A REVIEW ON AGGREGATION APPROACHES OF DISTRIBUTED ENERGY RESOURCES

Edição n.º 26, 2.º Semestre de 2020

Abstract— *With the increasing penetration of distributed energy resources (DER) into the grid, the power system has suffered some changes to become more sustainable, flexible, and cost-effective. For this reason, a need for new ways of operating the power system is emerging. The control of DER such as PV power, controllable load, demand response (DR) programs, energy storage units, and electric vehicles will facilitate their integration by balancing operations in the electricity grid. The increase of DER is stressing the distributed nature of power systems, in terms of equipment and in terms of management and control. So, new entities such as aggregators are acting as mediators between end-users and grid operators to facilitate the management and control of the power system. This paper makes a review of different aggregation approaches that can be applied for the integration of the DER in the electric power system, based on recent literature. It focuses on the role of DR aggregators, load aggregators, and energy storage aggregators, and the concepts related to each of these topics are covered.*

Keywords—*Aggregator, Demand Response, Distributed Energy Resources, Energy storage, Load Aggregator*

I. INTRODUCTION

Reliability, sustainability, and cost-effectiveness energy service is a critical problem that is confronting the power grid nowadays. Also, the efforts to reduce greenhouse gas emissions (GHG) related to electricity production, oil crisis, and economic and environmental concerns have been leading to a fast increase in the deployment of generation based on renewable energy sources (RES), such as solar and wind power. To address these issues, distributed energy resources (DER), as sustainable and cost-effective resources, are urgently required in the power grid system [1] [2]. The massive deployment of DER, especially RES, has enhanced the value of operational flexibility and is transforming the power grid structure [3].

RES are a solution to reduce GHG emissions while meeting the needs due to the growth in electricity demand. However, the intermittent nature of RES creates multiple challenges, such as electric grid flexibility. The increase in electricity production from fluctuating renewable sources is creating a need for new ways of operating the power system. To overcome these issues, DER are combined with energy storage systems (ESS) and demand response (DR) programs to facilitate their integration by balancing operations in the electricity grid. This combination creates benefits for both sides of the grid, where end-users achieve economic benefits, and grid operators gain additional flexibility by allocating energy resources [4] [5].

The increase of DER (mainly generation resources but also energy storage and others) is stressing the distributed nature of power systems, in terms of equipment and also in terms of decision-making, management, and control. A large set of relatively new entities are acting in this new environment, such as generator aggregators, load aggregators, load service entities [6]. Aggregators are new entities in the electricity market that act as mediators/brokers between users and the utility operator and facilitate their interaction [7].

This paper aims to offer an overview of the role of aggregators, more specifically in the DER/RES context, such as demand response aggregators, load aggregators, energy storage aggregators, and electric vehicle aggregators.

This paper is structured as follows. After this introductory section, Section II presents the concept of an aggregator.

Section III, IV, V, and VI offers a comprehensive literature review of research and examples about demand response aggregators, load aggregators, energy storage aggregators, and electric vehicles aggregator, respectively. In section VII the main conclusions are presented.

II. AGGREGATOR CONCEPT

An energy aggregator agent can help to effectively manage the multiple resources from the demand side in the most efficient way. This new agent would be included between the demand side and the power system operator, such as Transmission System Operator (TSO) and Distribution System Operator (DSO) [8]. The objective of the aggregator is to increase its revenue while obtaining economic benefits for the end-users (by controlling their resources) and providing ancillary services to the grid operator [4].

The concept of aggregation emerges from the creation and commercial and technical management of a portfolio of flexibility assets intending to offer the combined flexibility as a commercial service. In a literature and business context, the use of these terms is not yet coherent. The business role and technical function of performing aggregation is referred to as the Aggregator. The concept of aggregators defined in [5] is illustrated in Fig.1, identifying aggregators as a business role, an entity as well as a technical aggregator infrastructure.

The physical domain addresses the electric interactions between DER and the power system. According to the legal and business domain, an aggregator entity is an intermediary, providing contractual relations with DER owners and system operators (as receivers of flexibility services). The aggregator entity assumes legal responsibility for the delivery of a contracted service. Concerning the control domain, the aggregator infrastructure coordinates the behavior of DER. Its requirements are formulated as flexibility services to system operators and asset management services towards asset owners [5].

In [2] another definition of aggregator appeared. The concept of aggregator has received special attention from the European Commission that identifies the aggregator as providing different power entities (i.e., utilities, DSO, TSO, Capacity Market) and also able to manage demand flexibility, such as load shedding and better load profiling.

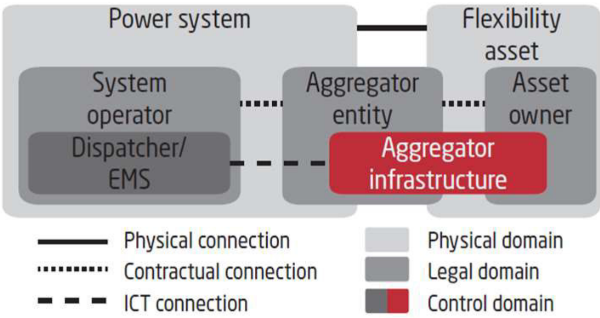

Fig. 1. Different domains of aggregator concept

III. DEMAND RESPONSE AGGREGATOR

Demand Response (DR) is a relevant strategy that contributes to enhance the energy efficiency of the electric grid and also enabling it to cope with the intermittency of the RES [2]. Thus, in this section, an introduction to the concept of Demand Response is first made. Next, the role of the Demand Response aggregator is presented.

A. Demand Response Programs

Demand Response consists of the technique of micromanaging the load curve by manipulating the demand side resources with active participation from consumers. It is a series of activities that react to the peak demand or electricity price by regulating or restricting the operation of consumer equipment resulting in benefits for all parties involved [9].

DR can be classified into two types:

- Peak clipping: when the total electricity demand remains inconstant and a financial incentive reduces peak load;
- Load shifting: features a fixed total demand, but where demand can be shifted forward or backward in time to off-peak hours.

In Fig. 2 the graphs show the differences between these two types of DR.

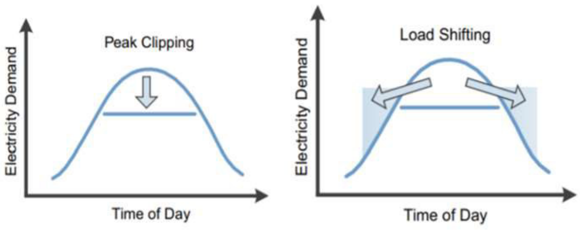

Fig. 2. Comparison between peak clipping and load shifting [10]

DR is seen as an effective and reliable strategy for the successful integration of RES, handling the demand curve using load flexibility whenever the system requires it [2].
A significant part of the DR potential exists in distributed, small, and medium-sized loads. It is not practical for a power system operator to interact directly with all these flexibility assets [11].

Current DR programs are roughly categorized into two types: price-based and incentive-based programs. The first type provides time-varying price signals to induce households to self-adjust their energy usage behaviors. Prices usually have a limited impact on electricity usage patterns of residential consumers and one possible reason is that households' monthly bill savings resulting from electricity usage behavior changes are trivial compared with the effort to make such changes. Further, households' price-elasticities of demand may be uncertain, unavailable, or hard to estimate. An alternative to price signals is an incentive-based program, such as direct load control. By offering consumers monetary incentives, direct load control programs enable the aggregator to control some of the flexible load in client's houses without significantly compromising their comfort. These flexible loads are scheduled and controlled by the aggregator instead of by individual consumers. The consumers can receive incentive payments without additional efforts besides enrolling in the program. As a result, peak load reduction would be more significant and controllable compared with price-based DR programs [11].

DR programs provide incentives to major consumers of electricity, usually in the form of monetary rewards, to reduce their electricity consumption in peak-demand periods. DR can take place at a very fast timescale, almost real-time. It also increases the stability of the power grid system and significantly reduces electricity generation cost and also CO_2 emissions. In general, these programs are designed to induce lower electricity consumption at times of high market prices or when grid reliability is endangered, as a way to manage power usage preferences to benefit not only end-users but also the whole system [2] [7]. The main objectives of a DR program are as follows [2]:

- Reduction of the total power consumption, so that mutual profit for the power utility and the end-users is achieved;

- Reduction of the total power generation (the need of activating more expensive power plants and building new ones to meet peak demand is mitigated);

- Change of the demand pattern, optimizing the end-user consumption;

- Reduction or even elimination of overloads in the distribution system.

To make DR programs operational, households need to have energy management systems (EMS) based on fully interactive Information and Communication Technologies (ICT), also making the most of the evolution of the Internet of Things (IoT). EMS are aimed at helping end-users optimizing energy usage, i.e., achieving energy savings and satisfying constraints on the quality of the energy services provided [2].

The process of a DR scheme begins at the System Operator (SO), which determines the demand volume that should be reduced or increased in a certain period. This information is reported to the DR Aggregator, which then selects the participating end-users based on their availability.

Considering the number of end-users that agree with the proposed DR scheme, the EMS calculates the total load flexibility that can be offered in reply to the SO request, the amount of flexibility to be used from each end-user, and reports it back to the SO. This process is illustrated in Fig. 3, indicating the main participants in the DR scheme [2]

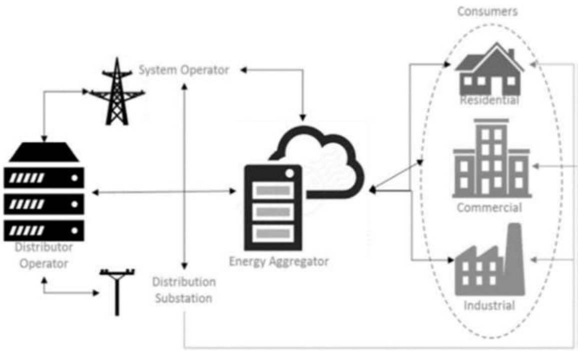

Fig. 3. Main participants in DR. [2]

B. The role of Demand Response Aggregators

Aggregators possess the technology to perform DR and they are also responsible for the installation of the communication and control devices (i.e., smart meters) at end-users' installations. The current role of aggregators amounts to paying a monthly fee to the contracted end-users (especially industrial ones) to gain direct control of their appliances. This way, in case of a peak-demand emergency they can turn off the energy-intensive appliances of the users (such as air-conditioning system) for a short period [7].

Since home users cannot negotiate directly with the operator, they enroll in a DR program provided by an aggregator. Since each aggregator represents a significant amount of total demand in the DR market, it can negotiate on behalf of the home users with the operator more efficiently. The aggregator aggregates several small residential DR assets into a larger unit, in order to increase their negotiation power. In this case, the aggregator has two roles. First, to provide DR services to the operator and secondly, to guarantee a reduced electricity bill to the end-users. Each aggregator tries to shape the load pattern of its users and receives compensation for the cost savings incurred to the operator due to this shaping [7].

In addition to the diversification of DR resources, various agencies engaged in DR services have also emerged. Among them, Load Aggregators (LA) are the most typical. The emergence of LA provides opportunities for smaller demand-side users to participate in DR and increase its effectiveness [12].

IV. LOAD AGGREGATOR

The increase of DER brought challenges to the control and stability of the power grid and the existence of Load Aggregator (LA) has become one of the solutions to this problem and has received a lot of attention and research [13]. In this section, the concept of LA is approached and some examples of applications of LA in power systems are given.

A. Concept

LA is a power load intermediary defined as an entity that acts as an intermediary between end-users that provide demand response resources and power systems participants who want to buy these resources, enabling users to access the electricity market efficiently and provide more flexible services and technologies. It not only deals with power grids but also provides its customers with electricity sales services independently. The existence of LA enhances the grid's ability to manage loads and users demand responsiveness and can reduce the operating costs of grid companies and users' electricity costs, while also making profits for themselves [13].

From a system operator's point of view, LA is a large power generator or load resource, which could provide schedulable generation capacity or ancillary services (regulation, spinning reserve, and operating reserve). From the consumers' perspective, LA can provide them with a better demand response environment and reduce their electricity costs [13].

A LA is considered as a load-serving entity that participates in the wholesale electricity market to purchase electric energy to serve their customers in distribution systems. In electricity markets, individual customers located in a distributed system currently do not participate in the electricity wholesale market to buy electric energy. The load aggregators' objective is managing energy transactions and delivering sufficient power to its customers. However, electricity prices in the wholesale electricity market and load in distribution systems are changing all the time.

In a competitive market, the load aggregator is a price taker, i.e., it cannot influence the electricity price. Meanwhile, the load is normally priced inflexible. Thus, the operation strategy for the load aggregator to manage energy costs is very limited [14].

With the increasing penetration of RES (such as wind power and solar PV power), the electricity price becomes more unpredictable. So, accurate forecasts of load and electricity prices are essential for managing energy purchasing costs while meeting load demand. Renewable DG technologies suitable for residential use, such as solar panel roof, are being gradually implemented by residential customers because the load is partially offset. Although the penetration of such DG is relatively small, load forecast accuracy could be affected by the unpredictable generation from renewable DG. As a result, the load aggregator is facing a higher level of price and load uncertainties [15].

Load aggregator manages many power users with characteristics of geographically dispersed, different load types, and different using manners, such as air-conditioning, electric cars, commercial buildings, and so on. These different load types are illustrated in Fig. 4. The users provide loadable resource capacity, start time, duration, and other information to the load aggregator. The LA, through a contract with the user, obtains part of the electricity terminal equipment decision-making power [16].

The user and the LA sign contract on the DR trigger

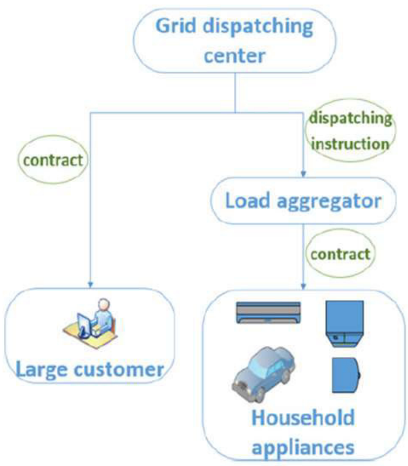

Fig. 4. Relation between the user, load aggregator, and the grid dispatching center [16]

condition, load interruption amount and time, the compensation amount, and other details. The triggering conditions are grid reserve capacity is insufficient or partial overloading; power supply gap caused by other uncertainties; the grid load reached more than 95% of the maximum load in the previous year; system peak-valley rate reaches 20% and above [16].

B. Examples of applications of Load Aggregator

As is well known, DR is related to peak hour load management. Therefore, load aggregators are contracted to manage these loads. The following are some examples of how LA implement DR mechanisms.

[11] proposes bidding strategies and compensation mechanisms for a LA that implements the direct thermostat control program in their household. Residential consumers are aggregated and represented by some LA. Individual households buy electricity from the LA and the LA buys electricity from the wholesale market. An LA's work was relatively simple in the past: it bids and purchases the amount of electricity equal to its forecast of the aggregate load. Recently, emerging technologies such as smart meters and smart home appliances, have enabled the LA to induce

its clients to reduce load during peak hours or to shift loads from peak hours to off-peak hours. By implementing these DR programs, an LA can redesign its bidding strategy and purchase less electricity when wholesale market prices are high, thus reducing its energy procurement cost. Meanwhile, the entire power system benefits because the peak load of the system is reduced, considering that the residential load accounts for a sizable portion of the total peak load. This paper studies a particular type of load control program that targets residential Heating/Cooling (H/C) loads. The LA strategically schedules the H/C load for each house and forms bidding curves and will also distribute part of the energy procurement cost savings to its clients.

The study in [13] presents an optimal control strategy for a LA with DR. The LA mainly serves for a regional load of residential areas and has a certain capacity of energy storage devices, distributed PV power generation, and diesel generators to ensure user reliability and improve benefits. LA participating in the power system operation can provide market regulator opportunities for DR resources such as simply adjustable loads and distributed power supplies. Although DR has a wide potential, the response strategy involves decision-making control and decision models which are constructed in this paper. As the results show, when the LA is equipped with PV and energy storage equipment, the benefit of DR is improved.

V. ENERGY STORAGE AGGREGATOR

Electric power systems are operated based on a real-time balancing of supply and demand without large-scale Electric energy storage (EES) resources. Intending to transform the actual grid into a more reliable, secure, and efficient smart grid, feasible applications of EES in power systems have started to be explored [17].

To overcome flexibility issues, RES are combined with energy storage systems (ESS) and DR programs to facilitate their integration by balancing operations in the electricity grid. [4]

Due to an increase in the use of renewable energy, the ESS becomes an essential part of the power grid market [18]. The integration of storage technologies has emerged as an option to expedite energy consumption from renewable sources by increasing the flexibility of the power system [19].

Energy storage units can provide flexible and continuous power in case of interruption or congestion during extreme demand. Also, ESS can store energy during off-peak hours to support the peak demand of the users thus can reduce the electricity prices [18]. This means that energy storage can store energy when there is less demand and release the stored energy back to the system during peak periods [19].

Electrical storage has many important characteristics and exceptional features that make it a vital element for the electricity grid. It can bring huge opportunities and challenges to the grid. Some of the useful services provided by ESS which make it an important element of the grid are electric supply reserve capacity and load following [18]. The major benefits of EES include electric energy time-shift, power supply capacity, and transmission congestion relief, etc. [17].

It is assumed that the energy storage units do not participate directly in the energy market and, instead, they interact with an aggregator that has access to the wholesale market [20]. These interactions are illustrated in Fig. 5.

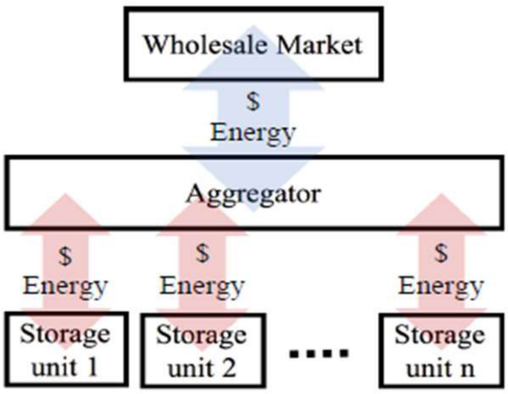

Fig. 5. Interactions between the wholesale market, the aggregator, and storage units [20]

These energy storage units have the potential of selling services to the power grid but may not be able to directly do so for two main reasons. First, their capacities are smaller than the required minimum. Secondly, the large number of these energy storage would make their management difficult even if they were allowed to participate. Therefore, aggregators act as mediators between the energy storage and the power system [20]. The options for the load aggregator to manage energy costs are very limited when there is no energy storage. With EES, operations are flexible for load aggregators to reduce energy costs while meeting the demand. This happens because the charging and discharging operations of EES are controllable and flexible and these operations are determined by the load aggregator [14].

Energy storage systems are especially desirable at the residential level and the adoption of household EES is expected to increase rapidly in the coming years.

In [19] the authors investigate a problem of optimal capacities of ESS and its optimal price for residential users who have their PV generation and a smart meter that can schedule activation of home appliances. The aggregator owns and operates an ESS and decides a unit price of storage to maximize her profit. Depending on the unit price of energy storage, price profile of electricity from the main grid, and consumers' renewable power generation capacity, each user determines his energy consumption schedule and a required amount of storage capacity to minimize the energy cost and purchase the amount of storage capacity from the aggregator. A user charges the remaining energy of the electric energy generated in its PV system and discharges its storage to satisfy demand.

[21] proposes an aggregator service for a residential apartment building with PV and Battery Energy Storage System (BESS). In recent years, these DER have been installed in residential units. The aggregator service for residential apartment buildings considers not only the benefits of the DER owners but also the residents in the building. In general, the aggregator service has two main features: managing PV and BESS and also selling electricity to the connected residents. Also, smart control devices are installed for the BESS and Electric Vehicle (EV) chargers to manage the charging and discharging functions and also, control devices are fitted into each apartment for the home appliances. With these smart devices, the aggregator service can monitor power flows, including any import or export of electricity from or to the grid, the consumption of each apartment, generation of the PV system, and operation of the BESS and EV.

VI. ELECTRIC VEHICLES AGGREGATOR

The demand-side resources represented by Electric Vehicle (EV) can be used as an energy storage unit after plugging in the power grid. By changing the watt level of power (charge or discharge), the EVs can provide multiple types of DR services. The large-scale EVs' access to the power grid brings new challenges to its security and stability. On the other hand, with the vehicle-to-grid (V2G) technology, the EVs can realize a bi-directional power flow with the power system and act as a BESS for the ancillary service to the power grid. When providing the V2G service to the power grid using the EV battery capacity, the EV user’s traveling demand should be considered and guaranteed. The EV aggregator (EVA) has been proved to be an effective resource for DR. The energy storage capacity for a single EV is limited. However, the energy storage capacity from a large scale EVs in an aggregator is considerable [22].

In the power system’s flexibility terms, EVs can be seen somewhat in between DR and energy storage as they can change their consumption profile but also provide energy arbitrage with their batteries. EV’s batteries are small in capacity and they can participate in wholesale markets jointly through EVA. EVA has generally been defined as an intermediary between EVs and market/SO where EVA buys/sells energy/ancillary services (AS) on behalf of EVs.

However, in reality, it aggregates EV chargers with connected EVs. EV can use/provide energy/AS to the grid only when it is connected to a charger operated by its aggregator [23].

The following are two examples related to different approaches of an EVA in power systems.

[23] observes EV as a mobile battery, not chargers. EVA should not aggregate specific EV chargers physically located at households, parking lots, or charging stations but the EVs with their batteries by themselves. The new concept of EVA is therefore named as electric vehicle battery aggregator (EVBA). EVBA could continue throughout the day to track the EV information (SOC, planned trips) as part of future IoT concepts and charge/discharge EVs on whatever charger they connect to.

A novel methodology of smart charging for EVA is presented on [24]. It allows EV charging at the lowest cost while complying with technical constraints required by the system operators. Moreover, EV users can choose among different customer choice products that meet their needs in terms of charging time. The EVA will have to optimize power delivered to the EV battery through the charging power rate. The results show that with the smart charging, the EVA can have benefits comparing to two cases of uncoordinated charging (constant charging power rate) while respecting the technical conditions required. The smart charging achieved significant savings that tends to be even more significant when EV penetration levels increase.

VII. CONCLUSION

The current power system has an increasing quantity of distributed energy resources and fluctuating power generation from renewable energy sources. To overcome the problems related to this integration in the power system, these resources are combined with demand response, energy storage systems, and electric vehicles.

All these strategies are used to improve the efficiency, security, and flexibility of the electrical system. This paper analyses some aggregation approaches and definitions based on various literature reviews.

It is proposed a review of the combination of distributed energy resources with demand response, as well as the concept of demand response. Also, it was presented the combination of distributed energy resources with energy storage units, such as electric vehicles. For these two combinations, it is intended various aggregation approaches. Another aggregation approach presented is the integration of distributed energy resources and loads in the power system, such as load aggregators. In all of these approaches, the aggregator is seen as an entity that facilitates the interaction between end-users and the grid operator.

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