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Intelligent load management in local and wholesale demand response markets

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Definition of Remuneration in an Aggregator Using Clustering Algorithms

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Abstract

Currently, the use of demand response programs and renewable energy resource are a reality in the power distribution network. Therefore, an efficient and optimal energy resource management is required for fully benefit from these new concepts of power system as well as avoiding energy wasting. In this paper, a methodology is represented in order to support the aggregator activities, with the aim of participation in the electricity market negotiations using aggregated distributed energy resources and demand response programs. Moreover, the presented model demonstrates the benefits of aggregator participation while promoting their inclusion. Additionally, a case study will test and validate the proposed methodology, which considers a university campus distribution network as aggregator network including 20 consumers and 26 renewable producers.

Keywords: aggregator, demand response, energy managemet system, clustering, optimization, smart grid

1. Introduction

The Distributed Renewable Energy Resources (DRERs), when managed by an aggregator, are represented as a unique resource with characteristics that reflect the aggregated resources [1], [2]. An aggregator managing a given number of resources or region, implies a simplification of processes to the operators, since the number of resources to be considered is reduced and energy negotiation and trade can be made [3]. Also, if Balance Responsible Parties (BRPs) exist, the activities developed by the aggregator can also provide useful services to the BRPs [4]. In fact, several countries of the European Union (EU) have introduced and accepted the concept of aggregators operating in their energy systems providing service mainly to consumers, and the usefulness of an aggregator is specially seen as a flexibility provider, through the gathering of active consumers that can participate in the aggregator's demand response programs [5].

Regarding production-side resources, the aggregator assumes the role of a virtual power plant, as referred before [6], [7]. These resources often belong to the consumers who can also produce (called Prosumers) and have small capacity of generation. This means a third party entity, namely aggregator, is required in order to aggregate these kinds of small and medium scale resources and participate them in the electricity market negotiation as a unique resource [8].

An aggregator model is also responsible for Demand Response (DR) programs [9]. DR program is defined as the modification of electricity consumption patterns in the demand side in order to response to the price changes or incentive payments, which can be due to any economic or technical reasons [10]. In this context, aggregator should gather all small and medium scale consumers who intend to participate in DR programs, and represent them as one DR resource. This means the aggregator can be considered as a flexible network player, which brings flexibility to the network by establish bidirectional contracts with end-users for DR programs to manage consumption resources [11].

This paper presents an optimization based aggregator model for small and medium scale DRER and DR management. Moreover, a methodology is provided to support the aggregator in its activities, with focus on the participation of aggregated DRERs and DR in energy markets, and on how the aggregator can benefit from this participation while promoting their inclusion. The presented methodology utilizes clustering algorithm in order to define remunerations.

After this introductory section, section 2 represents the model for aggregator and remunerations by focusing on the mathematical formulation of scheduling optimization problem. Section 3 provides the details regarding the case study, which contribute the developed model in a realistic distribution network of a university campus, and its results are illustrated in the same section. Finally, the main conclusions of the work are presented in Section 4.

2. Presented Model

In this section, the proposed methodology is explained and all its components, regarding the scheduling, aggregation, and remuneration activities performed by the aggregator will be demonstrated. The proposed methodology is shown in Fig. 1. At the end of the methodology, the output results are the energy and cost of each group of resources made, according to the specifications of the aggregator. With this information, the aggregator can negotiate in the market by bidding the available energy amount at a given price. However, the selling price must be equal or higher than the cost of each group to obtain profits or at least recover what was spent on distributed resources. The activities of the aggregator are divided in two types: upper-level and bottom-level activities.

The scheduling of resources considers external suppliers and two types of DRERs, namely, renewable resources and active consumers. For the production-side resources, the methodology considers a linear cost function for both distributed generators and external suppliers. Regarding active consumers, it is considered that these can be enrolled in three different types of DR, namely, load reduction, curtailment, and load shifting. In this way, only the reduction and curtailment energy amounts obtained are considered by the aggregator to be scheduled and therefore negotiated in the energy market. The load shifting model is based on [12]. In the case of the demand-side resources, the cost considered is also linear for reduction and curtailment, while load shifting is free.

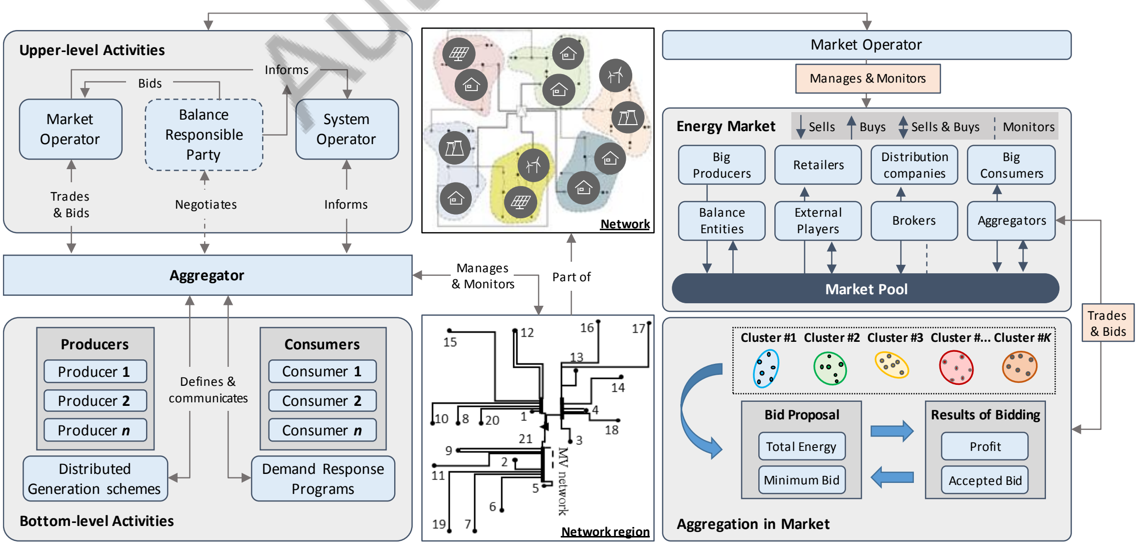

Fig. 1: Overall architecture of the proposed methodology [13].

Aggregation of resources is made using K-Means clustering algorithm, considering the observations of the energy scheduled and the discriminated cost of that scheduling. It is important to notice that the aggregation is only made considering the resources with participation in the scheduling, i.e., if the resource is not affected by the scheduling of the aggregator, then it is not considered in the aggregation process. The remuneration of resources is computed after the aggregation, since the groups need to be made to define a group tariff, i.e. the resources belonging to a given group are remunerated at the same price. In this case, it is considered that the maximum price in the group, which corresponds to the group tariff, will result in paying the most expensive consumers a fair amount, and the least expensive an incentive to participation since the payment is superior to their initial expected price. This ensures that most of the consumers are encouraged to participate in the aggregator's schedule.

In sum, each of the formed groups will represent a bid made by the aggregator in the energy market (seen as a bid group), considering the energy obtained from the resources within that group, and the respective group tariff as the minimal acceptance rate for the aggregator. The energy in each group corresponds to the sum of the scheduling obtained for the distributed resources in that same group. This type of analysis facilitates the activities developed by the aggregator, namely, by providing a simple decision strategy based on the financial balance computation of its participation in market.

The scheduling optimization reflects a Mixed-Integer Linear Problem (MILP), since it involves continuous and discrete variables. In this methodology, it is not considered that the aggregator is responsible for the technical verification of the network, i.e. this is assumed to be the operator's role. Equation (1) presents the objective function implemented for the aggregator's cost minimization. The resources considered for the objective function are: the energy bought from the external suppliers ($P_{(s,t)}^{Sup}$), the energy obtained from distributed generators ($P_{(p,t)}^{DG}$), and the demand flexibility (reduction - $P_{(c,t)}^{Red}$, curtailment - $P_{(c,t)}^{Cut}$, shifting -$P_{(c,t,d)}^{Shift}$.

$$
\begin{aligned}
& MinOC = \sum_{s=1}^{S} P_{(s,t)}^{Sup} \cdot C_{(s,t)}^{Sup} + \sum_{p=1}^{P} P_{(p,t)}^{DG} \cdot C_{(p,t)}^{DG} \\
& + \sum_{c=1}^{Cs} \left[\begin{array}{l} P_{(c,t)}^{Red} \cdot C_{(c,t)}^{Red} + P_{(c,t)}^{Cut} \cdot C_{(c,t)}^{Cut} \\ + \sum_{d=1}^{T} P_{(c,t,d)}^{Shift} \cdot C_{(c,t,d)}^{Shift} \end{array} \right] \\
& \forall t \in \{1, \ldots, T\}
\end{aligned}
\tag{1}
$$

The constraints of the proposed optimization problem consist of:

• The energy balance to assure the consumers are supplied according to their consumption needs;

• Technical generation limits of the external suppliers and distributed generators;

• Technical limitations of demand response programs;

• Limitations regarding the maximum amount of energy shifted out and into a given period;

• Maximum price of the resources belonging to each group.

Therefore, the key components of the proposed methodology, regarding the scheduling and remuneration of resources managed by the aggregator have been presented. In the next section, it is detailed the case study used to validate the present methodology.

3. Case Study

This section presents the description of the case study used to validate the proposed methodology. The considered network is composed by 21 buses, representing a university campus, as described in [14]. The network has 20 consumers classified by their average consumption, and 26 production generators classified by type of source.

The energy cost of both distributed generation and external suppliers, is considered constant in all periods. All producers, except the external supplier, can participate in aggregation for energy markets. Regarding the consumers, these are divided into five types: Domestic (DM), Small Commerce (SC), Medium Commerce (MC), Large Commerce (LC), Industrial (ID). This type of assignment is performed based on their average daily consumption. Fig. 2 presents the consumer's details considering their linear cost, by type of resource. The maximum reductions are 6% of the initial load for reduction, and 10% for curtailment and shifting.

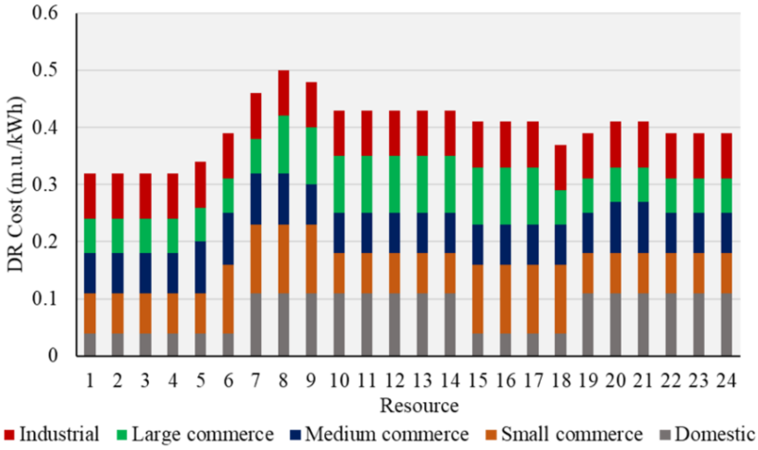

Fig. 2: Linear cost for load reduction and curtailment.

To simulate the participation in the energy market by the aggregator, a market place must be considered. A market pool ensures that several entities can propose energy bids, including aggregators. This kind of market ensures competition between participants, and therefore improves the outcome from the consumer's perspective. Therefore, a summary of the results obtained for the scheduling, aggregation, and remuneration processes is described in below, and more detailed information is available on [13].

The results concerning the market negotiation are focused on describing how the aggregator can use the results obtained to present a bid. First, the scheduling results for generation are presented in Fig. 3. It is considered an energy shortage from the external suppliers in the first 4 periods, being these able to support only 10% of their capacity, around 50 kWh.

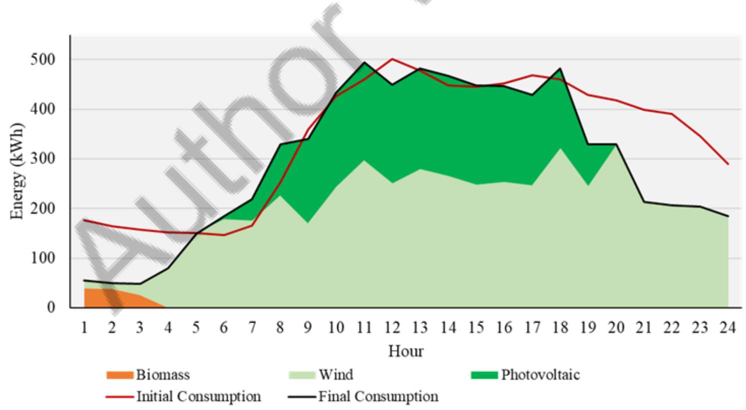

Fig. 3: Generation scheduling with initial and final consumption.

This causes the aggregator to apply DR programs that can balance the difference between production and expected consumption, in the periods where it is needed considering the minimization of costs. The scheduling shows a high penetration of distributed generation, expectable since the cost of it is lower than the cost of the external suppliers. The differences between initial and final consumption are related to DR actuation, namely, load reduction, curtailment and shifting.

The demand side management adjust the remaining energy differences between production and consumption when distributed generation is not sufficient. Moreover, during the periods of energy shortage from the distributed generators, load shifting is used to move consumption from those periods to more favorable ones, thus avoiding the buying of energy from the grid, which is more expensive. Moving on to the energy market's results, in Table 1, the results for the aggregation and remuneration of the resources are shown, regarding period number 12. The total energy and number of resources are outputs of the aggregation process, while the minimum bid tariff is from the remuneration process.

Table 1. Remuneration and aggregation results.

Bid group	1	2	3	4	5
Energy in DR groups (kWh)	6,09	9,49	4,04	17,18	3,55
Number of DR resources	1	1	1	2	1
Group tariff (m.u./kWh)	0,05	0,05	0,05	0,05	0,05
Energy in DG groups (kWh)	30,73	250,58	16,02	37,72	114,21
Number of DG resources	2	3	4	2	7
Group tariff (m.u./kWh)	0,03	0,05	0,06	0,03	0,05
Total Energy	**489,62**				

The results presented in Table 2 show that the aggregator could profit from the distributed resources energy sell in the energy market of around 489,62 kWh, a total of 24,10 monetary units. It is possible to conclude if a higher energy amount were sold, the aggregator would be able to rise considerably its profits from the negotiation. It is also relevant to notice that this evaluation is for a single period, for example, a given hour of the day as the case study presented suggests. Again, the profitability of the aggregator is also dependent of the offers and capability of negotiation in the energy market by the aggregator and existing competition. Using the proposed model, the operation of the aggregator becomes profit, from its market participation, even with a small-size region (20 consumers and 25 distributed generators). By controlling a larger region or number of resources, the aggregator gains more energy capacity for clustering, and as mentioned before, market negotiation.

Table 2. Financial balance for the aggregator.

Parameter	Value
Total costs using distributed resources (m.u.)	24,94
Market clearing price (m.u./kWh)	0,0976
Revenues obtained from market sell (m.u.)	47,78
Profit obtained by the aggregator (m.u.)	22,84

As mentioned before, the aggregation was made considering only the resources that participated in the aggregator's scheduling in each of the periods. Each period's aggregation therefore, considers the characteristics and scheduling of the resources in that time. Further on, a comparison is made regarding the influence of load shifting in the costs. The comparison is made between the total costs of the aggregator in the current scenario (WS), and in one when instead of load shifting availability, there is enough energy available from the external suppliers (WOS). In Table 3, the results of the scenarios comparison show that the influence of load shifting availability affects considerably the total costs of the aggregator, since these are mostly balanced by the contributions that distributed generators and external suppliers provide for the scheduling. In the scenario without load shifting the generation from external suppliers is raised in 50 kWh in the first four periods, obtaining a total of 100 kWh. This is performed so that energy balance can be obtained without load shifting.

Table 3. WS and WOS comparison.

Scenario		Value	Total
WS	Total costs using distributed resources (m.u.)	286,41	286,41
	Total costs using external suppliers (m.u.)	0	
WOS	Total costs using distributed resources (m.u.)	279,87	300,27
	Total costs using external suppliers (m.u.)	20,40	

4. Conclusions

This paper provided an optimal model for an aggregator who is responsible for managing small and medium scale distributed energy resources and demand response programs. A methodology was represented to support the aggregator activities that aims on the participation of its aggregated resources in the electricity market negotiations. Moreover, the developed methodology applied a clustering algorithm for remunerations of resources that participated in demand response programs.

The results obtained from case study showed that the aggregator can perform the scheduling according to the resources contribution, that has been applied through different programs such as demand-side resources. Therefore, the aggregator would be able to perform network balance and the participation of each resource. Moreover, the aggregation and remuneration results proved that the developed methodology affect the outcome of benefit for the aggregato. However, the aggregator can obtain the operation balance and a fair usage of distributed energy resources for its activities by using this methodology.

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