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Combining real-time and fixed tariffs in the demand response aggregation and remuneration

Cátia Silva[a], Pedro Faria[a,*], Zita Vale[b]

[a] *GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Porto, Portugal*
[b] *Polytechnic of Porto, Porto, Portugal*

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Abstract

The current Energy Market is not yet ready for the integration of the Smart Grid context. Concepts such as Demand Response and Distributed Generation, namely renewable energy resources, are not yet included in current business models in order to the system flow properly. Therefore, the authors propose a methodology that gathers all these concepts through the optimization, aggregation and remuneration of resources. The purpose of this paper will be to study the influence of the tariff used for the remuneration and incentive of the participants in the formation of the groups in the aggregation phase. Three studies were performed: aggregation with only the result of the optimization (schedule power for each resource); this result and the fixed tariff associated with each resource; result and a new tariff that considers real-time values.

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Keywords: Aggregation; Clustering; Distributed generation; Remuneration

1. Introduction

The electricity sector is undergoing changes in its market, resulting in a new model that introduces new opportunities for the small resources that until now could have been discarded, namely, units of Distributed Generation (DG), consumers that participate in programs of Demand Response (DR) or even prosumers–consumers that can produce, [1,2]. The focus on the intelligent integration of actions and behaviors of all users of the network has as main objective the management of the network in a sustainable, safe and economic way. Bidirectional communication will add a great value to achieve this goal, however a level of difficulty is also added to management due to the uncertainties associated with it, [3,4]. Nevertheless, the advantages that this approach may entail are immense by encouraging users not only to reduce their energy consumption through the signals given by the network, but also to increasingly integrate the generation of clean energy into it. One of the actions that may be essential and crucial in network management is real-time electricity price changes. Through this modification,

* Corresponding author.
E-mail address: pnf@isep.ipp.pt (P. Faria).

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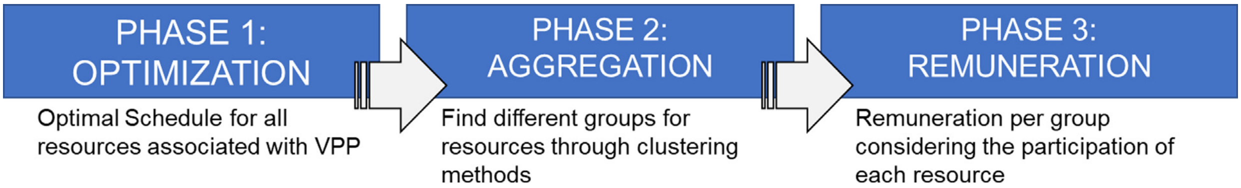

Fig. 1. Proposed methodology.

consumers will have access to this type of information and be able to change their consumption according to these signs. There is a need to change the existing tariff by modifying the tariff formation method — this must include a variable that considers a price that changes according to the period of the day, i.e., an indexed tariff. With this new tariff, the value of the energy tariff is indexed to the daily market price of electricity, which has an hourly variation. Thus, in this type of tariffs, the consumer sees reflected in his bill the changes in the price of electricity, with a commercial margin for the provision of the service of energy supply, defined by the marketer. Throughout of the paper, will be presented a model that will consider this new tariff definition. The solution suggested by the authors is a method that schedules optimally all the small resources associated with the aggregator, namely, the units of DG, consumers belonging to DR programs and prosumers. This is the development of previous works, [5,6], and results in a model that proposes the remuneration of these small resources by participating in conjunction with the aggregator for effective community management. To remunerate these elements fairly, groups are formed through a clustering method. The goal is to provide the aggregator with a significant amount of energy to participate in the market. With this, a new opportunity is given to these resources — participate more directly with the transactions made in the energy market. Each group will have an associated tariff and this rate should consider the new indexed tariff. For the paper, the authors propose to understand the influence that this tariff will have on consumers belonging to DR programs. In other words, when applying the proposed methodology to a case study, the influence of the new rates on the formation of remuneration groups will be analyzed. These groups will have a major effect on the success of this methodology since, in addition to assisting Virtual Power Player (VPP) in the management of the associated community, it can also serve as an incentive for continuous collaboration and participation, or even as promotion for new resources join the aggregation

2. Methodology

This section will present in more detail the methodology proposed by the authors to assist VPP in the management of the associated community. Fig. 1 presents the different phases of the methodology.

The initial phase is composed by an optimal scheduling problem that has as main objective the minimization of operating costs. Eq. (1) shows the objective function of this model.

$$MinOF = \sum_{p=1}^{P} P_{DG(p)}C_{DG(p)} + \sum_{sr=1}^{Sr} P_{Supplier(sr)}^{reg}C_{Supplier(sr)} + \sum_{sa=1}^{Sa} P_{Supplier(sa)}^{add}C_{Supplier(sa)} + \sum_{c=1}^{C} P_{DR(c)}C_{DR(c)} + P_{NSP}C_{NSP} \quad (1)$$

where $C_{\mathrm{IncreaseRTP}}$ is Electricity cost increase for RTP; $P_{\mathrm{addSupplier}}$ is Scheduled power for an additional supplier; P_{DG} is Scheduled power for a DG unit; P_{IDR} is Scheduled power reduction for IDR resources; P_{NSP} is Non-supplied power; $P_{\mathrm{ReductRTP}}$ is Consumption reduction for RTP; $P_{\mathrm{regSupplier}}$ is Scheduled power for a regular supplier; $C_{\mathrm{addSupplier}}$ is Additional supplier cost; C_{DG} is Distributed generation cost; CIDR is Incentive based Demand Response cost; $C_{\mathrm{InitialRTP}}$ is Initial electricity cost for RTP resources; C_{NSP} is Non supplied power cost; $C_{\mathrm{regSupplier}}$ is Regular supplier cost.

In this way, the associated resources are DG units, consumers participating in DR programs defined by VPP and suppliers. The last ones enter into the problem in the event that the DG does not meet the needs of consumption. Through the variables and parameters — characteristics of each resource, an optimization will be performed to understand the optimal contribution of each of them for a given period. Price and operating restrictions are

Table 1. Consumers characterization.

Designation	Reduce	Cut	RTP	Initial price [m.u./kWh]
Domestic	●			0.12
Small commerce	●			0.18
Medium commerce		●		0.2
Large commerce		●		0.19
Industrial			●	0.15
Total Nº of DR	19 996	167	147	20 310
Total capacity [kWh]	8676	1106	11 571	21 354.36

considered in this optimization as well as operational restrictions imposed by the VPP in order to achieve its objectives.

In the second phase it is proposed the aggregation of resources through a clustering method. These groups will be useful for the remuneration of resources. The definition of these groups is done considering the results obtained in the previous phase — the power scheduling for each of the resources, and the tariff associated with each one. In this paper, the objective will be to understand the influence of the tariffs on the creation of these remuneration groups. One of the studies considers the creation of a new tariff that is composed by the sum of a fixed tariff — tariff established by the energy supplier, and an indexed tariff — tariff that varies according to the market price and has hourly variation. A method of clustering namely, k-means, will be used in order to compare several k clusters. This study was carried out using software R.

Finally, the last phase of the methodology — the remuneration of the groups. Aggregate resources will be rewarded for collaboration with the VPP for effective operation management. This phase serves as a motivation and as a promotion for new candidates in the community. The goal is to achieve the cooperation of the entire community in order to reach a point where network management can flow optimally. Each resource will be rewarded for the participation according to the amount of energy that contributed and the tariff of the group to which they belong. This amount will be paid only at the end of the schedule.

3. Case study

This section presents the case study used to prove the feasibility of the methodology proposed by the authors. An actual distribution network of 30 kV fed through a high-voltage substation (60/30 kV) with the maximum capacity of 90 MVA was used for simulation purposes. This network supports a total of 20 310 consumers and 548 DG units. For optimization, the suppliers were also considered for the eventuality of the set available of DG units do not meet the consumption needs. Regarding consumers, there are 5 types: Domestic, Small Commerce, Medium Commerce, Large Commerce and Industrial. All consumers participate in DR programs, namely incentive based DR (reduce, cut) and real-time pricing. The participation of these consumers is restricted, and a maximum reduction is initially established for each type of consumer. Table 1 gives a summary of consumer information used as input for the optimization. This table shows the programs in which each type of consumer can participate, the initial price, the number of existing consumers per each program and the total capacity.

The focus of the study presented in this paper will be the producers or the DG units. There are different types in this database, namely, Small Hydro, Waste-to-energy, Wind, Photovoltaic, Biomass, Fuel Cell and Co-generation units. Table 2 gives a summary of the information used for DG units. This table presents the initial price (considered as fixed), the number of existing consumers per each program, the total capacity and the indexed tariff considered.

This information was used as input data for the first phase of the methodology-optimization. The results will be used for aggregation, which is the focus of this paper. The results obtained in the aggregation of DG units are presented in the next section

4. Results

In this section, the authors show the results obtained when applying the methodology proposed to the case study presented in the previous section. The objective is to understand the influence of the tariff applied to each producer in the formation of groups through the clustering methods. Three different situations were studied: the formation of groups with only optimization results; with the results of the optimization and a fixed tariff; with the results of

Table 2. DG characterization.

Designation	Nº of units	Capacity [kWh]	Fix tariff [m.u./kWh]
Wind	254	5866.09	0.07100
Co-generation	16	6910.10	0.00106
Waste-to-energy	7	53.10	0.05600
Photovoltaic	208	7061.28	0.15000
Biomass	25	2826.58	0.08600
Fuel cell	13	2457.60	0.09800
Small hydro	25	214.05	0.04200
Total DG	548	25 388.79 [kWh]	Indexed tariff [m.u./kWh]
			0.05444

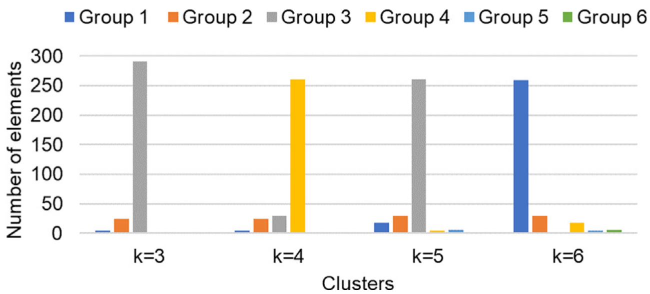

Fig. 2. Clustering — Only optimization results.

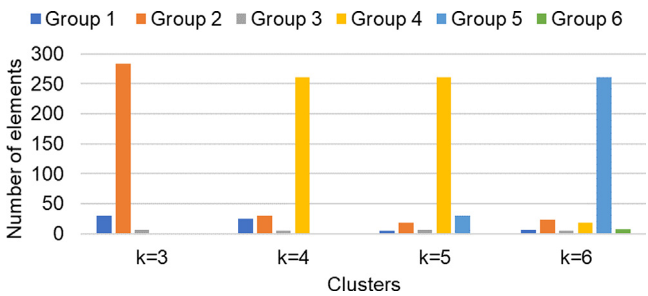

Fig. 3. Clustering — With optimization results and fix tariff.

the optimization and a tariff formed by two variables. The last case is further segmented into 5 different cases. By varying the percentage of weight for the fixed tariff and the indexed tariff in the formation of the final remuneration tariff, the scenarios are distinguished according to the percentage that each will have. For example, when there is a 50% fixed rate and 50% indexed tariff, the scenario will be called FIX 50 IND 50. The method used for the second phase of the proposed methodology — aggregation, is the method of clustering k-means and that the database used has only information on the producers associated with VPP, namely the results of the optimization carried out in the first phase of the methodology. Fig. 2 shows the results obtained for the first case where only the results of the optimization were introduced as input.

For Fig. 2, in k = 3, the group with the highest number of elements contains 291, the second 24 and the last one 5. In the case of k = 4, there was a reduction in the largest group, with now 261 elements, and the difference of elements would form the new group that was entered. For k = 5, two new groups with 5 and 6 elements were added. At k = 6, one of the elements of the largest group forms a group. Fig. 3 presents the results for the aggregation that is done considering the results of the optimization and the initial fix tariff.

Regarding Fig. 3, in k = 3, the largest group consists of 284 elements, the second 30 and the last 6. For k = 4, the group with more elements contains 261, the second 30, the third 24 and the last 5. In k = 5, from the third group of the previous case, 6 elements removed from that group to form a new group. Finally, k = 6, 7 elements

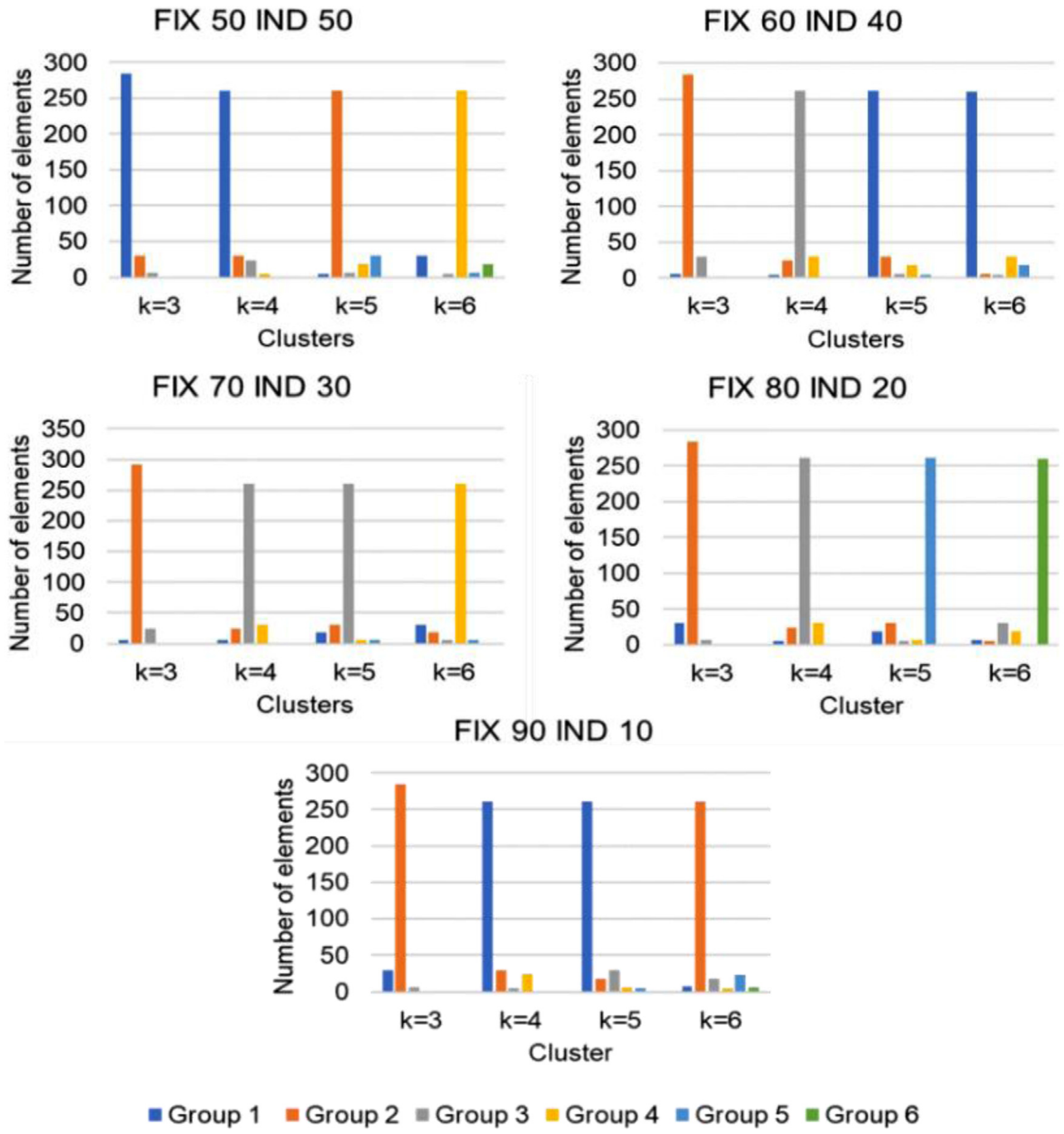

Fig. 4. Clustering — Scenarios with optimization and both tariffs.

removed from the group with 30 elements from the previous cases form the new group. Fig. 4 presents the results for the third case study, with different scenarios.

It is possible to observe that for all the scenarios there is always a group that stands out, formed mostly by about 260 elements. The FIX 70 IND 30 scenario formed groups with different number of elements from the remaining scenarios for all k studied and equal to the values resulting in the study in which only the results of the optimization were introduced as input — case study 1. For this database, the results did not vary much since as input there was only the result for a period and the associated tariff. Thus, it is concluded that with this producer database, despite the difference in the remuneration rate, the clustering method forms similar groups. It is presumed that with more information, for example in a case with a multi-period study, the results could be different. Through the tariffs obtained by group, the final remuneration for each of the scenarios was calculated. Table 3 shows these values in

Table 3. Final remuneration.

	K = 3	K = 4	K = 5	K = 6
FIX 50 IND 50	888.49	913.17	825.76	761.48
FIX 60 IND 40	902.52	932.14	827.25	766.30
FIX 70 IND 30	954.27	951.11	828.75	875.38
FIX 80 IND 20	930.60	970.08	830.24	829.34
FIX 90 IND 10	944.63	989.06	831.73	903.28

m.u. The final remuneration tariff per group was found through the maximum tariff found in each of the groups formed.

After analysis of Table 3, the lowest compensation values are obtained in k = 6 for all scenarios studied. Through the remuneration method proposed by the methodology, the VPP was able to remunerate the resources associated to it in a fair way. Through incentive of the remuneration at the maximum rate of each group, resources are encouraged to participate continuously, which is an asset for all involved.

5. Conclusions

To fill a gap in the energy market for business models that include the concepts of Demand Response and Distributed Generation, the authors proposed a methodology that optimizes, aggregates, and remunerates the small resources associated with a VPP. In the study of this paper, the authors analyzed the influence that the remuneration tariff can have on the formation of the groups in the second phase of the methodology. The database studied contained only information for DG units, and for a single period. The results showed that there was difference in the number of elements per group when comparing the first two case studies. Regarding the last case study, which suggested a new way of forming the remuneration tariff, the differences were not many since the results in the number of elements were equal to the cases previously studied. Regarding the final remuneration, the lowest value was found in k = 6 for all cases. The authors suggest as future work the same study, for a multi-period database, in order to provide the VPP with more information which may help to create more variation in group formation and see if exists some influence of the remuneration tariff

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References

[1] Espe E, Potdar V, Chang E, Espe E, Potdar V, Chang E. Prosumer communities and relationships in smart grids: A literature review, evolution and future directions. Energies 2018;11:2528. http://dx.doi.org/10.3390/en11102528.

[2] Faria P, Spínola J, Vale Z, Faria P, Spínola J, Vale Z. Distributed energy resources scheduling and aggregation in the context of demand response programs. Energies 2018;11:1987. http://dx.doi.org/10.3390/en11081987.

[3] Arias LA, Rivas E, Santamaría F. Preparation of Demand response management : Case study, 2018.

[4] Rathnayaka AJD, Potdar VM, Hussain O, Dillon T. Identifying prosumer's energy sharing behaviours for forming optimal prosumer-communities. In: Proc. - 2011 Int. Conf. Cloud Serv. Comput. CSC 2011 199–206. 2011, http://dx.doi.org/10.1109/CSC.2011.6138520.

[5] Silva C, Faria P, Vale Z. Discussing different clustering methods for the aggregation of demand response and distributed generation. In: 2018 IEEE symposium series on computational intelligence (SSCI). IEEE international conference on communications, control, and computing technologies for smart grids. 2018.

[6] Spinola J, Faia R, Faria P, Vale Z. Clustering optimization of distributed energy resources in support of an aggregator. In: 2017 IEEE Symp. Ser. Comput. Intell. SSCI 2017 - Proc. 2018-Janua, 1–6. 2018, http://dx.doi.org/10.1109/SSCI.2017.8285201.