first sub-plot of Figure 13) is maintained exactly at the substation limit relieving the congestion in this way and avoiding over-loading conditions, compared to the baseline case where no flexibility services are used for grid-level coordination. The primary objective of SUC4 is to relieve local congestion phenomena by reducing the overloading conditions to avoid any capacity limit violation at the substation level, considering the per phase limit of the transformer.

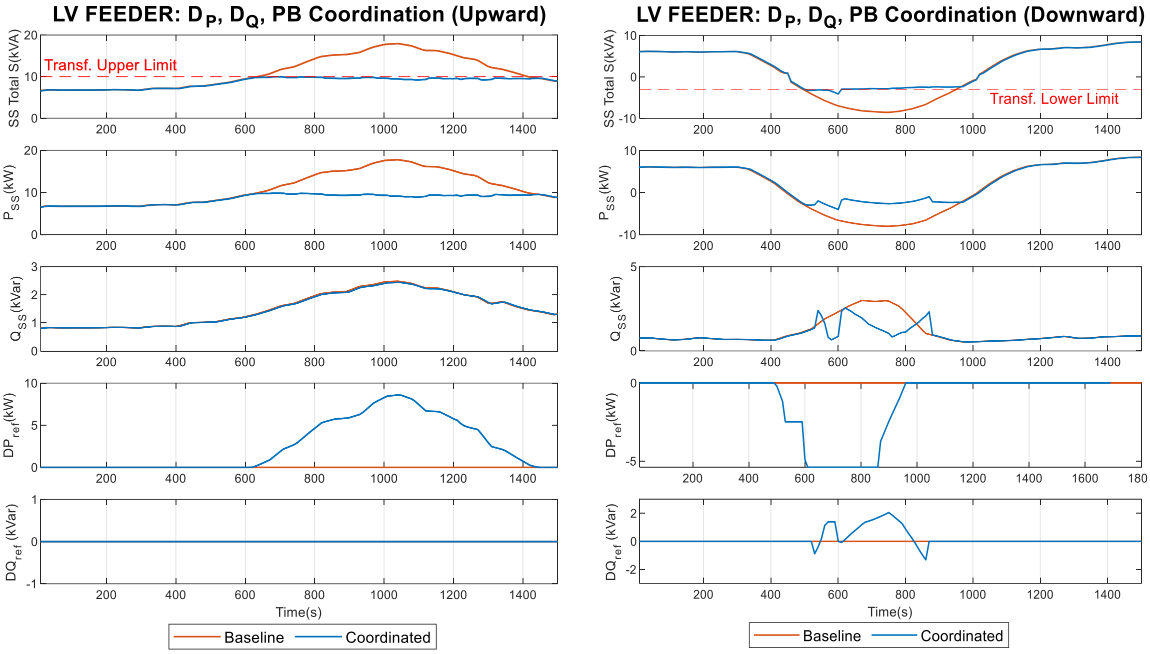
Active/Reactive (ΔP/ΔQ) power coordination and phase balancing (PB) to relieve congestion in a LV grid

A similar case for relieving congestion is demonstrated in Figure 14 for a LV distribution feeder. In this case, since LV are characterized by intense asymmetric loading conditions, Phase Balancing (PB) flexibility services is also utilized in order to symmetrize the loading conditions across the three phases in order to allow a more effective utilization of the existing grid capacity. Hence, in the cases where PB flexibility is also available, the coordination tool (SUC4) calculates first the PB coordination set-points for compensating (partially or totally) negative and/or zero sequence loading conditions, and then for the remaining overloading condition the active (ΔP) and reactive (ΔQ) control signals are calculated to cost-effectively relieve the congestion of the most congested phase as described in Section 4.4.4 of [1], while considering the activation price for the flexibility services as explain the MV demonstration case above. Then the total PB, ΔP and ΔQ signals are allocated to the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

awarded FSPs by the *Near Real-Time Local DSO Ancillary Services Market* to relive the LV distribution grid congestion at the substation level. The Figure 14(a) demonstrates the successful relief of congestion during forward power flow overloading conditions by utilizing PB and ΔP services, while Figure 14(b) demonstrates the relief of congestion during reverse power flow overloading conditions by utilizing PB, ΔP, and ΔQ services.

From the demonstrated cases in both MV and LV distribution grids, it is clear that the novel real-time coordination tool (SUC4) is able to successfully relieve congestion caused by forward or reverse overloading condition by coordinating flexibility services that are locally provided by FSPs.



(a)

(b)

Figure 14. Overloading conditions at a LV distribution grid when (i) FSPs do not provide any congestion management services (baseline); and (ii) FSPs are able to provide ΔP, ΔQ, and PB flexibility service according to SUC4 tool to relieve congestion under (a) forward and (b) reverse power flow overloading conditions.

3.3.2.2 KPI-based evaluation

A KPI-based approach is also utilized to evaluate the overall response of the congestion management scenario under different cases in MV and LV distribution grids. In this context, five main KPIs have been examined for the evaluation of this scenario: (i) KPI_N16 – Overloading (reducing of overloading conditions); (ii) KPI_N17 - Improvement on Voltage Limits Violations; (iii) KPI_N18 - Reduction of Energy Losses; (iv) KPI_N19 - Reduction of Loading Asymmetries; and (v) KPI_N20 - Power Factor Improvement. The achieved KPIs are described below.

KPI_N16-Overloading: The thermal loading improvement (TLI) through the provision of FSP services in both MV and LV distribution grid are shown in Table 8. In fact, the loading condition of grid is improved considerably by

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

coordinating the real and reactive power injection of the FSPs. In the case of the MV distribution grid the improvement is 19.31% while at the LV distribution grid an improvement between 43.02% and 53.33% is achieved (max and min from all the test scenarios). Furthermore, as it is shown in the LV grid, the provision of PB services on top of the ΔP and ΔQ coordination services achieves a slight improvement on the overloading condition as well.

Table 8: Thermal Loading Improvement

Grid level	Demonstration cases		TLI (%)
MV	ΔP and ΔQ coordination		19.31
LV	Forward power direction - Figure 14(a)	ΔP and ΔQ coordination	43.02
		ΔP, ΔQ and PB coordination	44.51
	Reverse power direction - Figure 14(b)	ΔP and ΔQ coordination	52.12
		ΔP, ΔQ and PB coordination	53.33

KPI_N17- Improvement on voltage limits violations: In both cases, without any coordination (considered as the baseline or BAU case) and with SUC4 coordination (considered as the R&I case), upper or lower voltage limit violations have not been detected in this scenario. Thus, the comparison of the improvement of this KPIs is not necessary for this scenario.

KPI_N18-Reduction of energy losses: The energy losses improvement (ELI) in all the cases of the congestion management scenario are presented in Table 9 when the coordination of ancillary services by the FSPs are provided. The table results indicate a reduction of energy losses at either MV or LV distribution grid is between 2.8% and 3.5% showing that the grid is operating in a slightly more efficient way when the real-time coordination tool (SUC4) is used.

Table 9: Reduction of Energy Losses

Grid level	Demonstration cases		ELI (%)
MV	ΔP and ΔQ coordination		3.2
LV	Forward power direction - Figure 14(a)	ΔP and ΔQ coordination	2.9
		ΔP, ΔQ and PB coordination	3.5
	Reverse power direction - Figure 14(b)	ΔP and ΔQ coordination	2.8
		ΔP, ΔQ and PB coordination	3

KPI_N19-Reduction of loading asymmetries: The Maximum Current Phase Unbalance Factor Reduction (MCPUFR) and the Average Current Phase Unbalance Factor Reduction (ACPUFR) KPIs are used to evaluate the impact of incorporating the phase balancing (PB) module in the coordination tool of SUC4 for dealing with the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

loading asymmetries, as shown in Table 10. Since Phase Balancing is only activated in 4-wire LV distribution grid, the KPI-based evaluation is considering only the LV distribution grid cases where over-loading were detected in either forward (Figure 14(a)) or reverse (Figure 14(b)) power flow direction. As it can be seen from Table 10, the loading asymmetries in the LV through the provision of the phase balancing services are considerably improved, with an MCPUFR and ACPUFR improvement between 31.78% and 49.8% in the two cases. This indicates a significant improvement on the load symmetrisation with more equal loading conditions across the three phase which is beneficial for the effective utilization of the existing grid capacity and for the power quality of the LV distribution grids.

Table 10: Reduction of loading asymmetries

Grid Level	Demonstration cases	MCPUFR (%)	ACPUFR (%)
LV	Forward power direction - Figure 14(a)	31.78	49.76
LV	Reverse power direction - Figure 14(b)	49.80	49.25

KPI_N20-Power factor improvement: By examining the different cases, a slight variation of the power factor is detected in either MV or LV distribution grids but in all cases the power factor is within the limits and thus, further analysis is not required.

An overall conclusion through the evaluation of the congestion management scenario is that the real-time coordination tool (SUC4) is able to successfully manage flexibility services by FSPs/prosumers in order to relieve congestion, symmetrize the loading condition and improve the power quality of the distribution grid, while a slight reduction of the energy losses is also achieved.

3.4 Evaluation of the market framework

The developed new market framework for ancillary services enables the effective collaboration among stakeholders in the electricity market to enhance stability and relieve congestion. The new market framework is integrated through the OneNet system to facilitate the standardized data exchange between Transmission System Operators (TSOs), Distribution System Operators (DSOs), market operators, and Flexible Service Providers (FSPs) or prosumers. The market operation is illustrated through two collaborative cases related to the corresponding market: (a) Intra-Day TSO FCR Ancillary Services Market (ID-TSO-FCR), and (b) Near Real-Time Local DSO Ancillary Services Market (NRT-DSO-AS). In the ID-TSO-FCR market case, the TSO procures FCR demand (through the ABCM-T platform) while DSO provides prequalification limits (through the ABCM-D platform), and FSPs submit generation offers for provisioning FCR. The market operator then clears the FCR product within a defined timeframe, updating participants on cleared results via the OneNet system. Similarly,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

in the NRT-DSO-AS case the DSO procure location-based demand bids for congestion management services (ΔP, ΔQ, PB), through the ABCM-D platform, while FSPs and/or prosumers offer generation capacity for flexibility services availability. Market clearing occurs based on submitted bids/offers, and the results disseminated to the relevant participants.

This framework underscores the importance of timely data exchange, with information provided via the OneNet system at least 15 minutes before each clearing period. This ensures efficient market and grid operation, enabling stakeholders to make informed decisions in real-time. Overall, the integrated approach fosters collaboration and coordination among market participants, promoting effective utilization of distributed resources and enhancing the reliability and sustainability of the electricity infrastructure. By standardizing information exchange and streamlining market processes, the framework supports cost-effective and environmentally friendly operation of the entire electricity system, aligning with broader goals of energy sustainability and resilience. The OneNet system interaction with participants in the electricity market is detailed below for the two market related cases.

3.4.1 Demonstration case for the ID-TSO-FCR market

To facilitate the IT-TSO-FCR market clearing process, the OneNet system receives comprehensive information for a 3-hour period at least 15 minutes before the initiation of the corresponding period. This data is supplied by FSPs linked to both TSO and DSO levels (generation offers for FCR provisioning), as well as from the TSO through the ABCM-T platform (demand bid for FCR needs). For a selected demonstration case, the market participation actions and the overall market results and market-based KPIs are demonstrated in the following sub-sections.

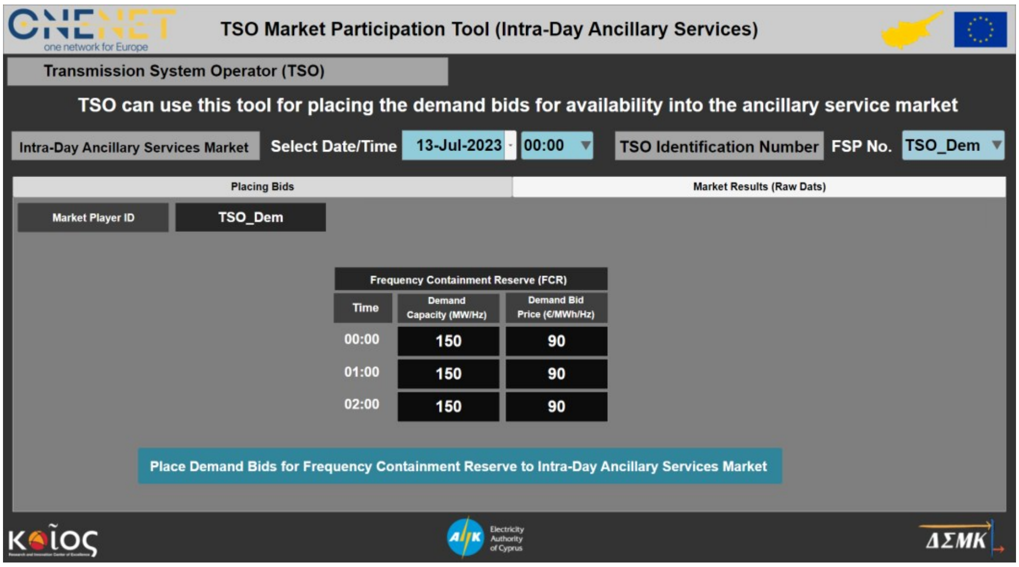
3.4.1.1 Demonstration of market participation and clearing actions

The main steps for submitting offers and bids, along with the market clearing process, for the ID-TSO-FCR market are outlined below.

Step 1: TSO procures the demand for FCR

TSO procures the demand for FCR to ensure system stability according to the foreseen operating conditions, through the ABCM-T platform. Through the developed user interface presented in Figure 15, TSO places the necessary information for the overall demand of FCR service for a 3 hour ahead timeframe. This information includes date, time, TSO's ID number, the amount of requested FCR (demand capacity) in MW/Hz for each hour, and the corresponding price for the FCR demand. By pressing the “Place Demand Bids” button, this information is converted into a CSV file and it is transmitted to the market operator via the OneNet system.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 957739



TSO Market Participation Tool (Intra-Day Ancillary Services)

Transmission System Operator (TSO)

TSO can use this tool for placing the demand bids for availability into the ancillary service market

Intra-Day Ancillary Services Market

Select Date/Time: 13-Jul-2023 00:00

TSO Identification Number FSP No.: TSO_Dem

Market Player ID: TSO_Dem

Frequency Containment Reserve (FCR)		
Time	Demand Capacity (MW/Hz)	Demand Bid Price (€/MWh/Hz)
00:00	150	90
01:00	150	90
02:00	150	90

Figure 15: Developed user interface for TSO to enable the submission of FCR demand bids.

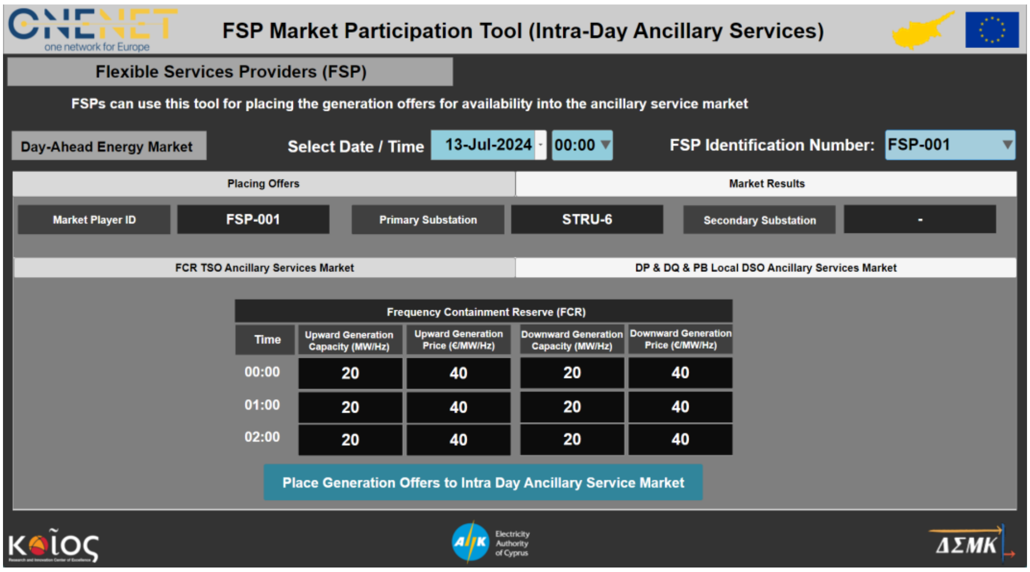
Step 2: DSO provides prequalification limits

On the other hand, DSO provides the prequalification limits for each substation according to the foreseen operating conditions (through the ABCM-D platform) for preventing TSO to award of flexibility services to FSPs that can cause congestion to the distribution grid. Through the user interface developed and integrated in the ABCM-D platform, as already shown in Figure 9, the pre-qualification limits are calculated for a selected timeframe of interest, and by pressing the “Export Limits” button, a CSV file containing the prequalification related information for each substation, including date, time, network operator's ID number, substation name, substation number, and upward/downward availability limits in kW is exported and transferred to the market operator via the OneNet system.

Step 3: FSPs submit the generation offers for FCR

FSPs submit their information regarding the generation offers for FCR through a dedicated user interface developed for facilitating the FSP market participation in TSO or DSO ancillary services market, as presented in Figure 16. Through this interface, each FSP submits all the generation offering information for ancillary services in an hourly basis for a three hour intra-day time window, containing date, time, FSP's ID number, main substation number, secondary substation number (if applicable), the amount of offered FCR (upward/downward offering capacity) in MW/Hz, and the corresponding offering price for provisioning the FCR service in €/(MW/Hz). By pressing the “Place Generation Offers” button, the information is processed into a CSV file, which is exported and transmitted to the market operator via the OneNet system.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 957739



FSP Market Participation Tool (Intra-Day Ancillary Services)

Flexible Services Providers (FSP)

FSPs can use this tool for placing the generation offers for availability into the ancillary service market

Select Date / Time: 13-Jul-2024 00:00

FSP Identification Number: FSP-001

Market Player ID: FSP-001

Primary Substation: STRU-6

Secondary Substation: -

Frequency Containment Reserve (FCR)

Time	Upward Generation Capacity (MW/Hz)	Upward Generation Price (€/MW/Hz)	Downward Generation Capacity (MW/Hz)	Downward Generation Price (€/MW/Hz)
00:00	20	40	20	40
01:00	20	40	20	40
02:00	20	40	20	40

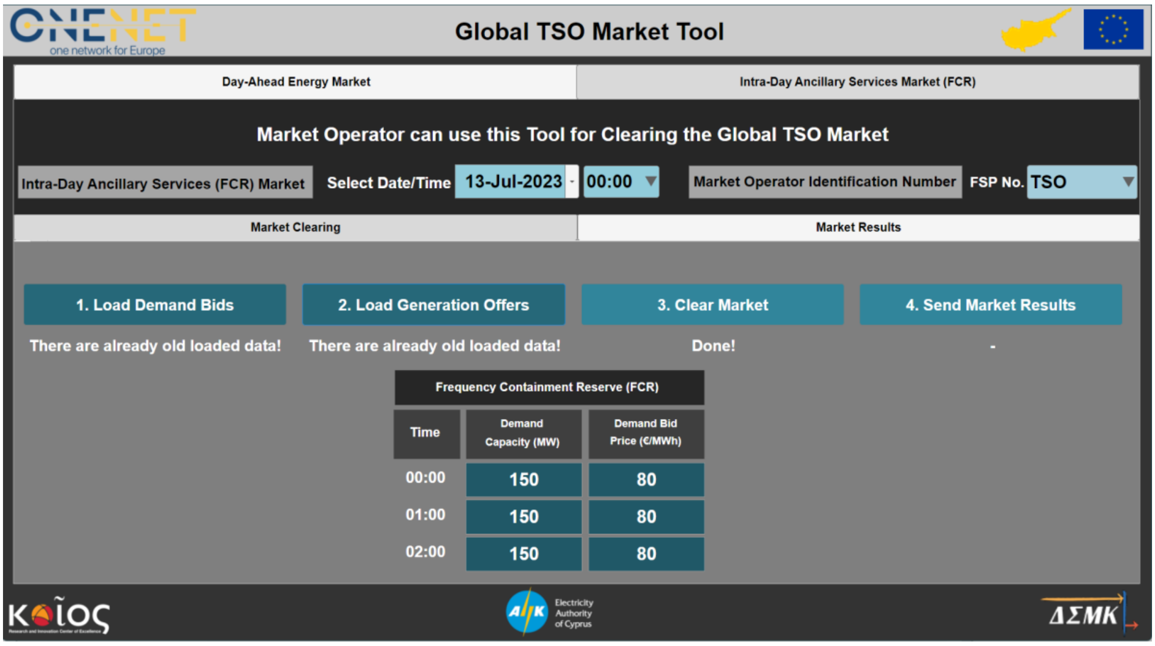
Figure 16: Developed user interface for FSPs to facilitate the submission of FCR generation offers.

Step 4: IT-TSO-FCR market clearing

After Steps 1-3, which must be completed up to 15 minutes before the clearing period starts, the IT-TSO-FCR market operator clears the bidding process for the period within a maximum 10-minute timeframe. This ensures that market results are available at least 5 minutes before the period begins. For initiating the clearing process, the market operator uses the developed user interface presented in Figure 17 to retrieve the required information by pressing the “Load Demand Bids” and “Load Generation Offers” buttons. Through these buttons the corresponding CSV files are download through the OneNet system, and then the clearing process can be executed by pressing the “Clearing” button.

Step 5: Informing FSPs and TSO about the market clearing decisions

Following market clearing, the market operator can inform the market participants about the related clearing decisions, by pressing the “Send the Market Results” button in the interface of Figure 17. Through this button, individual CSV files are extracted for each market participant. The CSV file for the TSO includes the total awarded FCR volume and the clearing price for this service. Similarly, the CSV file for each FSP (accessible by the TSO as well for evaluating the response of each FSP in case of a disturbance) includes the volume and clearing price for the FCR service awarded to the corresponding FSP.



Global TSO Market Tool

Day-Ahead Energy Market | Intra-Day Ancillary Services Market (FCR)

Market Operator can use this Tool for Clearing the Global TSO Market

Intra-Day Ancillary Services (FCR) Market

Select Date/Time: 13-Jul-2023 00:00

Market Operator Identification Number: FSP No. TSO

Market Clearing | Market Results

1. Load Demand Bids: There are already old loaded data!

2. Load Generation Offers: There are already old loaded data!

3. Clear Market: Done!

4. Send Market Results: -

Frequency Containment Reserve (FCR)

Time	Demand Capacity (MW)	Demand Bid Price (€/MWh)
00:00	150	80
01:00	150	80
02:00	150	80

Figure 17: Developed user interface for market operator to clear FCR product and inform all the market participants about the results.

3.4.1.2 Market results for FCR and KPI-based evaluation

The overall market operation for a selected demonstration case in the ID-TSO-FCR market is presented in Table 11, for a selected date (13/07/2023) and time window (00:00-03:00). The TSO demand bids (volume and price) for FCR are presented, as well as the generation offers (volume and price) submitted by each FSP. After the market clearing process, the common market clearing price for availability of FCR (pay-as-cleared) is also presented and the awarded volume for each FSP is demonstrated.

Two market clearing approach are presented in Table 11, demonstrating the clearing results (a) without incorporating the pre-qualification scheme, and (b) with the pre-qualification scheme. The initial case without the pre-qualification shows that the FSPs with the lower offering price have been prioritized in order to maximize the social welfare (according to the objective function of the market clearing algorithm) without considering any possible congestion that may be introduced to the distribution grid by activating FCR service in particular FSPs. Hence, in the case where the pre-qualification is not considered, the cleared price for FCR is 80 €/MW/Hz but there is a possibility to cause congestion to the distribution grid. In the second case, where the pre-qualification is properly considered in the clearing process, we can observe that the awarded FCR to FSP1 and FSP18 have been reduced to avoid potential over-loading conditions in distribution when activating the FCR services, and instead the FCR services awarded to FSP2, FSP6, and FSP9 is increased, as the next cheaper flexibility resources that can be provided without causing congestion. As a result, the cleared price for FCR is increased from 80

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

€/MW/Hz to 90 €/MW/Hz when pre-qualification is considered but any violation of the grid capacity limits is avoided ensuring a reliable and adequate operation of the distribution grid.

Table 11: ID-TSO-FCR market demonstration (bids, offers, clearing results) on 13/07/2023 (00:00-03:00)

Demand bids and generation offers submision					Cleared ancillary services market for HV grid (without prequalifications)					Cleared ancillary services market for HV grid (with prequalifications)				
Hours		h0	h1	h2	Hours		h0	h1	h2	Hours		h0	h1	h2
TSO bids	FCR (MW/Hz)	150	150	150	DSO cleared bid	FCR (MW/Hz)	150	150	150	DSO cleared bid	FCR (MW/Hz)	150	150	150
	Price (€/MW/Hz)	110	110	110		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 1 offer	FCR (MW/Hz)	20	20	20	FSP 1 cleared offer	FCR (MW/Hz)	20	20	20	FSP 1 cleared offer	FCR (MW/Hz)	3.53	3.53	3.53
	Price (€/MW/Hz)	40	40	40		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 2 offer	FCR (MW/Hz)	20	20	20	FSP 2 cleared offer	FCR (MW/Hz)	10	10	10	FSP 2 cleared offer	FCR (MW/Hz)	15.01	15.01	15.01
	Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 6 offer	FCR (MW/Hz)	20	20	20	FSP 6 cleared offer	FCR (MW/Hz)	0	0	0	FSP 6 cleared offer	FCR (MW/Hz)	7.36	7.36	7.36
	Price (€/MW/Hz)	90	90	90		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 9 offer	FCR (MW/Hz)	20	20	20	FSP 9 cleared offer	FCR (MW/Hz)	0	0	0	FSP 9 cleared offer	FCR (MW/Hz)	20	20	20
	Price (€/MW/Hz)	90	90	90		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 10 offer	FCR (MW/Hz)	20	20	20	FSP 10 cleared offer	FCR (MW/Hz)	20	20	20	FSP 10 cleared offer	FCR (MW/Hz)	20	20	20
	Price (€/MW/Hz)	70	70	70		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 11 offer	FCR (MW/Hz)	20	20	20	FSP 11 cleared offer	FCR (MW/Hz)	20	20	20	FSP 11 cleared offer	FCR (MW/Hz)	20	20	20
	Price (€/MW/Hz)	60	60	60		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 12 offer	FCR (MW/Hz)	20	20	20	FSP 12 cleared offer	FCR (MW/Hz)	20	20	20	FSP 12 cleared offer	FCR (MW/Hz)	20	20	20
	Price (€/MW/Hz)	60	60	60		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 14 offer	FCR (MW/Hz)	40	40	40	FSP 14 cleared offer	FCR (MW/Hz)	40	40	40	FSP 14 cleared offer	FCR (MW/Hz)	40	40	40
	Price (€/MW/Hz)	60	60	60		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90
FSP 18 offer	FCR (MW/Hz)	20	20	20	FSP 18 cleared offer	FCR (MW/Hz)	20	20	20	FSP 18 cleared offer	FCR (MW/Hz)	4.10	4.10	4.10
	Price (€/MW/Hz)	60	60	60		Price (€/MW/Hz)	80	80	80		Price (€/MW/Hz)	90	90	90

The overall ID-TSO-FCR market operation for the demonstration case above is also evaluated considering selected market-based KPIs.

KPI_H01 Number of FSPs: This KPI indicates the number of FSPs participating in the market to provide ancillary services to the grid. In the Cyprus demo scenario related to frequency balancing and ID-TSO-FCR market, *9 FSPs are participating* and submitting FCR generation offers in the intra-day ancillary services market.

KPI_H07 Number of transactions: This indicator measures the number of transactions including the number of bids submissions, offers submission, as well as the transaction related to the information of the market participant about the clearing results. For the particular demonstration case of the IT-TSO-FCR market operation, *a total of 20 transactions are involved in one cycle of market clearing*. These transactions include 1 bid submission by TSO, 9 generation offers submission by FSPs and 10 transactions for informing the TSO and the 9 FSPs about the market clearing results.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

KPI_H09A Volume of transactions – received bids (Availability) and KPI_H09B Volume of transactions-cleared bids (Availability): These indicators measure the volume of bids received in MW/Hz and the cleared volume regarding the FCR product for a 3-hour period in the demonstration case of the ID-TSO-FCR market. The results regarding these KPIs are presented in Table 12.

Table 12: Volume of received and cleared bids by the ID-TSO-FCR market

Product	Volume of received bids (MW/Hz)			Volume of cleared bids (MW/Hz)		
FCR (MW/Hz)	**h**	**h+1**	**h+2**	**h**	**h+1**	**h+2**
	200	200	200	150	150	150

Concluding remarks for the new ID-TSO-FCR market operation: The whole demonstration case regarding the ID-TSO-Market indicates a smooth process regarding the procurement of FCR flexibility by the TSO, the submission of generation offers for FCR by the FSPs, the clearing process by the market operator, and the information of the market participants about the clearing results. In the demonstration case, there is enough liquidity to ensure that the demand for FCR is satisfied and according to these market results the frequency balancing scenarios (already demonstrated in Section 3.3.1) have been performed highlighting the overall stability improve when FSPs is able to provide FCR service to the grid.

3.4.2 Demonstration case for the NRT-DSO-AS market (ΔP-ΔQ-PB)

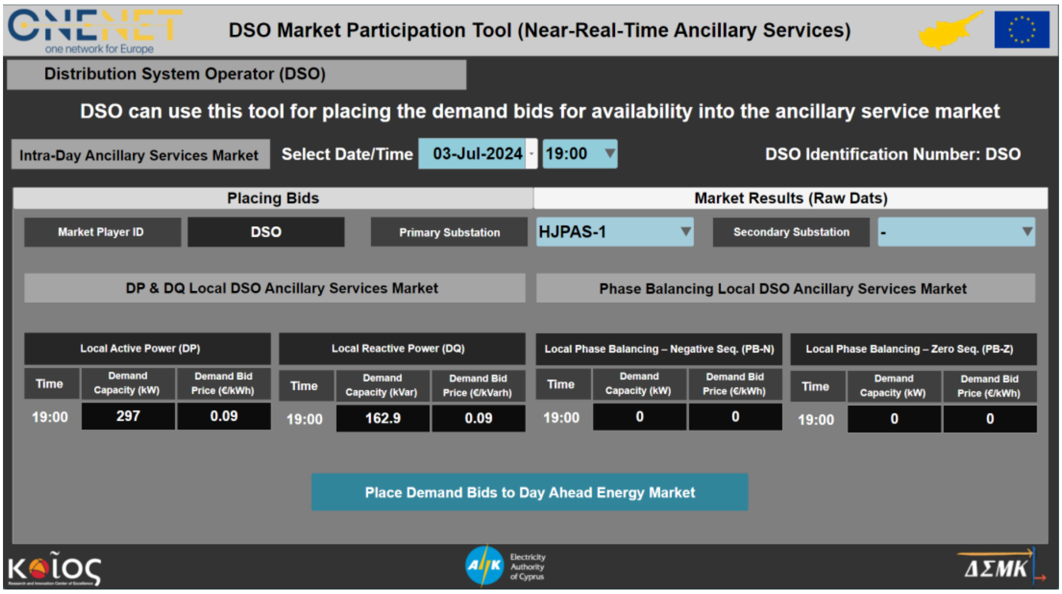
The NRT-DSO-AS market is responsible for enhancing DSO capabilities to manage local congestion phenomena. The clearing process is facilitated by the effective data exchange through the OneNet system every hour. The demand bids are submitted by the DSO at least 15 minutes before the near-real-time market window starts while the flexibility offers are provided by the local FSPs in the intra-day ancillary service market at least 15 minutes before the corresponding intra-day time window and are forwarded to the offers related to the congestion management are forwarded to the NRT-DSO-AS market. Then, the DRT-DSO-AS market operator is performing the clearing process and inform the market participants about the clearing results at least 5 minutes before the hourly slot of the corresponding near-real-time market. For a selected demonstration case, the market participation actions and the overall market results and market-based KPIs are demonstrated in the following sub-sections.

3.4.2.1 Demonstration of market participation and clearing actions

The main steps for submitting offers and bids, along with the market clearing process, for the NRT-DSO-AS market for congestion management are described below.

Step 1: DSO procures the demand for ΔP, ΔQ and PB availability required for congestion management

DSO procures the demand for local ΔP, ΔQ and PB services availability to ensure the effective congestion management to the foreseen operating conditions, through the ABCM-D platform. Through the developed user interface presented in Figure 18, DSO places the necessary information for the location-based ΔP, ΔQ and PB services envision to be required in the hour-ahead timeslot to deal with the local congestion. This information includes date, time, DSO's ID number, the amount of requested ΔP, ΔQ and PB services (demand capacity) in kW, kVar, and kVA$^{-/0}$ for the selected hourly interval, and the corresponding bidding prices for these services. By pressing the "Place Demand Bids" button, this information is processed into a CSV file and it is transmitted to the market operator via the OneNet system.



DSO Market Participation Tool (Near-Real-Time Ancillary Services)

Distribution System Operator (DSO)

DSO can use this tool for placing the demand bids for availability into the ancillary service market

Intra-Day Ancillary Services Market

Select Date/Time: 03-Jul-2024 19:00

DSO Identification Number: DSO

Placing Bids

Market Results (Raw Dats)

Market Player ID: DSO

Primary Substation: HJPAS-1

Secondary Substation: -

DP & DQ Local DSO Ancillary Services Market

Local Active Power (DP)

Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)
19:00	297	0.09

Local Reactive Power (DQ)

Time	Demand Capacity (kVar)	Demand Bid Price (€/kVarh)
19:00	162.9	0.09

Phase Balancing Local DSO Ancillary Services Market

Local Phase Balancing – Negative Seq. (PB-N)

Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)
19:00	0	0

Local Phase Balancing – Zero Seq. (PB-Z)

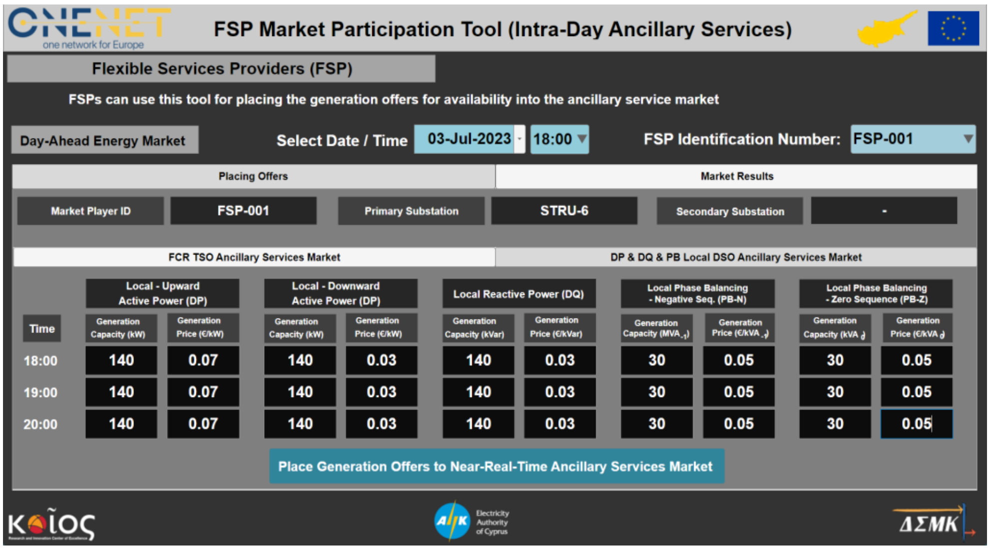
Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)
19:00	0	0

Figure 18: Developed user interface for DSO to enable the submission of local ΔP, ΔQ and PB demand bids.

Step 2: FSPs submit the generation offers for location-based ΔP, ΔQ and PB services to the NRT-DSO-AS market

FSPs submit their generation offers for ΔP, ΔQ and PB services, indicating their locations as well, to enable their market participation in DSO ancillary services market, by using the developed interface presented in Figure 19. It is noted that all the ancillary services generation offers (e.g., FCR, ΔP, ΔQ, PB) are submitted to the intra-day market considering a 3 hour slots, and then FCR offers are forwarded to the ID-TSO-FCR market while location based ΔP, ΔQ, and PB offers are forwarded to the corresponding local NRT-DSO-AS market to be cleared every hour. Through the developed interface, each FSP submits all the generation offering information for congestion management ancillary services in an hourly basis for a three hour intra-day time window, containing date, time, FSP's ID number, main substation number, secondary substation number (if applicable), the amount

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739



FSP Market Participation Tool (Intra-Day Ancillary Services)

Flexible Services Providers (FSP)

FSPs can use this tool for placing the generation offers for availability into the ancillary service market

Select Date / Time: 03-Jul-2023 18:00

FSP Identification Number: FSP-001

Market Player ID: FSP-001

Primary Substation: STRU-6

Secondary Substation: -

	FCR TSO Ancillary Services Market				DP & DQ & PB Local DSO Ancillary Services Market					
	Local - Upward Active Power (DP)		Local - Downward Active Power (DP)		Local Reactive Power (DQ)		Local Phase Balancing - Negative Seq. (PB-N)		Local Phase Balancing - Zero Sequence (PB-Z)	
Time	Generation Capacity (kW)	Generation Price (€/kW)	Generation Capacity (kW)	Generation Price (€/kW)	Generation Capacity (kVar)	Generation Price (€/kVar)	Generation Capacity (MVA$_{-1}$)	Generation Price (€/kVA$_{-1}$)	Generation Capacity (kVA$_0$)	Generation Price (€/kVA$_0$)
18:00	140	0.07	140	0.03	140	0.03	30	0.05	30	0.05
19:00	140	0.07	140	0.03	140	0.03	30	0.05	30	0.05
20:00	140	0.07	140	0.03	140	0.03	30	0.05	30	0.05

Figure 19: Developed user interface for FSPs to facilitate the submission of ΔP, ΔQ, PB generation offers.

of offered ΔP volume (upward/downward offering capacity) in kW, the amount of offered ΔQ volume (upward/downward offering capacity) in kVar, and the amount of negative or zero sequence phase balancing (PB^{-}/PB^{0}) volume in $kVA^{-/0}$, and the corresponding offering prices for each flexibility service. By pressing the "Place Generation Offers" button, the information is processed into a CSV file, which is exported and transmitted to the market operator via the OneNet system.

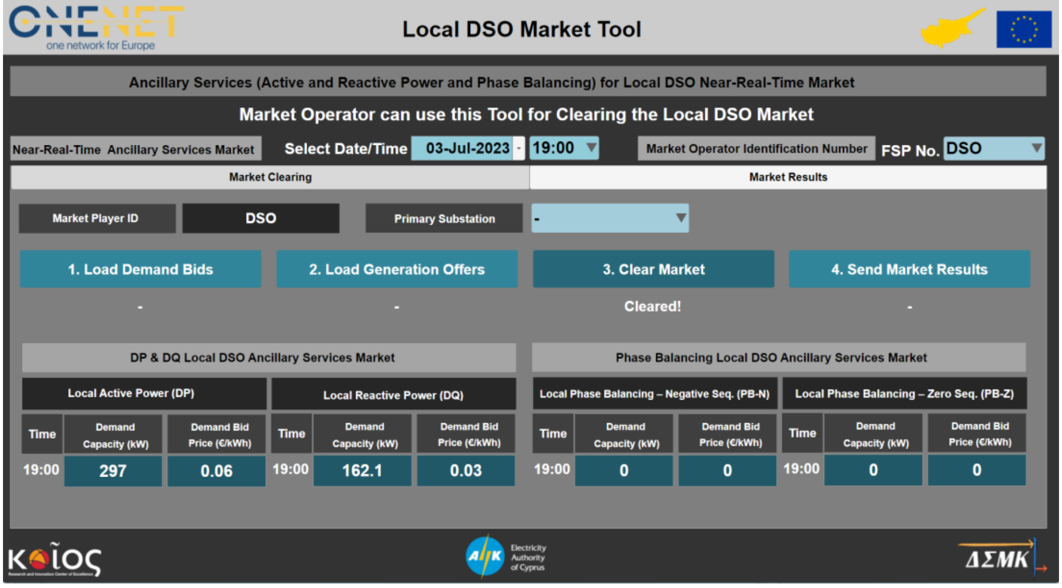
Step 4: NRT-DSO-AS market clearing

After the bidding and offering submission, which must be completed up to 15 minutes before the clearing period starts, the NRT-DSO-AS market operator performs the clearing process to ensure that market results are available at least 5 minutes before the period begins. For initiating the clearing process, the market operator uses the developed user interface presented in Figure 20 to retrieve the required information by pressing the "Load Demand Bids" and "Load Generation Offers" buttons. Through these buttons the corresponding CSV files are downloaded through the OneNet system, and then the clearing process can be executed by pressing the "Clearing" button.

Step 5: Informing FSPs and TSO about the market clearing decisions

Following market clearing, the market operator can inform the market participants about the related clearing decisions, by pressing the "Send the Market Results" button in the interface of Figure 20. Through this button, individual CSV files are extracted for each market participant. The CSV file for the DSO includes the total awarded ΔP, ΔQ and PB services volume and the clearing price for each service. Similarly, the CSV file for each FSP (accessible by the DSO as well for evaluating the response of each FSP during real-time coordination) includes the volume and clearing price for the ΔP, ΔQ and PB services awarded to the corresponding FSP.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739



Local DSO Market Tool

Ancillary Services (Active and Reactive Power and Phase Balancing) for Local DSO Near-Real-Time Market

Market Operator can use this Tool for Clearing the Local DSO Market

Near-Real-Time Ancillary Services Market

Select Date/Time: 03-Jul-2023 19:00

Market Operator Identification Number

FSP No.: DSO

Market Clearing | Market Results

Market Player ID: DSO

Primary Substation: -

1. Load Demand Bids: -

2. Load Generation Offers: -

3. Clear Market: Cleared!

4. Send Market Results: -

DP & DQ Local DSO Ancillary Services Market						Phase Balancing Local DSO Ancillary Services Market					
Local Active Power (DP)			Local Reactive Power (DQ)			Local Phase Balancing – Negative Seq. (PB-N)			Local Phase Balancing – Zero Seq. (PB-Z)		
Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)	Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)	Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)	Time	Demand Capacity (kW)	Demand Bid Price (€/kWh)
19:00	297	0.06	19:00	162.1	0.03	19:00	0	0	19:00	0	0

Figure 20: Developed user interface for market operator to clear ΔP, ΔQ and PB products and inform all the market participants about the results.

3.4.2.2 Market results for congestion management and KPI-based evaluation

The overall NRT-DSO-AS market operation for selected demonstration cases (a) in a specific location of a MV distribution grid and (b) in a particular location of a LV distribution grid are presented in this sub-section.

Demonstration case 1: NRT-DSO-AS market for ΔP and ΔQ in a specific MV distribution grid

The overall market operation for a selected demonstration case in a specific MV grid of the NDT-DSO-AS market is presented in Table 13, for a selected date (03/07/2023) and time window (18:00-21:00). The selected market operation is directly related to the first case of the congestion management scenario already demonstrated in Section 3.3.2.1. The DSO demand bids (volume and price) for ΔP, ΔQ services (without requesting any PB services) are presented, as well as the generation offers (volume and price) submitted by each FSP for the location-based flexibility services. After the market clearing process, the common market clearing price for availability (pay-as-cleared) is also presented in an hourly basis for the interval between 18:00-21:00 and the awarded volume for each FSP is demonstrated, showing that the FSPs with the lower offering price have been prioritized in order to maximize the social welfare (according to the objective function of the market clearing algorithm) while ensuring enough availability of flexibility services to allow DSO to manage congestion. As indicated by the first demonstration scenario for congestion management (Section 3.3.2.1), the awarded flexibility services were able to satisfactory manage congestion and relieve overloading conditions in the local MV distribution grid.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Table 13: NRT-DSO-AS market demonstration (bids, offers, clearing results) for MV grid on 03/07/2023 (18:00-21:00)

Demand bids and generation offers submision				
Hours		h0	h1	h2
DSO bids	DP (kW)	0	297	238.94
	Price (€/kW)	-	0.09	0.15
	DQ (kVar)	0	162.9	81.959
	Price (€/kVar)	-	0.09	0.1
	PB$^-$ (kVA$^-$)	0	0	0
	Price (€/kVA$^-$)	-	-	-
FSP1 offer	DP (+/-) (kW)	140/-140	140/-140	140/-140
	Price (€/kW)	0.07 /0.03	0.06 /0.03	0.05 /0.03
	DQ (kVar)	140	140	140
	Price (€/kVar)	0.03	0.03	0.03
	PB$^-$ (kVA$^-$)	30	30	30
	Price (€/kVA$^-$)	0.05	0.05	0.05
FSP2 offer	DP (+/-) (kW)	110/-110	110/-110	110/-110
	Price (€/kW)	0.05 /0.02	0.06 /0.03	0.07 /0.04
	DQ (kVar)	110	110	110
	Price (€/kVar)	0.02	0.03	0.04
	PB$^-$ (kVA$^-$)	30	30	30
	Price (€/kVA$^-$)	0.045	0.045	0.045
FSP3 offer	DP (+/-) (kW)	140/-140	140/-140	140/-140
	Price (€/kW)	0.06 /0.04	0.06 /0.04	0.05 /0.04
	DQ (kVar)	140	140	140
	Price (€/kVar)	0.04	0.04	0.04
	PB$^-$ (kVA$^-$)	30	30	30
	Price (€/kVA$^-$)	0.06	0.06	0.06
FSP4 offer	DP (+/-) (kW)	110/-110	110/-110	110/-110
	Price (€/kW)	0.06 /0.02	0.05 /0.02	0.04 /0.02
	DQ (kVar)	110	110	110
	Price (€/kVar)	0.02	0.02	0.02
	PB$^-$ (kVA$^-$)	30	30	30
	Price (€/kVA$^-$)	0.03	0.03	0.03

Cleared ancillary services market for LV grid				
Hours		h0	h1	h2
DSO cleared bid	DP (kW)	0	297	238.94
	Price (€/kW)	-	0.06	0.05
	DQ (kVar)	0	162.09	81.959
	Price (€/kVar)	-	0.03	0.02
	PB$^-$ (kVA$^-$)	0	0	0
	Price (€/kVA$^-$)	-	-	-
FSP1 cleared offer	DP (+/-) (kW)	0	0	128.94
	Price (€/kW)	-	0.06	0.05
	DQ (kVar)	0	0	0
	Price (€/kVar)	-	0.03	0.02
	PB$^-$ (kVA$^-$)	0	0	0
	Price (€/kVA$^-$)	-	-	-
FSP2 cleared offer	DP (+/-) (kW)	0	47	0
	Price (€/kW)	-	0.06	0.05
	DQ (kVar)	0	52.09	0
	Price (€/kVar)	-	0.03	0.02
	PB$^-$ (kVA$^-$)	0	1.6	0
	Price (€/kVA$^-$)	-	0.06	-
FSP3 cleared offer	DP (+/-) (kW)	0	140	0
	Price (€/kW)	-	0.06	0.05
	DQ (kVar)	0	0	0
	Price (€/kVar)	-	0.03	0.02
	PB$^-$ (kVA$^-$)	0	0	0
	Price (€/kVA$^-$)	-	-	-
FSP4 cleared offer	DP (+/-) (kW)	0	110	110
	Price (€/kW)	-	0.06	0.05
	DQ (kVar)	0	110	81.959
	Price (€/kVar)	-	0.03	0.02
	PB$^-$ (kVA$^-$)	0	0	0
	Price (€/kVA$^-$)	-	-	-

The overall NRT-DSO-AS market operation for the demonstration case above is also evaluated considering selected market-based KPIs.

KPI_H01 Number of FSPs: This KPI indicates the number of FSPs participating in the market to provide either ΔP, ΔQ or PB services to the MV grid. In the corresponding demonstration case for the NRT-DSO-AS market, associated with the congestion management scenario (see first demonstration case in Section 3.3.2.1), *4 FSPs are participating* and submitting for ΔP, ΔQ and PB generation offers in the near-real-time ancillary services market.

KPI_H07 Number of transactions: This indicator measures the number of transactions including the number of bids submissions, offers submission, as well as the transaction related to the information of the market

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

participant about the clearing results. For the particular demonstration case of the NRT-DSO-AS market operation, _a total number of 10 transactions are involved in one cycle of market clearing_. These transactions include 1 bid submission by DSO, 4 generation offers submission by FSPs and 5 transactions for informing the DSO and the 4 FSPs about the market clearing results.

KPI_H09A Volume of transactions – received bids (Availability) and KPI_H09B Volume of transactions-cleared bids (Availability): These indicators measure the volume of received and cleared bids for in ΔP, ΔQ and PB in kW, kVar and KVA^{-}, respectively, in an hourly basis between 18:00 and 21:00 on 03/07/2023 in the specific NRT-DSO-AS associated with the selected MV grid. The results regarding these KPIs are presented in Table 14.

Table 14: Volume of received and cleared bids for the selected MV grid in the NRT-DSO-AS market

Grid level	Product	Volume of received bids			Volume of cleared bids		
MV		**h**	**h+1**	**h+2**	**H**	**h+1**	**h+2**
	ΔP (kW)	500	500	500	0	297	239
	ΔQ (kVAr)	500	500	500	0	162	82
	PB (kVA^{-})	120	120	120	0	0	0

<u>**Demonstration case 2:**</u> **NRT-DSO-AS market for ΔP, ΔQ, and PB in a specific LV distribution grid**

The overall market operation for a selected demonstration case in a specific LV grid of the NDT-DSO-AS market is presented in Table 15, for a selected date (11/07/2023) and time window (12:00-15:00). The selected market operation is directly related to the second case (LV – upward congestion) of the congestion management scenario already demonstrated in Section 3.3.2.1. The DSO demand bids (volume and price) for ΔP, ΔQ, and PB services are presented, as well as the generation offers (volume and price) submitted by each FSP for the location-based flexibility services. After the market clearing process, the common market clearing price for availability (pay-as-cleared) is also presented in an hourly basis for the interval between 12:00-15:00 and the awarded volume for each FSP is demonstrated, showing that the FSPs with the lower offering prices are prioritized to maximize the social welfare while ensuring sufficient availability of flexibility services to manage congestion. As indicated by the second demonstration scenario (LV – upward congestion) for congestion management (Section 3.3.2.1), the awarded flexibility services were able to satisfactory manage congestion and successfully relieve overloading conditions in the local LV distribution grid.

The overall NRT-DSO-AS market operation for the demonstration case above is also evaluated considering selected market-based KPIs.

KPI_H01 Number of FSPs: This KPI indicates the number of FSPs participating in the market to provide either ΔP, ΔQ or PB services to the specific part of the LV grid. In the corresponding demonstration case for the NRT-DSO-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

AS market, associated with the congestion management scenario (see second demonstration case in Section 3.3.2.1), 2 FSPs are participating and submitting for ΔP, ΔQ and PB generation offers in the near-real-time ancillary services market.

Table 15: NRT-DSO-AS market demonstration (bids, offers, clearing results) for LV grid on 11/07/2023 (12:00-15:00)

Demand bids and generation offers submision				
	Hours	h0	h1	h2
DSO bids	DP (kW)	-2.485	-5.39	0
	Price (€/kW)	15	15	15
	DQ (kVar)	1.39	2.605	0
	Price (€/kVar)	10	10	10
	PB$^-$ (kVA$^-$)	3	3	3
	Price (€/kVA$^-$)	10	10	10
FSP1 offer	DP (+/-) (kW)	7 / -7	7 / -7	7 / -7
	Price (€/kW)	11 / 6	11 / 6	11 / 6
	DQ (kVar)	7	7	7
	Price (€/kVar)	6	6	6
	PB$^-$ (kVA$^-$)	2	2	2
	Price (€/kVA$^-$)	6	6	6
FSP2 offer	DP (+/-) (kW)	6 / -6	6 / -6	6 / -6
	Price (€/kW)	5 / 5	5 / 5	5 / 5
	DQ (kVar)	6	6	6
	Price (€/kVar)	5	5	5
	PB$^-$ (kVA$^-$)	1.6	1.6	1.6
	Price (€/kVA$^-$)	5	5	5

Cleared ancillary services market for LV grid				
	Hours	h0	h1	h2
DSO cleared bid	DP (kW)	-2.485	-5.39	0
	Price (€/kW)	5	5	-
	DQ (kVar)	1.39	2.605	0
	Price (€/kVar)	5	5	-
	PB$^-$ (kVA$^-$)	3	3	3
	Price (€/kVA$^-$)	6	6	6
FSP1 cleared offer	DP (kW)	0	0	0
	Price (€/kW)	5	5	-
	DQ (kVar)	0	0	0
	Price (€/kVar)	5	5	-
	PB$^-$ (kVA$^-$)	1.4	1.4	1.4
	Price (€/kVA$^-$)	6	6	6
FSP2 cleared offer	DP (kW)	-2.485	-5.39	0
	Price (€/kW)	5	5	-
	DQ (kVar)	1.39	2.605	0
	Price (€/kVar)	5	5	-
	PB$^-$ (kVA$^-$)	1.6	1.6	1.6
	Price (€/kVA$^-$)	6	6	6

KPI_H07 Number of transactions: This indicator measures the number of transactions including the number of bids submissions, offers submission, as well as the transaction related to the information of the market participant about the clearing results. For the particular demonstration case of the NRT-DSO-AS market operation, *a total number of 6 transactions are involved in one cycle of market clearing*. These transactions include 1 bid submission by DSO, 2 generation offers submission by FSPs and 3 transactions for informing the DSO and the 2 FSPs about the market clearing results.

KPI_H09A Volume of transactions – received bids (Availability) and KPI_H09B Volume of transactions-cleared bids (Availability): These indicators measure the volume of received and cleared bids for in ΔP, ΔQ and PB in kW, kVar and KVA$^-$, respectively, in an hourly basis between 12:00 and 15:00 on 11/07/2023 in the specific NRT-DSO-AS associated with the selected LV grid. The results regarding these KPIs are presented in Table 16.

Table 16: Volume of received and cleared bids for the selected LV grid in the NRT-DSO-AS market

Grid level	Product	Volume of received bids			Volume of cleared bids		
LV		**h**	**h+1**	**h+2**	**H**	**h+1**	**h+2**
	ΔP (kW)	13	13	13	-2.49	-5.39	0
	ΔQ (kVAr)	13	13	13	1.39	2.6	0
	PB (kVA^{-})	3.6	3.6	3.6	3	3	3

Concluding remarks for NRT-DSO-AS market operation: The demonstration cases in both MV and LV grids regarding the selected NRT-DSO-AS market indicates a smooth and seamless process regarding the procurement of ΔP, ΔQ and PB services by the DSO, the submission of generation offers for congestion management related services by the FSPs, the clearing process by the market operator, and the information of the market participants about the clearing results. In all the demonstration cases, there is enough liquidity to ensure that the successful market clearing and the market results have been utilized in the congestion management demonstration scenarios (of Section 3.3.2) where it has been successfully demonstrated that the provision of ΔP, ΔQ and PB services by location-based FSPs and the proper real-time coordination of these services by the DSO is able to cost-effectively relieve congestion and improve the power quality and efficiency of distribution grids.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

4 Greek Demo Description

This chapter will present the basic inputs regarding the Greek Demo and provide the readers with the description of the actions conducted within the Demo in the last three years. It can also be treated as an introduction to the next chapter, dealing with the proper evaluation of the results achieved through this demo.

4.1 Overall description

For the Greek Demo, the first thing to be specified is the area that was considered as the area of interest. This time, that was the area of Crete and Peloponnese, highlighted in the map in Figure 21. Here, blue colour has been used to mark the area of Peloponnese, whereas red colour marks area of Crete.

Figure 21: The area of interest for the Greek Demo.

Before the start of any activities foreseen in the scope of the demo, necessary set of input data had to be defined and collected. In line with that, the data on network in the marked areas was gathered, on all voltages from 400 kV all the way down to 20 kV. This was aligned with the basic principle of the demo, by which the grid would be modelled to the level of lowest voltages and single energy entities. This gave the total of 50 substations in the Peloponnese region and one substation in Crete Island (that was due to the interconnection between Crete and Peloponnese. Moreover, there was information on 161 OHLs, 13 SPPs and 37 WPPs in affected area.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Since this kind of data collection revolved around the constant communication between the partners involved in the demo, it is clear that one of the major risks that could potentially harm the activities of the demo was the lack of the coordination between the partners. However, if there was any concern of this happening, it has been relieved swiftly, in the first several months of the project duration. The information flow between the partners has been flawless throughout the project, with particular efforts undertaken by the colleagues from the Greek system operators – IPTO (for the transmission system) and HEDNO (for the distribution system). In particular, the employees of IPTO that were active on the OneNet project volunteered to undertake the effort required to deliver the high-quality data. It needs to be stated, however, that some of the data had to be delivered twice, since the initial collection referred to the period during which the system of Crete was isolated from the system of mainland Greece. However, since the connection has been established in 2021, it was deemed better to use the updated information related to the state valid at the moment of the completion of the envisaged activities.

Two Business Use Cases (BUCs) were identified regarding the Greek Demo. Those BUCs can be seen in the list below, together with the respective brief descriptions needed for the adequate comprehension of the validation and evaluation scenarios that will be in focus of Chapter 5 of this report:

- BUC 1: Enhanced Active Power Management for TSO-DSO coordination. This BUC was based on improved identification of the available flexibility resources, focused primarily on the DSO voltage levels, together with the enhanced identification of the power system flexibility needs, focused on the TSO voltage level grid. Along with that, this BUC considered the time horizon that is quite longer and the geographical scope wider than the ones that are commonly in use today, which is achieved through the simultaneous market and grid simulations backed up by AI based calculation engines. The objectives of this BUC, among others, included the improvement of the frequency stability of the system, load flow and contingency monitoring and forecasting, enabling the predictive congestion management, and better flexibility service providers' identification and planning. As can be seen, this BUC has been directly related to both of the modules of F-channel platform, with the Forecasting Module serving for prediction of the system state and Coordination Module being in charge of achieving the information flow among the participants in the energy market.
- BUC 2: Enhanced severe weather condition management and outage management for TSO, DSO and micro grid operator. This BUC was focusing on enhanced severe weather condition management with predictive maintenance algorithms, combined with the enhanced storm and icing predictions in order to prevent the power system from running into dangerous topological or operational regimes. The objectives of this BUC, among others, included the predictive maintenance and outage management in the grid, enhancing severe weather condition management, as well as the early warning of the operators related to risk of potentially harmful system states. It is clear this BUC was even more focused on the forecasts than the first one, with its main target being giving the system operators the warning on possibly risky situations well in advance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

These Business Use Cases had a total of eight System Use Cases (SUCs) directly related to them. The short insight into each of those system use cases can be found in the following paragraphs:

- SUC 1: Improved production and consumption prediction for DSO and microgrid voltage levels. This SUC is related to BUC 1. The scope of this use case includes the improvement of the production and consumption predictions, focused mainly on the DSO voltage level, considering longer time span and wider geographical scope than commercially available tools for the sake of grid observability and easier state monitoring.
- SUC 2: DSO, DG and PoI management. This SUC is also related to the BUC 1. It was supposed to focus on the development of the user-friendly Register of PoIs that would contain the overview of the characteristics of the selected system regions while focusing on the necessary regular periodic updates and data archiving.
- SUC 3: Change View – different aggregation level simulations. Once again, this SUC is related to the BUC 1. It focuses on giving the user an option of manually defining the domain of the DSO/microgrid or TSO voltage level region of interest for which the simulations will be run in order to optimize the resource usage.
- SUC 4: Improved congestion management process on TSO and RSC side. This System Use Case is related to BUC 1 of the Greek Demo. It revolved around the improvement of the short-term predictions of the load, production and transmission capacities, based on the accurate weather forecasts. This was followed by the contingency analysis and capacity calculations through the usage of the data obtained from grid operators.
- SUC 5: Storm and Icing predictive maintenance process in TSO, DSO grid and local microgrid. This SUC was related to BUC 2. Its scope enveloped prediction of severe weather conditions, such as storms or forming of ice, which not only assists the operators of the system in scheduling the maintenance of the elements, but also significantly aids them in avoiding the potential consequences of those severe weather conditions.
- SUC 6: Outage management process in TSO/DSO grid and local micro grid. This use case is also related to BUC 2 of Greek Demo. It aimed at the potential increase of the reliability of outage and maintenance plans of the SOs by granting them a more accurate insight into conditions under which the system may be forced to operate. This would help the SOs in changing the maintenance and outage plan accordingly.
- SUC 7: Improved frequency control on TSO side. This SUC is again related to BUC 1. It was envisaged to consider the situation in which the imbalance jeopardizes the frequency stability, thus requiring immediate response. Needed action from SO side is composed of optimal identification and consequential activation of the available flexibility resources that could be used to mitigate the consequences of such an event.
- SUC 8: Improved Voltage control on DSO and TSO side. This SUC was also related to BUC 1. It considered the situation in which the potential over- or under-voltages are foreseen, with enough time remaining for the proper reaction, including the activation of the FSPs that could provide support in such a situation.

4.2 Scenarios of Greek Demo

There are four scenarios included in the Greek Demo related to the Use Cases from the previous subchapter. The first three of them are related to the BUC 1 of the Greek Demo, with the fourth covering the scope of interest of the BUC 2. The remainder of this subchapter will be organized in such a manner to provide some basic information on each of these scenarios.

BUC 1 – Scenario 1: Contingency identification and mitigation

This scenario takes into account the potential situation in which the contingencies in the distribution and the transmission grids are spotted in advance by the application of the enhanced system state prediction tools, with the precondition being availability of the high-quality data. Mentioned contingencies are obtained as one of the results of the calculations done on the unified simulation model, based upon the production and grid capacity predictions determined by considering the specialized weather forecasts. When the contingency is seen and the measures for mitigation are suggested, the goal is to achieve the recommended system state (i.e., to implement the listed measures). The needed flexibility resources are coordinated by the system operators for the needed active power regulation services to be provided to the grid. The flexibility services that will be included in this process are nominated by the market beforehand (declaring the availability through the bids) and their bids have been prequalified. Once the command is given to the flexibility sources, their response is observed, with the report on this check given to the market operator afterwards. The actors included in this scenario are the system operators, aggregators, prosumers, and FSPs that can provide the necessary flexibility to the system.

BUC 1 – Scenario 2: Coordinated voltage control

This scenario is based upon the possible situation in which the severe overvoltage or undervoltage states in the distribution and transmission grids are spotted in advance by application of enhanced system state prediction tools. The mentioned system state estimations are obtained as one of the results of the calculations performed on the simulation model, based upon the demand, production and capacity predictions determined by utilizing the weather forecasts. The states like the ones that are highlighted here can endanger the power system voltage stability of the system, making their forecast and timely mitigation a task of utmost importance for the proper operation of the future power systems. In case a warning for the possible voltage instability is issued, the DSO coordinates the flexible resources to provide the requested amount of the reactive power flexibility. It should be said that the flexible resources that participate in this scenario have previously been awarded by the market (declaring their availability through the bids) and their bids have been prequalified. This service is not limited to the DSO level, as it is also possible to use the reactive power from the TSO level through the interconnection transformers (transformers between the grids of TSO and DSO), equipped with the tap change possibility.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

BUC 1 – Scenario 3: Improved power regulation through mFRR and aFRR

This scenario is based on the way of possibly improving gathering of information on the flexibility resources in the grid (referred to as primary reserve or FCR, secondary reserve or aFRR, and tertiary reserve or mFRR) and the complementary identification of the flexibility needs of the system. The primary targets for an improvement are the reliability of the carried-out calculations, the accuracy of results obtained via analyses, the precision with which the identification of the system needs and resources is performed and the extension of the time horizon that can successfully be enveloped by the estimations. For all of this to be achieved, however, a process similar to those already described for the former two scenarios has to be followed, especially when it comes to steps such as updating grid model in order to ensure its compliance with the most up-to-date calculations regarding the generation, load and transfer capacities. Once a need for the reserve activation is reported, the resources that are available are coordinated in such a way that the necessary amount of flexibility (in this case, that would be the reserve) is provided to the system, thus mitigating the problem that occurred before the initiation of this scenario. Along with this, it needs to be said that the flexibility resources (in this case, the resources providing the reserve) participating in the scenario have previously been selected by the market operator, after that had declared their capability to provide those services through the appropriate bids. Also, their bids, before getting chosen for the participation in this scenario, needed to go through the prequalification procedure. It can be seen that this scenario can either be observed separately or it can be combined with the previous two scenarios that are related to the same BUC into one or multiple series of the sequential events occurring in the observed grid.

BUC 2 – Scenario 1: Early severe state warning system / prevention and restoration

In order to avoid severe damages of the equipment and load losses, it is of utmost importance to prepare the power system elements for the incoming severe weather conditions, as well as for the power system conditions that could occur as a consequence of those weather conditions. For that to happen, it is necessary to provide the operators with the improved identification of the severe weather conditions, so that they can predict the potentially harmful system states and contingencies in order to avoid the potential consequences. The forecasts have to be given in a more precise manner and envelop a longer time horizon than what is being done today, with the improved identification of the system flexibility needs and available resources that could be utilized to saturate the spotted needs being just as important. The process itself starts similarly to those included in other scenarios, with the weather forecast provider informing the operators of the expected climatic conditions and the units in the operator companies creating the unified grid model based on those forecasts. Then, calculations are done on these models, with the employees working on those calculations monitoring the appearance of any possibly dangerous system regimes. If such a regime happens, the critical outages and the critical elements that could be at risk in case those outages are listed, followed by the mitigation measures determined by experts, based on the established set of the flexibility resources available to the operators for the designated purposes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

4.3 Development and integration

The F-channel platform is web-based, client-server application for the TSO-DSO coordination. It uses high-resolution weather forecasting, Artificial Intelligence methods, GUI-based georeferenced projection of the grid on the map, and cloud calculation engines. The F-channel platform envelopes and implement set of common functionalities for SOs regarding the improvement of the forecasting ability and efficiency in various given time frames, limiting volume of flexibility needs in the process, as well as identification and prequalification of flexibility resources willing to procure grid services through "market-to-network" coupling of the alternative solutions. In order for that idea to come to life, the architecture shown in Figure 22 has been selected in the early stages of the project.

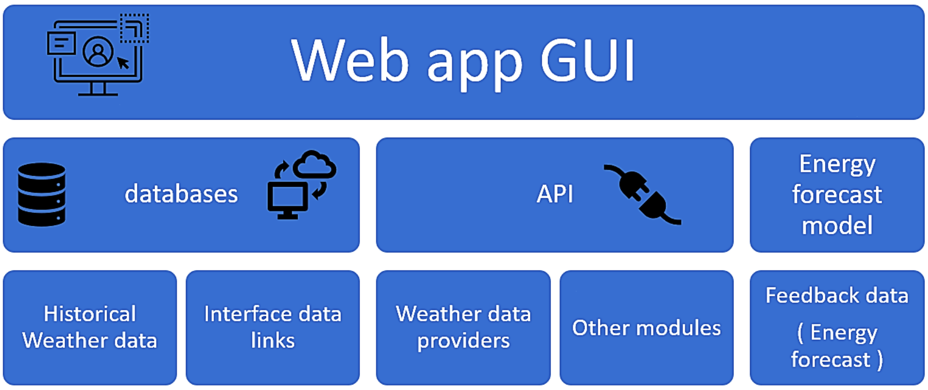
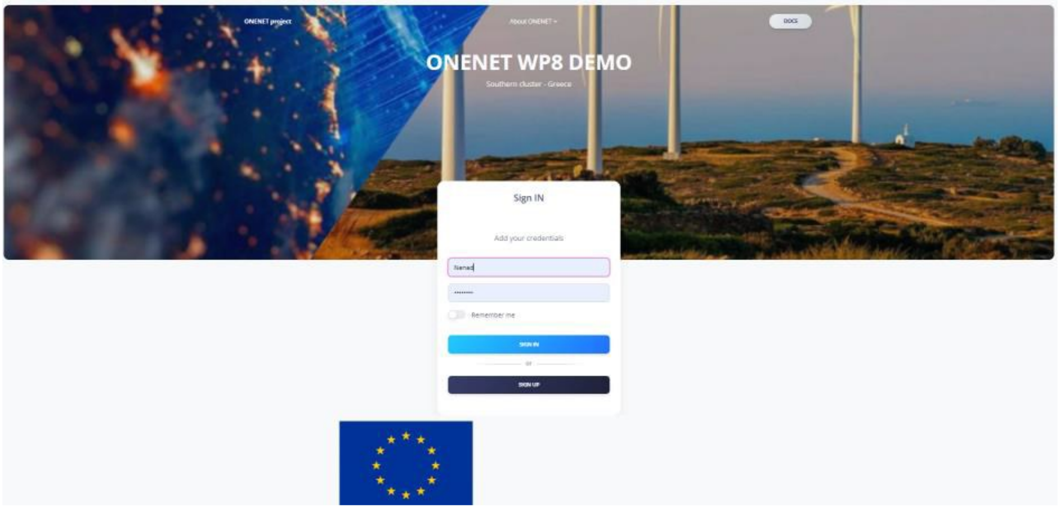


Figure 22: Basic architecture of F-channel platform.

The F-channel platform is accessed by the user by typing the web address of the server hosting the F-channel platform into the internet browser. Once that is done, the user is greeted by a "Log in" screen as the first screen with a pop-up window in which the username and password of the user have to be provided. The appearance of log-in screen, based on the large number of other similar screens known to users, can be seen in Figure 23.



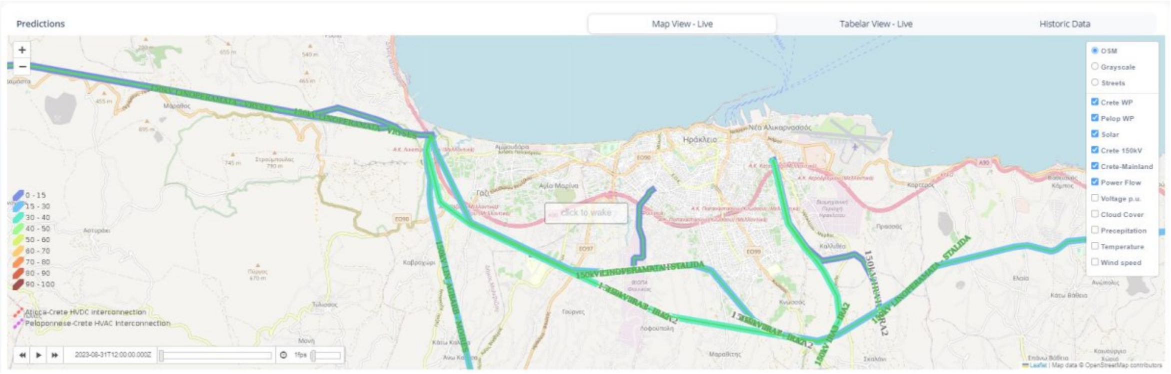
Nenad

Figure 23: Log-in screen of the F-channel platform.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

4.3.1 F-channel Forecasting module

The functionalities offered to the platform user depend on the role that a certain user plays in the energy market. Functionalities of the F-channel platform have been divided into two major modules: Forecasting module and Coordination module. Forecasting module is equipped with an appropriate GUI based on the georeferenced map presentation. The F-channel's Forecasting module is capable of energy production forecast for wind and solar units, load flow, voltage profile simulations and the weather parameters forecasts, including the severe weather conditions identification. Results are shown on a GIS based map (Map View) and in the tabular view. For the Map View, the layers were created on the map, with each of the layers corresponding to one of the weather or technical parameters in the area of interest. For both of those, colour coding has been implemented in order to make reading the results and forecast off the map simple even for the inexperienced users. As an example of this, the diagram in Figure 24 can be used, with the load flow results shown as the different colours of the lines in the grid of the analyzed region. The blue shades show the relatively low loading of the lines and the red shades indicating the high loading of the lines. Similar to that, different colours of the nodes in grid indicate the voltage values of those nodes, with colours varying from blue to yellow, depending on voltage values.



● OSM
○ Grayscale
○ Streets
☑ Crete WP
☑ Pelop WP
☑ Solar
☑ Crete 150kV
☑ Crete-Mainland
☑ Power Flow
☐ Voltage p.u.
☐ Cloud Cover
☐ Precepitation
☐ Temperature
☐ Wind speed

Figure 24: Load flow results, shown in the appropriate layer of the map.

For this to be achieved, apparently, the digital twin of the grid in the regions included in the demo needed to be created, with some of the points proving to be trickier than the others. Such was, for instance, the examination of the behaviour of the demand, depending on the category to which that demand belonged. In this part of demo, four typical daily diagrams of load change have been created, one for each category – household load, industrial load, commercial load and EV chargers. Based on the diagram, the potential of certain demand type for provision of flexibility could also be estimated. The developed EV charger daily diagram can be seen in Figure 25. The orange colour marks the weekday's load behaviour and the grey colour symbolizes the behaviour of the load during the days belonging to the weekends. As expected, it was noticed that the demand of EV chargers during the weekends is not the same as during the weekdays, depending on the activities and plans of the owners of the vehicles. This should be considered when deciding upon the amount of flexibility that this type of resources can add to the energy market.

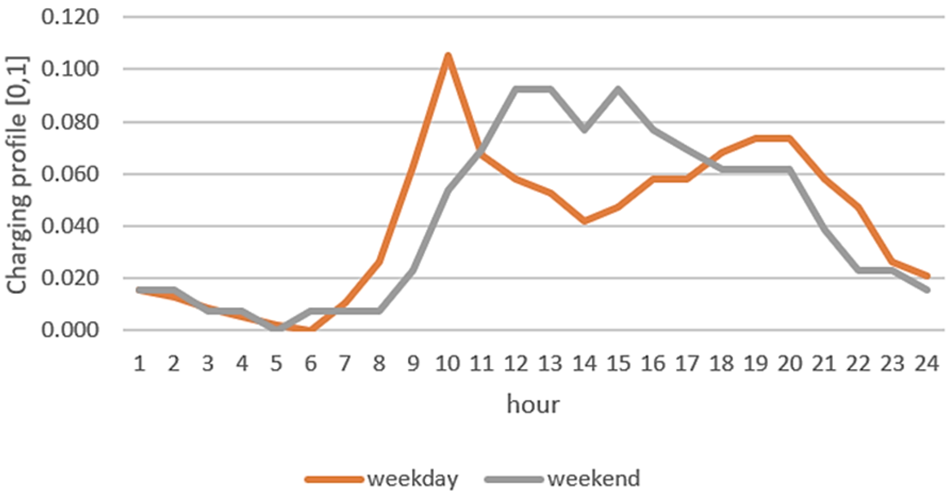
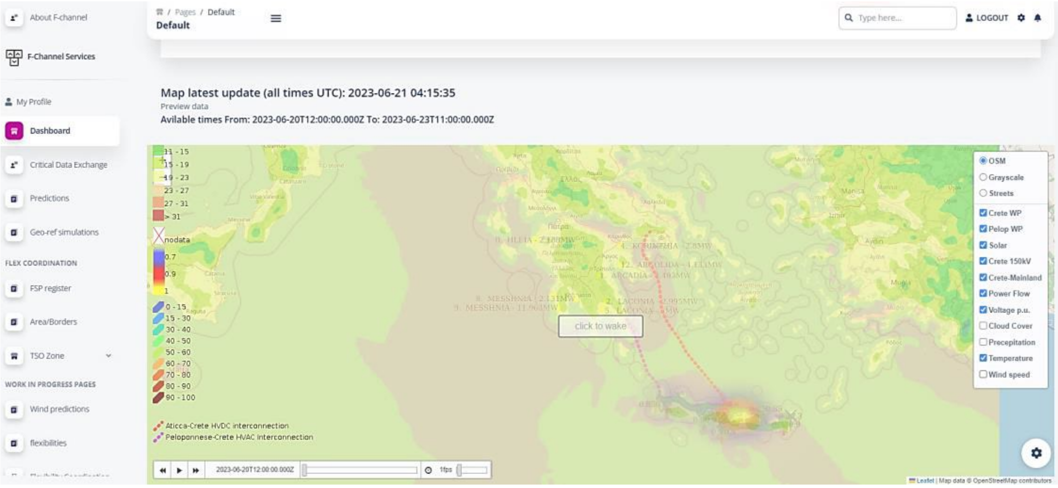


Figure 25: Daily diagram of the EV charger demand power.

In addition to the grid layers, the Forecasting module also includes the weather layers, showing the forecasts of the climatic indicators relevant for the operation of the different parts of the power system. For example, the map shown in Figure 26 shows the values of temperature in the entire region of interest. This is rather important, since the temperature variations can affect a number of the elements of the system, such as the lines (for which the rise of temperature reduces the transmission capacity) or the solar production units (for which the efficiency of the generation varies depending on the temperature). As illustrated here, this parameter is also colour coded.



Map latest update (all times UTC): 2023-06-21 04:15:35
Preview data
Avilable times From: 2023-06-20T12:00:00.000Z To: 2023-06-23T11:00:00.000Z

● OSM
○ Grayscale
○ Streets
☑ Crete WP
☑ Pelop WP
☑ Solar
☑ Crete 150kV
☑ Crete-Mainland
☑ Power Flow
☑ Voltage p.u.
☐ Cloud Cover
☐ Precepitation
☑ Temperature
☐ Wind speed

Figure 26: Temperature layer on the map in F-channel environment.

In addition to the temperature, as shown in the previous diagram, the Forecasting module also gives its users the possibility of showing the forecasts for other weather parameters of interest, such as wind speeds, coverage of clouds and the precipitation. All of these parameters are, together with the grid parameters, such as the WPP and SPP productions and ampacities, shown on the separate layers of the map, increasing the understandability of the obtained results and giving the users the clear signal of the system state in the upcoming periods of time.

4.3.2 F-channel Coordination module

The F-channel Coordination module for providing grid services for balancing and congestion management challenges was also finalized in the scope of Greek Demo. Within this module, TSOs and DSOs have interfaces towards the Flexibility Register and the TSO-DSO Coordination Platform. These SOs were given the interfaces towards FSPs, market operators, metering data administrators and consent administrators. Data exchanges were foreseen at TSO level for interoperability towards the distribution system. It was not foreseen that any market data will be shared directly between SOs. Grid data will, on the other hand, be shared directly between the SOs in order to meet requirements related to the existing practices related to the network security and operational stability regular checks. TSO and DSO will, along with that, be able to share information related to future flexibility needs, calls for flexibility tenders, flexibility purchase offers, grid data for qualification and finished auctions, flexibility requirements that are checked against operational and asset-based constraints and activation requests within their systems. One of the submodules of this module of F-channel platform is the Auction Submodule, in which the market participants are provided with the week-ahead to day-ahead frequency responses, re-dispatching auction-based procurements of the capacity reserves and comprehensive list of available flexibility products. In this submodule, the flow of the auction needed to be assumed, as shown in diagram given in the Figure 27.

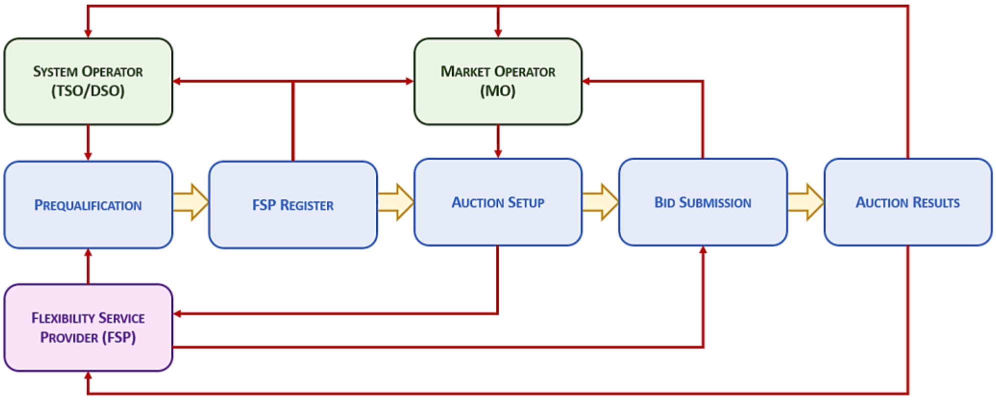
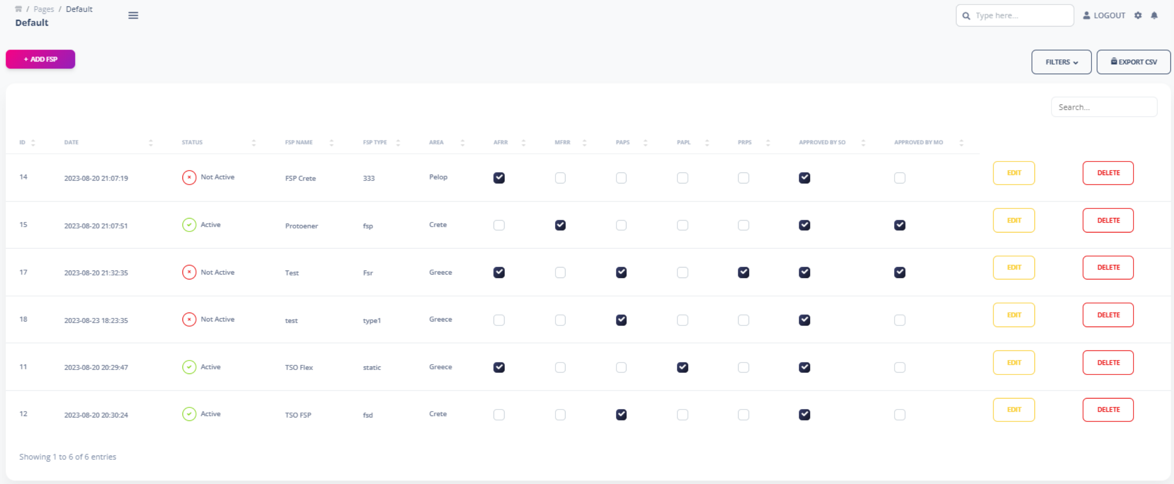


Figure 27: Assumed flow of the auctions in the F-channel platform.

As can be seen, the entire auctioning process can roughly be divided into five sequential steps, out of which the first two take place way before the need for the product is even established. The first step here would have to be the precondition for the remainder of the procedure, since the provision of the services by the energy entities can only be expected if those entities are capable of providing those services at all. In order to ensure

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

that, the entities go through the prequalification process, after which, if it goes successfully, the entities are added to the unified FSP register. This register represents one of the main contributions of the Greek Demo, since it gives the operators instant overview of all of the potential FSPs that are available for certain services to the system at any time. The screenshot of the part of platform dedicated to FSP register is given in Figure 28.



ID	DATE	STATUS	FSP NAME	FSP TYPE	AREA	AFRR	MFRR	PAPS	PAPL	PRPS	APPROVED BY SO	APPROVED BY MO		
14	2023-08-20 21:07:19	Not Active	FSP Crete	333	Pelop	☑	☐	☐	☐	☐	☑	☐	EDIT	DELETE
15	2023-08-20 21:07:51	Active	Protoener	fsp	Crete	☐	☑	☐	☐	☐	☑	☑	EDIT	DELETE
17	2023-08-20 21:32:35	Not Active	Test	Fsr	Greece	☑	☐	☑	☐	☑	☑	☑	EDIT	DELETE
18	2023-08-23 18:23:35	Not Active	test	type1	Greece	☐	☐	☑	☐	☐	☑	☐	EDIT	DELETE
11	2023-08-20 20:29:47	Active	TSO Flex	static	Greece	☑	☐	☐	☑	☐	☑	☐	EDIT	DELETE
12	2023-08-20 20:30:24	Active	TSO FSP	fsd	Crete	☐	☐	☑	☐	☐	☑	☐	EDIT	DELETE

Showing 1 to 6 of 6 entries

Figure 28: F-channel platform – FSP register.

After the prequalification process and addition of the FSPs to the register, they are allowed to participate in the auctions organized for responding to the needs spotted in the system. However, the following of those auctions can, even for the most experienced experts on the topic, turn out to be quite a tiresome and confusing task, especially if there is more than one auction taking place at the same time. Since each of those auctions would be either for the different timeframes or for the different products, it is understandable how this could confuse not only the FSPs, but the operators as well. To make this less tiresome, the F-channel platform's Coordination module also includes the Auction wizard, with the basic view of this part of the platform shown in Figure 29. Along with information on the status of each step in the auction, the platform also shows the details on the dates and times on which the activities were completed and/or dates and times by which those activities should be done, allowing the full overview of the currently active auctions to the user.

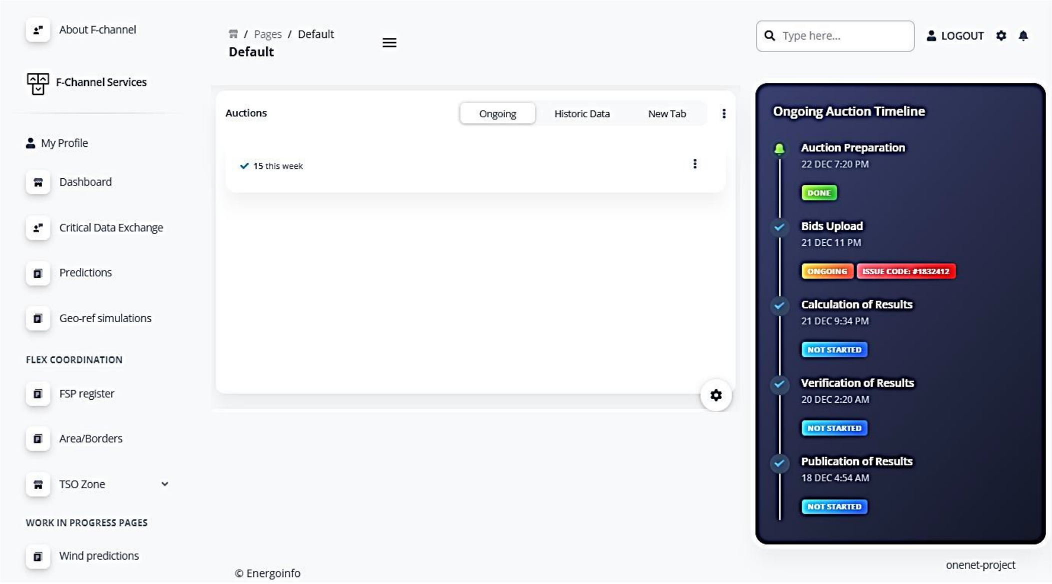
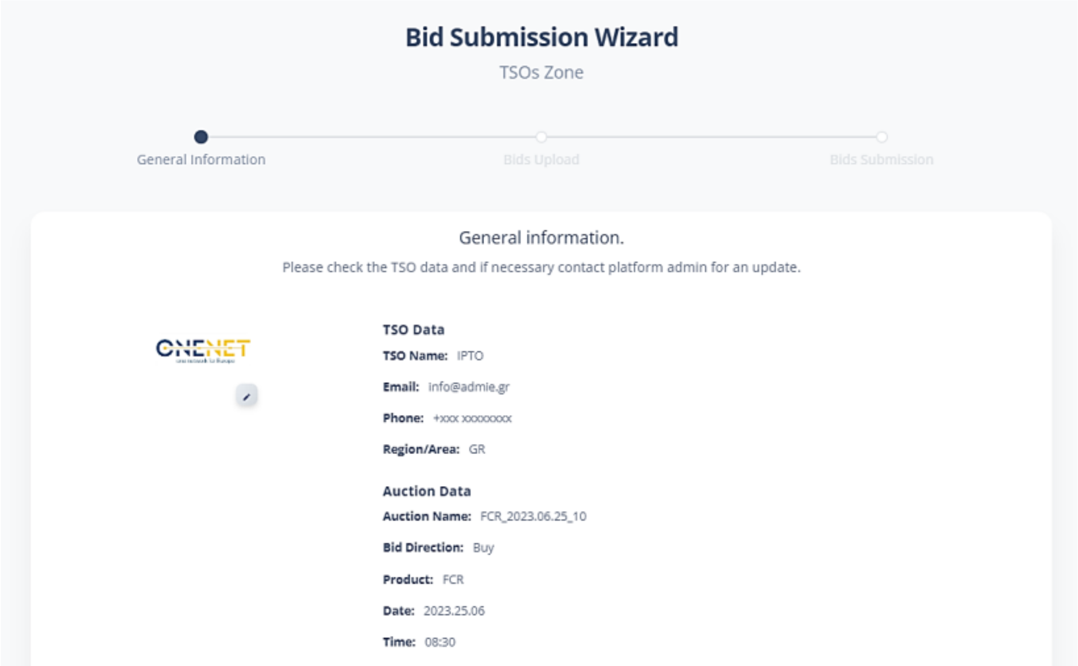


Figure 29: F-channel platform – Auction Wizard.

In addition to making the following of the auction process simpler, the F-channel platform makes the submission of the bids for those auctions easy via Bid Submission Wizard. This part of the platform incorporates three steps, out of which the first is the confirmation of the general information on the user that exists on the platform (such as contact mail addresses, roles and associated phone numbers). The second and third of these steps deal with the upload of the bids and the submission of the bids. The appearance of the screen that covers the first of those three phases of the bid creation and submission is given in Figure 30.



General information.

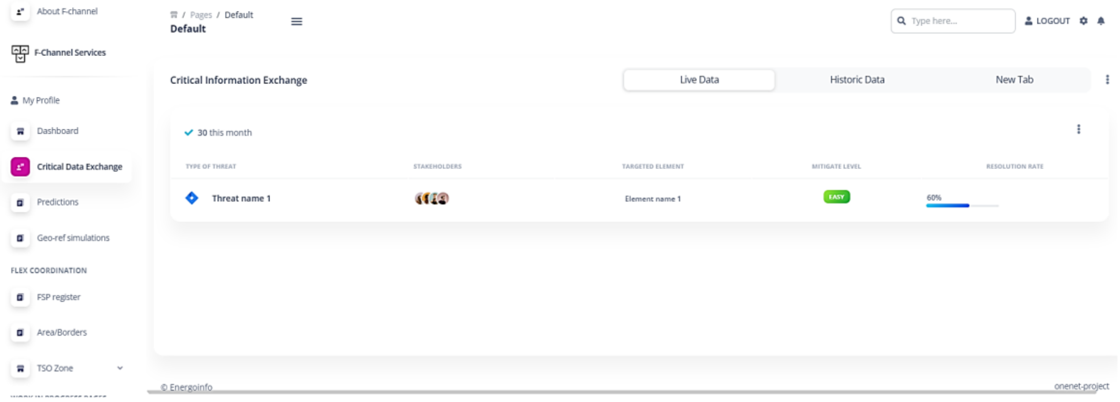
Please check the TSO data and if necessary contact platform admin for an update.

TSO Data
TSO Name: IPTO
Email: info@admie.gr
Phone: +xxx xxxxxxxx
Region/Area: GR

Auction Data
Auction Name: FCR_2023.06.25_10
Bid Direction: Buy
Product: FCR
Date: 2023.25.06
Time: 08:30

Figure 30: F-channel platform – Bid Submission Wizard.

Finally, one additional area of the F-channel platform's Coordination module that needs to be mentioned is one that allows the exchange of the critical information on the system, allowing the SOs to predict the potentially harmful states of the grid and react accordingly. This area of the platform is shown in Figure 31.



Critical Information Exchange

✓ 30 this month

TYPE OF THREAT	STAKEHOLDERS	TARGETED ELEMENT	MITIGATE LEVEL	RESOLUTION RATE
Threat name 1		Element name 1	EASY	60%

Figure 31: F-channel platform – Critical Information Exchange.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

5 Greek demo evaluation

This chapter will present the process of evaluating the Greek Demo achievements, starting from the basic facts about the evaluation and moving on to the concrete results reached within the demo, shown primarily in form of the KPIs. Those KPIs have been defined near the start of the activities on the OneNet project, but have turned out to be appropriate for intended purposes of checking whether the efforts invested in Greek Demo were fruitful and aligned with the plans set in advance or not.

5.1 Validation and evaluation framework

Regarding the validation framework, the KPIs that were used in this step can be divided into three separate categories, with the type of evaluation applied varying from one category to another. The categories that were used for division and organizing KPIs for the Greek Demo were:

- Market-based KPIs;
- Scenario-based KPIs;
- Regional KPIs.

As already mentioned, each of these three categories needed the proper methodology for evaluation assigned to them. In line with it, it can be stated that the market-based KPIs of the Greek Demo used the evaluation of the available market-related data for some of the assigned KPIs, whereas the other KPIs added to this category needed several simulations of the energy market operation to be performed in order to be calculated. At this point, it would be good to point out that the authors of this solution are aware that the evaluation would have been even more relevant if there was a possibility to do the testing in practice, the fact that there is no existing framework for communication between the SOs in Greece at the moment and further market is not operational yet prevented that kind of testing and validation from happening. Nevertheless, the outcomes of the simulations indicated that practical testing would simply prove already established applicability of the implemented features of the F-channel platform in the everyday work of participants in energy market.

The second out of three categories of KPIs was based on scenarios listed within the Subchapter 4.2 of this report. For those KPIs to be tested, it was necessary to try to spot the critical situations in the system. That could only be done once the digital twin of the grid in the analysed areas was developed, since it required that the weather forecasts had to be paired with the technical characteristics of the grid in order to determine the forecasted system state on the desired time-horizon. The system state forecasting included the predictions of the SPP and WPP production, demand in the grid, and ampacities, after which those would be fed into the model of the grid. The load flow was done on the model updated in that way, indicating the potential criticalities in the grid and giving the system operators enough time to react and to resolve those criticalities well in advance, which is one of the main benefits of integrating the reliable forecasts into the developed grid models.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Finally, the third category of the KPIs covered the regional aspect and extending beyond the area covered by Greek Demo. To be more precise, this kind of KPIs was related to the Regional BUC, determined on the level of the entire Southern cluster of the OneNet project. Southern cluster regional BUC aimed at enhancing regional cooperation through provision of early warnings regarding potentially hazardous weather conditions and cyber threats. This was achieved by exchanging information about cyber security and severe weather condition forecasts between the Greek and the Cypriot demos. Predictive maintenance algorithms along with enhanced storm predictions were developed in the Greek Demo to prevent the system from reaching dangerous topological or operational states. Additionally, information exchange processes and an early warning system for potentially hazardous weather conditions and cyber threats was introduced for the Cypriot TSO and DSO to avoid dangerous power system regimes, which could lead to damages to the critical infrastructure. Some of the goals of this BUC were the improvement of cyber security in the systems, critical infrastructure and information protection, enhanced severe weather condition management, and early warnings on the potentially hazardous power system topologies and regimes. For all of these KPIs to be properly monitored, constant communication had to be established between the weather stations positioned throughout the area of interest and the servers that would store the relevant information. Based on that data, the critical weather and system conditions could be identified. Similar approach was used for the other aspect of interest for this category, being the cyber threats. Since those are becoming more and more severe with each day passing, it is clear why they were chosen as one of the focal points of the activities for enhancing the communication within the region.

The comprehensive list of KPIs relevant for the Greek Demo can be found in Table 17. Here, the first and second columns indicate the identifier of the KPI, used throughout the OneNet environment. The third column of this table gives information on the category of the KPIs to which each of them has been assigned. Description of the results obtained for every KPI can be found in the following subchapters, divided by category of the KPIs.

Table 17: List of KPIs relevant for the Greek Demo

KPI number	KPI name	KPI category
KPI_H01	Number of FSPs	Market-based
KPI_H07	Number of transactions	Market-based
KPI_H09A	Volume of transactions (power)	Market-based
KPI_H12	Percentage of avoided technical restrictions (congestions)	Scenario-based
KPI_N23	Number of successfully predicted hazardous power system regimes and cyber threats	Regional
KPI_N24	Number of successfully predicted severe weather conditions	Regional

5.2 Evaluation of market-based KPIs

This subchapter will, along with showing the results obtained for the market-based KPIs of the Greek Demo, also serve as the showcase example of the way in which the KPIs have been incorporated into the activities of the Demo. Accordingly, each of the KPIs relevant for this part of the report will be observed individually, with the small table preceding the part of text containing the results. The table will be the basis for the comprehension of the achieved results, since it will include the description of the KPI (created before the start of the practical activities within the demo), together with the formula needed for its calculation and the expected benchmark value that needed to be exceeded for the demo to be considered a success from the point of view of the observed KPI. The only situation in which the KPIs will not be described individually will be the situations in which the KPIs are entwined enough to justify the common examination. Those situations will be elaborated further when the appropriate KPIs are reached in the text.

The first of the KPIs that were related to the functioning of the energy market in Greece was the one identified as KPI_H01. The details on this KPI can be found in the Table 18, given below this paragraph.

Table 18: Relevant characteristics of the KPI_H01.

Information	Value
Identifier	KPI_H01
Name	Number of FSPs
Formula	N_{FSP}
Variables	N_{FSP} – number of FSPs participating in the activities of Demo.
Calculation methodology	By observing the number of the FSPs active in the Greek Demo and assigning them to the appropriate categories.
Target value	>20

This KPI has been treated as one of the most important KPIs within the Greek Demo, since it not only vouched for the quality of the conducted procedures, but also indicated the interest of the potential service providers for the participation in the real-life situations in which the system might need flexibility in the future. Therefore, it was a remarkable relief when it turned out that the number of FSPs not only reached the designated target, but exceeded it four times. To be precise, the number of FSPs in the Greek Demo was 83, out of which:

- 4 were the consumers;
- 1 was the aggregator;
- 13 were the solar parks;
- 63 were the wind parks and
- 2 were battery storages.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

As can be concluded, the evaluation based on the first analysed KPI turned out to be quite a success. The next two KPIs can be seen as an example of the situation in which the indicators are so well connected among each other that they can also be treated together. These two KPIs are KPI_H07 and KPI_H09A, both dealing with the simulated transactions on the energy market. The basic information on them can be found in the table below. In this table, upper half (marked with (a)) deals with the relevant characteristics of the KPI_H07 and the lower half (marked with (b)) covers the essential details on the KPI_H09A.

Table 19: Relevant characteristics of the KPI_H07 (a) and KPI_H09A (b).

(a)

Information	Value
Identifier	KPI_H07
Name	Number of transactions
Formula	$N_T = \sum_{T} n_{Bids,t}$
Variables	$n_{Bids,t}$ – number of transactions in the timeframe t; T – entire observed timeframe.
Calculation methodology	By applying the formula given above.
Target value	>0

(b)

Information	Value
Identifier	KPI_H09A
Name	Volume of transactions (Power)
Formula	$VT_P = \sum_{T} \sum_{I} P_{i,t}$
Variables	VT_P – Volume of bids received considering power (kW or kVAr); $P_{i,t}$ – Capacity offered by i-th resource in time t (kW or kVAr); I – Set of potential flexibility resources.
Calculation methodology	By applying the formula given above.
Target value	>0

For the first of these, it should be stated that the total number of transactions was 35 (3 for CM and VC+, 5 for CM and VC-, 9 for mFRR+, 16 for mFRR-, 1 for aFRR+ and 1 for aFRR-). For the latter, the total capacity of those transactions was 25000 kW (4000 kW for CM and VC+, 5000 kW for CM and VC-, 2000 kW for mFRR+, 5000 kW for mFRR-, 4000 for aFRR+ and 5000 kW for aFRR-). As can be seen, the evaluation went successfully

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

for both of these KPIs, since the achieved vales greatly exceeded the set targets for their respective performance indicators.

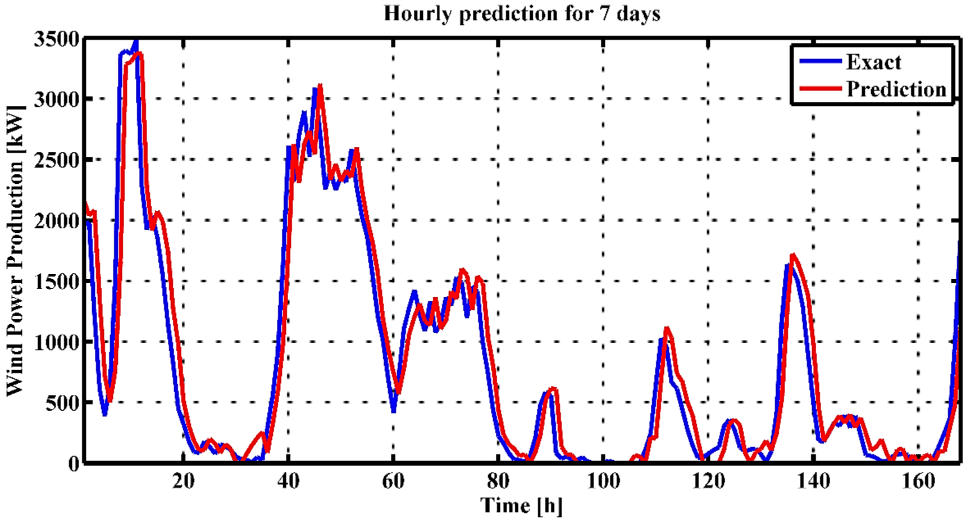
5.3 Evaluation of scenario-based KPIs

As for this part, it can be noticed that there was only one KPI covering the scenarios of the Greek Demo. This is, however, firmly reliant on the mentioned characteristic of those scenarios, by which all of them can come to be simultaneously and can, therefore, be observed together. This kind of situation in the system represents rather critical state, so it was rather important to properly test the capability of the platform in aiding the operators in avoiding such conditions. As illustrated by the assigned KPI, the basic point in this was the development of the forecasting methodology accurate enough that the operators could rely on it and start acquiring the services in advance, based on the results of the obtained forecasts. This allows the operators to react not only when some issue in the system arises, but pre-emptively, before the actual event occurs. This, in turn, significantly reduces the possibility of the consequences of those events. The characteristics of KPI_H12 can be seen in Table 20.

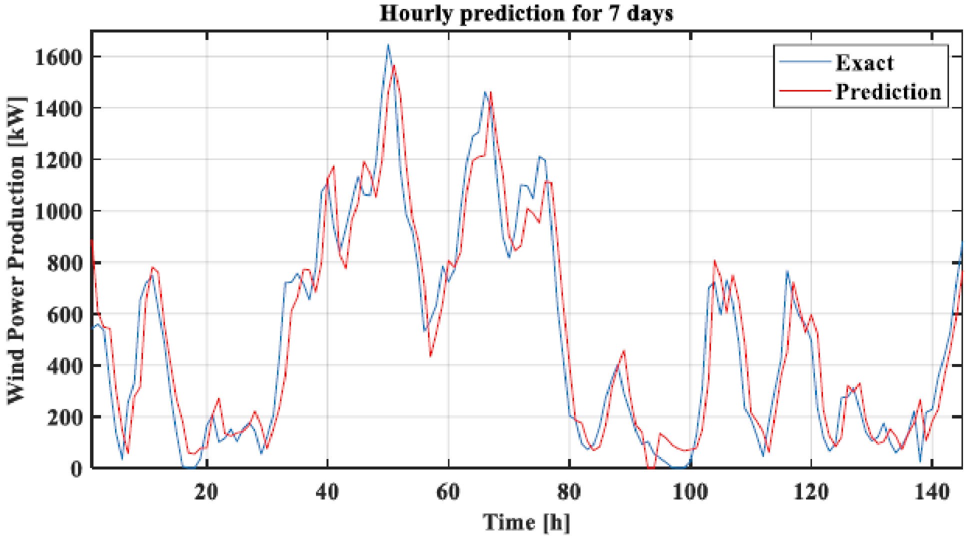
Table 20: Relevant characteristics of the KPI_H12.

Information	Value
Identifier	KPI_H12
Name	Number of avoided technical restrictions (congestions)
Formula	$ATR_{\%} = \frac{N_{TR_{Flex}}}{N_{TR}} \cdot 100$
Variables	$ATR_{\%}$ – Share of avoided technical restrictions; N_{TR} – Total number of avoided technical restrictions; N_{TRFlex} – Number of restrictions resolved by flexibility services.
Calculation methodology	By applying the formula given above.
Target value	5% improvement compared to the current state.

Before moving on to the showcasing of the acquired value of this KPI, it should be highlighted that the success regarding this performance indicator relied heavily upon the accuracy of the forecasts obtained via the F-channel platform. In order to make the forecasts as precise and reliable as possible, F-channel platform combined ANN (artificial neural network) methods with the high-resolution weather forecasts to find the connections between the weather parameters and the technical parameters. This, in turn, resulted in the high-quality forecasts of the technical parameters, such as production of SPPs and WPPs, demand in the grid, and the ampacities of the lines. To illustrate the effects that this kind of approach had on the accuracy of the forecasts, it should be mentioned that, by using ANN, average MAPE for one-week period for WPP 1 (one of WPPs in area of interest) was equal to 3% and the average MAPE for WPP 2 (other WPP in the region of interest) was equal to 1%. As a benchmark, the MAPE of the WPP forecast (market schedules) is typically around 9%, highlighting the improvement made by the usage of ANN methods. For those plants and for that week, diagrams comparing the ANN forecast and real-life values were created. Those diagrams are given in Figure 32, with parts (a) and (b) referring to two WPPs.



(a)



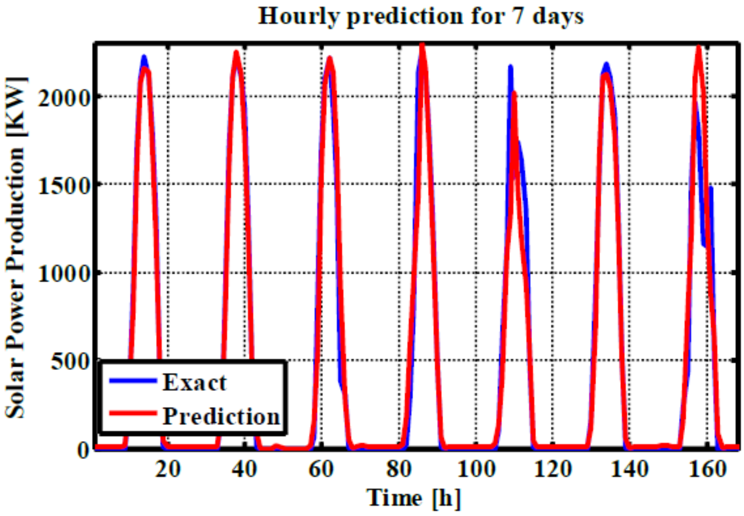
(b)

Figure 32: Comparison of forecasted and measured production values for WPPs.

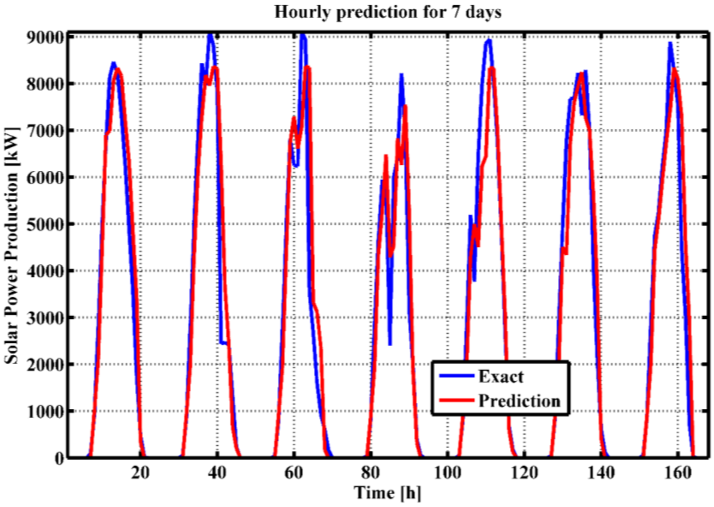
As can be observed here, forecasted values of WPP production followed the real-life values nearly without mistake, proving that the application of the ANN methodology of this task was the right decision to make. To show that this is true for more than just wind power plants, similar analysis can be made for the solar power plants as well. Here, by using ANN, average MAPE for one-week period for SPP 1 (one of SPPs in area of interest)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

was reduced to 1% and the average MAPE for SPP 2 (other SPP in the region of interest) was reduced to 4%. As a benchmark, the MAPE of the SPP forecast typically belongs to the range between 5% and 10%, emphasizing the improvement made by the usage of ANN methods. For those plants and for that week, diagrams comparing the ANN forecast and real-life values were created. Those diagrams are given in the Figure 33, with parts (a) and (b) referring to two SPPs. Once again, the blue colours of the lines show the values that were measured in real-life, whereas the red colours on the lines illustrate the values obtained by applying the developed ANN forecasts.



(a)



(b)

Figure 33: Comparison of forecasted and measured production values for SPPs.

It is apparent from the figures that the quality of the forecasts done for the SPPs is just the same as already seen for the WPPs. Once the forecasts of this accuracy are fed into the model, it is possible for the system operators to reliably claim that, if the problem is observed in the model, similar situation could occur in reality.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

This would mean that the proper services should be acquired in order to avoid the consequences of the congestions or the voltage issues that would occur otherwise. In line with that, during the demonstration simulations, all technical restrictions (congestions) were avoided through the ancillary or system services offered via the platform. This means that the result that was obtained for this KPI is equal to 100%. Admittedly, this is also due to the fact that only a small region in Greece, between Peloponnese and the island of Crete, was taken into considered in the demo, so no major congestions could be detected in this region. Greek TSO contributed at this point and compared the obtained results to the data valid for the current state, verifying that the desired improvement related to the aspect of operation encompassed by this KPI has indeed been achieved.

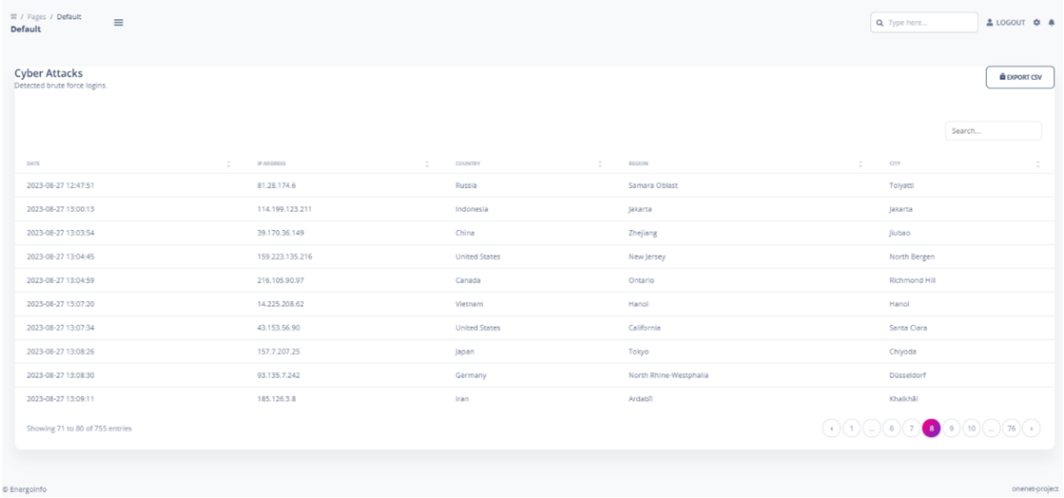
5.4 Evaluation of the regional KPI

Finally, the third group of the KPIs relevant for the Greek Demo was the one focusing on the regional aspects of the critical situation spotting and information exchange regarding those situations. For purposes of needed evaluation and validation of the activities conducted related to this aspect of functioning, there were two KPIs that were defined and followed. The basic characteristics of the first of them can be found in Table 21.

Table 21: Relevant characteristics of the KPI_N23.

Information	Value
Identifier	KPI_N23
Name	Number of successfully predicted hazardous power system regimes and cyber threats
Formula	$CFC_{\%} = \frac{C_{fc,c}}{C_o} \cdot 100$
Variables	$CFC_{\%}$ – Share of foreseen hazardous regimes and cyber threats; $C_{fc,c}$ – Number of foreseen hazardous regimes and cyber threats; C_0 – Total number of hazardous regimes and cyber threats.
Calculation methodology	By applying the formula given above.
Target value	1% improvement compared to the current state.

The database with the critical information regarding the system, allowing the SOs to predict the harmful states and react accordingly, is shown in Figure 34 below. This database constantly gets filled with potential threats to the system. This means that there is also a comprehensive archive of the threats, allowing their detailed examination later on. This means that not only critical events get archived, but this allows the users to get back to them at some later point and verify that the causes of them have been successfully identified and, as a result of that, resolved.



Cyber Attacks
Detected brute force logins.

DATE	IP ADDRESS	COUNTRY	REGION	CITY
2023-08-27 12:47:51	81.28.174.6	Russia	Samara Oblast	Tolyatti
2023-08-27 13:00:13	114.199.123.211	Indonesia	Jakarta	Jakarta
2023-08-27 13:03:54	39.170.36.149	China	Zhejiang	Jiubao
2023-08-27 13:04:45	159.223.135.216	United States	New Jersey	North Bergen
2023-08-27 13:04:59	216.105.90.97	Canada	Ontario	Richmond Hill
2023-08-27 13:07:20	14.225.208.62	Vietnam	Hanoi	Hanoi
2023-08-27 13:07:34	43.153.56.90	United States	California	Santa Clara
2023-08-27 13:08:26	157.7.207.25	Japan	Tokyo	Chiyoda
2023-08-27 13:08:30	93.135.7.242	Germany	North Rhine-Westphalia	Düsseldorf
2023-08-27 13:09:11	185.126.3.8	Iran	Ardabīl	Khalkhāl

Showing 71 to 80 of 755 entries

Figure 34: Part of database containing the threats to the system.

It is clear that the KPI_N23 can be treated as two-fold: one part of KPI is related to the potential cyber security attacks or even breaches, whereas the second part deals with the successful prediction of the possibly hazardous states of the system in the area of interest. In line with that, it should be mentioned that, from the cyber security side, Southern cluster had 9990 attacks from the different addresses. Since all of those are addresses from which the attack happened, the value of the KPI (from this side) is equal to 100%. Of course, these were not foreseen in advance, since they do not depend upon any factor that can be analyzed, but on the free will of the attackers. Nonetheless, it can be foreseen that security breach would cause the system to go into critical state, so the detection and blocking of such information leakages can be considered equal to the prediction and preventive resolution of those critical system states that would come to be in case the attempted cyber-attack succeeded. This justifies the conclusion of KPI value, given above. The geographical distribution of the addresses from which the identified attacks happened (by the countries from which the IP addresses originate) can be seen in the bar diagram, enclosed in Figure 35.

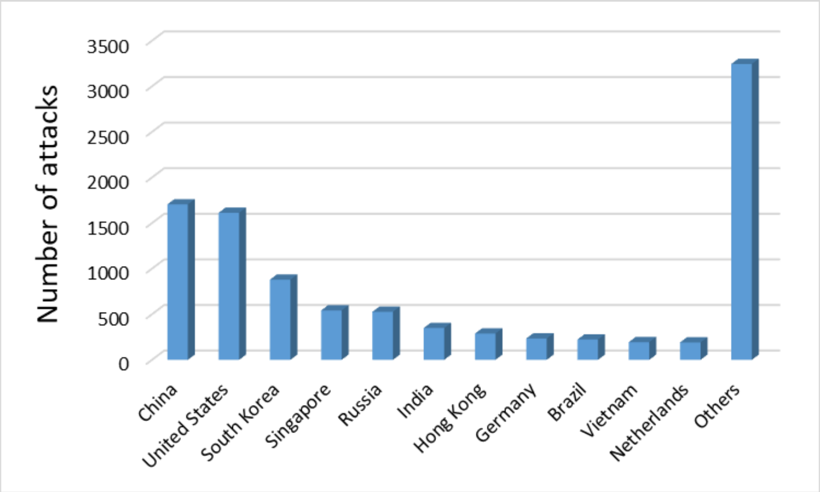
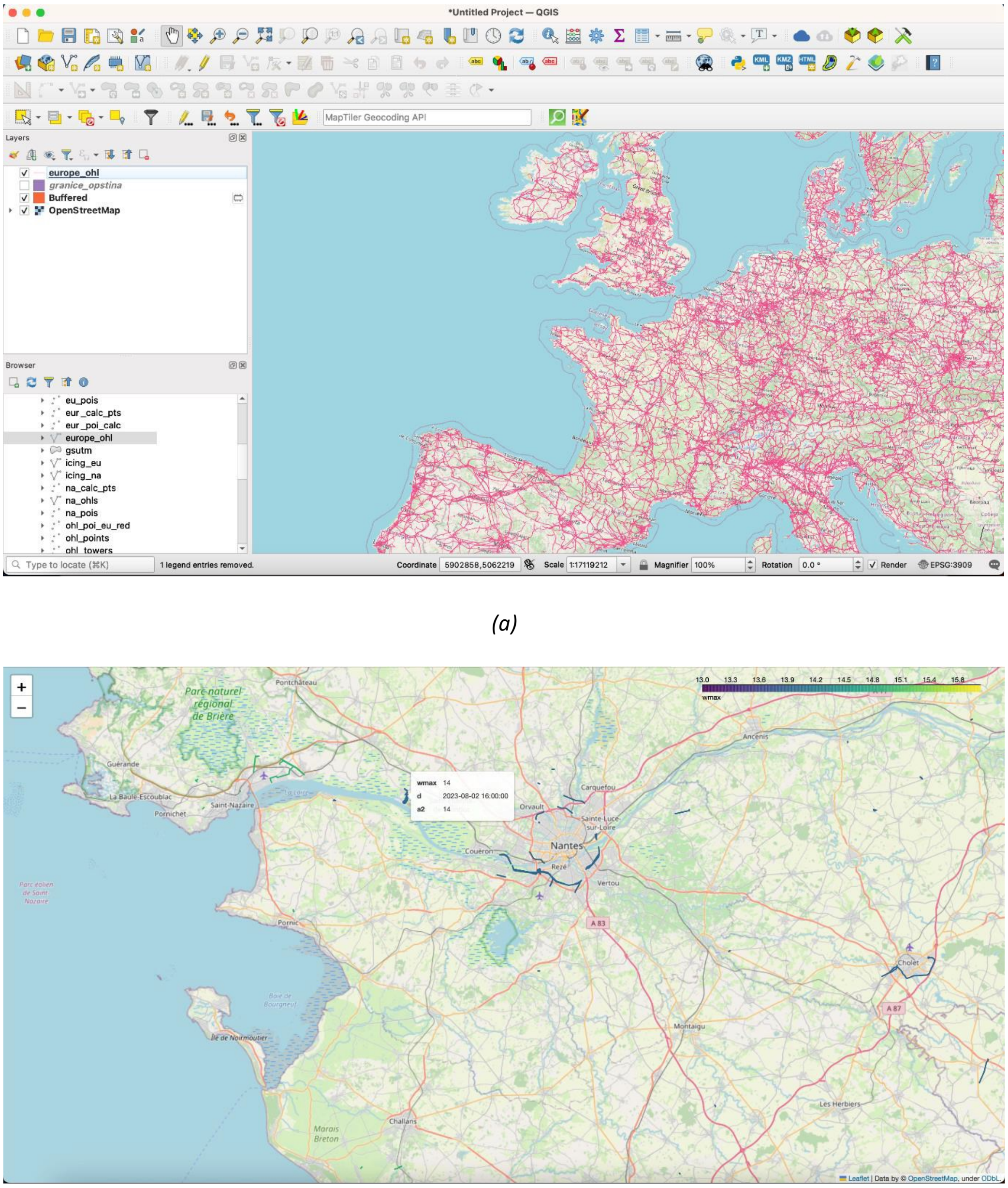


Figure 35: Countries of origin of the identified cyber-attacks.



(a)

(b)

Figure 36: Monitoring of elements for the critical weather conditions.

It is also worth noticing that most of the detected attacks took place in the Autumn of 2023, indicating that the situation regarding the cyber-security became more and more severe as the time went on. This trend can be seen as universal and not limited to the scope of the OneNet project, as seen in numerous successful hacker attacks on the different SOs in Europe. In line with that, it should be repeated that this issue will become even more prominent in the years to come, so the importance of having the solution that provides at least some level of safety from it should not be underestimated by any means. For the second part of this KPI, it should be said that the hazardous regimes related to the severe weather conditions do not appear that often in Peloponnese

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

and Crete, observation environment was extended to include the other European systems. In line with this, parts (a) and (b) of Figure 36 show the elements in Europe monitored for detection of critical weather conditions (a) and severe conditions that have been identified by the F-channel platform during the project's lifetime (b).

For the severe weather condition predictions, number of possible situations in the emulation environment is 27309 from August 2023 (8341 related to the icing and 18968 related to wind). This proves that the value of the KPI_N23 remains 100% even when the second enveloped aspect is taken into consideration. Here it should be mentioned that the expansion of the geographical scope was done solely to have a bigger population of cases that are considered in analysis, but similar results would be reached if only Peloponnese and Crete were looked at for long enough (sufficient for critical weather conditions to occur). This was also confirmed by the colleagues from the Greek TSO, justifying in turn the extension of geographical scope of observation. Moreover, this kind of assessment can be treated as the introduction into the last KPI of this demo, explained in detail in Table 22.

Table 22: Relevant characteristics of the KPI_N24.

Information	Value
Identifier	KPI_N24
Name	Number of successfully predicted severe weather conditions
Formula	$$CFC_{\%} = \frac{C_{fc,c}}{C_o} \cdot 100$$
Variables	$CFC_{\%}$ – Share of forecasted severe weather conditions; $C_{fc,c}$ – Number of forecasted severe weather conditions; C_0 – Total number of severe weather conditions.
Calculation methodology	By applying the formula given above.
Target value	1% improvement compared to the current state.

Regarding the selection of what would be considered severe weather condition, F-channel platform monitors wind speeds over 12 m/s, wind speeds under 5 m/s, icing, precipitation and storms. This allows the operators to prepare for the potential problems in the system that would be caused by severe weather. In line with this and with the fact that (as mentioned in the previous KPI's description), a total of over 27000 severe system conditions due to the critical weather conditions were spotted, this KPI can be considered successfully achieved, although difficult to quantify. What this means will be clarified in the remaining paragraphs of this subchapter.

The difficulty in quantification was founded in mentioned fact that there were no significant critical weather conditions in the area of interest for this Demo. Therefore, in order to show the capabilities of the monitoring systems to spot the harsh climate, it was necessary to extend the scope of the observed region and to include the various other parts of Europe (such as Scandinavia, for example). Here, it was possible to detect the severe weather conditions that could affect the operation of the system. However, this made way for another problem.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

Namely, since these areas did not belong to the demo, the needed data regarding the real-life situation in those systems was not at disposal of partners involved in Greek Demo. Therefore, it was not possible to conduct the verification of the conclusions brought by analysing results in platform by comparing them to the measurements.

Nonetheless, since the meteorological model that was used for the detection of the potential critical states was the same one that was also applied when the forecasts of the productions of wind and solar units had been performed, it was safe to say that the model is accurate enough for the obtained results to be reliable. This was further supported by the precision of forecasts of the generation powers of those units (illustrated in this report under the KPI_H12), which was a reason for the partners in the Greek Demo to state that the KPI_H24 has been successfully reached. This has also been confirmed by the Greek TSO that contributed and stated that there was no critical weather condition in the region of interest for the Greek Demo, thus justifying the decision to extend the observation area to the remainder of Europe and drawing conclusions from the analyses done by using the model with extended observation area. This statement completes the chapter related to KPIs in this demo.

6 Conclusion

This deliverable outlines the evaluation activities carried out in the Southern cluster demos of the OneNet project, in Greece and Cyprus. These demos aimed to introduce cutting-edge solutions to tackle current and future challenges encountered by the power systems of both countries, especially in managing the high RES penetration. To evaluate the performance of the various innovative solutions, a KPI-based approach was used. This deliverable explains how these KPIs were calculated and presents their values for both demos, along with a detailed discussion of the outcomes.

The evaluation of the Cypriot demo involved assessing 17 KPIs related to grid and market operation. These KPIs provided a comprehensive understanding of the effectiveness of the solutions deployed for provision of grid flexibility services. Specifically, the results from the demonstration and evaluation of the three SUCs in the Cypriot demo, focusing on grid monitoring, pre-qualification of limits, and evaluation of FSP response showed high accuracy in real-time monitoring for both transmission and distribution grids, effective prequalification of operational limits, and strong commitment from FSPs to market obligations. Furthermore, from the assessment of the frequency balancing scenario it was revealed that the participation of the flexible RES to frequency support improve the system stability, through the improvement of ROCOF and frequency nadir. The congestion management scenarios demonstrated the effectiveness of coordinating FSPs in relieving congestion in both MV and LV grids, with improvements in thermal loading, energy losses, and loading asymmetries. Additionally, metrics related to market participation highlighted the active involvement of DERs and FSPs in electricity markets, while at the same time the seamless collaboration of all the key stakeholders was demonstrated.

The OneNet Cypriot demonstration provides valuable insights into optimizing and operating islanded power systems more effectively. Key solutions and practices have emerged from this demonstration, shedding light on managing transmission and distribution grids in a cost-effective manner. Specifically, four important lessons have been identified. Firstly, the operation of an ancillary service market can promote flexibility within islanded power systems, as demonstrated in the Cypriot demo, emphasizing the critical need for strengthening flexibility in systems with limited connections to larger grids. Secondly, real-time monitoring of the power system proves essential for timely activation of flexibility resources, facilitating grid stability by enabling swift responses to fluctuations in demand or unforeseen events. Thirdly, the demo underscores the necessity of robust communication infrastructure for effective grid monitoring and management, emphasizing the importance of high-speed, reliable communication networks for seamless data exchange between grid components, control centres, and distributed energy resources. Lastly, establishing reliable prequalification schemes for offers from distributed resources participating in frequency support services is crucial for ensuring the normal operation of distribution grids, mitigating the risk of congestion, and optimizing grid performance. These lessons are invaluable for informing policies, regulations, and roadmaps devised by energy stakeholders, thereby facilitating informed decision-making and enabling a smoother transition towards sustainable energy practices.

The evaluation of the Greek demo's achievements is also based on selected KPIs that are categorized into market-based, scenario-based, and regional. The market-based KPIs demonstrated strong participation from FSPs to the demo activities something that exceeded the target values of the demo. Scenario-based KPIs highlighted the accuracy of forecasting methodologies in predicting technical restrictions and congestion avoidance, while regional KPIs pointed out the importance of early warning systems for weather and cyber threats. Overall, the analysis of KPIs across various categories demonstrates the successful implementation of the Greek demo, meeting all project objectives. Through innovative forecasting techniques and collaboration frameworks, the Greek demo can play a pioneer role in addressing energy market challenges and mitigating risks associated with technical and environmental factors.

Regarding the lessons learned of this Demo, the relevance of communication among the participants in the Demo for its successful completion and valuable conclusions was underlined in bold. In addition to this, it was confirmed within the demo that the accuracy of the forecasts of system state could be the key to the appropriate reservation of sufficient capacities for the flexibility purposes (such as aFRR and mFRR). This will become more and more prominent as the share of the variable renewable sources in the system grows, since each of those introduces the new level of uncertainty in the functioning of the grid. Also, the high number of the cyber threats that was detected draws the attention to the risk to which the systems in the future will be exposed due to the potential hacker attacks and underlines the need for the usage of secure communication protocols and data storages in order to avoid the leakages of the sensitive information. All of the lessons have been discussed within the scope of the Greek demo and were marked as important from the sides of all of the included partners, but especially from the perspective of the Greek TSO and DSO.

In conclusion, the evaluation of the Southern cluster demos in Greece and Cyprus showcases the significant advancements made in addressing the challenges of their power grids. Through the implementation of innovative solutions and the use of KPIs to assess performance, both demos have demonstrated remarkable success. Overall, these demos have not only met their objectives but also set the base for future developments towards the green energy transition in the Southern Europe.

References

[1] OneNet project, Deliverable 8.3, “Development and implementation of the “ABCM” platform”, Sept. 2023, [online] Available: https://onenet-project.eu/wp-content/uploads/2023/12/OneNet_D8.3_V1.0.pdf

[2] KU Leuven Energy Institute. "EI Fact sheet: The current electricity market design in Europe". https://www.mech.kuleuven.be/en/tme/research/energy_environment/Pdf/ei-factsheet8-eng.pdf.

[3] M. Mathioulakis, and M. Lykidi, "Implementation of the Target Model: Regulatory reforms and obstacles for the regional market coupling", 2019.

[4] OneNet project, Deliverable 8.1, “Requirements specification of the pilot projects in Greece and Cyprus”, Sept. 2021, [online] Available: https://onenet-project.eu/wp-content/uploads/2022/10/D8.1-Requirements-specification-of-the-pilot-projects-in-Greece-and-Cyprus.pdf.

[5] OneNet project, Deliverable 8.2, “Development and implementation of the “F-Channel” platform”, Sept. 2023, [online] Available: https://onenet-project.eu/wp-content/uploads/2023/10/OneNet_D8.2_V1.0.pdf.

[6] OneNet project, Deliverable 5.1, “OneNet concept and requirements”, Sept. 2021, [online] Available: https://onenet-project.eu/wp-content/uploads/2022/10/D51-OneNet-Concept-and-Requirements.pdf.

[7] OneNet project, Deliverable 2.3, “Business Use Case for the OneNet”, Sept. 2021, [online] Available: https://onenet-project.eu/wp-content/uploads/2022/10/D2.3-Business-Use-Cases-for-the-OneNet.pdf.

[8] OneNet project, Deliverable 3.4 “Regulatory and demo assessment of proposed integrated markets”, Aug. 2023, [online] Available: https://onenet-project.eu/wp-content/uploads/2023/09/OneNet_D3.4_V1.0.pdf.

[9] OneNet project, Deliverable 2.4, “OneNet priorities for KPIs, Scalability and Replicability in view of harmonized EU electricity markets”, Dec. 2021, [online] Available: https://onenet-project.eu/wp-content/uploads/2022/10/OneNet_Deliverable_D2.4_v2-28122021.pdf.

[10] OneNet project, Deliverable 11.1, “Evaluation of OneNet demonstrators”, Oct. 2023, [online] Available: .http://www.onenet-project.eu/wp-content/uploads/2024/02/OneNet_D11.1_V2.0.pdf

[11] “SEL-5073 Synchrowave Phasor Data Concentrator Instruction Manual,” Schweitzer Engineering Laboratories, Inc. , WA, USA.

[12] H. Wise Wire Energy Solutions Limited, “OneNet – ActiveProsumer Final Report”, Final Report, March 2023.

[13] Jeremy Lin, Fernand H. Magnago, *Electricity Market Theories and Applications*, Chapter 8, John Wiley & Sons, Inc., Hoboken, New Jersey, 2017

[14] Juan M. Morales, Antonio J. Conejo, Henrik Madsen , Pierre Pinson , Marco Zugno, *Integrating Renewables in Electricity Markets*, *Operational Problem*s, Chapter 3, 2014.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 957739