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Optimal Rescheduling of Distributed Energy Resources Managed by an Aggregator

João Spínola, Pedro Faria, Zita Vale

GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering - Polytechnic of Porto, Porto, Portugal

Abstract

Distributed energy resources integration into energy markets and power systems operation has been one of the main concerns of operators and other entities, mainly because of the recent growth and the features that these resources can provide. The need for managing tools that provide solutions to these concerns is evident, and can be addressed through several ways. The present paper proposes a model for the integration of distributed energy resources into power systems operation using an aggregator. The management considers the aggregator's perspective, and therefore, the objective is to minimize the costs of system balance. For this, it is proposed a re-scheduling of resources, i.e. after a first scheduling with individual prices the resources are clustered, and for each group, a tariff is defined and applied to each of the resources that belong to it, being then scheduled again considering the new group tariffs.

Keywords: aggregator, demand response, energy markets, smart grid

1. Introduction

Distributed energy resources have been on the raise since the energy market liberalizations, since new and more sustainable technologies gain more relevance, both for the operators of power systems and consumers [1]–[4]. Several countries provide incentives to the consumers to adopt these kind of technologies through promoting schemes and monetary incentives [5]–[7]. In this context, two major concepts arise as the most preferable and easily implemented, distributed generation and demand response [8]–[10]. For the first, it defines that generation is scattered along distribution networks and located more near consumption centers [11], [12], while the latter, defines that consumers can provide flexibility to the power system by adjusting their consumption in certain periods, being given price or monetary incentives/signals in return [13], [14]. Moreover, aggregators gain a significant importance in the latter concept, since small-size resources (as consumers) that are involved, individually are far beyond the possibility of participating in energy markets due to the requirements that each market imposes [15]. In this way, aggregators facilitate the integration of distributed energy resources by providing a virtual resource built of many small-size resources.

Besides aggregators, virtual power plants and microgrids represent solutions to integrate distributed energy resources, however, the first is only relevant for the participation in energy markets while the latter is only to management of resources and not so focused in the energy markets [16]. In this way, aggregators present a hybrid solution that complement the management of resources with energy markets participation.

Additionally, [17] presents a model for the communication between the consumer's smart meter and the aggregator, providing useful information that the aggregator can use to perform an appropriate scheduling, that considers the consumer's preferences and characteristics. In [18], the authors propose a flexibility provider approach to the aggregator's operation, through the implementation of demand response programs, namely, load shifting, load curtailment, and load recovery. The model proposed also includes the participation of the aggregator in the balancing, day-ahead, and forward contract energy markets.

The current literature often approaches the aggregator's activities through a bottom and upper level models [18], [19], which in the first case consider that the aggregator's activities starts conditioned by the resources availability and characteristics [20], [21], and in the second case, focus is given to the negotiations that the aggregator performs during its participation in the energy markets [22], [23]. These two approaches consider different sides of the aggregator's activities, and that give this entity such a relevant position in the integration of smart grid concepts in current power systems.

The present paper addresses a model for the rescheduling of distributed energy resources, given group tariffs defined by their clustering. The clustering is only applied to the resources that participated in the scheduling, so that the prices from non-participant resources do not affect the group tariff. The group tariff is defined by the average of the resources prices, that belong to a given group. After the clustering is made, a new scheduling is made considering all of the resources as in the first, however, the prices of the resources that were included in the clustering are updated according to the group tariff of which they belong to. Both schedules consider demand response and distributed generators, being these separately clustered into several groups, i.e. there are groups for consumers and other groups for distributed generators. The proposed model intends to provide a management tool for the minimization of the aggregator's operation costs, and simultaneously provide decision support for the participation in the energy market.

2. Rescheduling of Resources

As mentioned before, the rescheduling of resources intends to provide the aggregator with an optimal solution for the minimization of operation costs. The proposed methodology is shown in Fig. 1, which explains the lower and upper level that compose the aggregator's activities. In the management level, the resources communicate to the aggregator their information, which may include capacity, user preferences, tariffs, amongst others, that is later on addressed by the aggregator to perform the scheduling. In the aggregation level, the aggregator uses the energy scheduled and prices of each individual resource as basis to perform the clustering, in order to obtain the resource distribution amongst the groups and the respective tariffs of each.

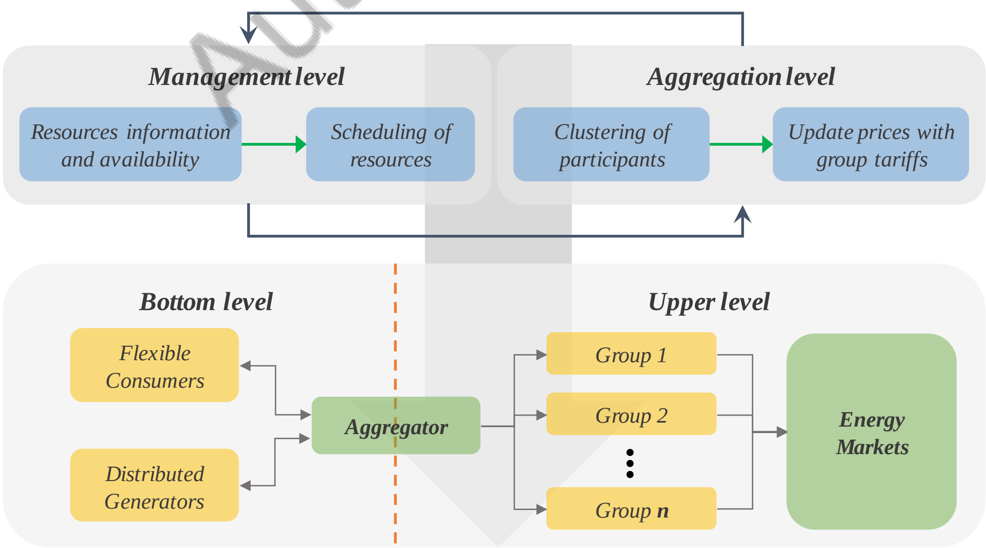

Fig. 1: Scheme of the proposed methodology.

Equation (1) represents the objective function implemented in the proposed methodology, which includes the consideration of external suppliers, distributed generators, and demand response programs (load reduction and curtailment). The aggregator when managing a small region composed of several resources, assumes a role of operator, and therefore must ensure the balance of this small region, i.e. the power system. In this context, equation (2) translated the load and generation balance that guarantees the security and reliability of the network.

$$\min Operation\ Costs$$
$$\sum_{s=1}^{S} P_{(s)}^{Sup} \cdot C_{(s)}^{Sup} + \sum_{p=1}^{P} P_{(p)}^{DG} \cdot C_{(p)}^{DG} + \sum_{c=1}^{C}\left(\left[P_{(c)}^{Red} + P_{(c)}^{Cut}\right] \cdot C_{(c)}^{Red} + P_{(c)}^{ENS} \cdot C_{(c)}^{ENS}\right) \quad (1)$$

$$\sum_{s=1}^{S} P_{(s)}^{Sup} + \sum_{p=1}^{P} P_{(p)}^{DG} = \sum_{c=1}^{C}\left(P_{(c)}^{Load} - P_{(c)}^{Red} + P_{(c)}^{Cut} + P_{(c)}^{ENS}\right) \quad (2)$$

Regarding the generation limits, these are imposed for external suppliers and distributed generators, equation (3) and (4), respectively. In the case of external suppliers, these limits are relatable to the ones applied to a normal consumer, by defining a maximum level of energy that can be supplied giving a certain contract established. For distributed generators, these are limited according to their current or expected production levels, since most of these units do not rely on fossil fuels to operate, but rather on renewable resources.

$$P_{(s)}^{SupMin} \le P_{(s)}^{Sup} \le P_{(s)}^{SupMax}, \forall s \in \{1,...,S\} \quad (3)$$

$$P_{(p)}^{DGMin} \le P_{(p)}^{DG} \le P_{(p)}^{DGMax}, \forall p \in \{1,...,P\} \quad (4)$$

In what concerns consumers, these can provide flexibility through load modification programs, namely, reduction, curtailment, and energy non-supplied (ENS), although the last has a high cost for the aggregator. In the load reduction program and energy non-supplied situation, the aggregator can modify the consumer's load dynamically – equations (5) and (8), while on the curtailment program the load is shed in a given energy step – equations (6) and (7).

$$P_{(c)}^{RedMin} \le P_{(c)}^{Red} \le P_{(c)}^{RedMax}, \forall c \in \{1,...,C\} \quad (5)$$

$$P_{(c)}^{CutMin} \le P_{(c)}^{Cut} \le P_{(c)}^{CutMax}, \forall c \in \{1,...,C\} \quad (6)$$

$$P_{(c)}^{Cut} = P_{(c)}^{CutMax} \cdot \lambda_{(c)}^{Cut}, \forall c \in \{1,...,C\}, \lambda_{(c)}^{Cut} \in \{0,1\} \quad (7)$$

$$P_{(c)}^{ENSMin} \le P_{(c)}^{ENS} \le P_{(c)}^{Load}, \forall c \in \{1,...,C\} \quad (8)$$

Also, so that the demand response programs do not provide flexibility in an uncontrolled form that can affect the consumer's important activities, the proposed methodology includes equation (9), which provides a limitation of demand response amounts in the load reduction and curtailment programs, through a maximum of *a* percent of the original expected load – in this case defined as 0,6 (60%).

$$P_{(c)}^{Red} + P_{(c)}^{Cut} \le a \cdot P_{(c)}^{Load}, \forall c \in \{1,...,C\} \quad (9)$$

After the scheduling of resources, the clustering considers *k*-means algorithm with energy scheduled as base data for its process. The *k*-means clustering algorithm starts with a random assignment of elements to the desired groups, and then iteratively computes the distances between the several elements minimizing the following equation (10). Equation (11) represents the need for a given resource to be assigned to a group, i.e. all resources must be assigned to a group [24].

$$J(T,Q) = \sum_{i=1}^{K}\sum_{j=1}^{N} \gamma_{ij} \cdot \left\| x_j - m_i \right\|^2, \qquad \gamma_{ij} = \begin{cases} 1, if\ x_j \in cluster\ i \\ 0, otherwise \end{cases} \quad (10)$$

$$with \sum_{i=1}^{K} \gamma_{ij} = 1, \forall j \in \{1,...,N\} \quad (11)$$

The algorithm has as inputs a partition matrix with resources (objects) to be clustered in the rows, and several variables (observations) in the columns. This is represented in equation (10) through T, while Q represents an initial solution that can be given (cluster prototype or centroids matrix) [24]. The output of the algorithm returns a column vector with the group indexes for each of the resources, and with this is possible to obtain relevant parameters, such as, energy capacity/schedule, group tariff, and number of resources.

In the present section, it was approached the proposed methodology and all of its components and contextualization (as showed in Fig. 1). Moreover, the mathematical formulation used in the methodology and the resources that compose it, was also presented and explained.

3. Case Study

The case study that is evaluated with the proposed methodology, is composed of 117 generation units, of which one is an external supplier (others are distributed generators), and 90 consumers. There are several types of distributed generators, namely, photovoltaic, biomass, wind, small hydro, and co-generation, with different individual prices. Table 1 shows the resource’s characteristics, namely, total energy available in the time considered (day), price applied to each type of resource, and the number of resources per type.

Table 1. Generation units characteristics.

	Total Energy (kWh)	**Price (m.u./kWh)**	**nº of Resources**
External supplier	240,00	Dynamic	1
Wind	52,40	0,0964	53
Biomass	10,80	0,1231	1
Photovoltaic	39,59	0,1560	60
Small Hydro	22,39	0,1014	1
Co-generation	50,40	0,0796	1
Total	**415,58**	-	**117**

In Fig. 2, it is presented the energy available from each type of resource, in each period, and also the dynamic energy price of the external supplier. Also, generation is clearly sufficient to meet demand, giving possibility for distributed generators to be sufficient for satisfying consumption. The contribution of demand response in this case will be only reflected in a cost perspective, i.e. demand response is used only to reduce the operation costs of the aggregator.

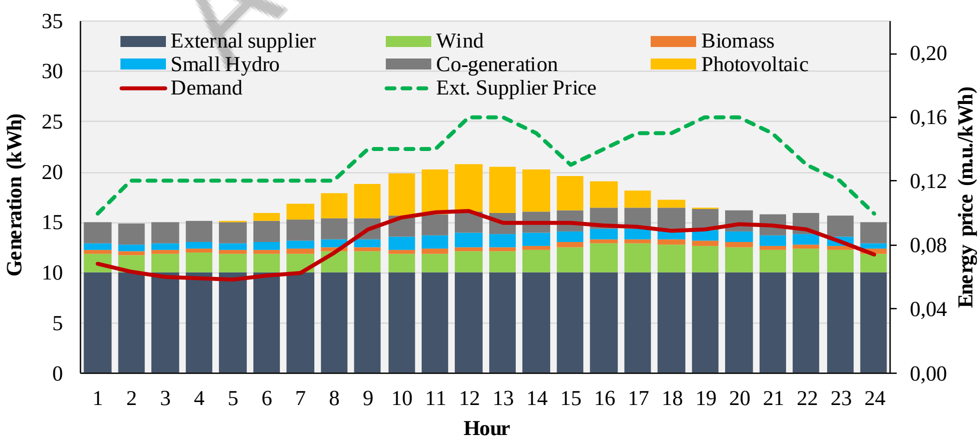

Fig. 2: Available generation through the periods and dynamic price (ext. supplier).

The dynamic price of external suppliers allows the aggregator to manage its operation costs, since there are periods where supply is cheaper and can balance this with the use of distributed generators and demand response accordingly.

4. Results

The results presented concern the implementation of the proposed methodology in the case study, with special focus on the rescheduling of resources after the clustering. The resources prices are changed after the clustering (for the second scheduling), according to the group tariff. The group tariff is obtained through the prices average of the elements in the group, and then is applied to the resources as their prices for the new scheduling. The analysis of the rescheduling is performed for a single period, that in this paper corresponds to period 12, matching the consumption peak.

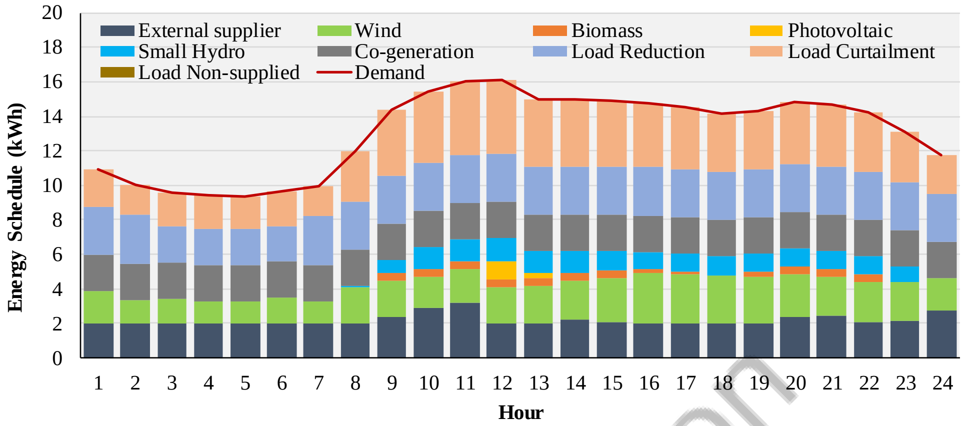

Fig. 3: Initial scheduling of resources.

Following the first scheduling of resources, Fig. 3, only the resources that participated in this scheduling are considered further in the clustering, such that the non-participants do not influence the group tariff obtained.

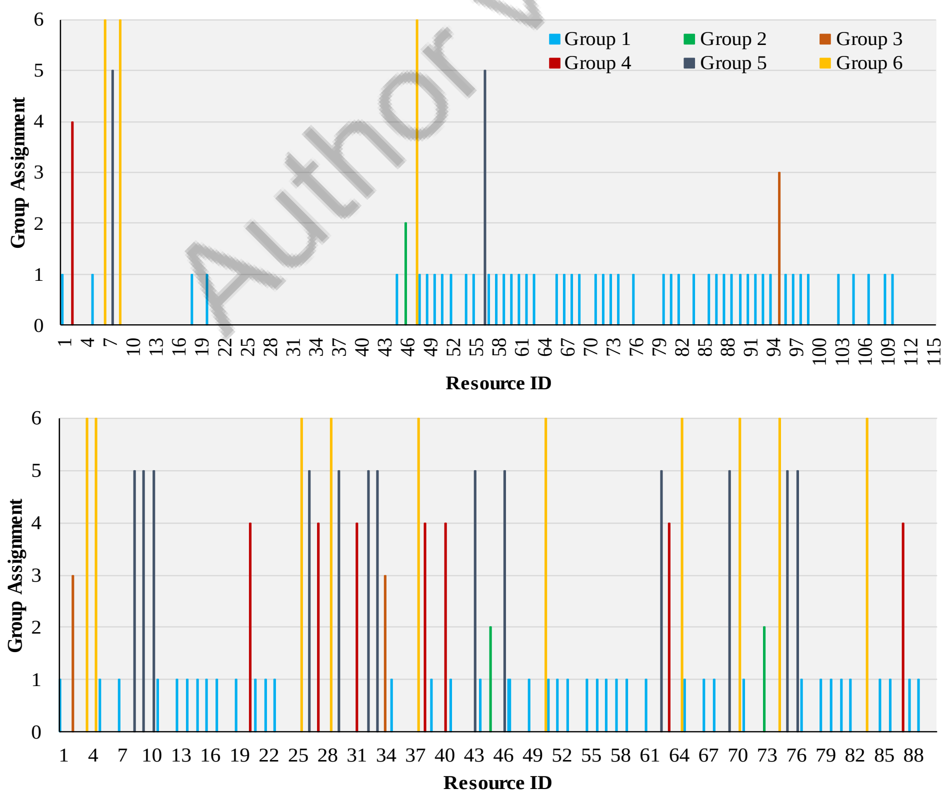

Fig. 4: Group assignment for each resource, in period 12 – Upper for DG, Lower for DR.

In Fig. 4, it is presented the group assignment obtained for each resource in period 12, considering that the non-participants are shown with a group assignment equal to zero. One can also see that the majority of the participant resources are clustered into group 1, due to their energy capacity and respective schedule. In Table 2, it is presented the obtained results for the clustering in a summarized form for each of the groups, namely, the energy schedule, group tariff obtained, and number of resources. In period 12, only 59 of the 116 distributed generators participated in the scheduling and therefore were clustered into six groups. The group tariffs will now be applied to the resources belonging to the respective group, in the new scheduling.

Table 2. Results for the clustering in period 12.

		Group energy (kWh)	Group tariff (m.u./kWh)	nº of Resources	Group energy (kWh)	Group tariff (m.u./kWh)	nº of Resources
Group Number	**1**	1,0247	0,0975	51	1,7415	0,1000	41
	2	1,3768	0,1014	1	0,7875		2
	3	2,1000	0,0796	1	0,6229		2
	4	0,4500	0,1231	1	1,4188		7
	5	1,8239	0,1262	2	1,6441		13
	6	0,2924	0,1162	3	0,8268		10
Total		**7,0678**	**-**	**59**	**7,0415**	**-**	**75**

With these results, the cost reduction regarding the first scheduling is around 4,22%, considering that in the second schedule the group prices obtained in the clustering are applied to the schedule participants – the new schedule is as presented by Fig. 5. The figure reveals an increase of use of photovoltaic units, when comparing with Fig. 3.

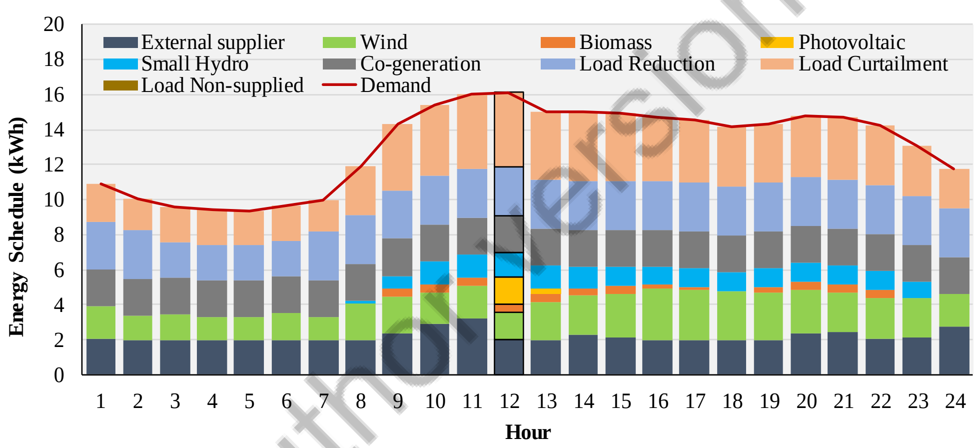

Fig. 5: Final scheduling of resources, for period 12.

5. Conclusions

The present paper addresses a rescheduling model for the aggregator's operation, considering distributed generators and demand response providers. Considering that the aggregator performs clustering processes to evaluate its market participation, this can also be used to identify resources that can become cheaper when approached with a group tariff, facilitating therefore their participation into a scheduling. The proposed methodology obtains a rescheduling of resources considering group tariffs, giving possibility to the aggregator to choose between market participation or resources scheduling in isolation mode, resembling a microgrid's operation.

The results obtained show that the aggregator, by using clustering and group tariffs to address several resources, can indeed reduce its operation costs, through an efficient use of resources potential under different operating conditions. As mentioned before, in case of more profit is obtained, the aggregator can choose to participate in energy markets, such that the groups and respective tariffs are already computed, facilitating in this way another one of the activities of the aggregator's interest.

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