PLATFORM FOR OPERATION OF DISTRIBUTION NETWORKS

Platone

PLATform for Operation of distribution NEtworks

D4.7

Mesogeia demonstration: meta-analysis and lessons learned

The project PLATform for Operation of distribution NEtworks (Platone) receives funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no 864300.

Project name	Platone
Contractual delivery date:	31.08.2023
Actual delivery date:	30.08.2023
Main responsible:	Stavroula Tzioka, HEDNO
Work package:	WP4 – Greek Demo
Security:	P
Nature:	R
Version:	V1.0
Total number of pages:	20

Abstract

The deliverable D4.7 'Mesogeia demonstration: meta-analysis and lessons learned' elaborates on the key lessons learned after the completion of the Greek demo within the Platone project. Based on the experience gained, issues encountered and successes of the demo, this deliverable aims to provide a holistic analysis of the methodologies implemented in the Mesogeia pilot project and a reflection to all the topics that were studied from the original conceptualization of the demo all the way through the final and complete implementation. The report details constructive feedback to all aspects concerning the Greek demo, such as the tools and algorithms developed specifically for the Greek demo (State Estimation tool and variable Distribution Use of System tariffs design tool), the Use Cases' definition, the customer engagement activities, the systems interoperability, the Phasor Measurement Units (PMUs) installed on site. Overall, the Greek demo constituted a steep learning curve for them, with some important takeaways not only for the Greek Distribution System Operator, but also for all consortium's partners, as well as some concrete proposals for valuable future work.

Keyword list

lessons learned – state estimation – DUoS tariffs – flexibility – PMU – SMU – platform – data integration – interoperability – Use Case – customer engagement – Platone Open Framework

Executive Summary

Project Platone envisions 'Innovation for customers, innovation for the grid.' Under the H2020 program for a 'single, smart European electricity grid,' Platone focuses on 'Flexibility and retail market options for the distribution grid.' Shifting from centralized conventional centralized power systems to flexible and decentralized modern power systems, Platone employs blockchain to create the Platone Open Framework, addressing modern DSO power needs. This framework aims to facilitate flexible grid management, innovative energy markets, and secure data handling. It is open source, integrates external solutions, and complies with regulations to facilitate the flexibility activation for system operators. Tested in European demos (Greece, Germany, Italy), Platone also connects with traditional TSOs through an open-market approach.

This deliverable aims to provide a high-level presentation of the methodologies and tools deployed by the Greek demo, followed by the lessons-learned along with potential future approaches based on the findings of the Platone project. . The concept of the Greek demo revolves around harvesting flexibility by means of incentivizing the consumers through variable Distribution Use of Systems (DUoS) tariffs. The design of the tariffs is facilitated by the deployment of advanced state estimation, namely the State Estimation (SE) tool. Moreover, advanced metering devices, namely Phasor Measurement Units (PMUs), were installed, enhancing the network observability. Finally, the Platone Open Framework was adapted to the specific needs of the Greek demo.

As the project draws to a close and the Greek demo has completed its objectives, it is important to note that the combined use of the SE tool with the variable DUoS tariffs algorithm offers considerable benefits to the DSO in terms of enabling flexibility provision and limiting curtailment costs. Also, the installation of PMUs has yielded valuable lessons for the importance of observability in a distribution network and for the developments that the hardware itself needs in order to make it attractive for large scale deployment.

The combination of these components with the modular Platone Open Framework architecture offers significant advantages to the DSO in terms of interoperability with existing infrastructure. On the other hand, it also emphasizes the necessity for customization of the platforms to the DSO's specific needs and constraints. The constraints that need to be met range from country-specific regulatory obstacles to any kind of technical issues such as data harmonization, integration of legacy systems, etc.

With respect to the customer engagement activities, the Greek demo gave special attention in developing an effective customer approach considering that Platone as a project established novel technical solutions in order to primarily provide customer-centric services. Although the solution proposed by the Greek demo could not be directly implemented with the participation of customers due to regulatory obstacles, a series of dissemination events that took place (e.g., workshops, questionnaire) provided valuable feedback and ensured stakeholder's involvement throughout the early stages of the project's development. Throughout the report, particular emphasis is given to the practical insights gained, allowing for an informed assessment of the effectiveness and viability of the Platone Open Framework as a transformative solution for modern DSOs. This evaluation will serve as a foundation for potential future approaches and the broader adoption and adaption of the Platone Open Framework within the energy sector.

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1 Introduction

The "PLATform for Operation of distribution Networks – Platone" project aims to create a two-layer Blockchain-based architecture called the Platone Open Framework. This architecture includes an "Access Layer" connecting customers to the DSO and a "Service Layer" linking customers and the DSO to the Flexibility Market environment. The two layers are connected through a Shared Customer Database with certified data accessible to relevant stakeholders. This framework enhances stakeholder involvement and enables efficient network management. Data from various sources, like weather systems and smart devices, will be processed on platforms for DSOs, TSOs, markets, customers, and aggregators. Additionally, the DSO Technical Platform serves as the framework's core, empowering DSOs to securely and effectively manage the distribution grid. It encompasses tools and services for grid monitoring, control, and enhanced security, reliability, and quality. The platform also handles flexibility requests from the Market Platform and facilitates negotiations. It's directly linked to the DSO's conventional SCADA system through an open API, ensuring seamless communication between the new DSO Platform and the SCADA systems. The innovative Platone architecture contributes to a carbon-free society goal by 2050, fostering new market mechanisms and active grid management [1].

Within the context of the Greek demo, HEDNO tests the effectiveness of the Platone Open Framework by leveraging its architecture and by establishing a valuable brand new and complete IT environment. This environment is incrementally developed to facilitate the deployment and integration of different services such as the state estimation tool, ancillary services to the TSOs, and the optimal control of Distributed Energy Resources (DERs) which respectively improve the grid observability, provide cost-effective frequency-related and non-frequency related ancillary services to TSOs, and alleviate line and voltage violation problems.

1.1 Task 4.6

Task 4.6, “Validation Results Analysis & Feedback,” is directly related to this deliverable. This process was initiated in the final months of the Platone project after completing the Greek demonstration activities and with the goal of ensuring that Mesogeia pilot results meet the defined Use Cases (UCs) and specifications of the Greek demo within Platone. By leveraging a validation framework specifically tailored to the challenging conditions of the Greek demo, the effectiveness of the proposed solution is thoroughly assessed. Also, feedback is provided in retrospective, offering valuable insights to conclude the innovative work accomplished over the project’s duration.

1.2 Objectives of the Work Reported in this Deliverable

The objective of this Deliverable is to offer an overview of the Greek demonstration, presenting the methodologies, tools and services developed and integrated within the Platone framework at a high-level. Subsequently, the main conclusions and lessons learned from the demonstration are detailed and discussed. The goals of this meta-analysis are to ascertain the applicability of the solutions proposed by the Greek demo and the Platone Open Framework in general and to form the basis for any similar future work.

1.3 Outline of the Deliverable

Chapter 2 provides a brief presentation of the methodologies deployed in the Greek demonstration and the Mesogeia site. Chapter 3 is dedicated to the lessons learned during the development and integration of the algorithms within the proposed solution of the Greek demo. Additionally, this chapter provides insights derived from other aspects of the Greek demo such us the utilization of new infrastructure in the context of the Platone project as well as the UCs definition process and customer engagement activities. Chapter 4 is looking to explore potential future work based on the achievements of the Platone Greek demo. Lastly, Chapter 5 concludes this report by assessing the applicability of the Greek demo solution and proposing future approaches to adopt the Platone Open Framework solution.

1.4 How to Read this Document

In order for the reader to gain a comprehensive understanding of the lessons learned from the Greek demonstration, it is essential to provide a detailed description of the Greek demo solution and its components. However, this is not the scope of the current document. Instead, a thorough presentation of the demo set up can be found in D4.5 [2].

For more in-depth information on the individual components, the revised Platone Open Framework is described in D2.2 [3]. Additionally, the platforms utilized in the Greek demo, namely the Platone DSO Technical Platform (DSOTP) and the Blockchain Access Layer (BAL), are covered in D2.8 [4] and D2.13 [5], respectively. Regarding the tools and services employed in the Greek demo, the SE tool is presented in detail in D4.2 [6] and the algorithms for ancillary services to the TSO and optimal DER control are described in D4.3 [7] and D4.4 [8], respectively.

2 Greek demo overview

The Mesogeia area in the Attica region, which serves Athens as well as the islands Kea, Andros and Tinos, is the location of the Greek demo. The Mesogeia region encompasses a mixture of rural, urban, and suburban areas, providing electricity to approximately 225,000 customers through its Low Voltage (LV) and Medium Voltage (MV) networks, including households and small, medium, and large industries. The region benefits from various installations of renewables, including wind farms and Photovoltaic (PV) systems, such as net metering and rooftop PVs.

For the purposes of the Greek demo, a portion of the Mesogeia area has been designated as the test site. Two radial distribution feeders, namely P210 and P490, originating from the Nea Makri HV/MV substation, have been selected for the implementation of the Greek demo UCs and for the installation of PMUs. Both feeders consist of overhead lines with a nominal operating voltage of 20 kV. Overall, the test network consists of 338 nodes each one representing a bus, and 337 branches each one referring to a line connecting two buses. In Figure 1, an approximation of the network considered for the feeder P210 is represented. The network comprises residential consumers connected to the LV grid, commercial PV producers connected to the MV grid and industrial consumers that are also connected to the MV grid.

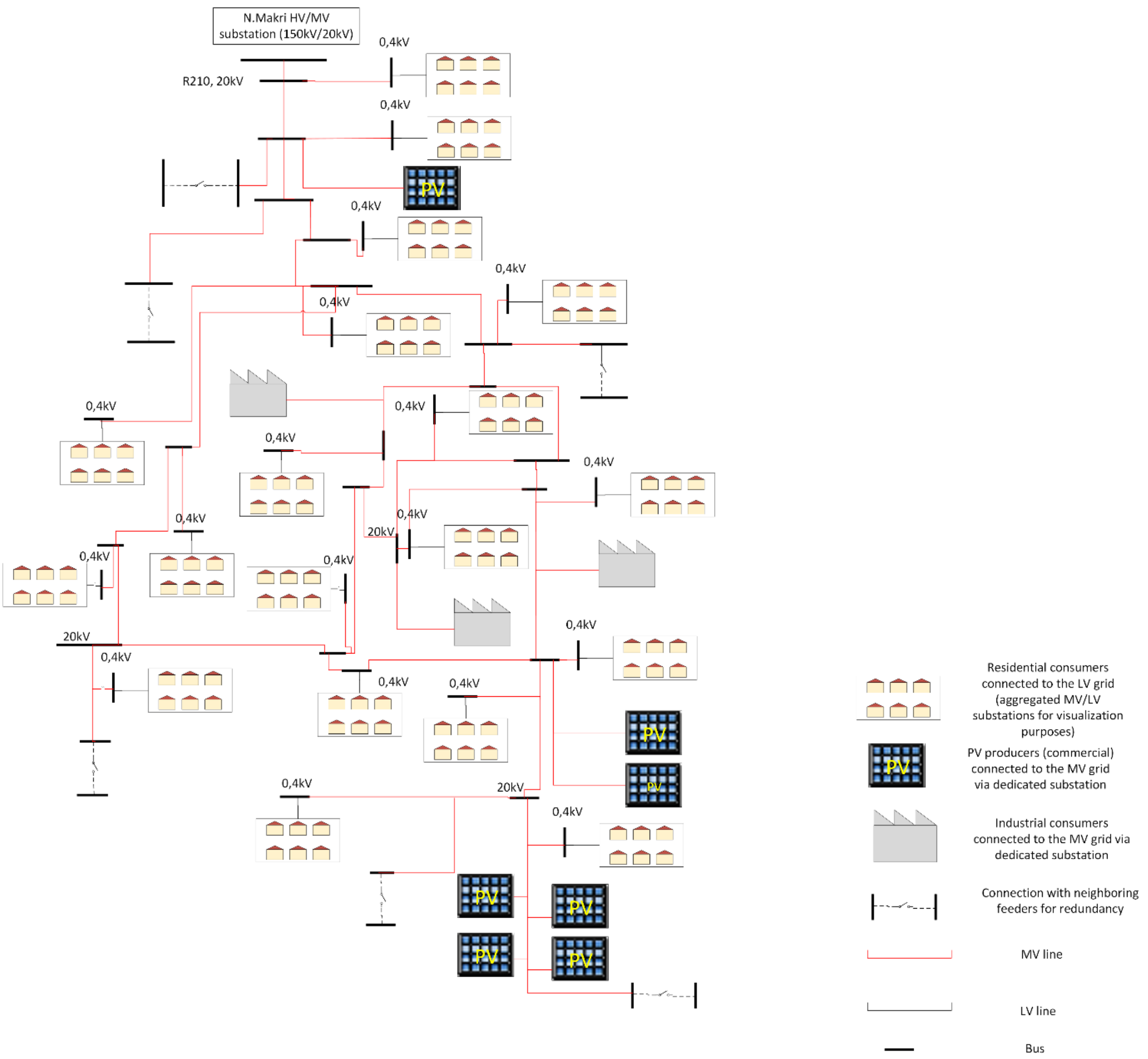

Figure 1: Graphic representation of feeder P210 and legend.

Within Platone WP4, HEDNO and NTUA collaborated and conceptualised the idea of testing novel methodologies to trigger flexibility provision and optimal DER operation in the distribution network. It became evident from the beginning that an improved knowledge of the grid conditions would greatly contribute to the success of these methodologies. However, currently in the Greek distribution network, the available real-time measurements are limited to those gathered by the Supervisory Control and Data Acquisition (SCADA) system at the High Voltage/Medium Voltage (HV/MV) substations, with the downstream part being mostly unmonitored since only MV customers are supported by telemetry (Automated Meter Reading (AMR) services). This highlighted the need for developing a solution that would exploit the available data in a smart way to achieve advanced grid observability. Therefore, the Greek demo (NTUA in specific) developed an SE tool that is capable of improving significantly the grid observability to provide the necessary input for designing flexibility provision services. Additionally, this tool will remain a valuable grid monitoring asset for the DSO.

The SE tool is executed every 15 minutes; it exploits the measurements obtained from the pre-existing infrastructure (SCADA, AMR) and the newly installed Synchronized Measurement Units (SMUs[1]) in order to deliver estimates of the power injections (P, Q) and voltages (magnitude and phase) of all network nodes of the Greek pilot site. Importantly, pseudo-measurements for unmeasured nodes are used in order to ensure the observability of the Greek pilot site and, thus, the solvability of the SE task. The achievement of complete grid observability and the availability of reliable estimates of its operating state allow the DSO to use ancillary services through the Platone Open Framework which integrates various functions and services into a single Platform. Specifically, for the Greek demo, the SE tool acts as an enabler for a sophisticated model to design variable Distribution Use of System (DUoS) tariffs with a view to controlling the DERs indirectly in an optimal way. Figure 2 illustrates a detailed architecture of the Greek demo, showcasing the various tools and services that were essential for the successful implementation of the Platone project.

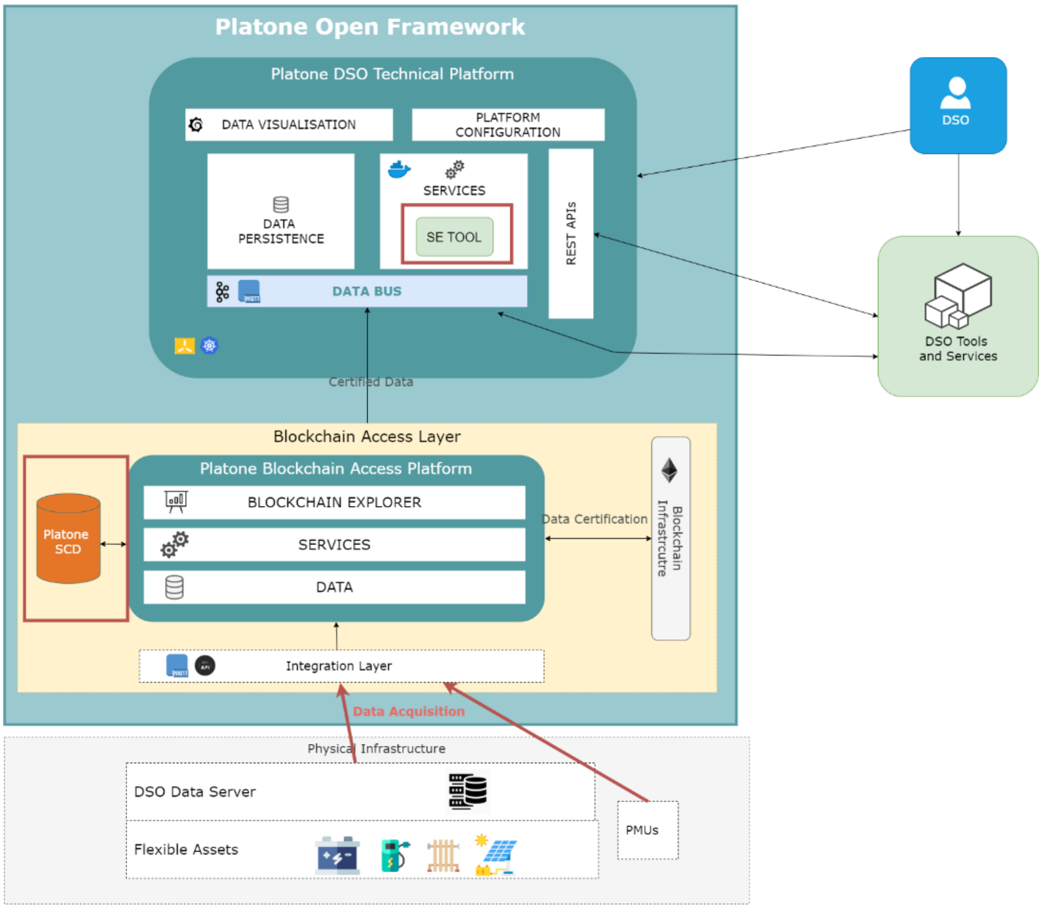

Figure 2: Greek demo architecture.

[1] The terms PMU and SMU are used interchangeably in this document with the SMU being the evolved version of the Low Cost PMU developed by RWTH. SMU is the umbrella term and can be flexibly configured to work as a waveform measurement unit, power quality analyzer, and PMU depending on the specific applications. Please read more here: https://www.mdpi.com/1424-8220/22/14/5074

It is important to note that due to the absence of regulatory sandboxes in Greece for testing totally novel concepts such as the use of variable DUoS tariffs as the key incentive for prompting flexibility provision, end-to-end implementation and examination of the Greek solution could only be achieved through a purpose-built validation framework. The Greek demo designed a validation framework in which all actors and entities that participate in the examined UCs, including the DSO, TSO, aggregators, prosumers and grid customers, were designed and modelled based on actual historical data. As it is common practice in similar studies, in order to test the efficacy of the algorithm for optimal DER control in enabling flexibility, the occurrence of additional network congestions was projected.

3 Lessons-learned

The tools developed for the Greek demo (i.e., the SE tool and the variable DUoS tariffs design tool) along with the platforms and advanced metering systems (PMUs) developed specifically for the Platone project showcased the effectiveness and the huge potential of the Platone Open Framework as a whole, in advancing grid operations and optimizing the integration of DERs within the distribution network. The results of the Greek demo emphasize the importance of harnessing the available flexibility, especially in light of the increasing demand needs and installed Renewable Energy Sources (RES) capacity anticipated in the upcoming years [9].

In this chapter, these results are further discussed, and the valuable lessons learned throughout the project's duration, from concept to application are presented. By carefully examining all encountered obstacles that hindered the Greek DSO's efforts in implementing the proposed solution within the Platone Open Framework, this chapter seeks to assess the applicability of the solution within the context of the Greek DSO, HEDNO, and its potential for scalability to other DSOs as well.

For the remainder of this chapter, a subsection is dedicated to each component/topic of the Greek demo solution, studied in the Mesogeia site. These topics include the PMUs, the DSOTP, the BAL, the SE tool, the variable DUoS tariff design tool, the DSO Data Server, as well as the UCs' and the Customer Engagement methodologies. Each subsection delves into the specifics of the implementation and its findings, providing a comprehensive understanding of the achievements and insights gained from the Greek demonstration.

3.1 Phasor Measurement Units

Within the Platone project, the first-ever installation of PMU devices in the Greek distribution network took place, providing high-frequency synchronized measurements. The Greek demo envisaged to use these data as input to the SE tool developed specifically for the Mesogeia pilot project to enhance grid observability. Throughout the PMUs' installation and integration process, a number of obstacles were met and valuable lessons arose.

A complementary objective for the installation of the PMUs at the Mesogeia site was to test their operation in high temperatures during the Greek summer, with the aim of improving the device's Technology Readiness Level (TRL). This aspect was successfully assessed after the installation of five PMUs in feeder P210. Apart from the ambient temperature, another important consideration for the proper operation of the PMUs that are installed inside the MV/LV substation pillars is their proximity to the three phase conductors (metal bars). In substations with very high continuous loads, these bars get heated and contribute to the overheating of the nearby devices. In the current installation of the PMUs, this has not been an issue as the substations of interest happen to feed low loads. In a future application or large-scale deployment this should be taken into account as an additional technical constraint.

It is important to highlight that for the time being the installed PMUs are fully operational despite the recent heat wave that Greece experienced, apart from one device which is displaying non-temperature-related problems. Hence, it can be said that that these specific PMUs can tolerate high temperatures, although it is suggested that they should be further tested in high load grid connection points.

A major lesson that became evident early on, though its impact on the timeline was not initially clear, was that the SMUs were not a plug-and-play solution. HEDNO in order to make the SMU useable had to select and fit current and voltage sensors for the SMU input signals after in-depth studying and thorough technical specifications' and components' compatibility assessment. This has been a time consuming process, which was further prolonged by significant delays in equipment procurement due to COVID-19 restrictions. This lack of a plug-and-play feature also hinders scalability for installation of PMUs in larger portions of the network, since a lot of effort and manpower is required prior to final installation. For a DSO with the complexity of HEDNO a ready-to-install solution customized to the needs of each region is important.

In conclusion, the installation of these devices holds immense significance for a DSO. The encountered obstacles were anticipated up to a point, considering that this is a device that is not yet in production. Nonetheless, the numerous advantages offered by this low-cost PMU device are noteworthy, particularly for areas facing challenges with the lack of advanced grid monitoring systems. The installation of PMUs has the potential to dramatically improve grid management, resulting in a prolonged equipment lifespan.

Moreover, given their benefits for the distribution network operation, an improved customer experience is promised for the users of the network.

As the PMUs installation has been a core piece of work completed by the Greek demo, a detailed analysis of lessons learned is presented in Chapter 3.2.6.2 of the deliverable D4.5. Some of the takeaways are not presented here for avoidance of repetition, therefore the reader is strongly encouraged to refer to D4.5.

3.2 Distribution System Operator Technical Platform

All the specific solutions developed for the Greek demo, along with functionalities and services, as well as the data originating from both conventional systems (SCADA, AMR) and the advanced metering systems installed in the distribution network (SMUs), are seamlessly integrated into the DSOTP. This platform is built upon an open-source extensible microservices architecture, allowing DSOs to deploy customized services as Docker containers and execute them on Kubernetes.

Despite the above-mentioned achievements by the full integration of data and services in DSOTP, the Greek demo had to overcome the obstacle of the SE tool being originally developed in Matlab software, which prevented the use of an open-source license for the Docker container image. Thus, additional effort was invested in translating the source code of the SE tool into Octave [10], the open-source equivalent of Matlab. Therefore, a notable consideration for deploying Docker containers with open-source licensing in the DSOTP is the use of open-source software for the development of the services.

Another area of improvement is the absence of a predefined, user-friendly User Interface (UI) for the platforms' applications, making the Platform less accessible and beneficial for DSO employees. Each microservice deployed to the DSOTP requires the development of a specific UI based on its functionalities. Additionally, the incorporation of brief Business Intelligence reports could be considered as an essential feature to enhance the platform's usability.

Nevertheless, DSOTP's flexibility in adding or removing services has proven invaluable for the Greek demo and HEDNO in specific, which together with the other two demos constitute success stories to build on for any other DSO. In a rapidly evolving environment, the ability to adapt and accommodate DSO's changing needs is very important, and the DSOTP successfully offers this advantage. Furthermore, the platform's interoperability allows for the seamless exchange of services and data between DSOs, fostering the possibility of creating a collaborative community in the future, should the Platone solution gain widespread adoption.

3.3 State Estimation tool

The SE tool, developed by NTUA, provides excellent results in terms of accuracy when it comes to the calculation of the network state. It efficiently incorporates data from conventional and advanced metering systems, ensuring a comprehensive approach. The existence of such tool also enables the utilization of the knowledge provided for the network's state in additional services, such as the variable DUoS tariffs design tool implemented in the Greek demo. One of the key strengths of this solution lies in its scalability and replicability, making it available for implementation in other networks within Greece or even different countries [2].

Considering the locations of the installed SMUs and the phasors to be measured per individual unit, the experience from their deployment in the Mesogeia pilot site shows that technical constraints regarding specific candidate installation spots (MV/LV substations) prevent the real-world commissioning as dictated by an optimal placement scheme for SE purposes. For example, no SMU could be installed at the MV side of the MV/LV transformers which is an optimal location (e.g., at a strategical position in the feeder with high nominal capacity). The limiting factors for that included the absence of compatible MV components (voltage and current transformers) where the SMU could be connected to and the difficulty of procuring them due to high cost, supply chain issues etc. Additionally, the power supply interruption of a large number of customers needed for installation and future maintenance purposes in such spots was undesired for the DSO. Hence, the SMUs are placed at suboptimal locations, a fact which certainly affects the expected outcomes and complicates the implementation of the designed SE methodology.

Certainly, with proper information from the DSO, such issues can be taken into account by the optimal placement methodology performed by the SE tool using precise cost modelling. On the other hand, for a future large scale deployment, exploiting the knowledge already acquired by these first PMUs installations could be rendered really useful.

Overall, the SE tool provided valuable results for the Greek demo and constituted a key enabler for the validation of the variable DUoS tariffs scheme. Most importantly, SE tool integrated in the DSOTP remains an important asset for HEDNO not only for near real-time grid monitoring of the Mesogeia pilot site, but also for further research projects that can build upon its outputs.

3.4 Data management and Systems Interoperability

The synchronization among the conventional measurement data, as well as between them and the synchrophasor data, is a task of major importance for a static state estimator such as the SE tool. The developed algorithm processes snapshots of measurements, i.e., pertaining to a case where all of them are recorded at the same time instant (e.g., 01:00:00 pm) with a small tolerance for variation. Yet, in real-world operation, this condition rarely holds true; the experience from the in-field acquisition of measurements shows that, most times, the values from the SCADA at the HV/MV substation are not read at the reference time instant of the SE execution, i.e., for 15-min intervals, at 1:00, 1:15, 1:30 pm, etc. Apparently, this problem does not occur for synchrophasors. As regards the AMR data, since they are delayed and pseudo-measurements are used instead, which are generated based on the real-time actual data, there is no issue of synchronization.

During the implementation of the SE tool, the closest SCADA measured values to the reference time were selected via the application of a simple filtering scheme to the data streaming. These values were then provided to the SE algorithm. However, a more sophisticated solution based on the existing literature can be devised for further improvement.

Another issue encountered is the need for data converters due to the varying nature of the input data for the SE tool that complicates the implementation (bugs, updates get more complex, more labor needed etc.) and, in real-time conditions, may cause delays in data processing or increase the risk of missing data. The Greek demo dedicated considerable time and effort to design, program and implement data converters that would harmonize the Common Information Model (CIM) data models that the Platone Open Framework utilizes with the required input for the SE tool.

3.5 Variable Distribution Use of System tariffs design tool

The real innovation of the Greek demonstration lies in its proposed variable DUoS tariffs scheme which through extensive simulations has proven highly effective in capturing and exploiting the variability of energy generation and consumption through specific patterns. This algorithm for optimal DER control managed to represent successfully the network conditions of a whole year in just 4 day-types based on a sophisticated clustering process and not simply seasonal differentiation. Thus, by employing just few corresponding DUoS tariff patterns, the DSO can achieve significant operational cost reductions by harvesting the available DERs flexibility to mitigate generation and/or demand curtailment actions that they would need to take otherwise in order to avoid network limits violations.

A key outcome of the solution proposed by the Greek demo was that since the method uses only the DUoS tariffs to stimulate flexibility provision services, it does not entail any requirements for additional network infrastructure or network upgrades for a real-life application scenario. Hence, from a technical point of view, the method could be implemented within a short timeframe especially in an hourly variable DUoS tariffs scenario which does not present neither a high complexity nor significant issues related to users' acceptance (i.e., all users connected to a single power line are charged with the same DUoS tariff that varies on an hourly basis). The variable DUoS tariffs method could be easily replicated or scaled up in any other network, independently from the country of application [2].

It should be highlighted that the successful validation of the variable DUoS tariffs scheme was made possible by the SE tool developed within Platone. Knowing the network state is a prerequisite for the operation of the variable DUoS tariffs design tool, which is a true challenge in the real–life environment for most distribution networks due to limitations in grid monitoring. A crucial finding derived by the simulations carried out by the Greek demo indicates that using the estimated network state calculated by the SE tool as the input for the optimal DER control algorithm yields similar efficiency to having knowledge of the true network state. In short, the adoption of the variable DUoS tariffs scheme combined with a SE tool can offer numerous benefits for a DSO, allowing them to effectively harvest the available flexibility and optimize their grid operation.

3.6 Distribution System Operator Data Server

The DSO Data Server, operated by HEDNO, is a dockerized database that hosts DSO data. This includes network data (topology, SCADA data) as well as AMR data for both MV and LV customers. The primary function of the DSO Data Server is to facilitate data analytics and research activities. In a similar way like in other research projects that HEDNO participated in the past, Platone proved that having a dedicated infrastructure in the business dedicated to Research and Development purposes, such as the DSO Data Server, is a good practice.

Originally, the DSO Data Server was set up in 2020 to accommodate another Horizon 2020 project, WiseGRID [11]. With minor upgrades, it was able to fulfill the necessary requirements to deploy the Platone platforms and test the Platone Open Framework. By leveraging this existing infrastructure, the deployment process for Platone and the Greek demo was expedited, enabling efficient testing and validation of the project's methodologies and tools within a suitable research environment.

3.7 Use Case definition

The Platone UCs for the Greek Demo are extensively described in D4.1 [12]. A template, based on the UC Methodology outlined in IEC 62559 [13], was used for the definition of the UCs. The primary objective of establishing these UCs was to create a comprehensive roadmap at the onset of the Platone project, enabling extensive testing of all components within the Greek demo. This approach allowed for the identification of both benefits and potential obstacles.

An essential lesson learned from this process is the importance of continuous review and revision of the UCs throughout the project's duration. By undertaking regular assessments, any necessary amendments can be timely identified and incorporated, ensuring that the UCs remain aligned with the project's objectives and evolving needs. This iterative approach enabled appropriate UCs updates, thereby maximizing the effectiveness of the Platone solution and facilitating successful implementation.

3.8 Customer Engagement

Customer engagement in flexibility provision pilots can be challenging due to the nature of the projects themselves. For example, the Greek demo solution in Platone, in which flexibility is supposed to be motivated only by the DUoS tariffs that are inherently regulated, could only be validated in a real-life environment only if there were regulatory sandboxes in Greece for such testing purposes. Early discussions about the limitations of customer involvement, including the difficulty of conducting tests with actual participants, are crucial in such projects to identify and explore alternative customer engagement activities.

An effective alternative for gathering important customer feedback is through tailored questionnaires, like the one circulated by the Greek demo team to a diverse audience [14]. Moreover, customer engagement workshops and dissemination events, such as the Open Day and Study Tours organized during different stages of the project, serve as unique opportunities to gather valuable feedback and foster productive discussions [15].

By proactively identifying and implementing various customer engagement methods, projects can ensure stakeholders' involvement and effectively address the challenges associated with flexibility provision pilots. These efforts contribute to refining and enhancing the proposed solutions and lead to more successful outcomes in the long run.

4 Meta-analysis

As the Platone project reaches its conclusion, it was deemed necessary for the Greek demo to explore the possibilities for future work that would enhance the efficiency and the applicability of the innovative solutions that they developed. More specifically, the Greek demo looked into how they can further exploit the outcomes of the two deployed tools, namely the SE and variable DUoS tariff design tool, as well as the newly installed PMUs.

Regarding the PMUs, a potential larger-scale deployment could be taken into account, covering either the whole Mesogeia area or another region in Greece. Such a deployment, in conjunction with the use of the SE tool already integrated in the Platone DSOTP, could significantly enhance grid's observability and lead to a very high degree of certainty of the grid's conditions in a wider area. On another note, it is worth mentioning that there has been increased interest within HEDNO for the PMUs application in the MV/LV substations of the distribution grid. During the study tour that took place on 30/06/2023 [15] HEDNO technicians responsible for the maintenance of LV network expressed their concerns about critical nodes of the network with high load demand, because there is no real-time display of power data in such nodes. PMUs' installation in these locations would be of paramount importance, since it would provide the technicians with the necessary information about the loading conditions at the LV level and it would enable them to identify early imminent technical issues. This would result into a more stress free operation of the grid, which would eventually mean reduced maintenance costs for the DSO.

If such a large scale penetration of PMUs was to be realized, special consideration would be given in the increased data handling requirements. At the moment PMU data are available via the Platone DSOTP's inherent database. For a more scalable solution, instead of querying a database to retrieve the PMU data, it could be examined the possibility of querying the PMUs directly or establishing a web service where the client could login and view/download their data.

As far as the SE tool is concerned, its application in the Greek demo resulted in near real-time (data every 15 min) monitoring of part of the Mesogeia network, capability that the DSO didn't have before. Such a success makes it imperative that upon completion of the project the SE tool outcomes are presented to the HEDNO's Control Centre so that its benefits for grid monitoring and management purposes are further examined for large scale application in the distribution grid. Also, looking at how the tool can be further improved, some future work is suggested. At the moment the state estimation algorithm is based on a fixed network topology which considers that all switches are at their normal state. However, in real-world operation, the DSO responding to various technical conditions (e.g. potential violations of voltage, thermal limits) may reconfigure the network topology by changing the switches' position. In such a real-world scenario the network topology changes and the SE tool cannot run its state estimation algorithm. Hence, in the future a dynamic file could be built that would provide the SE tool with topology data/measurements from the switches.

As for the variable DUoS tariff design tool, an interesting next step would be to test its efficacy with the design of more than four day-type clusters. It has already been shown that even with just four day-types the algorithm resulted in significant mitigation of operational costs but it would be interesting to examine if increased day-types clustering could lead to further benefits, regarding network limit violation mitigation. Also, it is suggested that the tool gets additionally verified by using it to design tariffs for other networks (other than the Mesogeia topology), either intra-nationally or internationally. Finally, it would be of high interest if the tool is tested in a country where regulatory sandboxes would allow its application in a real-life environment.

5 Conclusion

The core work streams of the Greek demo were the development of the SE tool and the variable DUoS tariffs design tool for the optimal DER control, as well as the installation of SMUs for both SE and grid monitoring purposes. These work streams were articulated through the formulation of UCs developed according to the IEC 62559 standard, which played a pivotal role in ensuring the much-needed uniformity across all three Platone demos. What could be recognised towards the end of the project is the importance of continuous review and refinement of these UCs throughout the project's duration, so that any necessary amendments can be timely identified and incorporated, ensuring that the UCs remain aligned with the project's objectives and evolving needs. The whole set of Greek demo's activities has been a steep learning curve both for HEDNO and NTUA, offering valuable insights. Thus, key lessons were gained throughout the project's duration in the various topics studied.

The SE tool, developed by NTUA for Platone's Greek demo, demonstrates excellent results in terms of accuracy when calculating the network state of the Mesogeia pilot site topology. It can be undoubtedly stated that this specific solution was extensively tested in the Greek demo and it can be scaled and/or replicated in other networks within Greece or even abroad. An important learning point arisen by the SE studies is that the efficiency of the SE tool is significantly enhanced by incorporating PMU data, which underlined the importance of the low-cost PMUs' installation in the pilot project. To that end, there have been some major lessons learned regarding the optimal PMUs' placement methodology, so that the SE harnesses the PMU data in the most favourable way. The SE tool constituted the enabler for the validation of the variable DUoS tariffs scheme and being integrated in the DSOTP remains an important asset for HEDNO not only for near real-time grid monitoring of the Mesogeia pilot site, but also for further research projects.

The implementation of the algorithm for optimal DER control, i.e., the proposed DUoS tariff design, and facilitated by the SE tool's output, showed that significant benefits can be leveraged by utilizing variable DUoS tariffs to harness flexibility from consumers. This advantage is evident in the context of both Day-Ahead market and in Real-Time scenarios (e.g. frequency support request from the TSO). This dynamic DUoS tariffs scheme is ready for validation in a real-life environment once regulatory sandboxes get provisioned in Greece in the future. Also, the proposed approach for triggering flexibility provision based solely on DUoS tariffs does not entail any requirements for additional network infrastructure or network upgrades for a real-life application scenario. Hence, from a purely technical point of view, this method could be implemented within a short timeframe. Finally, the Greek demo proved the efficiency of the joint use of SE tool and the algorithm for optimal DER control via variable DUoS tariffs.

With respect to the grid observability, the Greek demo envisaged to enhance it via the implementation of the aforementioned SE tool, whose efficiency would significantly improve by the availability of PMU data. Considering that, along with the project's objective to test RWTH's low-cost PMU under Greece's extreme temperature conditions, the Greek demo installed five PMUs at the Mesogeia site. Detailed description of the PMUs' installation, as well as several lessons learned from all related tasks are analysed exhaustively in deliverable D4.5. Overall, substantial experience has been accumulated for both HEDNO and RWTH with numerous recommendations made for further development of the device that would further increase its TRL and would turn it to a plug-and-play solution with potential for effective commercialization. The successful installation of these five PMUs still represents a success story for the Greek demo, as it is the first time that PMUs are installed in the distribution network in Greece.

Another important point that can be made concerns the interoperability of the Platone Open Framework alongside legacy systems, pre-existing metering systems and newly developed tools, as well as the data harmonization of the data streams between the Platone platforms and these novel systems/tools. Even though the framework that Platone conceptualized was meant to be open, modular, and flexible, it became evident that considerable effort and time needs to be invested in ensuring the systems' interoperability and data handling. It is believed though that these efforts have been compromised by the benefits of the final complete Platone solution.

Apart from the technical aspects, Platone has always maintained a clear focus on offering customer-centric solutions. The framework of Platone and the proposals that it makes are proven to be valuable for the daily operation of any DSO, but public acceptance is also vital, especially where financial remuneration is concerned as in the example of the Greek demo with the variable DUoS tariffs. Various dissemination activities were undertaken by the Greek demo team, even during the Covid-19 crisis, in order to gather valuable feedback and foster productive discussions with various stakeholders. A wide acceptance of the Platone project was the result of these events, with audiences whose members came across various sectors such as the energy sector, academia, industry and consumers. Additionally, it was demonstrated that another effective alternative for gathering customer feedback is through questionnaires. Hence, a questionnaire was shared, responses to which made clear that potential future customers would be interested in modifying their consumption patterns given an economic incentive via variable DUoS tariffs existed, and they would like to be further informed about the innovative solution proposed by Platone Greek demo.

In conclusion, the Platone initiative introduces innovative tools and solutions to both consumers, RES producers, market players and DSOs to leverage flexibility and facilitate the energy transition in the upcoming years. Over the course of this four-year project, there have been numerous lessons learned by the partners of the Greek demo, which serve as a basis for HEDNO as well as other DSOs to build upon and plan future important work.

6 List of Figures

7 List of References

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8 List of Abbreviations

Abbreviation	Term
AMR	Automatic Meter Reading
API	Application Program Interface
BAL	Blockchain Access Layer
CIM	Common Information Model
DER	Distributed Energy Resources
DSO	Distribution System Operator
DSOTP	Distribution System Operator Technical Platform
DUoS	Distribution Use of System
HV	High Voltage
LV	Low Voltage
MV	Medium Voltage
PMU	Phasor Measurement Unit
RES	Renewable Energy Sources
SCADA	Supervisory Control And Data Acquisition
SE	State Estimation
SMU	Synchronized Measurement Unit
TRL	Technology Readiness Level
TSO	Transmission System Operator
UC	Use Case
UI	User Interface