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Business Models for Different Future Electricity Market Players

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1 Introduction

In traditional centralized power systems, power was produced by only bulk generators and delivered to the customers through transmission and distribution networks. In fact, the flow of power was totally unidirectional. In this way, generating companies, system operators, and large-scale retailers and customers were introduced as the main players of electricity markets. Regarding the conventional trading structure, small-scale electricity consumers were not able to participate in the markets. They were submissive ratepayers who were not subjected to the variation of the market prices. In this way, flexible capacities of small customers is not utilized in energy markets.

However, today's energy system is experiencing revolutionary changes due to the environmental crisis such as global warming. Environmental problems have led to an increase in the penetration of renewable resources in all levels of the power system. To this end, distribution network located customers are increasingly equipped with renewable resources (such as PV panels) which has produced a bidirectional flow of power. In this way, business models are key drivers incentivizing consumers to change to proactive consumers or "prosumers". Prosumers are end-users with the production capability who can change their consumption and production according to external signals (such as electricity prices) [1].

The other reason accelerating revolution of the power system is the recent development in ICT technology facilitates bi-directional communication, enabling prosumers and consumers to change their consumption power according to the system's needs [2]. Recently, new projects and market designs are developed aiming to focus on bringing customers at the heart of energy systems [3]–[5]. For this purpose, novel business models should be defined in order to shift the value proposition of the existing trading based on the power grid's requirements. They should attract more and more small-scale customers to play the role of prosumers. In addition to energy, the introduced business models should seek to exploit the maximum flexibility potential of demand-side resources so as to deal with problems related to the intermittency of renewable resources in the power grid [6].

In this regard, this chapter firstly introduces the existing and newly-emerged players participating in different markets and trading structures in a smart grid environment. These market players are prosumers, aggregators, virtual power plants (VPP), community managers, local market operators, and system operators including distribution system operators (DSO) as well as transmission system operators (TSO). Afterward, different business models and trading structures are introduced in the section. The business models and trading structures which are assessed in this chapter are: local electricity markets, peer-to-peer (P2P) trading, aggregator-based trading model, and flexibility local markets. In local markets, prosumers are assumed to trade locally under the supervision of a local market operator. In P2P trading, prosumers are able to choose their trading partners and trade energy bilaterally. In an aggregator-based model, however, prosumers negotiate contracts with an aggregator to provide the power system with energy. In each model, market participants are specified and their roles and responsibilities are defined as well. Finally, the chapter introduces a new local market structure for trading flexibility services. It proposes a structure in which small-scale resources will be able to provide both local and system-wide flexibility and ancillary services. This business model is a driver unlocking the flexibility potential of small-scale prosumers and consumers so as to participate in increasing the reliability and security of the local and system-wide power networks.

1.1 Prosumers

The new technological advances provide the ultra-fast bi-directional flow of information between end-users and utilities. In light of the new technology, end-users who were previously non-active consumers and submissive ratepayers are increasingly equipped with energy resources such as solar panels and smart meters. These consumers are now able to produce their own power as well as managing their consumption and production through the use of smart meters. They can also sell their surplus to the grid (through retailers and aggregators) and make profits accordingly. These emerging consumers who actively control their production and consumption are called proactive consumers or "prosumers" [2].

During different time slots, a prosumer may play the role of either a seller or a buyer. This role depends mainly on the prices of electricity (both selling and buying prices) as well as the prosumer's net power profile. In addition to renewable energy resources, a prosumer may have various flexible energy resources (FERs) including electrical storage (batteries and electric vehicles), and controllable appliances. FERs help the prosumer to better control their production and consumption. By scheduling the FERs, a prosumer is able to maximize its profits taking into account the external signals such as electricity prices.

Energy management systems (EMS) are responsible for obtaining the optimal operation pf FERs by considering the related operating constraints. The EMS is equipped with sensors and actuators for monitoring and controlling energy consumption and the production of prosumers [7]. This system should also satisfy the constraints imposed by the owner's convenience level. The other responsibility of EMS can be obtaining the optimal bidding strategy for the prosumer based on the data receiving from the local or retail electricity prices. The optimal scheduling of the FERs should be updated if the data on the prices update constantly (in the case that it participates in local markets). The EMS also needs to take into account the real-time preference of the owner. Accordingly, there are just a few appliances whose control will not interfere with the prosumer preference. The controllable appliances need to be inherently flexible appliances in terms of their working time or/and working power [8]. For some appliances, the EMS is able to change their operating power as well as their operating time. For example, EVs which can be charged with different power rates are in this group. In contrast, just working time of some appliances is allowed to be controlled. Washing machines and dishwashers are two examples.

A prosumer may adopt different strategies with different objective functions. They may aim to be self-sufficient. In this way, the prosumers try to be islanded, utilizing its flexible resources to capture the unbalanced power resulted from its renewable energy resources. Hence, islanded prosumers need to be highly flexible [9]. Hence, storage-based resources are required to make the prosumer highly flexible. On the other hand, a prosumer may decide to operate in the grid-connected mode. It means that it is able to trade electricity with the grid. The EMS decides on the amount of the imported and exported power based on the prosumer's objective function. Normally, it is more profitable for prosumers to consume their renewable production and sell the production surplus to the grid. However, in general, the energy policy and motivation programs play an important role in the decision making of the EMS. The prosumer may choose to provide flexibility services to the grid providing that there exist decent motivation schemes.

Some prosumers may choose to be aggregated with other prosumers and join a local community. In this regard, the independent prosumers cooperate with each other to enhance their own community. The community may aim to maximize its total profits, maximize its self-sufficiency, or minimize the environmental impacts of consuming and producing electricity. In the local community, a hierarchical control and management scheme is adopted. Therefore, each prosumer operates autonomously using its own local EMS. On top of the control layer, a central EMS coordinates the operation of its prosumers so as to achieve the community's objective function [9]. Fig. 1 shows the structure of a prosumer in islanded mode and in a community-based structure.

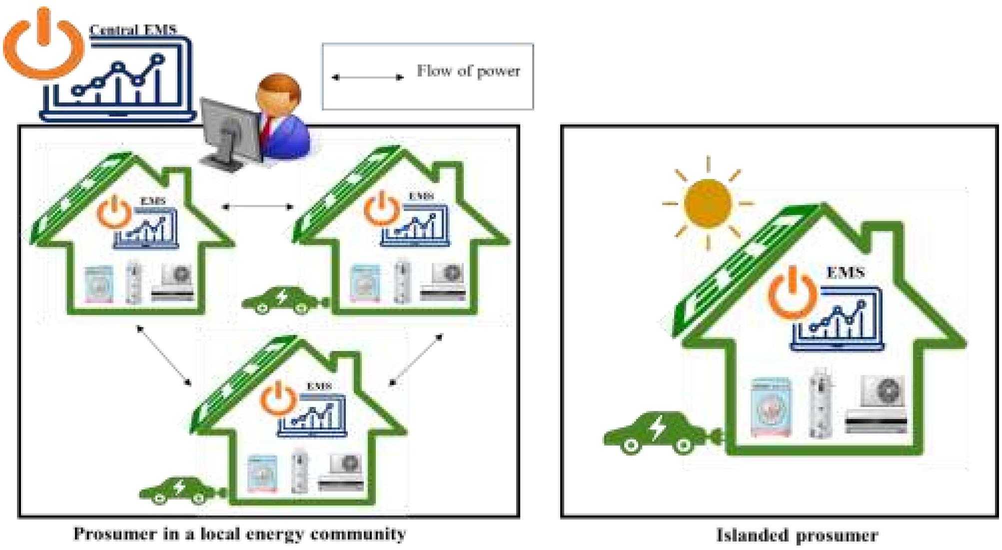

Figure 1. Structures of a prosumer in an islanded mode and in a community

Other prosumers may choose to negotiate a contract with an aggregator. In this regard, they give permission to the aggregator to provide a specified amount of energy or flexibility in specified time slots. They receive benefits if they fulfil their commitment. Thus, the aggregator plays the role of a broker between the prosumers and the utility (or wholesale markets if the aggregator participates in the markets). In the aggregator-based model, the objective function of prosumer's EMS is to schedule the FERs aiming to follow the predefined contract and the signals receiving by the aggregator.

1.2 Energy Communities

An energy community consists of a group of prosumers or/and consumers who voluntarily join the community with a specific goal. Energy communities can have various kinds of energy resources such as an energy storage system, photovoltaic arrays, and wind turbines which can be regarded as shared assets, meaning that they belong to all of the members. Forming the energy community can follow different objectives such as maximizing the community's total profits, minimizing its costs, or increasing the self-sufficiency of the members.

Different members can constitute different types of communities. In this regard, the community can be a residential energy community, an industrial energy community, etc.). The short physical distance between the members of the community can form a local energy community. In this kind of community, the local production aims to satisfy the local demand. Moreover, anyone from the neighboring area can voluntarily register as a member of this community and being supplied locally. In addition, the total income and costs of the community will be shared between the members [10]. Thus, the capital costs of the shared resources can be split between the members while they can all benefit the profits obtained from these resources. Regarding the management of the community, a non-profit manager which can be selected from the existing members of the community can be nominated and take the responsibility of community management as well as the related monetary and technical considerations [11].

An energy community can be considered as an independent player who may participate in wholesale or local markets. For instance, it can sell its production surplus to wholesale markets and/or provide ancillary services to the market operators. In this way, the main aim of the community is to maximize the total profits of its members by participating in the market.

1.3 Aggregators, VPPs, Community managers

In most power systems, small prosumers and consumers are not allowed or are not able to participate in the wholesale markets. In these markets, there are minimum capacities that each player needs to submit to the market. Thus, it prevents these players from taking part in wholesale energy and ancillary service markets. In addition, in the wholesale markets where small players are allowed to participate, the prosumers are not motivated enough to take part and compete against those large-scale players with huge capacities. Another reason is that a prosumer that is fully capable of providing flexibility services may lack the needed information. For instance, small consumers and prosumers often lack information on time slots in which system peaks will happen, the prices of provision different kinds of flexibility services, the available up-to-date technologies that can help them to manage their consumption and production, and the cost-benefit analysis regarding deploying these technologies. Besides, prosumers may do not have the ability and knowledge of forecasting the prices and build profitable bidding strategies, accordingly. In this situation, an aggregator act as a broker, aggregating prosumers to reach the permissible capacity utilizing a communication interface [12]. An aggregator may be responsible for intervening to fill information gaps between the system operators (TSO and DSO) and different agents.

An aggregator may be in charge of aggregating a specific FERs. For instance, it can be an EV aggregator [13], a DER aggregator [14], or an energy storage aggregator [15]. It also may aggregate prosumers/or consumers [16]. To a large extent, the aggregator can aggregate several microgrids or demand-response resources [17].

The main aims of aggregating several resources are participating in wholesale markets and/or contributing to the provision of flexibility services for the grid. The aggregator may decide to take part in electricity or/and ancillary service markets. For this purpose, it executes a contract with each participant for controlling its FERs or for selling a specified amount of energy and flexibility for some time slots. Some aggregators may offer dynamic tariffs or incentive programs to their aggregated prosumers and consumers. Hence, in the former situation, they control their resources indirectly.

Aggregators mainly run optimization problems in order to optimally schedule and coordinate their resources. They can be separated from the utility or they can be associated with and established by it. It should be noted that the scheduling and control actions taken on the aggregator's resources may affect the load flows, transformers and line thermal capacities of distribution systems. Hence, distribution network related constraints should be taken into account regarding the area which is controlled by an aggregator.

A VPP can be also regarded as an aggregated distributed energy unit. A VPP combines the capabilities of a number of distributed energy resources (DER) so as to increase power generation and enable them to trade energy with open markets [18]. A VPP can manage its internal DERs and controllable loads in an efficient way, making traditional fuel-based and renewable-based energy to operate together in harmony. Moreover, the efficiency and reliability of the system can be improved by the efficient integration of DER [19]. Furthermore, a VPP can increase synergy and interactivity by coordinating several DERs and EMS located in different areas. As the resources can be located in various areas, a VPP is able to manage resources to participate in providing voltage-based ancillary services as well as energy.

A community manager can be selected from one of the members of the community whose main goal should be in line with the objective of forming the community. In other words, the main goal for which the members gather together should be taken into account by the community manager. Thus, a community manager can be considered as one kind of an aggregator. The community may have some shared resources such as energy storage or renewable-based resources that should be scheduled by the manager of the community. In this light, the community manager needs to schedule these resources with the target to satisfy the total objective of the community. If the members gather together as a community aiming to increase their sufficiency, the manager should schedule the shared resources with the objective of satisfying the community's demand in every time slot. In this regard, the balance constraints and community's network should be taken into consideration by the manager of the community.

1.4 Market Operators

The main responsibility of a market operator as an autonomous entity is to match bids and offers of the electricity sellers and buyers. It can have different objectives based on the type of the market. For example, the market operator may aim to maximize the social welfare of the players, minimize the costs of generation units, increase the liquidity of the market, decrease carbon footprint regarding producing electricity, or minimize energy losses in the networks.

If the objective of the market is defined to be maximizing the social welfare of players, selling offers should be matched with buying offers in order to reach the pre-defined objective. In other words, the market operator accepts bids and offers such that the total selling and buying quantities match while the social welfare of the whole players is maximized. The market operator should also consider the imbalances of the market as the demand should be satisfied in every time slot.

Different pricing mechanisms can be deployed by the market operator. If it adopts "pay as bid" approach, the accepted sellers simply receive revenue according to the prices that they have previously offered through their offering curves. Similarly, buyers should pay for the energy according to the bids that they have submitted. The advantage of this pricing approach is that this mechanism is simple and intuitive for the different market players [20]. However, it cannot incentivize market participants enough to participate in the market competitively. In comparison, the market operator may deploy "uniform pricing" approach through which the sellers and buyers receive the same prices, corresponding to the intersection of the aggregated selling offers with the aggregated buying bids. This approach sounds to be pretty fair especially for trading electricity.

Moreover, the market operator should take into account the constraints related to the networks in its optimization problem. In this way, a mathematical model of distribution and transmission networks should be presented. The topology of the network, characteristic of the transformers and lines need to be considered in the formulation. The topology of networks describes the network graph which may vary according to the on-off status of switches.

1.5 Transmission System Operators (TSO)

The main responsibilities of TSOs in power systems are to maintain the frequency of the power system by keeping the balance between the generation and demand as well as regulating voltage and congestion management of transmission networks [21]. The frequency of the power system is controlled using different reserve products. For example, In Finland, the primary reserve is called FCR which requires to automatically react to the real-time frequency deviation in a constant way. FCR reserve itself is split up into two types which include frequency containment reserve for normal condition (FCR-N), and frequency containment reserve for disturbance condition (FCR-D) [22]. FCR-N is deployed all the time when operating the power system while FCR-D is procured when a large deviation of frequency happens [23]. Hence, FCR-D is not utilized constantly in all of the time slots. The other type of reserve is frequency restoration reserve which is categorized into automatic frequency restoration reserve (aFRR) and manual frequency restoration reserve (mFRR). These reserves are considered secondary and tertiary reserves as well. Automatic FRR is an automatically centralized reserve which is activated according to a power unbalance signal. The unbalance signal is calculated based on the frequency deviation in the Nordic synchronized area. In comparison, mFRR is deployed manually in some situations such as power outages, power-constrained violations regarding cross-border connections and also unexpected sustained activation of aFRR [24]. In addition to the above-mentioned services, a new type of reserve market has been introduced recently which is entitled "fast frequency reserve" (FFR). This reserve is responsible for capturing rapid frequency fluctuations in low inertia situations.

The online states of the power system determine the actions related to the congestion management of the transmission networks. In this regard, TSOs utilize Flexible ramping products (FRPs) along with ancillary service products in order to avoid congestion in transmission networks [24]. In addition, different active power and reactive power products may deploy by the TSO to regulate the voltage of the buses.

In order to better operate the power system, cooperation among TSOs is required. For instance, a study proves that optimal cooperation between TSOs will enhance flexibility in transmission networks which could in turn facilitate the higher penetration of renewable-based power into the system [25].

In general, as previously mentioned, TSOs utilize different types of flexible energy resources to enhance the flexibility of transmission networks. These flexible resources can be located in low-voltage (LV), medium-voltage (MV) or high-voltage (HV) networks [26]. In addition to generators which are large-scale flexibility providers, flexible resources connected to distribution networks have considerable potential for providing TSO-level flexibility services such as frequency services. Thus, a new structure for ancillary service markets is needed in order to exploit the potent flexibility of distribution network located resources.

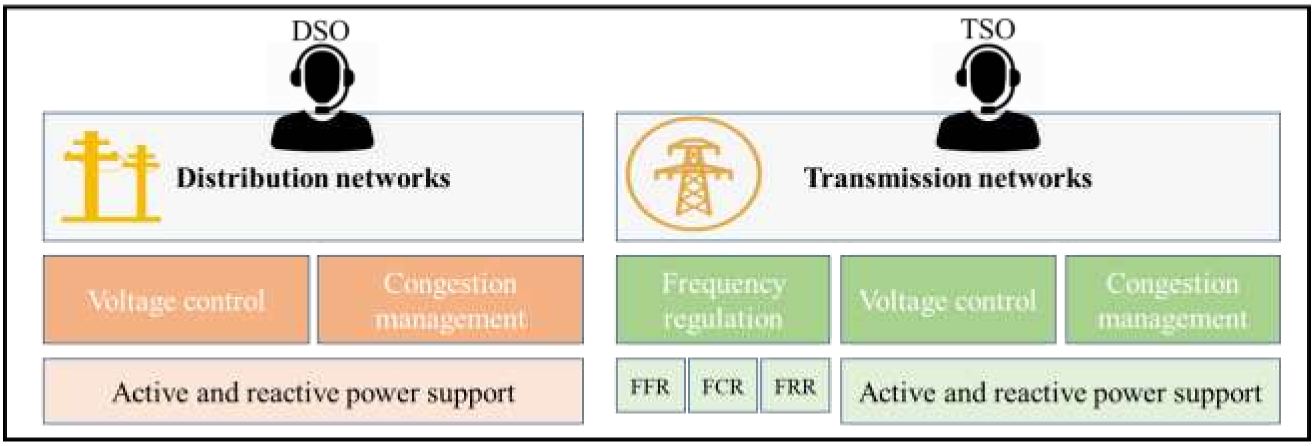

Figure 2. An overview of flexibility services adopted by system operators

1.6 Distribution System Operators (DSO)

DSOs' main responsibility is to operate the distribution networks. A DSO should ensure that voltages of nodes remain in the predefined levels and also it manages the power flowing through the network in a way that it does not create congestion and violate the thermal limits of the lines. Thus, congestion management of different feeders and also reactive power (Q)–voltage (U) management (QU- or Volt/Var) which is deployed for distribution network voltage control are also another vital responsibilities of DSOs [27]. However, with the growing number of renewable-based distributed energy resources, smart metering, smart grid technologies, the role of DSOs is going to undergo revolutionary changes.

DSOs in smart networks are burdened with various additional responsibilities. For example, they need to handle and collect the mass of data that receive from the smart meters, manage and use them for the forecasting and risk management as well as operation and planning of the distribution networks [26]. In addition, they may also need to manage local and microgrid markets in the future distribution system. Moreover, voltage control and congestion management of feeders are becoming more challenging owing to the high penetration of intermittent renewable-based power generation as well as the growing number of EVs with uncertain charging behavior in distribution networks. As a result, DSOs require to deploy more flexibility services in the future in order to address the new challenges associated with power variability and uncertainty.

For this purpose, the DSO should deploy both active power and reactive power flexibility of the distribution network located resources. These resources include storage-based resources, controllable appliances, and inverters of inverter-based DGs which can assist in enhancing the feeder transfer capability by absorbing or injecting the required amount of reactive power. As these FERs can be located in various nodes and locations, they can be enormously helpful for DSOs. In this way, the DSO can utilize distributed voltage control for voltage regulation purposes. According to the studies conducted by [28] distributed voltage control is one of the most efficient control actions which can be adopted by DSOs due to its low communication burden as well as its high control quality. In the distributed voltage control, the distribution system should be divided into different subsystems. Each subsystem has its own control areas. Each control area will work autonomously, aiming to optimize its local network [29].

Fig. 2 provides an overview on the services which can be provided for both system operators.

2 Business Models

Traditionally, there exist some wholesale markets for trading energy and ancillary services between different large-scale players. The only players who can participate in these markets are large-scale generating companies such as huge fuel-based generators, aggregators as well as some retailers who submit their required demand. TSOs also play the role of buyers in ancillary service markets. Regarding the traditional structure, small-scale resources such as prosumers cannot actively contribute to providing energy and flexibility services. For this reason, new business models and market structures have been defined in the recent studies, trying to involve more distribution network located customers and flexible energy resources as much as possible. In this section, these market structures are introduced and the participants and the trading architecture are discussed as well.

2.1 Local Electricity Markets

In the last decade, a rise in the production of distributed renewable energy was reported significantly. The high deployment of renewable energy sources can alleviate the problem of global warming and environmental issues. In addition, the growing amount of demand in the power system has led the policymaker to design different incentive programs so as to motivate consumers to turn into prosumers. As a consequence, a concept of local energy markets was brought forward. The local energy market (LEM) seeks to enable any prosumer to utilize the capacity of its energy resources and flexible resources at its highest potential.

Local energy markets can gather together different types of energy resources at different levels of the power system. In this way, it may create a competitive environment in which players can compete against the same-sized competitors. It means that for example, a distribution network located prosumer who has a capacity in a range of several kilowatts competes with the distribution network located prosumers with the same range capacities. In addition, local markets help to overcome challenges related to geographical limitations and lack of network infrastructure. In the local market environment, prosumers and consumers are able to trade throughout the local network (for example an islanded microgrid) in order to effectively utilize their available capacities. This helps to reduce the energy losses in the networks and lower the cost of energy since all of the flexible potentials of the end-users can be exploited [30].

Various market platforms can be used so as to connect various stakeholders and players in the local market. In addition, the local market can have different architectures. It can deploy different pricing mechanisms as well as a different market settlement which can affect the motivation of the players. Although several structures are available, the local market should follow two main goals. First, it should optimize the utilization of local energy resources and integrate distributed energy resources. Second, it needs to assure that there exist no discrimination, and create a competitive environment for trading energy.

2.1.1 Market participants

Different parties can be involved in local electricity markets. Prosumers and consumers are the main players of these markets, playing the role of both sellers and buyers. It means that prosumers submit selling offers for their surplus production while consumers bid to supply their demand. It should be noted that during some time slots, a prosumer may turn into a consumer since the amount of its demand exceeds the production.

The local market operator is responsible for matching selling offers with buying bids considering the offered prices and the required quantities. The local market operator can be a DSO. In other words, a DSO may operate several local markets in its territory. In situations in which the local market operator is an independent entity (i.e. the local market operator is not a DSO), it should be constantly in touch with the DSO to check whether the trading power does not violate the network constraints.

2.1.2 Local market architectures and clearing process

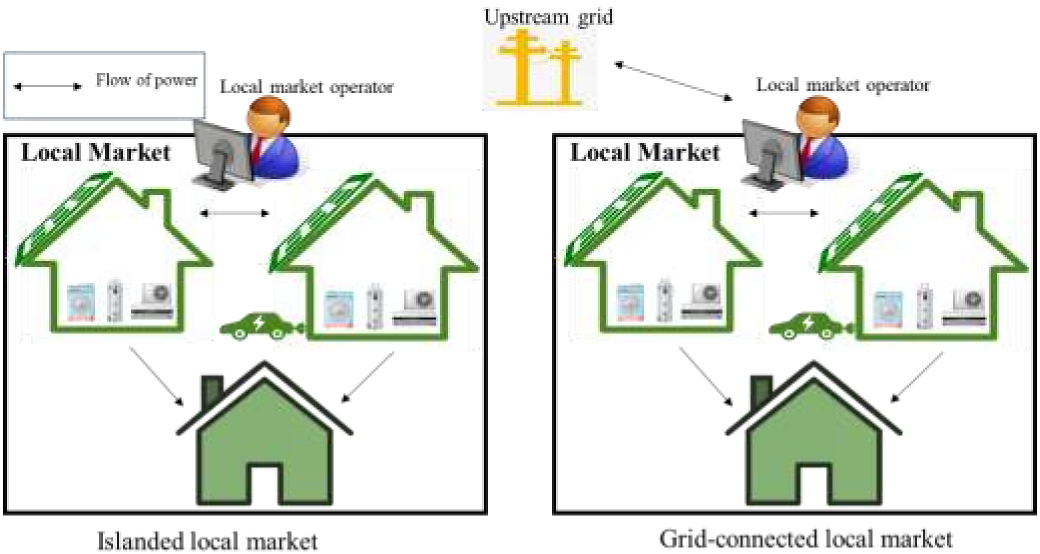

Figure 3. Islanded and grid-connected structures of a local market

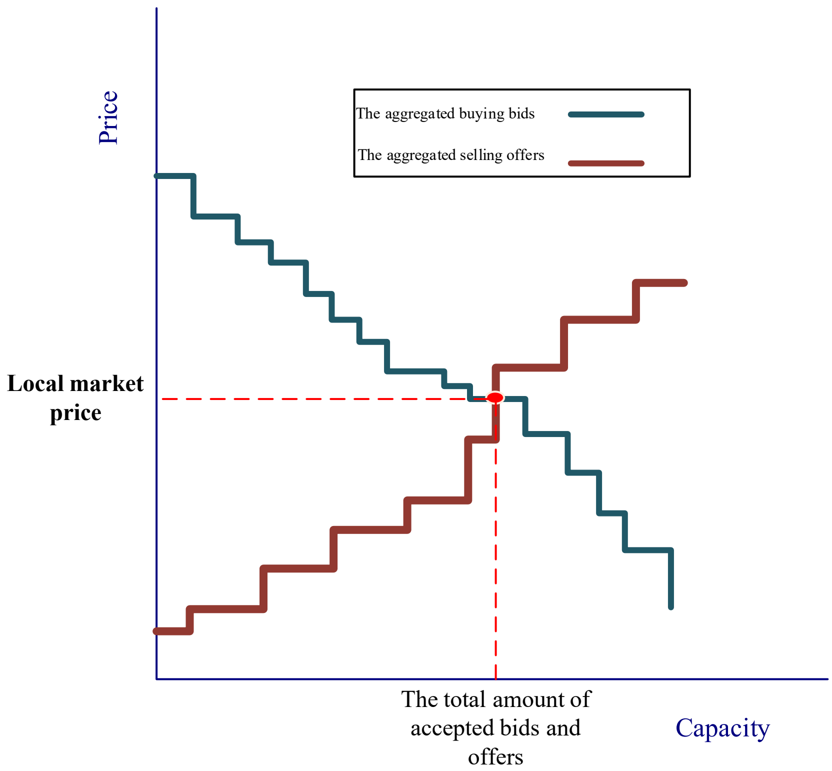

Figure 4. The clearing approach of a pool-based local market

A local market may form like an islanded microgrid, meaning that it acts as an autonomous network. This kind of local market aims at satisfying the local demand by utilizing local production. In this way, the local market should have enough production capacities and also flexible energy resources to meet the local demand. Additionally, the production surplus of this market may be curtailed during time slots in which the production exceeds the demand. In comparison, a local market operator can trade the surplus power with the upstream grid in order to satisfy the balance-related constraint. Fig. 3 describes the architectures of the above-mentioned two local markets. The second structure is more likely to exploit the maximum potential of local players since the production surplus does not need to be curtailed and remains unused.

A local market can have a pool-based architecture. In the pool-based architecture, players submit their bids and offers to the local market operator. The operator clears the offers and bids with regard to the main objective of the market. This structure is similar to the current structure of the pool-based wholesale markets. In this regard, in each time slot, the bids of demand are aggregated according to their prices in descending order. The offers of production are also aggregated according to their offered prices in ascending order. The intersection of the aggregated bids and offers determines the local market price in the studied time slot. The remaining production and demand will be traded with the upstream grid. Fig. 4 depicts the clearing approach of the pool-based local market. In contrast, a local market may have a peer-to-peer structure in which players may be given an opportunity to select their trading peers. This structure will be fully discussed in the following subsection.

2.2 Peer-to-peer (P2P) Electricity Trading

In a P2P trading structure, prosumers and consumers can trade electricity bilaterally. This trading structure aims to increase energy democracy and incentivize prosumers and consumers to be more active in energy sectors. However, it may have an adverse effect on residential participants while they need to be constantly active for meeting their required energy or for selling their production.

Considering the consumers' preferences in choosing their sources of energy is one of the drives which can promote P2P trading. These days, public awareness of the problem associated with global warming and climate change is rising. As a result, energy-related sustainability becomes more and more popular. Hence, P2P trading can pave the way for empowering consumers through providing them with their required information, the option to choose their source of energy, the ability to manage their consumption and production which can in turn leads to making profits or decreasing their energy costs. In addition to this, a consumer and prosumer may negotiate a long-term contract bilaterally with the satisfaction of both parties. In this regard, some may prefer to choose the neighbors as their trading partners to empower their local community.

P2P trading can be a suitable trading option for the network with weak interconnections. For example, in rural areas, this kind of trading may be beneficial as it decreases the costs of network reinforcement while incentivizing end-users to be equipped with renewable resources and become self-sufficient and making profits by selling their surplus production.

Nevertheless, the unsupervised P2P can result in some issues related to the reliability and security of the system. First, renewable-based power is extremely uncertain and volatile in nature. Thus, the seller who is equipped with this kind of resource needs to utilize flexible energy resources (such as storage) as well in order to fulfil its promises on supplying a specified demand. In addition, the unsupervised trading power may endanger network-related constraints. Some trading can result in congestions in the distribution network and some may violate the voltage threshold in distribution networks. Hence, the amount and direction of trading power should be checked beforehand by the DSO (or any other entity who is in touch with the DSO) in order not to violate the network constraints.

2.2.1 Trading participants

In P2P trading, a seller can trade with several buyers and vice versa. Sellers are prosumers or local communities which have production surplus. Buyers consist of consumers or local communities with unsupplied demand. As stated before, the DSO (or any other entity receiving signals from the DSO) should supervise the P2P trading between the local peers. In this regard, the peers need to give the DSO the information about their up-coming trading, the sellers and buyers. Then, the DSO should check whether the trading does not endanger the security of the local network.

2.2.2 P2P trading architecture

Authors in [31] have categorized the P2P trading structure into three different architectures for participants of distribution networks. These architectures are entitled "full P2P trading", "community-based P2P trading", and "hybrid P2P trading". In the full P2P trading architecture, small prosumers and consumers can trade energy with each other while in a community-based one, a prosumer or consumer should join a community. Then, communities can trade energy in a P2P trading structure. In a hybrid architecture, prosumers and consumers as well as communities can perform P2P energy trading. These architectures are depicted in Fig. 5.

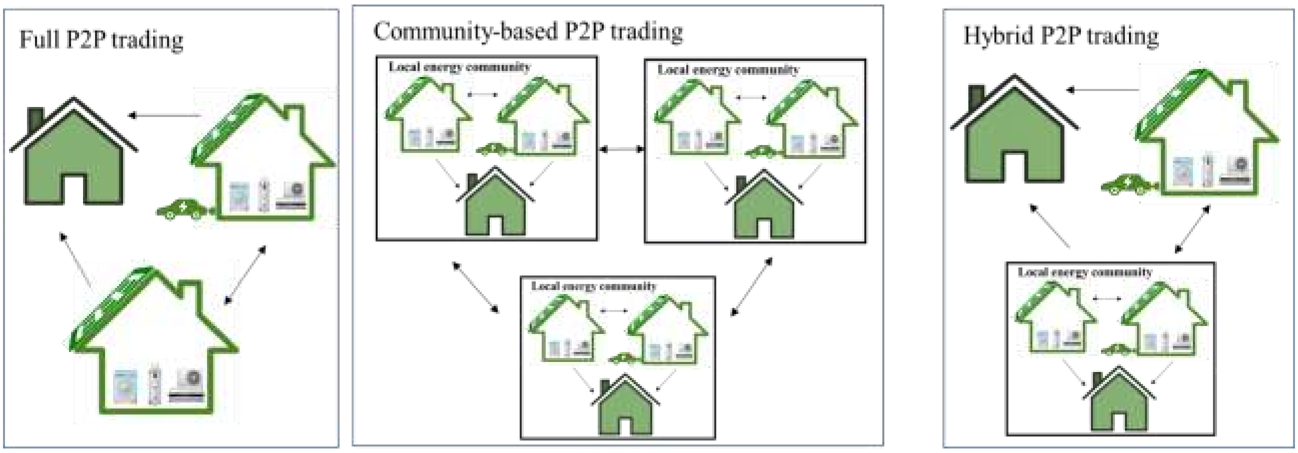

Figure 5. Different architectures of P2P trading

In order to deal with the imbalances resulted from the P2P trading of end-users, consumers and prosumers may decide to trade bilaterally with their neighbors while trading their surplus with the upstream grid. In this way, the peers can decide on their trading partners in the first stage. Then, if the demand of a consumer does not fully satisfy with the chosen peers, it can be supplied by the upstream grid. Similarly, if a prosumer has a surplus production after providing the promised demand, it is able to sell it to the upstream grid. Thus, this structure can fully cover the imbalances stemming from intermittent characteristics of renewable resources and exploit all of the potentials of the local resources. This structure is also illustrated in Fig. 6.

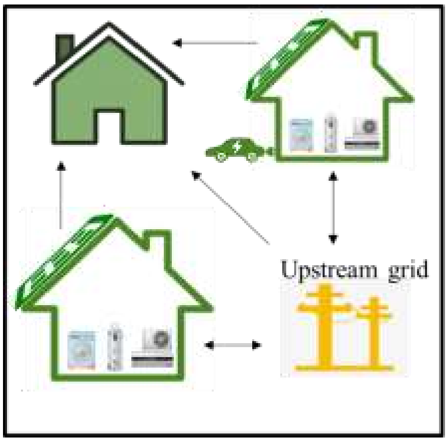

Figure 6. A structure of P2P trading in which players can trade their surplus with the upstream grid

2.3 Aggregator-based Electricity Trading

The number of aggregators who are participating in energy markets has been rising in the last decade [32]. Some European companies such Voltalis in France and REstore in Belgium are currently playing the role of an aggregator and participate in different energy markets [33]. Not only do they participate in wholesale energy markets by aggregating consumers and prosumers, they also provide some services for end-users such as consultancy tools, as well as optimization and monitoring-related equipment so as to have more control over them. The aggregators, then analyze the profiles of the end-uses and build a bidding strategy accordingly. In order to achieve a better income, a cooperative relationship between the aggregators and its resources is required [34].

2.3.1 Participants

In this structure, the aggregator purchases the energy or flexibility from the prosumers and consumers. In this way, the aggregator may define the groups of prosumers or/and consumers as well as appropriate tariffs for each group. The tariff can be determined according to the time of the day and also the services that the prosumers will provide. In addition, the aggregator may schedule DGs and FERs of consumers/prosumers and build a bidding strategy in accordance with the available forecasts obtained from the data which receive from smart meters. The aggregator may also take into account the uncertainties of renewables and errors of forecast when scheduling the resources [34]. Note that if the aggregator is only responsible for aggregating different kinds of DGs, it may call a VPP. Thus, the main role and responsibility of a VPP is similar to those of an aggregator.

From the viewpoint of consumers and prosumers, they may submit a list of their available resources to the aggregator and give permission to the aggregator to control these resources. They may negotiate contracts with the aggregator to grant him/her the permission. In this way, their FERs are controlled automatically regarding the signals which receive from the aggregator. The monetary amount that the prosumers receive and consumers should pay is in accordance with the contract that they have signed with the aggregator. In another architecture, the prosumers and consumers play active roles and schedule their resources on their own. In each time slot, they try to optimize their schedule according to the signals receiving from the aggregator as well as their own profits.

2.3.2 Aggregator-based trading architecture

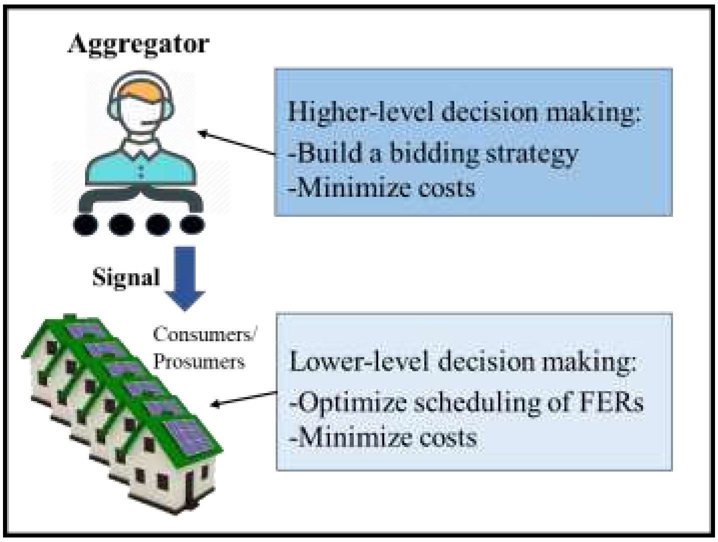

Figure 7. A two-level hierarchical architecture for the aggregator-based trading

The aggregator-based trading structure mainly consists of two-level hierarchical architecture [35]. In the higher level, an aggregator aims to minimize different terms of cost, including the incentives that should pay to the prosumers, the penalty costs incurred by not fulfilling the promises (which may be resulted from the uncertainty of renewables and error of forecast), and a term aiming at a fair distribution of profits/costs among the aggregated prosumers and consumers [35]. It should be noted that the aggregator needs to define the amount of exchanged active and reactive power of prosumers/consumers as well as the related incentives, beforehand.

At the lower level, consumers/prosumers receive signals regarding the power reference pattern which was set by the aggregator and schedule their resources. Fig. 7 illustrates this architecture.

In the architecture in which aggregator has full permission for controlling the resources, the scheduling problem turns into a single-level optimization problem. In other words, the lower level optimization which is performed by the prosumers and consumers is omitted from the problem.

2.4 Local Flexibility Markets

Consumers and prosumers are able to provide both system-wide (TSO-level) and local (DSO-level) flexibility services using their FERs. As stated before, electric vehicles, different kinds of storage as well as controllable appliances are examples of consumers' and prosumers' flexible resources. In terms of system-wide services, the active power flexibility of end-users can be aggregated and submitted to different ancillary services markets. When it comes to local services, Local flexibility services can be procured using the active power flexibility of prosumers and consumers from their FERs as well as reactive power support from inverters of DGs. Local flexibility services are those services helping DSOs to operate the network effectively. Both services associated with voltage regulations and congestion management can be regarded as local services.

In conventional power systems, prosumers and consumers do not play roles in providing system-wide and local services. However, recent studies are analyzing the active participation of small-scale resources in the provision of flexibility services. In this regard, local flexibility markets can assist in motivating consumers and prosumers to actively contribute to the provision of these services.

2.4.1 Roles of different participants

In local flexibility markets, system operators including TSOs and DOs play the roles of buyers while consumers and prosumers are sellers of the local market. Moreover, the presence of a local flexibility market operator is needed to settle the market and match selling offers with the buying bids. It should also determine the prices of flexibility taking into account the type of flexibility that the seller can offer. It is noticeable that providing system-wide flexibility services by the local flexibility market must not violate the constraints of the distribution network. Thus, the local flexibility market operator should be constantly in touch with the TSO to ensure that providing flexibility services does not endanger local network security.

2.4.2 Local flexibility market trading architecture

The trading architecture of the local flexibility market can be pool-based or in a form of P2P trading. In the pool-based architecture, all of the sellers and buyers submit their offers and bids, and the local flexibility market operator matches the selling offers with the bidding bids taking into account the network constraints. In comparison, the operators may negotiate bilaterally with the prosumers and consumers and determine the price accordingly. P2P architecture can be helpful for providing DSO-level flexibility services. In this regard, for example, a DSO can contact directly with the nodes related to feeders which are going to be congested.

3 Summary and Conclusion

In the last decade, small consumers become so motivated to change their roles from submissive ratepayers to proactive consumers (prosumers) who can make profits by managing their consumption and production. The reasons behind this revolutionary change is the newly-emerged advances in technology, the advent of smart meters, and the global awareness of environmental issues. In this regard, a growing number of small-scale end-users are equipped with renewable energy resources and storage-based resources as well as smart meters. However, the existing wholesale markets and trading structure are not able to follow this revolution. Hence, the existing markets fail to accommodate the prosumers' need. In addition, they cannot motivate consumers and prosumers to play active roles in providing the required network flexibility.

In order to exploit the maximum energy and flexibility potential of end-users new business model and trading structures are needed. Accordingly, this chapter analyze four different trading structures in which different prosumers and consumers can sell and buy energy. The first structure is related to local electricity markets where aims to incentivize small end-users compete with each other in a local environment. In this way, local consumption can be satisfied by the local production which in turn may decrease network losses. Another studied structure is peer-to-peer trading aiming to respect the players' preferences in choosing their trading partners. Peer-to-peer structure can promote energy democracy in the local level of power systems while motivating small-scale end-users to be more active. In comparison, aggregator-based structure introduces a hierarchical architecture which can be beneficial for consumers and prosumers who are not willing to be constantly active. In this situation, the aggregator may provide the aggregated prosumers and consumers with the required equipment and facilities so as to control them. Finally, the chapter proposes a local flexibility market seeking to satisfy the system operators' need. In this market, DSOs and DSOs can buy their needed flexibility from prosumers and consumers. Similar to local electricity markets, the architecture of the local flexibility market can be either pool-based or peer-to-peer-based. As a result, the introduced local markets and trading structure can be included in the future electricity markets.

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