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Rating consumers participation in demand response programs according to previous events

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Abstract

The energy sector, as many, is being adapted to meet environmental concerns and avoid fossil fuels. So, Smart Grids concept is promoted, penetrating Distributed Generation into the grid, namely renewable-based energy, providing an environmentally friendly alternative. Also, the consumers' role is empowered through Demand Response (DR). The consumers are incentivized to actively modify their consumption behavior receiving the proper remuneration. With this, the power system will decrease operation costs and DR can be used as an alternative to generation. However, manage these new and active resources as well as their transactions in the energy market is a complex task due to the uncertainty associated. Many factors can cause a non-response and the Aggregator must be able to manage these situations mainly when a certain target of reduction is required from the wholesale market. The authors proposed an approach including a Trustworthy Rank to select consumers for on DR events: consumers participate considering their reliability. In the present paper, the effects of the approach will be compared between two seasons, proving the viability on giving the correct information to the community manager and understanding how variable is the behavior of this rank at different times of the year.

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Keywords: Demand response; Energy market; Trustworthiness; Smart grids

1. Introduction

Currently, the energy sector is facing changes that will drive towards a more sustainable and efficient energy usage. The growing concern motivates all the intervenient on working in ways to preserve the environment to not compromise the natural resources of upcoming generations. For the energy sector, it is believed that Smart Grids concept is the future and can find the balance between social, energy, economic and environmental issues. The concept guarantees a more reliable and efficient market, empower the small players introducing Demand

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Response (DR), enabling bidirectional communication and penetrate Distributed Generation (DG) resources, namely renewable-based such as wind and solar, fighting the intensification of the greenhouse effect and air pollution. Although slow, the implementation of Smart Grids in real markets is starting and political efforts are being made to introduce DR and empower consumers, such as Directive 2019/944 providing common rules for the internal market [1]. The role from consumers in the energy market and their potential is crucial to take the step forward to a sustainable future. The definition of consumer is changing. Now, being able to participate in the transactions in the market, understand their consumption and find ways to improve and reduce their costs, even produce their energy as prosumers, it creates a new player in the energy sector, a more active and conscious one. Yet, it will take time, education, and resources until taking rational decisions. Still, Ilieva et al. [2] highlight the impact of millennials actions and how there are different from previous generations. Their sensitivity to environmental aspects makes them more ready to embrace "green initiatives". Considered as the type of users that will be responding to energy flexibility signals, promote local and sustainable energy production as well as consumption. However, the actual business models do not include or can deal with the uncertainty associated with these new resources. The unpredictable behavior, from both consumers and DG units, increase the complexity of managing the network. An entity was created to be responsible for the transactions in local communities with active players — the Aggregator. Many models in the literature were created finding solutions to optimally manage and to aid and decrease the difficulty of the [3–5]. However, the authors found the necessity to search for a way to increase reliability in the network namely when DR events are triggered, considering the uncertainty associated with the small consumers' behavior. As Good [6] reminds, most of the studies are shaped given end-users as always rational and economic agents, and the uncertainty behind their random behavior must be considered. Taking a step forward from previous works [7], the methodology proposed in the present paper was designed to select trustworthy consumers to be selected for a DR event. Considering a DR target required from the wholesale market, the Aggregator must rely on the active consumers in the community to achieve the goal. The idea is assigning a trustworthiness rank considering previous experiences and, for the case of none, the low rank is attributed and continuous participation with good results will rise their reputation. Having this information, the Aggregator will opt for the more "reliable" for this task. The proposed methodology can optimally manage several resources: the mentioned DR program participants, DG units and the joint from those concepts. A more detailed explanation of the process is present in Section 2.

The present paper is divided into five sections. Section 1 is an introduction to the theme approached. Section 2 details the proposed method. The case study, the results, and the discussion are presented in Sections 3 and 4. Finally, the conclusions from the study are summarized in Section 5.

2. Materials and methods

The authors proposed a method including a trustworthy rank (TR) considering past experiences from the active consumers with DR events through time: Current Reduction (CR) being the actual reduction in the present event, Last event Day (LD) being the performance from the last event in the same period and Historical Rank (HR) is the average from previous performances within the same context, explained on Fig. 1.

The innovation from previous works is the influence from different contexts, namely different seasons, as the consumers' behaviors change through the year. The higher the rank, the more trustworthy is considered the active consumer giving useful information to the Aggregator for the following DR events on the same context. The lowest rank is attributed to the first participation, and consumers must continuously contribute to obtaining an improve. At the beginning of the DR event, the Aggregator selects the consumers with TR higher than a denominated minimum to participate and schedules them with the remaining resources.

The objective function aims to minimize operational costs from the perspective of the aggregator and fairly remunerate active consumers (Eq. (1)). Let PDG be the power for each p DG resources; PDR is the flexibility from each c consumers; PSUP is the power from each s external suppliers and PNSP be the non-supplied Power. Each of these variables has an associated cost. To achieve the balance between consumption (Pinitial) and generation, the Eq. (2) is added. The remaining constraints introduce inequations used to bound to all resources involved. From Eq. (3) to Eq. (6), control the DR event targets and the amount of reduction from each active consumer.

Eqs. (7) and (8) constrain DG units on upper and lower bounds. Eq. (9) restrict the amount of DG used. Eq. (10) provides an upper limit for external suppliers and Eq. (11) restrict the total amount of generation from this source.

$$Min\ OF = \sum \left[\mathrm{P_{DG}}\,(\mathrm{p},\ \mathrm{t})\,\mathrm{C_{DG}}\,(\mathrm{p},\ \mathrm{t}) \right] + \sum \left[\mathrm{P_{DR}}\,(\mathrm{c},\ \mathrm{t})\,\mathrm{C_{DR}}\,(\mathrm{c},\ \mathrm{t}) \right]$$

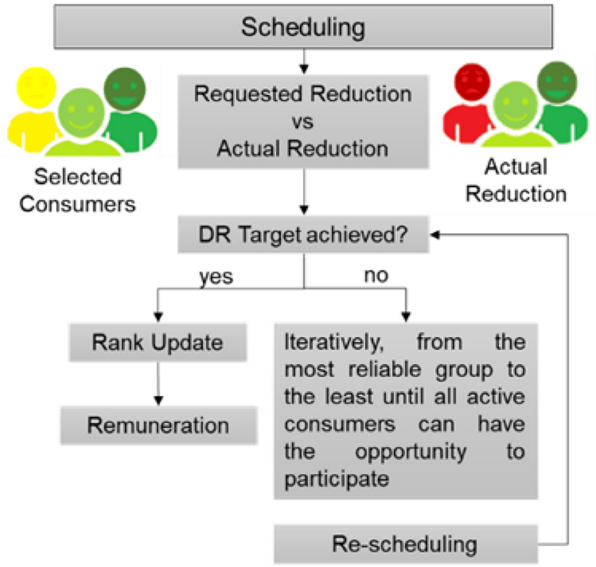

Fig. 1. Proposed methodology.

$$+\sum [P_{SUP}(s,\ t)\, C_{SUP}(s,\ t)] + P_{NSP}(t)\, C_{NSP}(t) \tag{1}$$

$$\sum[P_{\mathrm{initial}}(c,\ t) - P_{\mathrm{DR}}(c,\ t)] = \sum[P_{\mathrm{DG}}(p,\ t)] + \sum[P_{SUP}(s,\ t)] + P_{NSP}(t) \tag{2}$$

$$P_{\mathrm{DR}}(c,\ t) \le P_{\mathrm{DR}}^{\mathrm{Max}}(c,\ t) \tag{3}$$

$$P_{\mathrm{DR}}(c,\ t) \ge P_{\mathrm{DR}}^{\mathrm{Min}}(c,\ t) \tag{4}$$

$$\sum[P_{\mathrm{DR}}(c,\ t)] \le DR_{\mathrm{target}}^{\mathrm{Max}}(c,\ t) \tag{5}$$

$$\sum[P_{\mathrm{DR}}(c,\ t)] \ge DR_{\mathrm{target}}^{\mathrm{Min}}(c,\ t) \tag{6}$$

$$P_{\mathrm{DG}}(p,\ t) \le P_{\mathrm{DG}}^{\mathrm{Max}}(p,\ t) \tag{7}$$

$$P_{\mathrm{DG}}(p,\ t) \ge P_{\mathrm{DG}}^{\mathrm{Min}}(p,\ t) \tag{8}$$

$$\sum[P_{\mathrm{DG}}(p,\ t)] \le P_{\mathrm{DG}}^{\mathrm{Total}}(t) \tag{9}$$

$$P_{SUP}(s,\ t) \le P_{SUP}^{\mathrm{Max}}(s,\ t) \tag{10}$$

$$\sum[P_{SUP}(s,\ t)] \le P_{SUP}^{\mathrm{Total}}(t) \tag{11}$$

Performed the scheduling phase, the requested reduction is compared with the actual response. If DR target is not achieved, the remaining consumers are called, iteratively, allowing increasing their rank. After achieving the goal, proceeds the following stage where the rank is updated. Compensation for the response plays as an incentive to motivate a continuous contribution to DR events and it is done after the update. For the present paper, the purpose is to investigate the performance of the proposed methodology for distinct seasons. It is known that consumers behaviors and willingness to participate in DR events can be different throughout the year. The innovative element from previous works done by the authors is the addition of uncertainty regarding context. The following section will detail each assumption considered in the case study developed.

3. Case study

To prove the viability of the proposed approach, the authors wanted to simulate the current implementation of DR in the real world. A database with 20,310 consumers between ten communities was considered, and the main characteristics can be seen in Table 1.

The one with a higher average of trustworthiness from previous events was considered (406 consumers where 263 are active elements). Is composed mainly by households where, usually, the approach is reducing the impact of

Table 1. Characterization of consumers in the ten communities.

Type	Domestic	Small commerce	Medium commerce	Large commerce	Industrial
# elements	10,168	9828	82	85	147
Energy [kWh]	9369.35	7983.35	11,254.75	10,880.48	23,142.48
Max Load Reduction [kW]	4684.7	3991.7	15,756.7	9792.4	20,828.2

DR events in their comfort and wellbeing. For example, one of the age range to likely have a lower response or not willing to participate are the elderly. Ilieva et al. [2] wrote about how the elderly may have problems or be inhibited from using certain technologies. Alexander [8] refers to a more critical matter and presents evidence that elderly consumers, being more fragile, will not seek out or apply for "low income" programs due to their necessities. Information extracted from official entities affirms that almost 35% of the population with private households is composed of people above 65. In this scenario, the same percentage of the dataset will not participate in DR events (35%) and the remaining established DR contracts, being some of them not willing to participate at the weekend. Spring and Autumn were the chosen seasons considering April and October. Two different event types were considered: Event Type 1 (ET1) occurs between 1 pm–3 pm represented by 13 to 15 and Event Type 2 (ET2) occurs between 6 pm–8 pm represented by 18 to 20. A wide range was studied to see the variety of responses in the selected periods. It is also considered a DR target of 100kW per period of the event (each divided into periods of 15 min). The risk of not achieving the goal is high, considering the uncertainty of behaviors from users, however, the limit from the model is tested to include all the active members and understand if the information obtain is useful for the Aggregator. TR goes between 1 and 5 and rank 3 is the minimum in the first active consumers' selection.

4. Results and discussion

Fig. 2 presents the comparison between the selected and the actual participants as well as the actual and requested reduction for DR events. The darker color charts represent the which was trigged on Monday (a), Tuesday (c), Thursday (e), and Sunday (g). The lighter color chart represented ET2 and was tested for the remaining weekdays. The proposed approach was able to always reach the DR target in events from April by calling the remaining active consumers, the value of 100 kW in every 15 min from the DR event was achieved by the optimization (Requested line on Fig. 2). Ideally, this would happen in the actual line as well, and the target of reduction would be accomplished. However, in the simulation, not all the selected users responded as expected. The authors considered them has not always rational and active agents, and that assumption had an impact as can be seen in the Actual curve from Fig. 2. The group with a higher percentage of non-responses was rank 1. Taking as an example Fig. 2(a) at 13:30, from the rank 1 elements was requested 13,62 kW and the actual value was 2,12 kW.

These achievements highlight the necessity and the importance of focusing on consumers and ways to increase their willingness to participate in DR events but also find models to avoid high risks on the management side perspective. Fig. 3 presents the results from October.

The darker color charts represent the ET1 which was trigged on Tuesday (a), Wednesday (c), Friday (e), and Monday (g). The lighter color chart represents ET2 and the remaining weekdays. Once again, the DR target could be achieved by the active consumers, but their actual responses were different from the requested. The elements on lower TR groups were again essential to achieve the goal. However, a distinct month did have a greater impact on the overall reduction since the value was always between 80 kW and 100 kW as in April. The authors prove the viability of the model on finding useful information from the community behavior. Also add a step forward on design solutions to deal with consumers, an important role in the future energy market.

5. Conclusions

Empowering the consumer's role in the energy market is one of the main topics on the Smart Grid approach. However, introducing DR programs on the management can be a complex task considering the uncertainty. The authors proposed a model where a Trustworthy Rank was created to provide the Aggregator with valuable information from active consumers. Two different events were created and triggered throughout April and October to compare the impact of the seasons on the model. Also, on the contrary of several models on the literature, the consumers were assumed as not always rational and economic agents, so their response was difficult to predict, and the target was not achieved. Regarding the season impact on the ranks, being a studied as group, the effects were not noticed. For future works, find ways to motivate positive responses on DR events and penalize for non-responses.

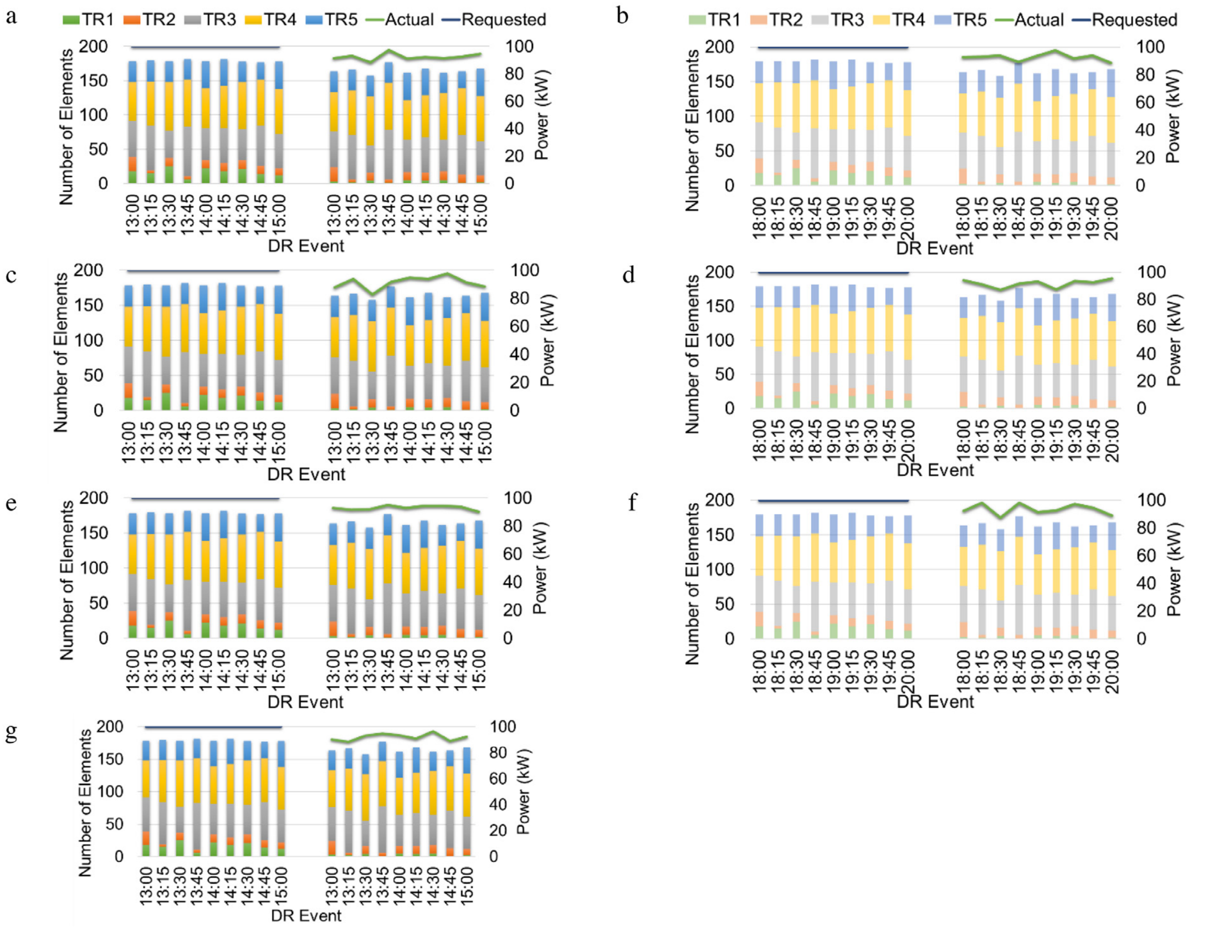

Fig. 2. Participants and Average Rank in DR events from April: ET1 (a), (c), (e) and (g). ET2 (b), (d), (f).. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

CRediT authorship contribution statement

Cátia Silva: Data curation, Formal analysis, Investigation, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Pedro Faria:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Zita Vale:** Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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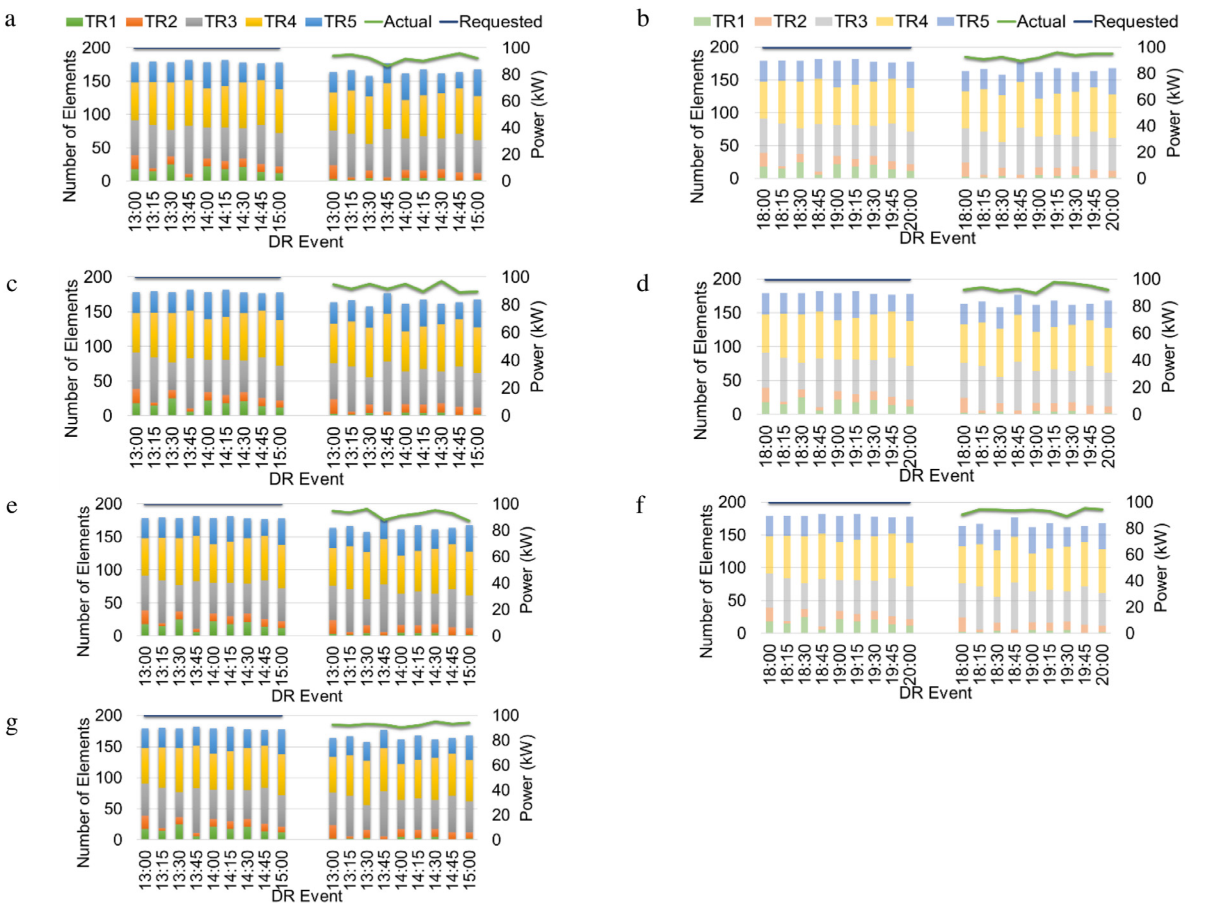

Fig. 3. Participants and Average Rank in DR events from October: ET1 (a), (c), (e) and (g). ET2 (b), (d), (f).. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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