A Consumer Trustworthiness Rate for Participation in Demand Response Programs

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Abstract: Local energy communities with information from the real-time market may improve the market operation but also increase the complexity of the management problem thanks to the uncertainty associated with the actual response of these resources. For instance, consumers with price knowledge may change their power consumption to lower-cost periods. The authors present a model to deal with uncertainty from the point of view of the Aggregator: apply reliability rates to each consumer according to their actual response in events of Demand Response (DR). The consumers with higher rates are chosen to participate in the energy market. To compute the final rate, three different independent rates are used: Historical rate with past information, Cut-rate from the response in the actual period and the Last Day Rate which is the final reliability rate from the previous day. In the present paper, the influence of each independent rate, through the weight used, is studied.

Keywords: Demand Response, Uncertainty, Aggregator, Smart Grids, Optimization

1. INTRODUCTION

Demand Response (DR) is one of the main interests when applying the concept of Smart Grids in the current network. Through bidirectional communication, small resources have more information about real-time transactions. Furthermore, the evolution of the technology in this area introduces new devices, such as smart appliances, which are able to give some flexibility in the power consumption of the consumers, when connected to the network. All the conditions are gathered to apply the definition of DR, being the end-user reaction to price changes over time. Several benefits can arise from this approach in the point of view of the entity who manage a local community, for instance, increasing the system reliability and reduce electrical costs to the participants (De Paola, et al. 2017). However, as an individual, small resources don't own the capacity to participate directly in the energy market. The Aggregator is introduced as the entity to gather and manage the resources who are willing to participate in these events. The main purpose of the Aggregator is to be the intermediary to the transactions with the wholesale electricity market (Khezeli, et al. 2017).

To successfully manage a local community, the real-time balance between generation and consumption must be achieved. Introducing the DR concept and Distributed Generation (DG) in the scheduling of resources will increase the uncertainty: giving a possibility of small units to take part in the local market equilibrium, for instance, photovoltaic panels from a prosumer or rely on the reaction of a residential consumer. In this way, the Aggregator must find strategies to increase the reliability of the resources clustered (Faria, et al. 2016). Giving this dilemma, the authors propose a model to deal with uncertainty coming from the small consumers when reacting to events of DR. Previous works from the authors of the present paper, were able to optimally manage a local community. The optimization is able to deal with these small resources, DG and consumers willing to participate in DR events, independent of the size of the dataset or the types of resources included.

In the present paper, the proposed methodology is innovative in attributing a reliability rate to each consumer. In other words, considering that an Aggregator as a goal of reduction – DR target. It is essential to understand which consumers this entity can trust to reduce at a specific moment. This reliability rate is updated according to the actual response overtime. In the present paper, the idea is to understand the influence of each rate that forms the final reliability rate: historical rate (HR), cut-rate (CR) and last day rate (LDR). These rates are used in different stages of the model and are obtained independently. The goal is to analyse the effect of weight variation of each rate in the final groups formed. Three tests have been performed. Results such as requested reduction and actual reduction; answers below the requested and higher will also have an impact, are worth studying.

The present paper is structured into five different sections. Section 1 served as an introduction to the topic addressed and a brief explanation of the proposed work. Section 2 presents a more detailed description of the proposed method. Section 3 describes the assumptions for the case study as well as the local community selected from the dataset to prove the feasibility of the methodology. In Section 4 the analyse of the results is done. Section 5 presents the conclusions derived from the present studies.

2. PROPOSED METHODOLOGY

Section 2 presents the proposed methodology in detail. The present paper focuses on the Aggregator and in their interaction with the consumers. In this way, the authors proposed a method to deal with the consumers' actual response to DR programs, i.e., the request for a reduction. According to the response, to each consumer is assigned a Reliability Rate. Depending on the stage of the model, the way of calculation is different relying on several independent rates: historical rate (HR), cut-rate (CR) and last day rate (LDR). HR is attributed according to the existing past data of the consumer. So, or the Aggregator has previous information on the consumer, or the value starts in 0 and can decrease and increase according to the response. The CR is defined by the actual response of the consumer for the giving period: if the value is higher, equal or lower than the requested reduction. The LDR is the rate given to the consumer for the same period in the previous day.

Fig. 1 presents the model pattern and how the final rate is formulated according to each stage. Considering the first time that reliability rates are applied, Fig. 1 initial rate depends only on the prior data from the DR programs actual response of each consumer, i.e., HR. An optimization used for Scheduling the resources in the local community is applied. It is important to mention that, in the first stage of Scheduling phase, only consumers with higher reliability rates than the selected minimum are chosen to participate. Since a DR target is applied, if the selected consumers were not able to achieve this goal, all the remaining consumers are called to participate in a later scheduling, the Re-scheduling stage.

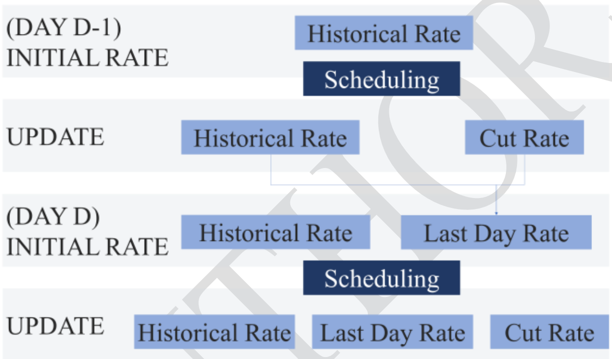

Fig. 1: Definition of the Final Rate for Day (D)

Being used already in previous works from the authors, for example (Silva, et al. 2019a) and (Silva, et al. 2019b), the idea is to minimize the operation costs and increase the profits for the Aggregator by balancing the small resources, such as consumers participating in DR programs (P_{DR}) and DG units (P_{DG}). This model also can be applied to prosumers and is capable to manage a larger number of resources or only one type of resource. The Aggregator must collect information from all the aggregated resources in order to apply this method, for example, it's important to know price and capacity limits of the DG units (minimum and maximum), initial load curve, the price and reduction capacity of the consumers belonging to DR programs.

Although this optimization can be functional to microgrids in island mode – when the operation is done isolated from the national or local electricity distribution network, for the cases where this concept isn't applied, external suppliers were added, and two types can be found: regular (P_{SUPR}) and additional (P_{SUPA}). It was considered that p is the number of DG units, c is the number of consumers, sr is the number of regular suppliers and sa is the number of additional suppliers. Equation 1 presents the objective function attributing a cost to each parameter and all the constraints are shown from Equation 2 to Equation 12.

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

$$\sum_{c=1}^{C} [P_{Load(c)}^{Initial} - P_{DR(c)}] = \sum_{p=1}^{P} P_{DG(p)} + \sum_{sr=1}^{Sr} P_{SUPR(sr)} + \sum_{sa=1}^{Sa} P_{SUPA(sa)} + P_{NSP} \quad (2)$$

Equation 2 represents the balance between demand and generation. As can be seen, in the left side, to the initial load is reduced the demand response possible curtailment and on the right side, the sum of all the DG units and external suppliers. If well managed, the production side is enough to suppress all the consumption but for extreme situations, the variable Non-Supplied Power (P_{NSP}) was added. The goal is to maintain this value always null.

The constraint associated with DR programs is presented in Equation 3, Equation 4 and Equation 5. The first restricts the maximum value of reduction, stated in the contract with the consumers.

$$P_{DR(c)} \leq P_{DR(c)}^{Max}, \quad \forall c \in \{1, \ldots, C\} \quad (3)$$

Equation 4 and Equation 5 control the maximum and minimum for DR Target, respectively. This value was introduced, and it will be a determining factor in the Scheduling phase, as aforementioned. If the second stage – Re-scheduling – is needed, all the consumers have the opportunity to increase their rate by participating in the management of the local community with the requested reduction. Values of reduction lower than the expected may prejudice the consumer's reliability rate.

$$\sum_{c=1}^{C} P_{DR(c)} \leq DRTarget_{max} \quad (4)$$

$$\sum_{c=1}^{C} P_{DR(c)} \geq DRTarget_{min} \quad (5)$$

The generation resources' constraints are presented through Equation 6 to 12. The first three (Equation 6 to Equation 8) create the upper and lower bounds for DG units and also restrict the total amount of generation used from these technologies.

$$P_{DG(p)} \le P_{DG(p)}^{Max}, \ \forall p \in \{1, \dots, P\} \tag{6}$$

$$P_{DG(p)} \ge P_{DG(p)}^{Min}, \ \forall p \in \{1, \dots, P\} \tag{7}$$

$$\sum_{p=1}^{P} P_{DG(p)} \le P_{DG}^{TotalMax} \tag{8}$$

The remaining equations refer to Regular and Additional Suppliers. Equation 9 and 11 create the upper bound and Equation 10 and 12, as well as Equation 8 for DG units, limit the quantity available from each type of external suppliers in the network. The Aggregator, with this approach, has more power in the scheduling.

$$P_{Supplier(sr)}^{reg} \le P_{Supplier(sr)}^{regMAX}, \forall \in \{1,\dots,Sr\} \tag{9}$$

$$\sum_{sr=1}^{Sr} P_{Supplier(sr)}^{reg} \le P_{Supplier(sr)}^{regTOTAL} \tag{10}$$

$$P_{Supplier(sa)}^{add} \le P_{Supplier(sa)}^{addMAX}, \forall \in \{1,\dots,Sa\} \tag{11}$$

$$\sum_{sa=1}^{Sa} P_{Supplier(sa)}^{add} \le P_{Supplier(sa)}^{addTOTAL} \tag{12}$$

Returning to Fig. 1, updated reliability rate is accomplished taking into account the results from scheduling. Now, the CR is introduced and with HR, the final rate for Day (D-1) is determined and used to the next day in the same period. Moving to the Day (D), HR and LDR are considered to the initial rate. Another Scheduling is performed. This time, the three rates will be considered for the final rate for this period. The model is repeated according to Day (D).

Now, the following questions arise: should the HR have more impact on the final reliability rate of the given period? It is more important what has been done in the past? The Aggregator should still trust in this consumer although in this period didn't respond according to the expectations? Or should the CR be higher and punish/exonerate for the answer in this period where the Aggregator needed the most? What about the LDR? Is important? The idea is to perform a sensitivity analysis, which is defined as the study of the influence of a certain independent variable in a particular dependent one under a given set of assumptions (Liu, 2008). The approach used is the local sensitivity analysis being a One-at-a-time (OAT) technique. As the name suggests, this method analyze the effect of a parameter keeping the other fixed.

3. CASE STUDY

In the present case study, a dataset from a real Portuguese distribution network with five types of consumers (total of 20 310) willing to participate in DR programs and seven types of DG units (total of 548) is used. Table 1 present the detailed characterization of the small resources in the 10 local communities existing in this database, Consumers and DG units respectively. The DR target selected was 100 kW.

Table 1: Small Resources Characterization

CONSUMERS			
Type	**#Elements**	**Capacity (kWh)**	**Initial Price (m.u./kWh)**
Residential	10,168	21,354.36	0.12
Small Commerce	9,828		0.18
Medium Commerce	82		0.20
Large Commerce	85		0.19
Industrial	147		0.15
Total	20,310		
DG UNITS			
Type	**#Units**	**Capacity (kWh)**	**Tariff (m.u./kWh)**
Small Hydro	25	25 388.79	0.0961
Waste-to-energy	7		0.0900
Wind	254		0.0988
Photovoltaic	208		0.2889
Biomass	25		0.1206
Fuel Cell	13		0.0945
Co-generation	16		0.0975
Total	548		

To attribute an initial rate to each consumer, the information for a whole year was processed resulting in an HR: for each consumer, 5 samples from previous weeks, in the same day of the week and in the same period of the day were taking into account. The studied dataset is divided into periods of 15 minutes – considering the fact that the lower the step, the higher the confidence of the results. In this way, a day is composed of 96 periods.

Highlighting the fact that this study was done in two consecutive days at the same period (for example when a peak load occurs), the selected days of the week were Tuesday (Day (D-1)) and Wednesday (Day (D)) for the same period – 3 pm or period 60. All the rates in the present study went into a range between 1 and 5. The weights in each formulation of the Reliability Rate (Fig. 1) should vary to produce several combinations and examine the influence of each independent rate in the final result. Regarding Table 2, it represents the number of elements per rate – group, according to the initial rate of Day (D-1) which considers the only HR.

Table 2: Consumers per rate in the selected community

Group	**1**	**2**	**3**	**4**	**5**
Elements (#)	215	68	66	43	14

In the initial rate stage, only member with rates higher than the designated minimum are selected to the optimization stage. In the present study, Group 3 is the minimum rate considered. An assumption regarding CR was considered: the weight attributed to this rate may never be null since the actual response and reduction from the consumer it's an essential element to this study.

4. RESULTS

In the present section, several results were analysed to understand the influence of each independent rate in the final reliability rate. In this way, several results are analysed and compared: the comparison between the initial number of consumers in a group and the updated number after the scheduling phase; also, how many of them were selected; the amount of requested and actual reduction, and which ones responded lower or higher than the requested. Section 4 is subdivided according to the stage and tests performed for each: 10 different studies for the final reliability rate in Day (D-1) – Test 1; 9 different studies for the initial reliability rate in Day (D) – Test 2; and 6 different studies for the final reliability rate in Day (D) – Test 3.

The initial reliability rate from Day (D-1) rely only on HR from each consumer. In this way, the Scheduling Results for Day (D-1) are the base for the following studies and are presented in Table 3.

Table 3: Scheduling Results from Day (D-1)

Group	1	2	3	4	5
# Initial Elements	215	68	66	43	14
# Selected	0	0	36	19	7
Requested (kW)	0	0	64.61	24.05	11.33
Actual (kW)	0	0	68.61	23.64	11.21
Total Reduction (kW)	103.46				

Taking into account the weight from CR and HR – the two independent rates that constitute the final reliability rate for Day (D-1), the resulting number of elements for each test is presented in Fig. 2.

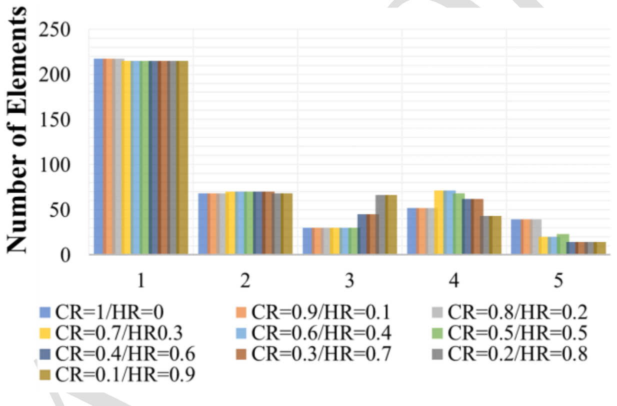

Fig. 2: Test 1 – Weight Variation Influence (step 0.10)

The effect in Group 1 and Group 2 was small since the actual reduction was null, and only elements from higher groups descend to these lower levels. Group 3 started with a low number of elements in the first tests – CR had higher influence and according to their performance, the climbing to higher levels is distinct. As the HR increase its weight, Group 5 sees their elements move to under levels. Thus, the levelling speed depends on the percentage that is assigned to the CR: higher CR, the easier the group climbing. However, this may not be desirable as the past information may prove otherwise (dissimilar behaviours) and although these consumers have responded accordingly, it is expected that levels above the designated minimum will do so. Therefore, consumers in this limit should be treated differently and the levelling speed, to higher or lower groups, should be more controlled.

The noticeable turning point happens when the weight assigned to each rate is the same. Yet, the authors decide to study, in the present paper, the anterior and posterior weights to compare and understand the behaviours. Yet the remaining combinations were performed although not presented. In this way, three different paths for Test 2 are possible and the resulting number of elements per group are presented in Fig. 3.

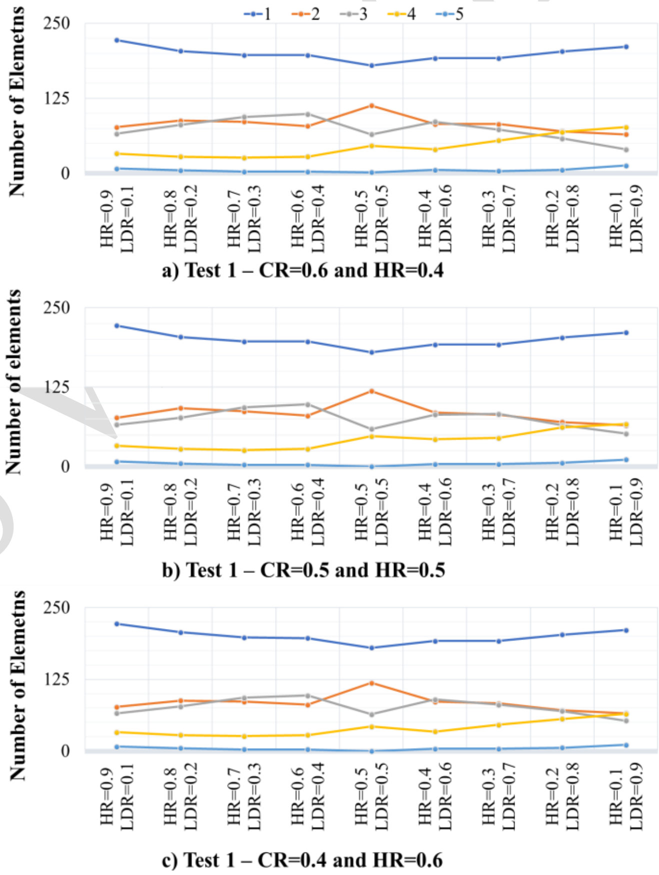

Fig. 3: Test 2 – Weight Variation Influence (step 0.10)

Analyzing Fig. 3 by groups, Group 1 tendency is very similar in all tests. Regarding the curve that represents Group 2, in the first experiments, the trend follows the curve for Group 3, increasing in the number of elements. However, the curves reverse directions between step 0.8 and 0.7 (Group 3 with higher number of elements) and between 0.6 and 0.5 from HR (Group 2 with higher number of elements), reaching the highest element disparity when HR=0.5 and LDR=0.5 (Fig. 3b). When LDR has less influence from the last day actual reduction of the consumer, the curves from Group 2 and Group 3 reach their minimum difference, almost overlapping. About Group 4, the higher the percentage of LDR, the number of elements in this group increased: when the weight of the consumer's history is lower, the ease of switching groups is higher and depends, of course, on the response of the consumer during the same period of the previous day. In this case study, elements from Group 3 had better performance than the remaining requested groups since Group 4 and 5 results were lower than expected. In this way, and according to the percentage attributed to CR, these elements increased their level of reliability. Since the disparity of elements is higher when HR=0.5 and LDR=0.5, the authors opted for following this combination. Test 3, presenting only the optimization results for this selected test. Consequently, and taking into account this assumption, the Test 2.1 results from the Test 1 with higher CR; the Test 2.2 results from the Test 1 with the same weight for both rates and finally, Test 2.3 results from the Test 1 with higher HR. The resulting combinations of Test 3 had a step of 0.33 since three different rates were used to perform the final reliability rate of the consumer, as presented in Table 4.

Table 4: Test 3 – Weights per Rate

Test	3.0	3.1.1	3.1.2	3.2.1	3.2.2	3.3.1
HR	0	0	0	0.33	0.33	0.67
CR	1	0.33	0.67	0.33	0.67	0.33
LDR	0	0.67	0.33	0.33	0	0

The first scheduling was enough to achieve the DR target and, giving this, possible responses from the groups above the minimum will be considered to also understand the influence in these elements. Individual cases will be studied in the following subsection. Table 5 shows initial number of elements per group and the scheduling results for Test 2.1.

The number of elements selected to participate in DR event came from Group 3 to Group 5 in a total of 60 consumers. Although, without request, elements from Group 2 reduced 32.80 kW, resulting in a total reduction of 166.48 kW. In this situation, the actual reduction per group is higher than the requested. Fig. 4 shows the update of number of elements per group for each Test 3 performed, according to their actual response: if Selected and answered lower than requested; Selected and answered higher than requested and Not Selected.

In order to evaluate each of these final tests, a set of assumptions was established regarding the actual response, generating some alerts if there were elements in these conditions. For instance, when a selected consumer reduced lower than the expected and the final reliability rate is higher than the previous: 13 consumers are in this situation for T3.1.1 (null weight for HR). Test 3 with lower number of warnings was T3.2.1, where the LDR had no influence.

Table 5: Test 2.1 – Scheduling Results

Group	1	2	3	4	5
# Initial Elements	180	113	65	46	2
# Selected (Test 2.1)	0	0	38	21	1
Requested (kW)	0	0	70.73	28.50	0.77
Actual (kW)	0	32.80	92.56	39.52	1.61
Total Reduction (kW)	166.48				

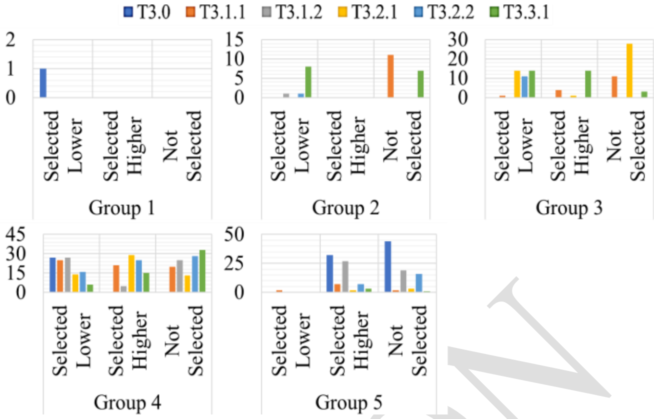

Fig. 4: Test 3 – Number of elements per group (Test 2.1)

For the following test, Table 6 presents initial and selected elements and the reduction results per group. Highlighting the fact that Group 5 don't have elements in this test.

Table 6: Test 2.2 – Scheduling Results

Group	1	2	3	4	5
# Initial Elements	180	119	59	48	0
# Selected (Test 2.2)	0	0	36	24	0
Requested (kW)	0	0	68.82	31.18	0
Actual (kW)	0	37.00	73.57	39.18	0
Total Reduction (kW)	149.75				

In order to achieve the 100kW for the DR target, 36 elements from Group 3 and 24 from Group 4 were selected, reducing a higher value than the expected as group. Also, Group 2 elements reduced without being selected.

Fig. 5 shows the updated reliability rate for the consumers who participate in the DR event, selected and not selected.

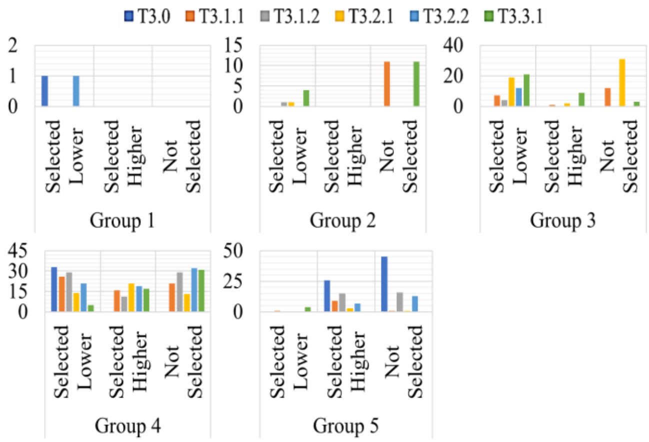

Fig. 5: Test 3 – Number of elements per group (Test 2.2)

The test that generates more warnings was T3.1.1 and the one with better performance regarding this matter was T3.2.1. Finally, the scheduling results from Test 2.3 are presented in Table 7 and the updated number per group according to the actual response in Fig. 6. It can be concluded that when weights are equal, better performance was achieved. Also, in cases where the LDR could not be included, the CR should be higher than HR.

Table 7: Test 2.3 – Scheduling Results

Group	1	2	3	4	5
# Initial Elements	180	119	64	43	0
# Selected (Test 2.3)	0	0	41	19	0
Requested (kW)	0	0	75.89	24.11	0
Actual (kW)	0	36.49	79.37	34.00	0
Total Reduction (kW)	149.87				

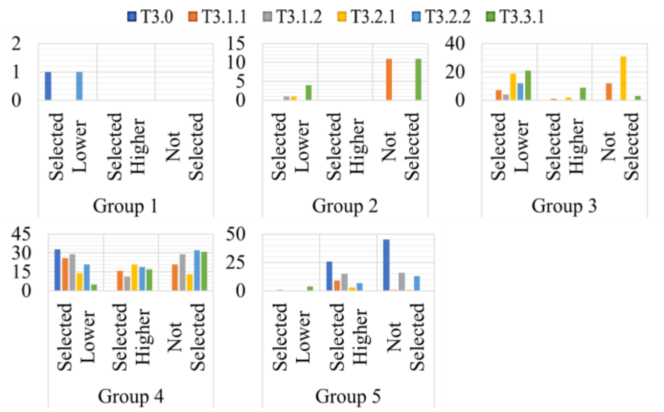

Fig. 6: Test 3 – Number of elements per group (Test 2.1)

In order to further study the result combination in this case study, the following parameters are now selected: the final reliability rate from Day (D-1) has 60% of influence from the CR and 40% from HR (Test 1); the initial rate to Day (D) is composed by 50% of LDR and 50% of HR (Test 2); the final reliability rate for Day (D) used 33% of each independent rate.

Looking at the elements that were not selected to participate, Group 2 was the one with higher reduction. Highlighting the fact that consumers with this characteristic, were not selected and yet reduced, had a CR = 5. All the 25 elements from initial Group 2, through this combination of weights for independent rates, were able to move up to Group 3. The elements not selected from initial Group 3, six of them were able to increase their rate. Regarding Group 4, only two ascents to a higher group since their HR was 4 and the LDR was 5. The consumers selected which had a lower response than the expected stayed in the initial group. Regarding the elements from Group 3 which were selected and reduced higher than expected, only one stayed in the same group, the remaining saw their updated rate increase one level. The final Group 5 is constituted by two elements: one who managed to ascend from Group 4 and another who, by answering the higher than requested, managed to keep up.

6. CONCLUSIONS

To achieve a DR target and deal with the uncertainty from small resources, the authors present a solution to manage local communities. According to the actual response to requested reductions, each consumer has independent rate associated: historical information (HR), information from the reduction of the previous day (LDR) and the reduction from the current period (CR). According to the stage of the model, these independent rates will be used to form the final reliability rate for the studied period. The goal was understanding the influence of each independent rate in the final result, in the several stages of the model. When there is no information on the previous day, CR should have more influence. The speed of change of reliability group depends on this factor and thus, the higher its weight, the higher the rate update of a given consumer. However, HR must also be considered to control abrupt variations. In the case where the three independent rates were used, the assignment of equal weights obtained the best performance. As future works, independent rates should be analysed; same study for different days focusing on one consumer, i.e., how the long-term variation weight of CR influence in an individual consumer. Another assumption that can be interesting is the limitation of the actual amount of reduction: if the total reduction is higher than the DR target, the Aggregator will have no advantage in reducing the value above offered by the consumer but that information can be used to improve the reliability rate of the nominated consumer.

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