A novel approach for flexibility trading in the distribution network

Matej Pečjak, Chloé Fournely, Edin Lakić
University of Ljubljana, Faculty of Electrical Engineering
Laboratory of Energy Policy,
Ljubljana, Slovenia
{Matej.Pecjak; Chloe.Fournely; Edin.Lakic}@fe.uni-lj.si

***Abstract*—This paper presents a novel approach for flexibility trading in the distribution network. It combines capacity trading for limited network capacities and flexibility trading for ancillary services to Distribution System Operators. Capacity trading aims at avoiding network congestion and can be seen as a market-based substitute for dynamic tariffs. The operation and management of the market is carried out through a tool called MARKETFLEX, which combines a market platform with new market mechanisms that enable the optimal utilization of flexibility at the best price. The tool provides a single point of access to the market at local and wholesale level. Namely, local flexibility should be available to the Transmission System Operator as it can be beneficial for the whole power system. The presented market platform uses a decentralized architecture based on blockchain technology.**

***Index Terms*--aggregator, ancillary services, blockchain, flexibility, local electricity market, local flexibility market, market platform**

I. INTRODUCTION

The inconstancy of global energy markets, the growing number of Distributed Energy Resources (DERs), and the emergence of prosumers, call for new mechanisms for electricity trading. High volatility in power production due to intermittent Renewable Energy Resources (RES) generation and high demand from loads such as Electric Vehicles (EVs) and heat pumps (HPs) are forcing changes in the planning and management of power networks. The new circumstances increase the need for flexibility and the provision of Ancillary Services (AS) not only for Transmission System Operators (TSOs) but also for Distribution System Operators (DSOs), the latter being in charge of the networks where the majority of DERs and above-mentioned loads are connected. Recent trends in power network management and power trading include local electricity and flexibility markets whose operation can support the operation of power networks, but requires novel, advanced market mechanisms and the active participation of all market actors. To achieve this, it is essential that the market operation takes into account network conditions and allows for effective communication between the market and the network operator. Several EU Member States have started to discuss the possible options for implementing local flexibility markets, some have even started some pilot projects, while others do not see the short-term need for the development of such markets as they are not currently facing any grid issues [1]. However, with the implementation of the new EU strategy to phase out Internal Combustion Engine (ICE) vehicles, an increase in the use of EVs and the associated increased strain on the network is expected almost anywhere. Also, the Art. 32 of the Electricity Directive Incentives for the use of flexibility in the distribution networks stipulates that Member States shall provide the necessary regulatory framework to allow and provide incentives to DSO to procure flexibility services [2]. With the Clean Energy Package (CEP) in place, DSOs now have a framework at the European level to utilize flexibility. DSOs' role in this sense is to act as neutral market facilitators in order to reduce network investment costs and network end-user' costs. However, market-based solutions are not the sole means by which the DSO can procure flexibility. In addition to market-based procurement options, tariff incentives are the basis for network end-users to adapt their consumption patterns to network capacities. Consequently, one of the proposals is to include network tariffs in market-based flexibility procurement. In line with the CEP, and in order to empower customers and to ensure active market participation, market-based solutions for flexibility procurement should be pursued by default [3]. Several research projects and initiatives are underway to address local flexibility trading. Most of them include wholesale market access [4], [5], [6], [7], [8], [9], while some of them only focus on the local scale [10], [11], [12].

This paper presents the research and development activities for the establishment and management of local flexibility markets developed within the project X-FLEX [13]. The general idea is to offer market participants a common marketplace that combines market platform and market mechanisms that consider the network conditions assessed by the responsible DSO. To enable fair and non-discriminatory participation of all flexible resources not only at the local but also at the wholesale level, the integration of local and wholesale markets is necessary, as the service of small-scale providers might be beneficial for the entire power system. The main novelty of the presented approach compared to similar tools is the introduction of non-price based mechanisms for market clearing. The following sections focus on the technical

characteristics of the proposed market design and the developed market platform, which are combined in a tool called MARKETFLEX. Section II presents the market design, Section III details the modules of the MARKETFLEX tool, and section IV highlights the blockchain technology used for the market platform.

II. DISTRIBUTION NETWORK FLEXIBILITY MARKET DESIGN

Both economic and technical factors must be considered in the design of any electricity market, as a market that does not take into account the constraints of the grid cannot be implemented [14]. This is the only way to maximize the use of DERs. Any local electricity market generally encourages trading at a local level, allowing participants to reduce their energy costs and (at least partially) relieve the transmission network congestion. In the formulation of electricity markets, the adjective local refers to e.g. a neighbourhood, a district, or a community, all of which are at the level of the distribution network. Local flexibility markets can be considered as a subset of Local electricity markets where the commodity is flexibility, not electricity itself. In power networks, flexibility is a rather broad concept, referring to a modification in consumption or production patterns in response to price or any other signal that results in a service being provided to the power network. An illustration of the local flexibility market and its integration with the wholesale electricity market is presented in Figure 1.

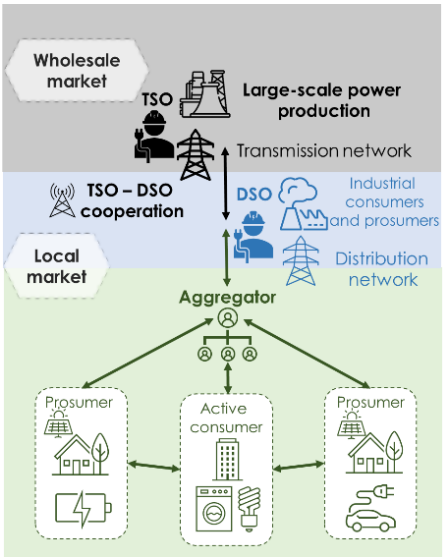

Figure 1. Local market integration with the wholesale market

An important aspect of market design is the definition of market participants. In the distribution network, new market participants, known as prosumers, are network users who can both consume and produce electricity. Some active consumers do not own electricity generation assets but are able to shift their consumption and reduce their peak load. Both types of network end-users have in common that they are unlikely to be active market participants, but they can provide the flexibility of their assets, which are controlled and managed by aggregators.

Similar to wholesale AS markets, recommendations on the use of flexibility frequently state that the availability and the actual activation of flexibility should be separated. The approach presented in this paper has followed a similar methodology. It combines capacity trading and flexibility procurement for the network operator (DSO or TSO).

A. *Capacity market*

The capacity market itself is not an entirely new concept. Policymakers in Europe and elsewhere are increasingly concerned that liberalized wholesale electricity markets do not provide the incentives to build adequate generation capacity. This issue could be solved through conventional capacity markets, which are mainly designed for large-scale generation capacity providers, in order to prevent outages when market clearing cannot be done due to insufficient amount of generation [15]. In addition, there is also a market for cross-border transmission or Net Transfer Capacities (NTC). The purpose of the local capacity market as part of the local flexibility market in our approach is to enable market-based allocation of limited network capacities to avoid congestion in the distribution network. If flexibility trading solely is designed to solve network problems, capacity trading integration is designed to prevent them. The available network capacities shall be determined by the DSO through power flow simulations, taking into account uncontrollable load consumption and RES generation forecast. This approach requires a detailed knowledge of the power profiles of network end-users and their flexible devices such as EV chargers, battery energy storage systems (BESS), HPs, etc. The design of the capacity market supports Day-Ahead Market (DAM) and Intraday Market (IDM) trading of limited network capacities. Two clearing mechanisms have been developed for both types i) *Premium capacity* and ii) *Social equity*. The logic applied in the case of *Premium capacity* is to give priority to market participants willing to pay the highest price. In this case, the payment may replace dynamic tariffs or represent an additional payment for network use that could be spent on the grid reinforcements. The *Social equity* market design does not involve any financial charges and can be seen as a form of community market, favouring first-come-first-served or highest demand. More details on the market design and clearing algorithms can be found in [16].

B. *Flexibility market*

In the local market design presented, the flexibility market is designed as an AS market for the DSO to procure flexibility on a market basis. The Flexibility and the Capacity market do operate in parallel but at different times. The flexibility market runs only in case of DSO' request for flexibility. Generally, in the flexibility market, there is only one buyer – the DSO – and several providers – aggregators – competing to provide the service. The market clearing is done in a way that the service is provided at the lowest price.

C. DSO-TSO coordination and wholesale market integration

The design of local flexibility markets should allow for the effective use of flexible resources and their services. Therefore, the market design should allow participants to offer their service also to other parties e.g. TSO and in any available market, which could be beneficial for the whole power system, not only for the local grid. This approach requires coordination between the market and system operator at the local level and, even more importantly, between DSO-TSO. The coordination scheme between DSO and TSO is one of the key elements for the establishment of a local market, which are presented in [1].

III. Operation and Deployment of the Local Flexibility Market

A. Market operation

The precondition for each asset to participate in the market is to be first registered in a device registry. The device registry contains the most important information about the flexible devices in the local market to facilitate their deployment and seamless assignment to the assets portfolio. The information needed for each device includes a unique device ID, the device type (storage, generation, load), the maximum output power of the device, the node associated with the location (the connection point as defined by the DSO) and the feeder associated with the location. These fields are common to all devices. Some additional information can be considered from specific devices, such as the minimum operating power and capacity in the case of BESS. Once a device has been registered in the device registry and added to the aggregator's assets portfolio, the aggregator can start placing bids for that particular device.

Market bids are of two types: divisible and non-divisible. The divisibility of the bids applies in the case where the requested capacity cannot be provided, but a smaller capacity is available. The divisible part of each bid must be greater or at least equal to the minimum power of each device. The bid for each unit requires the following parameters:

- Device ID,
- Quantity: the amount of required capacity,
- Time period: referring to activation time,
- Price,
- Timestamp: referring to the time of placing the bid,
- Type of the product: divisible or non-divisible.

B. Deployment of the market

The deployment of the market design presented is managed through three main market modules and supporting functionalities of the MARKETFLEX tool. The trading platform allows for the direct participation of aggregators, Balancing Service Providers and DSOs, while owners or operators of small-scale flexibility resources participate indirectly. The three main market modules are:

- The Local flexibility trading module,
- The Wholesale spot market module,
- The Wholesale ancillary service module.

The components of the MARKETFLEX tool are presented in Figure 2.

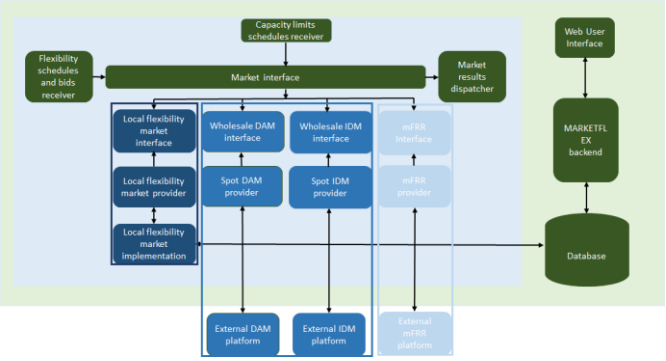

Figure 2. Components of the MARKETFLEX tool

In addition to the three market modules, the components of MARKETFLEX also include Flexibility schedules and bids receiver, Capacity limits schedules receiver, Market results dispatcher, Market interface, Database, tool backend and Web User Interface.

1) Local market module

The Local market module supports capacity trading as well as the provision of flexibility services to the DSO in the local area, as these two services are integrated. As mentioned in Section II, by local area, the distribution network below the transformer level is meant. The local area is divided into independent trading zones at the feeder level. For the provision of AS, the zones may be coupled to provide a (sub)optimal solution for the operation of the network. For capacity trading two types of markets are supported: DAM and IDM. The Local market module is integrated with the external tools through the Market interface, Flexibility schedules and bids receiver, Market results dispatcher and capacity limits schedules receiver components. The external systems interact through Kafka topics.

The interface approach of the tool provides an internal Market interface from which specific market interfaces are created, for all markets supported by the tool. The Local market module is deployed together with the Web user interface, tool backend and PostgreSQL components. All these components are needed to provide supporting functionalities also described below.

2) Wholesale spot market module

The wholesale spot market allows market participants to trade on already established wholesale spot markets. To achieve this, integration with an external energy exchange is needed. In this case, the MARKETFLEX tool acts as an intermediary party between the local market participants and the energy exchange. The main role of the market module in this case is to verify that the participation on the wholesale level does not jeopardize the operation of the local network.

Also in this configuration, the wholesale spot market module incorporates the network information. The market clearing process is carried out by the external energy exchange and the participants from the local level are not favoured in any way over other participants. The function of this module is to allow market participants a single access to the different markets in which they can provide their services.

3) Wholesale ancillary services market module

The third module is the AS market module which provides market participants with the ability to trade on wholesale AS markets. Specifically, the MARKETFLEX tool supports the manual Frequency Restoration Reserve (mFRR) market. For the purpose of development and testing, the connection to the platform developed as part of the CROSSBOW project [17] has been used. The main role of the local market platform in this context is to forward the bids on the mFRR market platform and again ensure that their activation does not jeopardize the operation of the local network. In the case of un-liquidity in the flexibility requests of the DSO, this function enables a service that could be valuable for the TSO. The AS market platform from CROSSBOW is a unique mFRR market platform dedicated to TSOs for uniform cross-border access to ancillary services. Connection to other similar market platforms is also possible.

4) Supporting functionalities

The supporting functionalities of the MARKETFLEX tool include user authentication and login service, participants registration and management, market management and enrolment and the device registry. User authentication and login are managed by the Keycloak Authorization and authentication server [18]. In addition to a direct connection for sending and receiving market information through Kafka topics, the MARKETFLEX also enables market participation through the market platform user interface. The interface is presented in Figure 3.

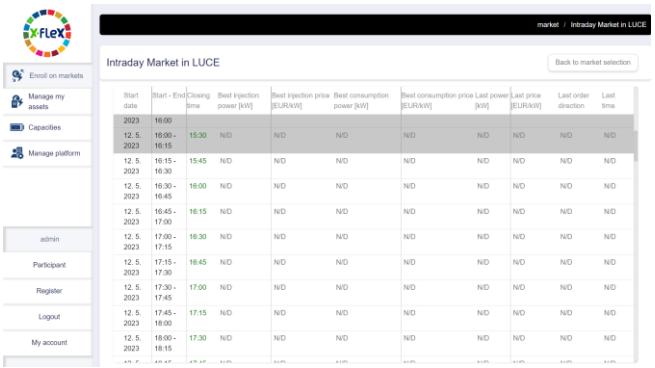

Figure 3. Marketflex interface

Market management supports the creation of new markets with parameters such as market opening time, location and market clearing algorithm, price resolution, order granularity, minimum and maximum quantity, and maximum and minimum price. All parameters are part of the creation and editing of an existing market. Each market participant must first enroll in the market in which wishes to participate. The MARKETFLEX tool can use the internal device registry or connect to an external version of the device registry. This feature can be used in the case the tool is part of a wider ecosystem and the device registry is used by several tools, for example with the tool for optimizing the schedules of flexible devices. All the supporting functionalities are necessary for the efficient and transparent functioning of the market.

IV. Blockchain Technology and Smart Contracts

Blockchain technology is used in the MARKETFLEX tool to achieve decentralization of the market platform. With the decentralized approach, the platform is no longer owned and operated by a centralized entity, but it is managed by the market participants themselves. This approach eliminates the need for a trusted third party that would otherwise keep the platform up and running. The two different approaches of centralized and decentralized market operation, the latter also known as peer-to-peer, are presented in Figure 4.

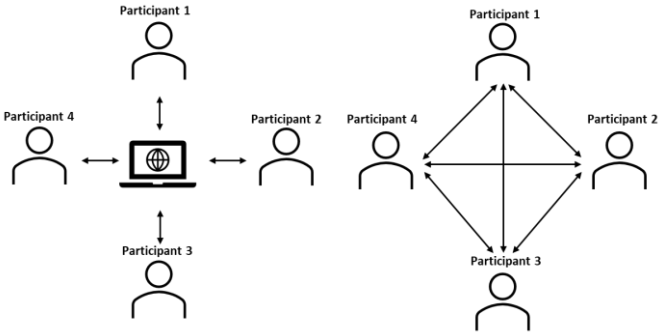

Figure 4. The concept of local market operation with a centralized trusted third party vs. peer-to-peer approach.

The design with the centralized entity raises the question of who should take on this role. The most obvious answer would be the DSO. However, the DSO is already a market participant and taking on the role of a market operator may lead to conflicts of interest. The best case would be an independent market operator, but this raises the issue of remuneration, especially in the case of the *Social equity* market design where no fees are introduced. In general, the involvement of a third party would result in reduced financial benefits for all market participants. In a decentralized approach market participants can be awarded for keeping the platform via smart contracts and with the implementation of tokens. The decentralized approach is also more robust and resilient in the event of an outage, as opposed to a centralized approach as outages are limited to a single participant. The same applies to the security of the platform. Potential cybernetic attacks on a centralized platform are much easier than on a decentralized platform replicated among numerous nodes.

Blockchain technology enables smart contracts that implement uniform rules in a blockchain network. The use of smart contracts allows the implementation of rules applied during each truncation by all network nodes. With the use of

smart contracts different processes related to business logic are automated. In the presented local market, smart contract verifies whether the market participants really have the right to offer a service for a specific asset. The same logic is applied to each node in the blockchain network, and the data is stored in the ledger of each node. Any potential abnormality can easily be detected if the result of one node differs significantly from the results of all other nodes. This could be a signal for a transaction not to be executed. In this way, trust in the blockchain network is built. In the MARKETFLEX tool, blockchain is used to perform trading using smart contracts. The trading platform uses smart contracts to automate the whole process from recording the ownership/management of each asset, recording the funds held by market participants and recording final transactions. The deployment concept of the Local market module in terms of the blockchain is presented in Figure 5.

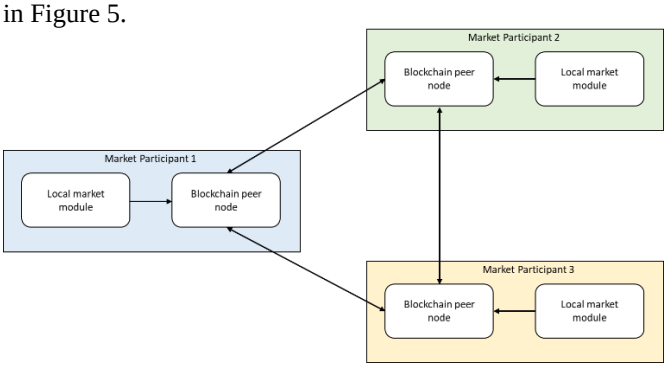

Figure 5. Blockchain deployment concept in MARKETFLEX tool for Local market module

The wholesale spot market module and the Wholesale AS market module are both linked to an external platform where the trading process is already defined and cannot be changed. However, in this case, the blockchain is used to provide a decentralized validation of the results produced by the wholesale market platform. Transactions are stored in the blockchain network and validation is possible for all market participants. This ensures that the behaviour of the centralized platform is kept and verified by all parties, as this improves trust in the way the platform operates.

V. CONCLUSIONS

The feasibility of market-based solutions for flexibility procurement in the distribution network is closely linked to the needs of the DSO, the accuracy of consumption and generation forecast, the number of flexible devices, and perhaps most importantly, the willingness of the owners of the flexible devices to participate in the market. In addition to any regulatory barriers to the establishment of local flexibility markets, the main challenge to their establishment is to ensure sufficient market liquidity. This can be ensured by integrating different markets. An independent market platform can create a market for different buyers, not only for DSO, and thus make market participation attractive for different actors. In any case, the main objective should be to use flexibility at its best value. This approach was also followed in the presented case. The MARKETFLEX tool serves as a link between the different energy system stakeholders, encompassing the transmission and distribution networks. The main innovation of the MARKETFLEX tool is the establishment of a local flexibility market at the distribution network level, which combines capacity trading for limited network capacities and a market for the DSO to procure flexibility service from flexible devices. The capacity trading presented is not only meant for loads but also for generators in case their connection to the network is constrained due to voltage conditions. This option allows generators to participate in the market instead of having a firm network connection 100% of the time, which may be severely limited. In the proposed market design, flexibility services from the distribution level can also be offered to the TSO, while ensuring the secure operation of the distribution network. An important aspect of the presented novel approach is to have information on the network conditions from the DSO. The role of the MARKETFLEX tool is to check the network constraints and perform the validation of market transactions. The presented tool has already been successfully tested in the Slovenian pilot site of Luče. The final results of the testing activities will be reported at the end of the X-FLEX project in autumn 2023.

ACKNOWLEDGMENT

The research was supported by the European Union's Horizon 2020 research and innovation program LC-SC3-ES-1-2019, Flexibility and retail market options for the distribution grid – Innovation Action – under the project name X-FLEX – Integrated energy solutions and new market mechanisms for an eXtended FLEXibility of the European grid (grant number 863927). The funding bodies had no involvement in the preparation of the manuscript.

REFERENCES

[1] X-FLEX Project, "D5.1 Overview and outlook of market mechanisms," 2021.

[2] "Official Journal of the European Union," *DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU,* 14. 6. 2019.

[3] Eurelectric, "Recommendations on the use of flexibility in distribution networks," April 2020.

[4] C. C. Z. A. L. S. H. W. B. Heinrich, "EcoGrid 2.0: A large-scale field trial of a local flexibility market," *Applied Energy*, vol. 261, no. 114399, 2020.

[5] INTERFLEX, "Local Flexibility Markets," 2022. [Online]. Available: https://interflex-h2020.com/results-and-achievements/local-flexibility-markets/. [Accessed 8. 5. 2023].

[6] G. E. K. D. C.-M. C. E. B. a. M. T. Pressmair, "Overcoming barriers for the adoption of Local Energy and Flexibility Markets: A user-centric and hybrid model," *Journal of Cleaner Production*, vol. 317, no. 128323, 2021.

[7] ENERA, "enera - der nächste Schritt der Energiewende," 2021. [Online]. Available: https://projekt-enera.de/. [Accessed 9. 5. 2023].

[8] NODES, "NODES flexibility market," 2021. [Online]. Available: https://nodesmarket.com/flexibility/. [Accessed 7. 5. 2023].

[9] gridX, "Build customized digital energy solutions," 2022. [Online]. Available: https://www.gridx.ai/. [Accessed 10. 5. 2023].

[10] P. e. a. Olivella-Rosell, “Optimization problem for meeting distribution system operator requests in local flexibility markets with distributed energy resources,” *Aplied energy,* vol. 210, pp. 881-895, 2018.

[11] PICLO, “Piclo Flex,” 2022. [Online]. Available: https://www.piclo.energy/product. [Accessed 8. 5. 2022].

[12] EPTA, “Energy Trading Platform Amsterdam - the energy trading platform for all,” 2021. [Online]. Available: https://etpa.nl/en/. [Accessed 10. 5. 2022].

[13] X-FLEX Project, “Description of X-FLEX,” [Online]. Available: http://xflexproject.eu/. [Accessed 30. 8. 2021].

[14] Y. M. G. L. Mohsen Khorasany, “Market framework for local energy trading: a review of potential designs and market clearing approaches,” *IET Generation, Transmission & Distribution,* pp. 5899-5908, 2018.

[15] P. A. O. S. S. CRAMTON, “Capacity Market Fundamentals,” *Economics of Energy & Environmental Policy 2,* vol. 2, pp. 27-46, 2013.

[16] X-FLEX, “D5.3 Design specification of the MARKETFLEX tool,” 2021.

[17] Crossbow consortium, “Clean Energy Across Europe,” [Online]. Available: https://crossbowproject.eu/. [Accessed 2. 2. 2023].

[18] KEYCLOAK, “Open Source Identity and Access Management,” [Online]. Available: https://www.keycloak.org/. [Accessed 14. 3. 2023].