Real-life demonstration of blockchain based flexibility trading between FSPs and DSO

Real-life demonstration of blockchain based flexibility trading between FSPs and DSO

İbrahim Gazioğlu
Smart Systems, R&D
Osmangazi Electricity Distribution Company
Eskisehir, Turkey
ibrahim.gazioglu@oedas.com.tr

Thong Vu Van
EMAX
Brussels, Belgium
thong.vuvan@emaxgroup.eu

Ali Fuat Büyük
Smart Systems, R&D
Osmangazi Electricity Distribution Company
Eskisehir, Turkey
ali.buyuk@oedas.com.tr

Tuğçe Eren
Smart Systems, R&D
Osmangazi Electricity Distribution Company
Eskisehir, Turkey
tugce.eren@oedas.com.tr

Le Anh Tuan
Department of Electrical Engineering
Chalmers University of Technology
Gothenburg, Sweden
tuan.le@chalmers.com

Carmen Oana
Simavi
Bucharest, Romania
carmen.oana@simavi.ro

***Abstract*—This study demonstrates the flexibility trading process between a distribution system operator (DSO) and potential flexibility service providers (FSPs) using a framework consisting of a blockchain-based P2P trading platform and other auxiliary platforms. Within this framework, a demo study was conducted with real distribution system's assets and systems on the trading platform where the DSO specified its flexibility needs and FSPs were able to offer their flexibilities to support the DSO. In the study, vehicle-to-grid (V2G) compatible electric vehicle charging station and stationary battery storage system were used as flexible assets. The trading process was conducted within the specified time and price range through the platform, involving the FSPs and the DSO. As a result, the flexibility was provided to a local LV grid, leading to a 17% reduction in the load of the distribution transformer owned by the DSO.**

Keywords—P2P trading, blockchain, grid flexibility, electric vehicle, V2G, EV chargers, battery storage system.

I. INTRODUCTION

Since energy production with renewable sources is dependent on natural conditions and is unstable, it will bring a new challenge: how to meet energy demand continuously with variable sources. At this point, energy storage systems have started to be used. Through these storage systems, surplus energy can be stored and used later when the demand increases. Thus, it was concluded that as storage systems are added to the grid, a more flexible structure can emerge. In addition, it was realized that the batteries of electric vehicles could also be used to provide more flexibility to the system. Especially, Vehicle-to-Grid (V2G) technology drew attention since it enables bidirectional power flow between EVs and the grid. Even without V2G, EV batteries can be used for load shifting and peak shaving activities to improve grid flexibility. According to the IEA, if an aggressive growth scenario occurs, the number of EVs could reach 380 million by 2030. This would lead to a significant increase in storage system capacities if EVs can be included in the electricity market [1].

When all these development processes are considered, it is evident that end users will play a significant role in the electricity market, including EV users and prosumers. However, this also presents another challenge: How can end users transfer electricity among themselves. There needs to be an easy and reliable process for the transfer and payment procedures.

The system in which energy transfer is facilitated between nodes in the grid is called a P2P (peer-to-peer) trading system. In this newly created system, blockchain technology has taken center stage to establish a transparent, reliable, and user-friendly trading environment [2].

Blockchain has the potential to promote energy efficiency, renewables and their integration into energy systems, by mitigating the risk of investments and ensuring transparency, integrity and traceability of technical and commercial transactions and reporting. Especially, the utilization of the blockchain in smart grids could offer various advantages to the electrical power system with increased security, improved data privacy, data transparency and immutability, removal of third-party control and trust, ubiquitous solution, and greater data accessibility. [3] Apart from the advantages, there are also some challenges/barriers in the implementation of blockchain technology such as regulatory issues, high energy consumption of blockchain technology, volatility of cryptos, and high trading and transaction costs of cryptocurrencies.[4]

Numerous researchers have conducted studies in the literature on P2P trading and payment systems. Ali et al. proposed a blockchain based P2P trading model that allows sellers and buyers to directly submit their bids into a system for a local energy market based in Australia and the results indicate that all participants were able to reduce their costs, congestion problems were mitigated, and profit margins saw improvements [2]. In their research, Kajaan et al. solely concentrated on the payment method within P2P trading and the results demonstrated the attainment of improved clearing prices, heightened participant motivation owing to better pricing, a more dependable payment system, and a reduction in grid congestion issues without the need for additional efforts from the DSO [5]. Alskaif et al. proposed two distinct methods for P2P trading and according to the findings, the distance-focused method yielded superior outcomes in terms of grid congestion reduction and encompassed a larger number of participants. Furthermore,

The work leading to this paper was part of the FlexiGrid project which has received funding from the European Union's Horizon 2020 Framework Programme under Grant Agreement No 864048.

979-8-3503-8106-1/23/$31.00 ©2023 IEEE

the utilization of blockchain for payments resulted in increased reliability for the stakeholders [6]. From a different perspective, studies also show that blockchain-based P2P systems reduce system costs, enhance energy efficiency, and improve scalability [7]-[8]. Also, research-based studies show that an environment that includes storage capacities and P2P trading would reduce grid congestion issues, provide better prices for consumers, and incentivize prosumers [9]-[10].

The present research gaps in P2P energy trading can be categorized into theoretical and implementation domains. Certain studies on P2P trading strategies within the blockchain environment frequently omit details about the implementation process, resulting in a deficiency of a comprehensive and effective consensus method for P2P energy trading. Therefore, in this study, implementation of a P2P trading process that incorporates blockchain technology is conducted in a real environment that comprises battery storage system and V2G enabled electric vehicles. The main contributions of the paper are the following:

- Development of three different platforms for control (EV management platform), monitoring (IoT platform) and flexibility trading (EFLEX platform) purposes;
- Testing of different flexible assets for flexibility provisioning with the proposed trading method;
- Establishment of enhanced communication between platforms and integrating them into one common framework to execute flexibility trading;
- Real-life demonstrations and assessment of flexibility trading with the developed platforms and assets.

II. Platform Details and Integration Schemes

The platforms that are mainly used within the scope of demonstration study and their roles were presented in Table 1. Detailed information about the platform structures can be found in the project's deliverables: D8.3 [11], D4.5 [12] D7.2 [13].

TABLE I. PLATFORM ROLES DURING THE DEMO STUDY

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

A. EV Management Platform

The EV Management platform takes on the role of the main management platform that is directly integrated with the assets in the OEDAS demonstration site. It communicates with the electric vehicle charging station and battery storage system on the field using OCPP 1.6J and Modbus communication protocols. Essentially, the main control signals are sent through this platform. The platform is also integrated with the FlexiGrid IoT and EFLEX platforms, allowing setpoints coming from there to be directly sent to the assets. [11]

B. IoT Platform

The IoT platform developed within the scope of the FlexiGrid project is designed to enable the monitoring and control of existing assets in the field in line with the demo activities carried out with DSO OEDAS, by sending signals.

All assets in the demo area (including transformer), have been integrated with the FlexiGrid IoT platform through an API prepared by OEDAS. Thus, real-time or 1-minute resolution data monitoring is possible through the IoT platform. The main purpose of the data monitoring can be stated as the verification of flexibility delivery and equipment control. Integration scheme can be seen in Fig. 1.

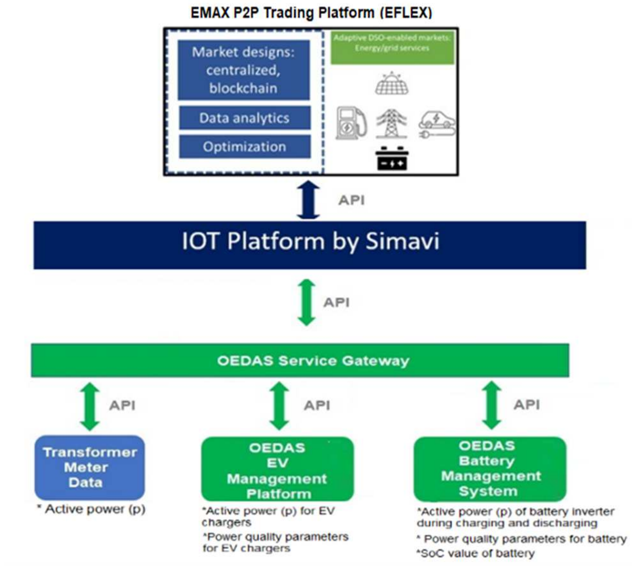

Fig. 1. Integration between OEDAS assets and IoT platform&P2P platform

Through the EV Management dashboard created within the IoT platform, it is made possible to create flexibility signals at any power level and for any desired time to be sent by the DSO to flexible assets (in this case, these are EVs and battery storage). The relevant dashboard of the IoT platform is directly integrated with the EV Management platform, and the corresponding flexibility signal can be generated within the IoT platform and transmitted to the assets. A visual representation of the created dashboard is shown in Fig. 2.

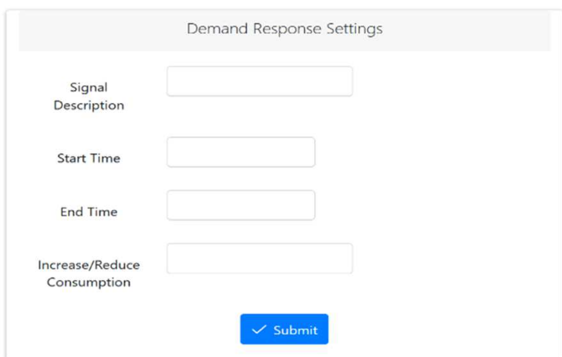

Fig. 2. Demand response dashboard of IoT platform [12]

C. P2P Trading Platform

As shown in Fig. 3, high-level system architecture has been depicted for the proposed flexibility market platform. The architecture comprises the following essential modules: Flexibility offer field, which resides at the prosumer level and connected to the devices using the IoT platform. This module is responsible for collecting flexibilities from various sources, including distributed energy resources (DER) and other tools such as EVs (vehicle-to-grid (V2G) or normal EVs as a load) and connected to the Flexibility aggregation or Broker module via consumer applications such as web API or mobile API. The Flexibility Broker module essentially aggregates the flexibilities generated at the Flexibility offer field and performs various optimization operations. This module is also connected to the smart meters and the cloud gateways for transmitting information gathered from the third module to the prosumer level. Finally, we have a market module, which is at the DSO level. Here we have the Flexibility Market Platform that will receive aggregated flexibilities from the Flexibility Broker and schedules the flexibility as per the pricing signals and overall renewable generations.

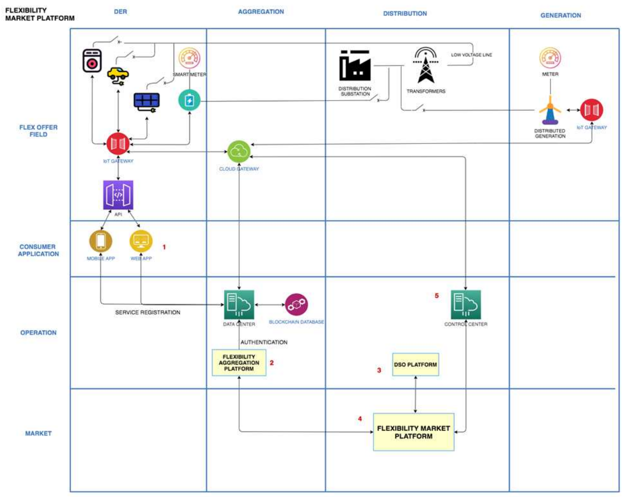

Fig. 3. EFLEX P2P trading platform architecture [13]

The process designed within the scope of the demo study is structured around the flexibility trading between FSP and DSO. It is possible to identify assets and manage offers/requests through the platform. The roles of the actors according to the structure are indicated in Table II.

TABLE II. ACTIONS OF DSO AND FSP IN EFLEX PLATFORM

Actions	FSP	DSO
Add new asset	X	X
Edit/list asset	X	X
Add new offer	X	
Edit/list offer	X	
Add new request		X
Edit/list requests		X
Matching		X
Payment		X
Settlement		X

The trading process is designed to be initiated through the EFLEX platform, controlled via the EV management platform, monitored and verified through the IoT platform, and ultimately finalized via transactions that will be made through the EFLEX platform. Within this framework, the structure established between the platforms and the envisioned scenario are presented in Fig. 4

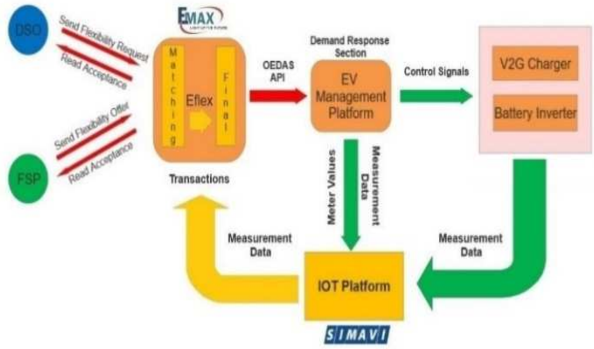

Fig. 4. Flow chart of the smart charging process

III. PROPOSED SCENARIO FOR THE PILOT STUDY

In a simplified view, the basic scenario of flexibility trading occurs between FSPs who own flexible assets (in this case, it is the owner of V2G vehicle and battery storage) and the DSO. The process should be evaluated separately from the perspective of both parties involved.

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

From the perspective of FSP, the process will be carried out by submitting offers to the platform in certain time periods based on the flexibility potential of the assets (battery storage system and V2G charging stations, see Fig. 5) available in the demo region, depending on their availability. When these offers are submitted, the SoC lower limit is assumed to be 20% for the stationary battery storage system. For values above this limit, the battery storage system can offer flexibility within the specified period with full capacity (+-10 kW) by giving an offer. For electric vehicle,, offers can be made when the vehicle is connected, so an offer will be created through the platform at least 1 hour before any vehicle is connected. The electrical availability details during the offer creation process for the V2G charging station are similar to the structure of the battery storage system. The only difference is that the minimum SoC limit for the electric vehicle is 30%. Discharge up to a maximum of 10 kW can be performed from the vehicle battery at SoC values of 30% or higher, and this value can be offered to the platform as flexibility offer.

IV. DEMONSTRATION OF THE TRADING PROCESS

Following the defined system architecture and scenario, the demo study was conducted in conjunction with the V2G charger and battery storage. Initially, DSO specified a flexibility requirement of 20 kW through the EFLEX platform, as can be seen in Fig. 6. Additionally, they communicated the price they envisaged for this flexibility requirement through the platform.

Fig. 5. Stationary battery (left) and V2G charger (right)

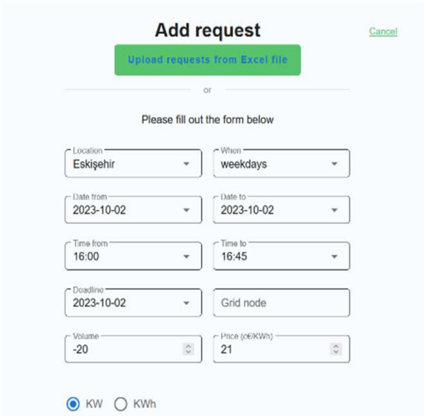

Fig. 6. Adding of the DSO's request via platform

Subsequently, this offer was listed on the interface of the EFLEX platform, which FSPs could also view. It enabled FSPs to make offers based on the assets they had at their disposal. In line with this scenario, two separate FSPs (owners of V2G vehicle and battery storage) offered to meet DSO's 20 kW flexibility requirement based on the discharge capacity of their assets (max 10 kW for each) and at the market price they specified. The offers made can be seen in Fig. 7.

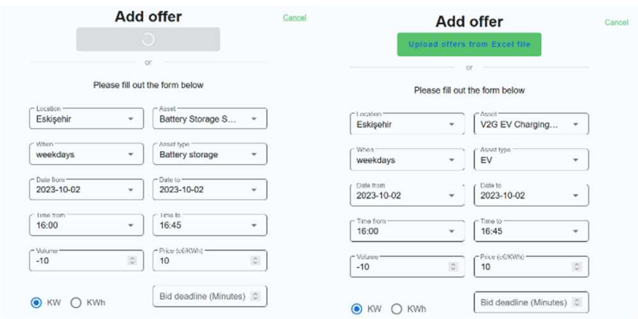

Fig. 7. Adding of the FSP's requests via platform

When creating requests and offers through the EFLEX platform, a certain amount of transaction fee is charged to system users. This transaction is carried out using the "Metamask" cold wallet with the use of cryptocurrency.

After entering DSO's request and FSPs' offers into the system, the matching algorithm of the EFLEX platform came into play to match the most suitable request with the offer. In this context, the matching can be seen in Fig. 8.

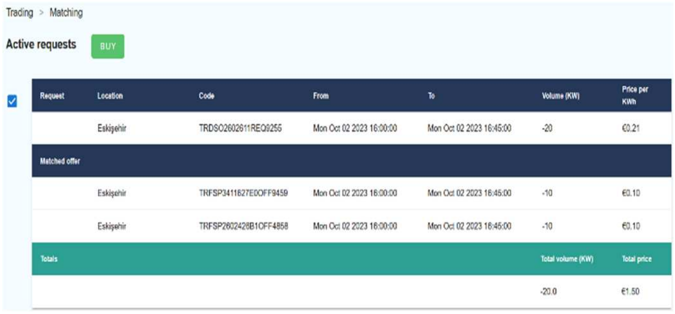

Fig. 8. Matching process of request and offers

As the next step, DSO sees this match in the matching tab of the platform. If the offer meets their requirements, they proceed to initiate the flexibility purchase by clicking on the "Buy" tab. As shown in Fig. 9, the payment here is also made using cryptocurrency (ETH).

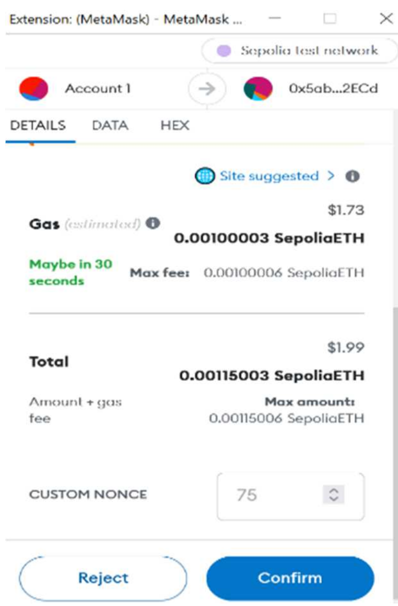

Fig. 9. Transaction conforming process via Metamask

With the completion of the matching process, the FSP is notified via email. Subsequently, upon the completion of the purchase, in accordance with the structure indicated in Figure 4 the relevant setpoint is automatically sent from the EFLEX platform to the EV management platform through a previously prepared API. This ensures the triggering of assets for discharge. The IoT platform plays a role in monitoring these operations and validating the discharged energy amount that ultimately occurs. Visuals obtained from the IoT platform regarding the discharge processes are shown in Fig. 10.

Finally, upon the completion of the discharge process within the specified date and time intervals, the measured energy value actually delivered through the assets is transmitted from the IoT platform to the EFLEX platform via a different API.

Fig. 10. Discharging charts for battery (lef) and V2G vehicle (right)

The main purpose here is to perform the validation process by comparing the total flexibility value requested by the DSO with the power provided by the assets. As a result of the process, it is observed that the combined delivery rate of both assets is around 95% (as can be seen in Table III).

TABLE III. ACTUAL DELIVERY RATES OF FLEXIBLE ASSETS

Asset	Time	Accepted Volume (kW)	Delivery Volume (kWh)	Final Price (cent/kWh)	Delivery Rate (%)
Battery Storage	16:00-16:45	-10	7.21	0.7	96
V2G Charger	16:00-16:45	-10	6.97	0.67	93
Total			14.18	1.37	95

To summarize, the flexibility requirement of 20 kW requested by the DSO has been met in increments by the FSPs, and the relevant trading process was managed through the blockchain-based P2P trading platform, EFLEX. The graph in Fig. 11 illustrates the flexibility obtained at the DSO's transformer, showing the base load of the transformer along with the load after the flexibility delivery.

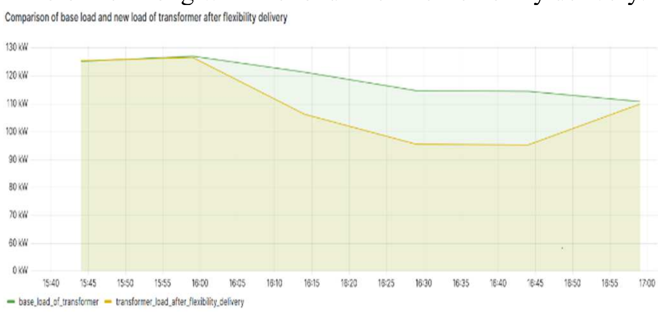

Fig. 11. Transformer loading before and after flexibility delivery

V. CONCLUSIONS

This study has demonstrated that flexibility trading between real assets and systems, as well as between FSPs and DSO, can be achieved through a blockchain-based decentralized system. The study demonstrated the seamless and dynamic interoperability of various platforms within the scope. In the demo, platforms owned by different stakeholders were integrated with the P2P trading platform, enabling advanced communication between assets and players. This achievement is particularly important in overcoming technological barriers that will be necessary to activate demand-side participation.

For this specific test that conducted in OEDAS grid, it can be concluded that the FSPs can generate revenue and the DSO can reduce potential overloads (in this case, percentage of the load reduction is approximately 17%) by using the flexibility provided by the FSPs.

With the growing prevalence of distributed battery storage systems and the promising flexibility potential of V2G technology, there is an anticipation that swift and decentralized solutions will gain even greater traction in the future. Consequently, along with regulatory advancements, it is likely that systems designed within the framework of this study will be employed for real-time monitoring of energy transfers and, ultimately, the invoicing process.

REFERENCES

[1] IEA, "Global EV Outlook 2023," IEA, Paris, 2023. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2023. [Accessed: 08 25, 2023]. [License: CC BY 4.0].

[2] L. Ali et al., "Blockchain-Based Local Energy Market Enabling P2P Trading: An Australian Collated Case Study on Energy Users, Retailers and Utilities," in IEEE Access, vol. 10, pp. 124429-124447, 2022, doi: 10.1109/ACCESS.2022.3224936.

[3] B.Lasse, Meng Q., Vesin B., Johannessen M.R., Brekke T., Laur I. " Blockchain for Smart Grid Flexibility " ICDS 2021 : The Fifteenth International Conference on Digital Society.

[4] Mladenov V., Chobanov V., Bobochikov T., Vu Van T., Gazioğlu İ., Rey T., Wuilloud G. " Trading process and flexibility energy service ", 2021, 13th Electrical Engineering Faculty Conference, BulEF

[5] N.A.M. Kajaan et al., "Blockchain-Based Smart Contract for P2P Energy Trading in a Microgrid Environment," J. Phys.: Conf. Ser., vol. 2312, p. 012020, 2022. DOI: 10.1088/1742-6596/2312/1/012020

[6] T. Alskaif, J. L. Crespo-Vazquez, M. Sekuloski, G. van Leeuwen and J. P. S. Catalão, "Blockchain-Based Fully Peer-to-Peer Energy Trading Strategies for Residential Energy Systems," in IEEE Transactions on Industrial Informatics, vol. 18, no. 1, pp. 231-241, Jan. 2022, doi: 10.1109/TII.2021.3077008.

[7] A. Kumari et al., "Blockchain-Based Peer-to-Peer Transactive Energy Management Scheme for Smart Grid System," Sensors, vol. 22, no. 13, p. 4826, Jun. 2022, doi: 10.3390/s22134826.

[8] M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "Blockchain-Based Peer-to-Peer Energy Trading System Using Open-Source Angular Framework and Hypertext Transfer Protocol," Electronics, vol. 12, no. 2, p. 287, Jan. 2023, doi: 10.3390/electronics12020287.

[9] H. Muhsen, A. Allahham, A. Al-Halhouli, M. Al-Mahmodi, A. Alkhraibat, and M. Hamdan, "Business Model of Peer-to-Peer Energy Trading: A Review of Literature," Sustainability, vol. 14, no. 3, p. 1616, Jan. 2022, doi: 10.3390/su14031616.

[10] Y. Zhou, J. Wu, and W. Gan, "P2P Energy Trading via Public Power Networks: Practical Challenges, Emerging Solutions, and the Way Forward," Frontiers in Energy, vol. 17, pp. 189-197, 2023, doi: 10.1007/s11708-023-0873-9.

[11] Gazioğlu İ. and Rey T. "Demonstration of flexibility measures and electricity grid services provided by local energy storage and EVs", FlexiGrid H2020 project (GA:864048) Technical Deliverable 8.3, 2023

[12] Vu Van T. and Senthil P. "Peer-to-peer Marketplace Demonstration", FlexiGrid H2020 project (GA:864048) Technical Deliverable 7.3, 2022

[13] Oana C. and Crucianu I "FLEXI-GRID Integration Report", FlexiGrid H2020 project (GA:864048) Technical Deliverable 4.5, 2023.