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# Active Building as an Electricity Network Service Provider

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## Abstract

The growing number of distributed generation (DG) units in the distribution networks along with the high penetration of intermittent renewable power has increased the need for flexibility in the distribution and transmission networks. Flexible energy resources can help system operators to operate their networks more efficiently and deal with the high penetration of DG units. In this regard, an active building can provide flexibility services for the distribution and transmission system operators through its flexible energy resources such as storage-based resources and controllable appliances. To analyze the flexibility potential of active buildings, this chapter firstly categorizes flexible appliances and devices of the building in terms of their degree of flexibility. After that, different flexibility services and their technical characteristics are introduced. Based on the technical consideration, the contribution of the active building to the provision of these services is discussed as well. Finally, the chapter analyzes the role of active building's energy management system in this process.

## 1 Overview

Increasing the penetration of intermittent and uncertain distributed energy resources (DER) challenges the stability and security of power systems. As a result, network operators including distribution (DSO) and transmission system operators (TSO) seek to deploy more flexibility services in order to better operate their networks as well as keeping the stability of the system between specific thresholds. In other words, system operators need to use the flexibility of different flexible energy resources in order to maintain stable and reliable operation of the power system.

The flexibility of the power system is defined as the continues adjustability of the operating point of the network to accommodate the variations and fluctuations of generation/demand in the system [1]. Flexibility services are provided by flexible energy resources [2]. Flexible energy resources can be located at different levels of the power system including distribution levels (DSO-level) or transmission levels (TSO-level). TSOs can procure their required flexibility services from DSO-level as well as TSO-level flexible energy resources. In this way, the resources can provide the TSO with various types of reserves, helping it to operate its network more efficiently. However, traditionally, conventional generators have been the main flexible resources providing reserves for the TSO. It means that the TSO has not been able to exploit the flexibility potential of those resources connected to the distribution networks [3].

Similarly, DSOs can utilize the flexibility potential of distribution-network-connected resources in order to operate their networks. These resources can provide the DSO with services related to congestion management like voltage control of the distribution network. However, currently, DSOs utilize traditional equipment such as transformer on-load tap changers (OLTCs) and re-dispatching in order to operate their networks. With the growing number of DG units in distribution networks as well as the high penetration of intermittent renewable power, these methods may not be applicable in the near future [4] and they should be increasingly be coordinated with DER control principles [5].

An active building (AB) as an end-user located in the distribution network, can have several flexible resources such as storage-based resources (e.g. electric vehicles (EVs) and batteries), and controllable appliances, enabling it to actively participate in the provision of flexibility. These flexible resources enable the AB to respond to the grid flexibility requirements and provide the system operators with their required flexibility. In this regard, this chapter aims to analyze the potential of ABs for the provision of flexibility services.

The chapter firstly categorizes the controllable appliances of an AB into high-flexible, medium-flexible, and low-flexible appliances. After that, the existing and potent flexibility services are assessed. These services will be split up into TSO-level (system-wide flexibility services) including those procured for normal operations and services obtained for disturbances and special circumstances. The DSO-level (local flexibility) services are also discussed in the chapter. These services need to be adopted by the DSO in order to maintain the reliability and high power quality in the distribution network. Moreover, the AB's capability to provide each introduced service is analyzed. Finally, the chapter assesses the role of AB's energy management system in the provision of flexibility services.

## 2 Flexible Appliances and Devices of an Active Building

An active building which is equipped with advanced information and communication technologies (ICT) has several flexible appliances which could be utilized for providing flexibility services to the system operators. Generally, the appliances and devices of an AB can be categorized into flexible and non-flexible appliances. Non-flexible appliances need to be only scheduled by the resident of the AB.

In other words, non-flexible appliances are not capable to provide flexibility services for the DSOs and TSOs.

In comparison, the working time and/or the power of flexible appliances can be controlled based on external signals sent by the system operators. However, the control and management of these appliances should not disturb the comfort of the customer. For example, in terms of thermostatically controllable loads (TCL), the desired temperature of the customer should be considered when the building offers flexibility services to the system operators.

Each flexibility service requires control of specific flexible appliances in ABs. For example, some services require high-flexible appliances which are able to react to the changes very fast. In comparison, some services can be activated by less-flexible resources which may be cheaper. In this regard, we categorize appliances into high-flexible, medium-flexible, and low-flexible appliances based on their degree of flexibility. Each type of flexible appliance is briefly introduced in the following subsections. In addition, Fig. 1 overviews the introduced flexible appliances of an AB. As can be seen in the figure, the energy management system (EMS) of the AB can control its flexible appliances by sending control signal to these devices.

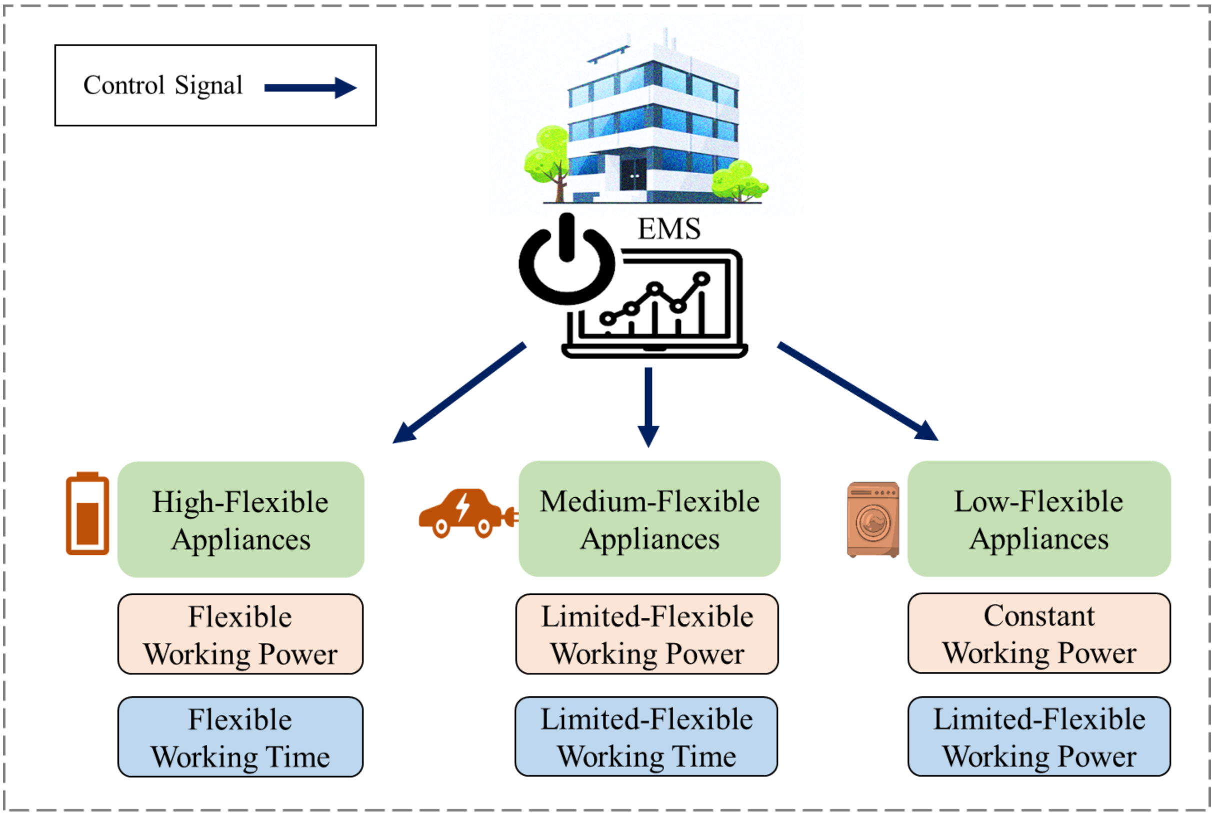


Fig. 1. Different categories for appliances and devices of an active building (AB)

### 2.1 *High-flexible Appliances and Devices*

An AB may have some appliances and devices which are highly flexible. These devices should have two features explained below:

- They should have high-flexible working time. In other words, the working time of devices can be adjusted according to the need of the grid. Moreover, the owner of these devices should not interfere in the working time of these appliances.
- They should have high-flexible working power. It means that the operating power of these devices can be controlled in a specific range. The only constraints restricting the operating power are those associated with the inherent characteristics of the device. In addition, the injection of the working power of high-flexible devices may be bi-directional. In other words, the device may provide the grid with upward flexibility services as well as downward ones. It should be noted that the occupant must not have any impacts on the operating power of these devices.

Battery energy storage is an example of high-flexible devices. The owner of an AB may have a battery in order to sell flexibility services to the grid. In this way, the owner can enjoy the monetary benefits of this device. The working time and power of the battery can be totally controlled based e.g. on the system operators need. The only constraints are those related to the stored energy and capacity of the battery. However, the owner does not interfere in the operation of the battery. In addition, the battery can provide the grid with both upward and downward flexibility. In terms of upward flexibility, the battery injects power into the grid. Regarding downward flexibility, the battery consumes power.

### 2.2 *Medium-flexible Appliances and Devices*

Medium-flexible appliances are defined to have the following features:

- The working time of medium-flexible appliances is also flexible. However, it is affected by the owners' comfort and preference settings.
- The working power of these appliances can be managed according to the need of the grid. However, the flexibility obtained from these appliances is restricted to the limits specified by the owner. The power injection of these devices may be bidirectional as well.

Inverter-based and thermostatically controllable loads whose power is controllable can be included in this category. The operating power and working time of these appliances are dependent on the desired range of temperature which is determined by the occupant of the AB.  In order to model the power of TCL appliances, the heat transfer process of these devices needs to be modeled based on the variation of ambient temperatures. Considering an HVAC as a TCL, the temperature of the AB must vary within a dead band, denoted by $T^{DB}$. The room temperature falls and rises based on the operating power and on/off status of the HVAC. Given that, the occupant sets the upper and lower limit to be equal to $T^{+}$and $T^{-}$ and thus the dead band would be $T^{DB} = T^{+} - T^{-}$. In this way, the working time and operating power should be set considering that the room temperature should not violate this range.

Electric vehicles (EV) which can be charged with flexible power can be another example. In this regard, the owner sets the desired time period during which the EV can be charged as well as its preferred status (e.g. the final state-of-charge of the battery of the EV). The grid operators can deploy the flexibility of the charging power of EVs by controlling the charging power within the predetermined time period. However, the EV should reach its desired status when the charging time period is up. In addition, the EV may also work in the V2G mode. In this regard, it can also inject power into the grid when needed. In conclusion, the management of medium-flexible resources is of vital necessity since they highly affect occupant comfort.

### *2.3 Low-flexible Appliances and Devices*

Other flexible devices that are not included in the two introduced types, form low-flexible devices. These devices are mainly controllable in terms of their working time. However, the owners may apply some constraints in order to restrict the operation of these appliances as well.

An EV that is charged with constant power is considered a low-flexible device. This is due to the fact that the charging power cannot be controlled. Besides, the EV owner determines a range of time slots during which the vehicle is allowed to be charged. In this regard, the EV should be managed to be charged in the specific time period determined by the owners. Besides, the owner may apply another constraint related to the final state-of-charge of the EV's battery. In this situation, charging the EV is highly restricted by the owner's preferences.

Some household appliances such as washing machines and lighting devices can be included in the low-flexible category as well. Regarding these appliances, their operating power is not controllable. However, they can be managed in terms of their working time. The owner may apply some constraints restricting the appliances' operating time. Regarding lighting devices, the management system should take into account the occupancy status, the daylight, and the personal preference of the building owner [6]. Thus, the full control of the lighting devices of the building requires smart equipment and photo-sensors that can manage the restrictions regarding the comfort of the owner.

## 3 Flexibility Services Provided by Active Buildings

ABs can provide various types of services to the grid in order to help system operators to effectively operate their networks. As a result, ABs can sell flexibility services to the DSO or/and TSO. If the AB sells services to the DSO, it provides DSO-level or local services. The flexibility services sold to the TSO are mainly procured to control the frequency of the whole system. Hence, TSO-level services are also called system-wide services. In the following subsections, we introduce different types of services that can be procured from ABs.

### *3.1 TSO-level Flexibility Services*

The TSO needs to ensure the secure operation of the power system by maintaining the balance between generation and load closely, moment by moment. Any type of imbalances results in frequency deviation from the nominal value. Hence, to control the frequency of the power system in different conditions of the system, TSO-level or system-wide flexibility services are deployed. In this regard, the TSO aims to procure a suitable type of reserves that suits the existing condition of the system. Accordingly, various flexibility services and reserves have been designed for normal, disturbance, and low-inertia situations. If ABs want to contribute to the provision of TSO-level flexibility, they should be aggregated via an aggregator who plays the role of a broker between ABs and the TSO. Without the aggregator, ABs are not able to participate in providing system-wide services since these services require a minimum flexible capacity which is more than the capacity of the building. In the following, TSO-level flexibility services associated with Nordic countries (especially Finland) are introduced and we assess the capability of ABs to provide these services. Fig. 2 reviews different services that can be provided for the grid.

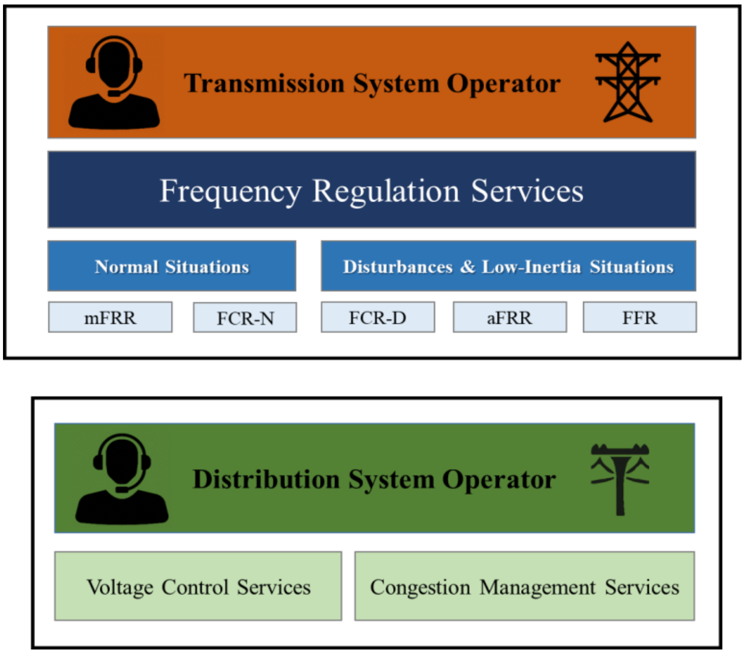


Fig. 2. Overview of the existing gird services in Finland (as an example of Nordic Countries)

### 3.1.1 SERVICES FOR NORMAL OPERATION

FCR-N and mFRR are two reserves used in normal operation of the system. In the following, the characteristics of these services are discussed.

#### 3.1.1.1 FCR-N

Regarding normal conditions, the TSO requires to constantly control the frequency of the system by activating fast reserves such as spinning reserves (in the U.S. [7]) or frequency containment reserves (FCR) (in Europe [8], [9]). FCRs for normal conditions (FCR-N) are utilized as primary frequency control. Activating FCR-N is the first action taken by the TSO in a decentralized fashion [10]. It is worth mentioning that the purpose of FCR-N is not to mitigate the consequences of a disturbance since it is used only in normal situations. FCR-N is an automatic control based on the local frequency measurements. Moreover, the reserve resource (e.g. an AB) deployed for the provision of FCR-N should pass the technical tests and be prepared for providing this service.

Regarding Finland, as an example of Nordic countries, the reserve resources providing FCR-N should be a symmetrical product [11], [12]. It means that the resources should be able to inject power as well as consuming it. In addition, the full amount of the upward reserve capacity needs to be activated in situations that the frequency is 49.9 Hz or less. Similarly, the full amount of the downward reserve capacity should be activated when the frequency is 50.1 Hz or more. When the frequency range is between 49.9 and 50.1 Hz, the amount of the activated capacity is proportional to the magnitude of the frequency deviation [11], as illustrated in Fig. 3.

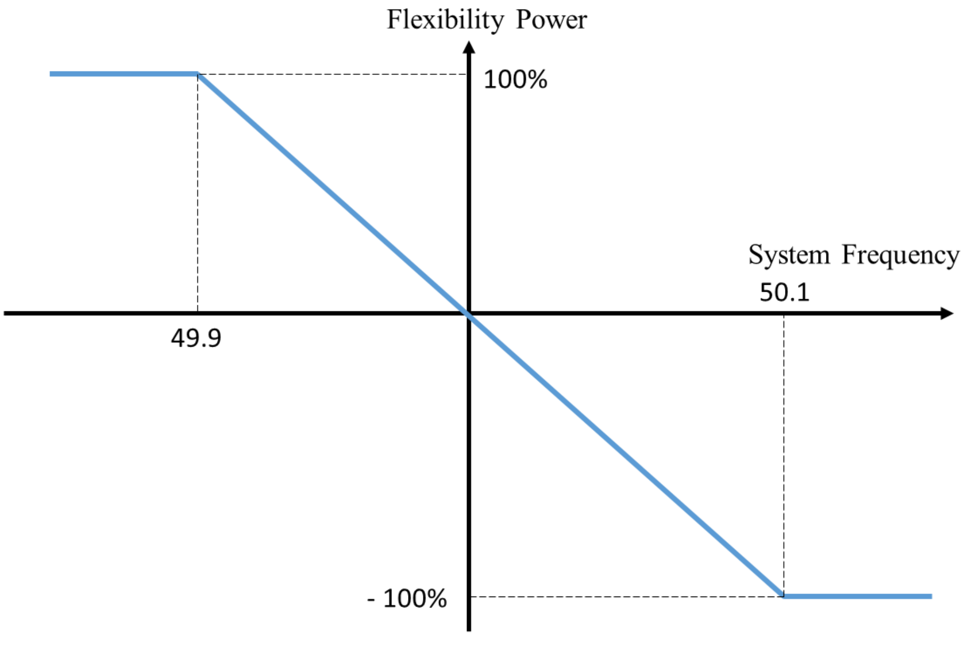


Fig. 3. The activation of FCR-N for each flexibility resource

A flexible resource may be capable of controlling its power continuously such as batteries or a relay-based one which can be managed in a piecewise manner. EVs which can be charged with several different power can be an example of piecewise-based resources. Considering FCR-N, the flexibility of the resource should be activated in three minutes. In addition, if the capacities of upward and downward flexibility are of a different magnitude, the smaller volume is taken for the provision of FCR-N [13].

Based on the technical considerations of the FCR-N, ABs with both upward and downward flexible resources can provide this service to the TSO. In this way, the minimum flexible capacity (minimum of upward and downward capacities) can be offered to the TSO. However, the corresponding device should be fast and flexible. Hence, the hinder actions taken by the owner are avoided so that the reserve capacity can be freely activated based on the instant need of the system. Nevertheless, the AB should take into account the constraints associated with the operation of the device. For example, if a battery is utilized for the provision of FCR-N, the capacity of the battery, its current SOC, and the minimum and maximum SOC should be considered when the AB is calculating its available flexible capacities.

#### 3.1.1.2 mFRR

Manual frequency restoration reserve (mFRR) is used to control the flow of the grid and helps to restore the faster reserves such as FCRs. In addition to this, manual FRR can be also utilized in the case of expected and deterministic frequency deviations [14]. The mFRR product should be adopted in normal operation [14]. Regarding Nordic reserve services, mFRR is localized to the extent that the synchronous system can be balanced at any moment [15]. Manual FRR is procured by the TSO according to its assessment of the local flexibility requirements. In this regard, the TSO should consider bottlenecks of its network and the dimensioning faults and procure mFRR accordingly. The reserve products associated with mFRR can be manually activated in fifteen minutes [14]. Thus, it can be suitable for slower flexible resources since they have more time to respond to the TSO's requests.

ABs can contribute to the provision of mFRR. In this way, they need to be aggregated by an aggregator in order to reach the permissible capacity. In addition, they should inform the aggregator about their available flexible capacities for providing mFRR and adhere to their schedules in real-time. The activated flexibility power is determined by the TSO in real-time. As an example, Ref. [16] introduces the participation of a local energy community which consists of several residential households in providing mFRR services.

### 3.1.2 SERVICES FOR DISTURBANCES AND LOW-INERTIA SITUATIONS

There might be several unexpected occurrences that cause frequency deviations and instability of the power system. In these situations, the TSO needs to be prepared by deploying different types of reserves. In Finland and Nordic countries, FCR-D is deployed for disturbances, fast frequency reserve (FFR) is procured for low-inertia situations, and automatic frequency restoration reserve (aFRR) is one of the main measures taken to avoid the weakening of the frequency quality of FCR-D [14]. In the following, these services are introduced according to the Finnish reserve products and markets. An overview of the reserves for non-normal operation of distribution networks can be found in Fig. 4.

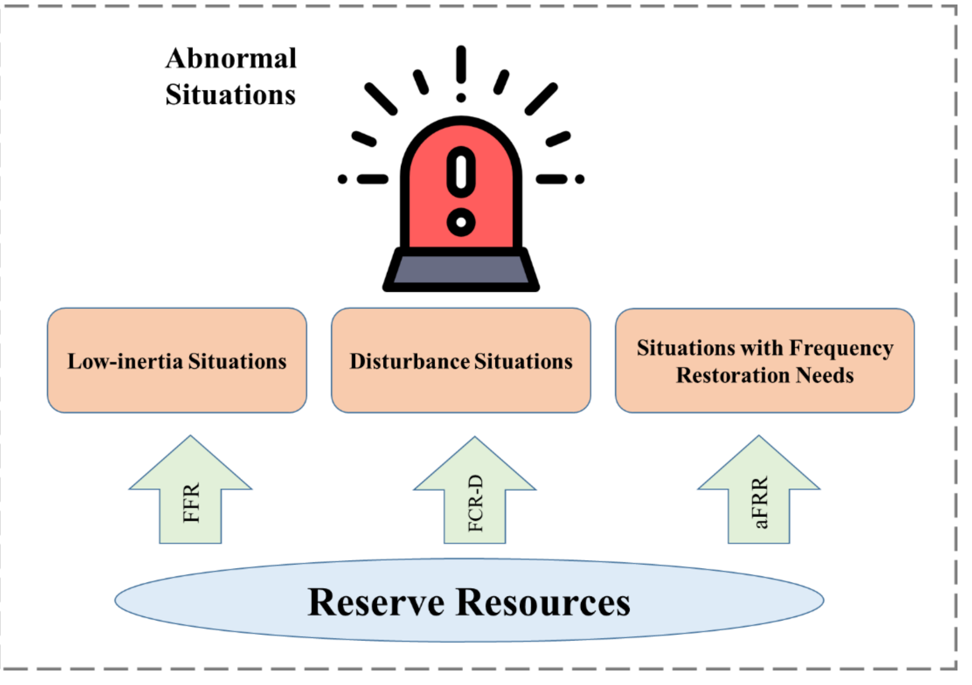


Fig. 4. Overview of reserves for non-normal situations

#### 3.1.2.1 FCR-D

Currently, the needed FCR-D capacity should be equal to the largest possible imbalance resulted from the loss of individual components such as generation units, lines, transformers, and bus bars. Thus, this type of reserve is required for low-frequency situations in the range between 49.5 to 49.9 Hz. As a result, upward flexible capacities are the only products required for providing FCR-D. If the frequency drops within the range of 49.5 to 49.9 Hz, the amount of the activated upward capacity should be proportional to the magnitude of the frequency deviation, similar to the FCR-N activation. Both linear-activated and relay-based devices can contribute to the provision of FCR-D. However, currently, the Finnish TSO restricts the total volume of relay-connected reserves procured for FCR-D [13]. In addition, the relay-connected reserve resources are not allowed to be aggregated with those activating linearly [13]. Regarding FCR-D, at least half of the reserve capacity needs to be activated in five seconds and the full volume should be activated in 30 seconds in situations that the frequency drops by 0.5 Hz [13].

Considering the mentioned technical considerations, ABs can participate in providing FCR-D using their upward flexible capacities. However, again the devices need to be flexible and so fast in order to be activated in less than 30 seconds without the intervention of the owner. Moreover, the device should be automatically controlled and the AB should be equipped with decent ICT technology so as to respond as fast as possible. It should be noted that for some medium flexible resources, the request of the system should be within the predetermined range of the utilization of the devices. For example, EVs as a flexible resource of ABs can also provide upward flexibility for FCR-D if the need of the system is compliant with the charging need determined by the owner in terms of time. As an example, [12] proposed charging stations that can provide FCR-D and FCR-N services for the grid.

#### 3.1.2.2 aFRR

Unlike mFRR, which is a locally adopted reserve, aFRR is a centrally controlled reserve in Nordic countries. In other words, the activation of aFRR is based on the frequency deviation within the synchronized Nordic area [17]. This product is considered as an automatic complement to aFRR services in the process of restoring frequency [17]. In fact, aFRR products need to restore the frequency to the nominal value while releasing FCRs which have been activated beforehand [17]. All Nordic TSOs specify the hours at which aFRR services should be dimensioned. In these hours, the frequency variations should be very challenging.

A reserve resource who wants to provide aFRR should activate its entire flexible capacity within 5 minutes after receiving the activation signal. In addition, it should start to respond no later than 30 seconds from the moment it receives the signal. Accordingly, the flexible devices of ABs are also able to provide aFRR if they are smart and equipped with decent communication technology. In this way, when the TSO requests for the activation of the flexibility, the flexible device should immediately react to the request regardless of the owner’s preference. It should be noted that most of the TSO-level services have capacity markets in which the reserve resource can submit its available flexible capacities. According to its offers, the reserve resource should adhere to its schedule that had been submitted to the capacity market and provide the TSO with its required flexibility.

#### 3.1.2.3 FFR

FRR should handle disturbances occurring in low-inertia situations [17]. These flexibility services are defined exclusively for under frequency circumstances since these low-inertia situations are considered much more critical than those with over frequency [17]. Therefore, upward flexible capacities are required for the provision of FFR. There exist two different FFRs defined in terms of activation durations. One is the long support duration FFR that the reserve resource should support the system for a duration of at least 30 seconds. In another type, which is named short support duration FFR, the resource supports the system for a duration of at least 5 seconds. In addition, there exist three different combinations of activation levels and their corresponding time for the full activation. Thus, the providers of FFR are able to freely select the most appropriate combination based on the characteristics and features of their flexibility resources. These combinations are [17]:

- 0.7 s for the activation of the full capacity at the activation level of 49.5 Hz
- 1.0 s for the activation of the full capacity at the activation level of 49.6 Hz
- 1.3 s for the activation of the full capacity at the activation level of 49.7 Hz

An AB should also submit its available upward capacity to the corresponding upstream aggregator. The type of the FFR service (in terms of the duration and the combination of the reserve) should be selected based on the flexible devices used for this purpose. However, as stated, the resource need to be deactivated based on the type of service. Hence, the AB cannot deploy those low-flexible appliances which are not interruptible such as washing machines.

## *3.2 DSO-level flexibility services*

DSO-level flexibility services are mainly referred to those services helping DSOs to better operate their networks. The main responsibilities of DSOs include congestion management and voltage control of the distribution networks [2]. ABs are able to provide DSOs with these two services. In the following subsections, the possibility of the provision of DSO-level services is discussed.

### 3.2.1 SERVICES RELATED TO CONGESTION MANAGEMENT

Modern power systems are heading towards smart grids along with the high penetration intermittent power produced by renewable energy resources and distributed generation (DG) units [18]. Additionally, the number of flexible loads such as storage-based resources is increasing in distribution systems which can be automatically controlled with newly-emerging advanced ICT technologies. The mentioned transition in electrical networks creates serious challenges for the operation of distribution systems [19]. On one hand, the DG units may alleviate congestions in the existing transmission grids as they decrease the required power transmitted to the end-users [20]. On the other hand, the excessive power produced by DGs along with the bi-directional flow of power in distribution networks can cause congestion in these networks [21]. For instance, the high amount of demand resulted from the simultaneous charging of EVs causes overloading of the network lines [22]. Hence, the uncoordinated operation of distributed-network-located resources can increase unexpected congestions in the distribution network.

In order to resolve congestion-related issues, the DSO can reinforce the network based on its identified and forecasted needs in the future [23]. This solution is long-term and requires costly actions and equipment. In this regard, the DSO may enhance the grid's hosting capacity for the high number of DGs and intermittent renewable resources by increasing investments in the infrastructure of the grid [1].

In the short-term, the DSO performs some actions to efficiently operate the network. One conventional approach is to change the setting and reconfigure the set points of elements of the network. The other method for the DSO is re-dispatching the DGs and generation resources of the network and requests for curtailment if needed. The mentioned approaches are not economically efficient for the DSO. In addition, some actions discourage the growth of DGs in distribution networks. However, in order to realize the green power system, investments in renewable-based DGs should increase.

One of the effective methods of managing congestion in the distribution network is using dynamic prices and tariffs in the network [24]. In this way, the DSO needs to predict congestion based on the forecasted load and generation of the network and determine dynamic prices accordingly. Thus, for example, by specifying greater electricity prices for the nodes associated with the congested feeders, the users located at these particular nodes are encouraged to decrease their demand. In addition, the DSO may design several local markets with the target to minimize its operational costs while causing the least discomfort to the participants. Another approach is to directly purchase flexibility from the end-users. In fact, the DSO may negotiate a contract with the end-user to control its flexible energy resources in some situations. It also can design flexibility markets asking participants to offer their flexible resources. The methods of congestion management in distribution networks are reviewed in Fig. 5.

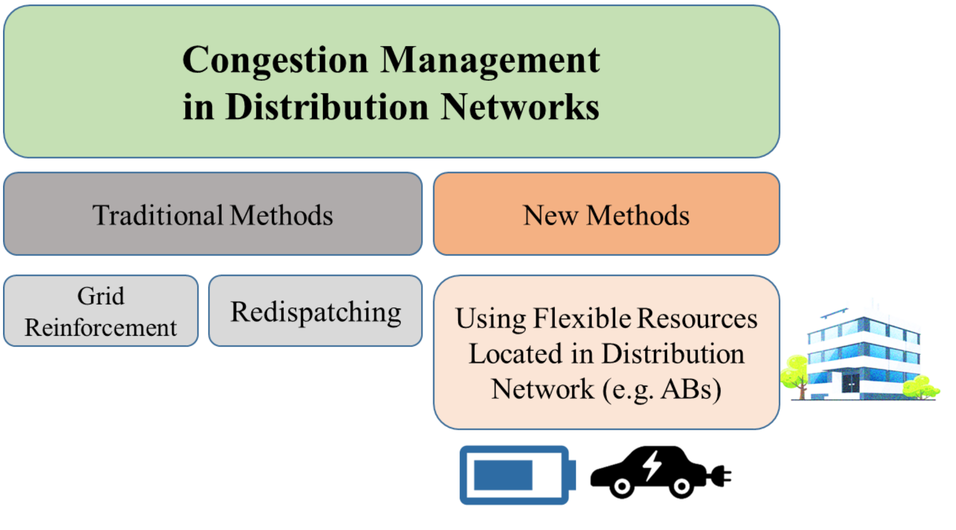


Fig. 5. An overview of the method used to manage congestion in distribution networks

Therefore, ABs can be regarded as potential congestion management service providers since they are able to actively react to the local market prices. It should be mentioned that the AB requires to be equipped with an energy management system (EMS) so to manage the building's flexible resources based on the local market prices or tariffs which were previously determined. Thus, according to the price signals and the comfort of the occupant, the EMS scheduled flexible energy resources of the building aiming to minimize the total costs of the AB. Every kind of flexible resources of the AB can participate in the provision of congestion-management services. This is due to the fact that compared to the fact flexibility services, such as FCRs, these services are not highly fast and is more predictable.

### 3.2.2 SERVICES RELATED TO VOLTAGE CONTROL

The growing number of DGs in distribution networks creates some regulation issues for the DSO which can affect voltage profiles as well as the power flow of this network. Moreover, the existing voltage regulation devices are mostly designed for the traditional distribution system without the high penetration of DGs [4]. Thus, the magnitudes of voltage which previously reduced along the distribution feeder, increase at the nodes with DGs [25]. Accordingly, DSO needs to deploy more effective actions to regulate the voltage in the distribution network.

Traditionally, DSOs deploy on-load tap changer (OLTC) transformers, switched capacitors (SC), and step voltage regulator (SVR) to regulate voltages of their networks [26]. These devices should automatically adjust the voltage using the estimation of voltage drops along with the network feeders. However, the power produced by renewable-based DGs is uncertain and volatile, adding uncertainties to the estimation of voltages in the network. In addition, the traditional voltage-regulation devices fail to rapidly track the variation of voltage resulting from the intermittent power of renewable DGs. If they change their status rapidly, for example for tap changing devices, it decreases their lifetime and increases the maintenance costs [4].

Regarding LV networks, active power can play a more significant role in regulating the voltages of the network [27]. Hence, the DSO can actively control and regulate the voltage of the distribution network utilizing the active power of flexible energy resources [31]. ABs which have flexible appliances and devices can be deployed as one of the resources to manage and control voltages in the distribution network. In this regard, the DSO should predict the flexibility need of the system associated with the voltage regulation. Afterward, the DSO should send signals to ABs at different nodes to react according to the signals. The ABs who respond to these requests should be compensated. Accordingly, the DSO needs to determine decent incentives for the ABs so as to adopt the maximum flexibility potential of these resources.

The control of voltage and flexibility management of ABs can be in a centralized or decentralized manner [4]. In a centralized method, the DSO receives the information on the online status of the network and determines the amount of flexibility required for each node. However, a comprehensive supervisory control and data acquisition (SCADA) system is required in order to manage the distribution network and deal with a huge amount of data receiving from sensors and meters. These data should be analyzed as well to find the set point for each flexible device with regard to the constraints imposed by each flexible appliance and devices.

In a decentralized approach, the DSO may shift the responsibility of the voltage control to local controllers. However, the controllers should be actively in touch with each other and act coordinately. For example, the management system of ABs who act as local controllers should communicate with each other in order to recognize the states of the network. In this way, they exchange information regarding their individual states and the control actions and try to reach a global solution to regulate the voltage of their local network. Multi-agent systems (MAS) are considered a potent technology that can implement the decentralized voltage regulation in distribution networks [28]. There also might be a central controller for each region with the responsibility of coordinating controllers and assisting the DSO with operating the network. In this way, ABs can exchange information with the central controller. Hence, the central controller aims to find the best operating point for each flexible device of the ABs. It is noticeable that the ABs should be located in the central controller's territory.

## 4 The Role of Energy Management System in Active Building

As previously stated, ABs are potent flexible resources that can provide system operators (both DSOs and TSOs) with flexibility services. Not only ABs can assist network operators, but also the smart technologies used in ABs can enhance the comfort level of the occupants by the automatic control of appliances and devices. Moreover, the ABs can bring considerable financial profits obtained from saving electricity costs as well as selling their flexible capacities. In addition to monetary benefits, ABs can pave the way for the transition of the power system to a sustainable, smart, and environmentally friendly electrical system.

The recently advanced ICT technologies enable ABs to follow a certain target and help the system operators to obtain their required flexibility from the ABs. Generally, the main target of the ABs is to minimize their electricity costs or maximize their profits by selling their productions. These productions can be in terms of energy or flexibility. If the ABs are integrated with production resources such as PV panels and small-scale storage-based resources, they are able to sell energy as well as flexibility. Otherwise, the ABs can schedule their flexible energy, aiming to sell flexibility. In this regard, the energy management system of the AB is in charge of scheduling its production and flexible devices. The owner of the AB may impose some constraints regarding their medium- and low- flexible energy resources. In this situation, the energy management system should consider these constraints as well as the operational limits related to each device. In other words, the energy management system of the AB should control and manage the appliances and flexible energy resources of the AB according to the types of appliances, the operating constraints of devices, the user's need and preferences, the objective function defined for the system, and the external signals associated with the particular service.

In general, the energy management system of ABs comprises several tasks including monitoring, scheduling, and controlling the flexible devices. Fig. 6 introduces some of these tasks. The energy management system may also be responsible for making bidding strategies for the AB or finding the most profitable and suitable services that the AB can provide for the system operators. This system may also able to change the consumption pattern of the occupant while considering his/her comfort and preference [29]. Each AB may have its own energy management system working autonomously. In another case, neighboring ABs can form a local energy community whose energy management systems are working cooperatively. In addition to the mentioned architecture, the flexible resources of ABs may be controlled centrally by the manager of the community [30]. In this case, there exists one energy management system for the whole community's members (ABs).

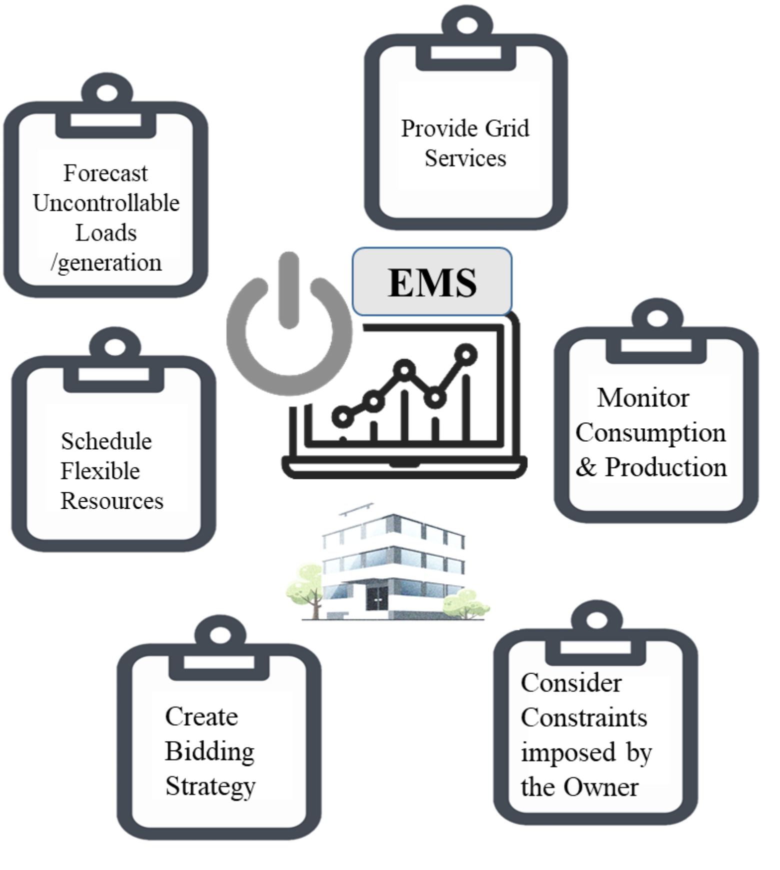


Fig. 6. Some tasks related to energy management system of an AB

Generally, the energy management system of the AB should consider several factors when scheduling the flexible resources of the building. In the following, we list these factors:

1- **The objective of the scheduling**: the energy management system requires to take into account the main objective of the household predefined by the occupant. The objective could be minimizing the total cost or maximizing the monetary profits of the building from providing flexibility services.
2- **The types of appliances and the related constraints**: the energy management system should consider the type of appliances in every process of management. The degree of flexibility (low, medium, high) is of importance. In addition, the preference of the occupant in utilizing the appliance, the working time, and the operational constraints are some factors that can vary based on the type of the devices. Moreover, constraints associated with the comfort level of occupants need to be regarded as well. It is worth mentioning that non-flexible appliances and devices of the AB should not be controlled by the energy management system. However, the consumption power of these devices should be forecasted, measured and monitored by the system in order to schedule flexible appliances and make bidding strategy in a more effective way.
3- **The type of flexibility service(s)**: The management system needs to select the services that are suitable for the AB. This decision should be made based on the available flexibility and the type of flexible resources of the building. Furthermore, the selected services should bring profits for the building. Thus, the energy management system may choose the most profitable services. It may select one or several services. However, regarding TSO-level services, there should be an aggregator so as to aggregate several small-scale flexible resources. Thus, the AB can submit its available flexible capacity to the aggregator. On the other hand, in terms of DSO-level flexibility, the AB can be directly in touch with the DSO or through a DSO-level aggregator, depending on the structure defined in the network.
4- **The promised services**: the scheduling process performed by the energy management system should be in line with the service that the AB had promised to provide. For instance, if the AB promised to reduce its consumption at peak hours, the working time of flexible appliances need to be shifted to other time slots. However, the occupant may apply some constraints related to the working hours of the appliances that are not in line with the promised services. In this situation, the system should warn the occupant against the huge penalty costs that he/she will be incurred if it does not adhere to the schedule.

5- **Bidding strategy:** there may exist a local market for energy and/or flexibility in which ABs participate and offer their availability [31]. In this way, the energy management system of the AB creates bidding strategies based on the objective of the building. The process of making a bidding strategy can be simultaneously done with the scheduling process. However, it is worth mentioning that the process of making an optimized bidding strategy can be extremely complicated since it requires analyzing information on the behaviors of the competitors and the need of buyers as well as predicting prices of the local market.

# 5 Summary and Conclusions

An active building (AB) as an end-user located in the distribution network, has several flexible resources such as storage-based resources (e.g. EVs and batteries), and controllable appliances, enabling it to actively participate in the provision of flexibility. These flexible resources enable the AB to respond to the grid flexibility requirements and provide the system operators with their required flexibility.

The flexible resources of ABs can be categorized based on their degree of flexibility. This categorization can help the energy management system of the AB to better manage and operate these devices. In addition, it can select potent grid services according to the category of the available appliances and devices. In this regard, the devices can be divided into high-flexible, medium-flexible, and low-flexible ones. The high-flexible devices are controllable in terms of their working power and operating time. The only constraints restricting their operation are those related to the technical characteristics of the device. However, the working power and operating time of medium-flexible devices can be limited by the constraints imposed by the customers of the building, as well. On the other hand, not only the working power of low-flexible appliances is not flexible, they are also highly restricted by their owners and the inherent operational limits.

Grid services that can be provided by the ABs can also be categorized according to their buyers. DSOs and TSOs are the main buyers of these services. Thus, TSO-level services that aim to help TSOs, can be deployed for both normal operation, disturbances, and low-inertia situations. In comparison, DSO-level services are procured by DSOs to control voltage and manage congestion in the distribution networks. ABs can provide both TSO-level and DSO-level services based on their available resources and devices.

To provide grid services, first, ABs need to be equipped with advanced ICT technology in order to react to the external signals sent by the operators. Moreover, the energy management system of the AB requires taking into account the main objective of the household predefined by the customer. Besides, the scheduling process performed by the energy management system should be in line with the service that the AB had promised to provide. Otherwise, if the AB fails to adhere to the schedule, it incurs huge penalty costs. In some situations, the DSO may form local markets in order to procure flexibility from customers. In this way, the energy management systems of ABs are also responsible for creating bidding strategies based on the status of the local market.

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