Demand Response in Energy Communities Considering the Share of Photovoltaic Generation from Public Buildings

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***Abstract*—This paper has as ambit to promote the importance of the prosumer and the sustainable development of a community's energy systems through the aid of the incorporation of renewable energy sources in the market and the concept demand response. Moreover, it is intended to efficiently use the energy surplus produced by the photovoltaic panels of the prosumers for self-consumption, distributed by the remaining members of the community. It is estimated that participants, through the energy management of the community, will be able to verify reductions in electricity bills, as well as be compensated for their contribution to demand response through remuneration. Thus, the proposed methodology contributes in an efficient and sustainable way to be implemented in a community, promoting the use of renewable energy.**

Keywords*— Demand Response, Energy Communities, Prosumers

Nomenclature

Acronyms

AC - Air Conditioner
WH - Water Heater
FH - Fan Heater
WM - Washing Machine
DW - Dishwasher
IL - Initial Load
FL - Final Load
PC - Pretended Cut
PV - Photovoltaic

Parameters

P_a - Power of the Appliance
P_{pv} - Power of the Photovoltaic

Variables

SPV - Total production from Photovoltaic
S_a - Total consumption related to appliance **a**
SC_a - Total of the Cuts of the appliance **a**
DP_i - Delta Power (Cut) in appliance type **i**

Indexes

a - Appliances (WH,AC,FH,WM,DW)
i - (1,2,3,4,5)

I. Introduction

With current technological developments, we can see that, in the energy market, the development of sustainable solutions is becoming more and more prominent, namely in the scope of smart grids [1], [2]. In this context, Smart Grids accompanies all processes from electricity generation to distribution and consumption through an electric system that uses bi-directional information communication technologies to achieve a system that is sustainable, efficient, and safe. [3]. Therefore, the demand for the implementation of decentralized and distributed electrical systems, rather than centralized electrical systems, is growing namely in the context of aggregators [4], [5]. The aggregated management of resources and consumers is currently also addressed as communities where the consumption of electricity to satisfy the socio-economic needs of a given community is targeted, namely by implementing Demand Response (DR) programs [7]. Thus, implementing decentralized and distributed electrical systems will contribute to the utilities to have more significant contact with the processes of production, distribution, and consumption of electricity, allowing them to become more active and to increase their knowledge on this subject [8].

In this context, when users consume and produce energy at the same time, makes them present a dual role, designated "Prosumer" [9], [10]. Aggregation of prosumers is also a possibility, namely in the context of buildings participation in DR programs [11]-[13]. However, it is noted that there are difficulties in finding a group of prosumers who can support the community in improving the efficient energy management in a cooperative way [9].

The concept of Energy Community, in which it is aimed to take the most significant possible advantage of the energy management of a locality, it is intended to use local energy resources with greater efficiency. Demand response is very relevant in this field as it allows to accommodate the diverse variations in the energy resources distributed based on natural sources as well as allows to adjust the process of alteration of the electricity in the market in real time, providing flexible and efficient management of the resources. [4], [6].

This paper presents a methodology driven to the use of DR program in the context of an Energy Community, where it benefits from the renewable energy produced by PV panels. The main objectives are to efficiently use the excess energy generated by the PV panels found in public buildings as well as to reduce the energy billing of the consumers, providing flexible loads with reduction of consumption or capacity of changing the consumption. Moreover, the consumers who

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contribute to this study will be compensated by remuneration resulted from the excesses of energy produced by PV.

In fact, the generality of the previous works addresses economic models based on optimization of resources use and optimal design of incentives for renewables use, namely photovoltaics. However, the specific problem and objective of this paper, which is innovative itself, relies on the definition of the way to share benefits of photovoltaic generation installed in public buildings so the energy community benefit from such profits. Demand response is applied in order to make the energy management more effective. The developed method proposes to share de photovoltaics benefits along the demand response participants according to the actual contribution.

Section I depicts the introduction to the theme and the main purpose of the paper in question. In section II, shows the flowchart of the methodology discussed, where all phases of the proposed model will be explained in section III. In section IV describes in detail the case of study of this article. The results of the selected scenario will be analysed in section V. Finally, section VI presents the main conclusions drawn from the work developed.

II. Approach

In this section, the proposed methodology will be presented in a detailed manner. Figure 1 shows the different phases of the business model proposed by the authors and a general description of each task.

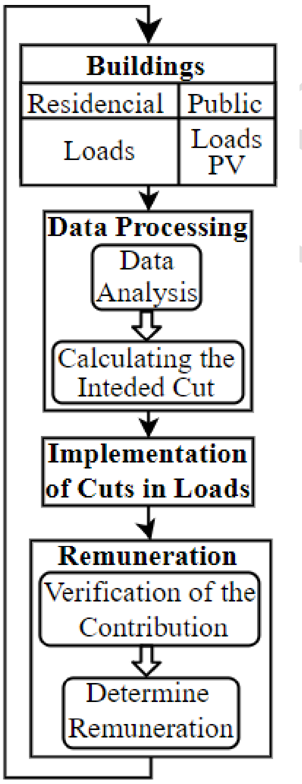

Fig. 1. Proposed methodology.

As can be seen in figure 1, the information that will later be treated comes from Public and Residential buildings, where these provide data on the power consumed by the loads and the energy produced by the PVs. However, only a small amount of residences is that it has PV panels installed. On the other hand, both also send the respective values of the tariffs that allow quantifying the expenses of their consumption. This information is collected in periods of 15 minutes where at the end of the day are 96 periods.

III. Problem Formulation

Regarding the Data Processing phase is concerned, it consists of two stages. The first step, Data Analysis, includes, for each period, to aggregate all the data of **n** consumers per load into one and, consequently, to determine the total power of the 5 loads consumed by all, that is, the IL. As you can see in the equations:

$$S_a = \sum_{k=1}^{n} P_{a(k)} \tag{1}$$

$$IL = \sum_{k=1}^{5} S_{a(k)} \tag{2}$$

After performing these calculations for each of the 96 periods, it is possible to elaborate a table that contains the initial charge of the community. Afterward, this procedure comes the Calculation of the Intended Cut, in which this part, taking into account the new data, consists of determining, by period, the cuts that are intended to act in the IL to find points of interest. That is points where it is meant to reduce consumption when energy is more expensive or to change consumption to time intervals where electricity is cheaper or where the production of PV panels is higher. The PC is calculated with the aid of the total power produced by the PV, and then the load cuts are applied in an orderly and individual manner to reduce the PC as much as possible to reach an acceptable value. Thus, succinctly, this phase intends to find the final value through the application of the complete incisions of the equipment in the PC. As for the PC and the SPV, these are calculated through the equations, where **m** is the number of existing PVs:

$$SPV = \sum_{k=1}^{m} \text{Ppv} \tag{3}$$

$$PC = IL - SPV \tag{4}$$

For the first cut, it's used the first appliance, WH:

$$Dp_1 = PC - SC_{WH} \tag{5}$$

For the second to the fifth cut, it is:

$$Dp_i = Dp_{(i-1)} - SC_{(a+1)} \tag{6}$$

Regarding the phase of Implementation of Cutting in Loads, it practically consists of applying indiscriminately, by period, the respective incisions calculated in the proper equipment in each building, that is, when applying the total cut of a specific apparatus, it is attributed in all the consumers who have values to cut, in order to reach an acceptable new state, this taking into account the final amount that is intended.

Concerning the Remuneration phase, this one presents two levels that are respectively a Contribution Verification and Determination of Remuneration. As for the first level, this is based on discovering, in each period, which consumers contributed to the application of cuts in each of the devices. Then comes the second stage in which, given the total energy cut applied in the community and the overall cut of all loads that each consumer applied, we can determine the percentage that each participant contributes to the study. Thus, together with the gain of the PV panels, the remuneration for each one is determined.

IV. Case Study

The main purpose of this section is to introduce the case study that was chosen to test the feasibility of the business model presented. The case study for the full paper will be based on a network community in the city of Alfandega da Fé, Portugal. Figure 2 illustrates the city map of Alfandega da Fé, by demonstrating the locations of the buildings available for this community.

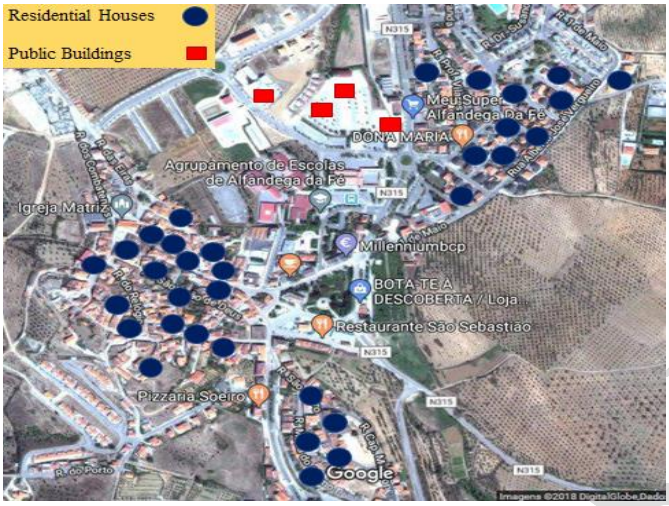

Fig. 2. Overview of the enrgy community area.

The network consists of 23 (33 houses but data of 23 houses are available) residential houses, and 4 public buildings including public Library, Municipal Market, Culture House, and City Hall. The main purpose of this case study is to survey the available electricity tariffs applied to these public and residential buildings. The public buildings and a few residential houses of this network community are equipped with PV system.

The library building has electricity contract with 34.5 kVA, and also is equipped with PV panels with 17.28 kW. The rated power of Municipal Market is 41.4 kVA, and also has 9 kW PV generation. Regarding the City Hall, there is an 8 kW PV system, with an electricity contract of 108 kVA.

Regarding the type of loads installed in buildings, the residences have different varieties of equipment, such as WH, AC, WM and DW, while the public only has AC and individual units of heating, i.e., FH.

TABLE I shows the number of units each consumer has of equipment as well as shows the total power spent by the loads and the total power consumed by all the appliances, for a day and in kW. On the other hand, it also reveals the type of consumer, through the letters R and P where the first represents the Residences and the second the Public and also discloses the tariff for each consumer in which there is only the bi-hour or three-hour tax. Regarding the variants to be tested, 4 cases will be elaborated to study the conduct of the community concerning the cuts of the equipment applied.

TABLE I. Information about the Consumers

Consumers	Type	#PV	P.PV (kW)	#AC	P.ACs (kW)	#WH	P.WH (kW)	#FH	P.FH (kW)	#WM	P.WM (kW)	#DW	P.DW (kW)	T.Power (kW)	Tariff	
															Bi	Tri
1-House	R	-	-	5	3,42	1	7,84	-	-	-	-	1	4,95	76,64	X	
2-House	R	-	-	2	6,57	1	3,16	-	-	-	-	1	0,39	43,06	X	
3-House	R	-	-	3	10,94	1	0,77	-	-	1	0,63	1	0,81	58,55	X	
4-House	R	1	1,5	1	12,46	1	0,63	-	-	1	0,91	1	1,60	64,23	X	
5-House	R	-	-	2	2,46	-	-	-	-	1	0,31	1	2,54	52,31	X	
6-House	R	-	-	2	0,46	-	-	-	-	-	-	1	1,11	48,11	X	
7-House	R	-	-	1	0,11	1	3,26	-	-	-	-	1	0,44	56,57	X	
8-House	R	1	1,5	3	3,09	1	0,86	-	-	-	-	1	0,15	31,49	X	
9-House	R	-	-	1	16,72	1	0,61	-	-	1	0,31	1	0,56	62,15	X	
10-House	R	-	-	2	0,15	-	-	-	-	-	-	-	-	22,25	X	
11-House	R	-	-	1	0,97	-	-	-	-	-	-	-	-	41,62	X	
12-House	R	-	-	1	-	-	-	-	-	-	-	-	-	7,92	X	
13-House	R	-	-	1	0,11	-	-	-	-	-	-	1	1,14	36,59	X	
14-House	R	-	-	2	0,04	-	-	-	-	-	-	-	-	21,57	X	
15-House	R	-	-	-	-	-	-	-	-	-	-	-	-	23,51	X	
16-House	R	-	-	2	16,01	-	-	-		-	-	-	-	32,67	X	
17-House	R	-	-	-	-	-	-	-	-	-	-	-	-	14,08	X	
18-House	R	-	-	2	2,42	-	-	-	-	1	0,54	1	1,51	37,06	X	
19-House	R	-	-	-	-	1	0,79	-	-	-	-	1	0,20	45,22	X	
20-House	R	-	-	3	0,26	-	-	-	-	-	-	-	-	22,31	X	
21-House	R	1	1,5	3	19,21	1	3,33	-	-	1	10,94	1	1,33	148,57	X	
22-House	R	-	-	2	0,81	-	-	-	-	1	0,51	1	1,28	37,33	X	
23-House	R	1	1,5	1	1,20	-	-	-	-	-	-	-	-	36,62	X	

24-Culture H.	P	-	-	6	645,60	-	-	1	18,00	-	-	-	-	929,16		X
25-Library	P	1	5	6	180,40	-	-	1	11,60	-	-	-	-	429,53		X
26-City Hall	P	1	5	6	424,20	-	-	1	7,40	-	-	-	-	529,88		X
27-M. Market	P	1	5	3	45,30	-	-	1	8,60	-	-	-	-	109,03		X

TABLE II shows the information of the different variants for each case where the first column refers to the peak value reached on the day and the second refers to the peak value from which the cuts in the respective loads will be implemented if the IL is higher than this, in each period. The third column indicates the number of periods in which the cut was made and the fourth column indicates the type of day of the week, being BD and WE, respectively Business Day and Weekend.

TABLE II. CASES OF STUDY

	Peak load [kW]	Target peak load [kW]	Nº of activation periods	Week day	PV (%)
Case1	39	35	7	BD	B
Case2		35	7	WE	B*150
Case3		36	3	BD	B
Case4		38	1	BD	B*150

It should also be noted that the term BD means that both public and residential buildings apply cuts to the equipment while in the WE only the residences apply them. Finally, the fifth column shows the percentage added to the base value (B) produced by the PV that will later be used to compute the respective calculations.

Taking into account the equations shown in Chapter II, it is possible to delineate the graph that explains the behavior of the loads and the PVs of the community in one day, as can be seen in Figure 3.

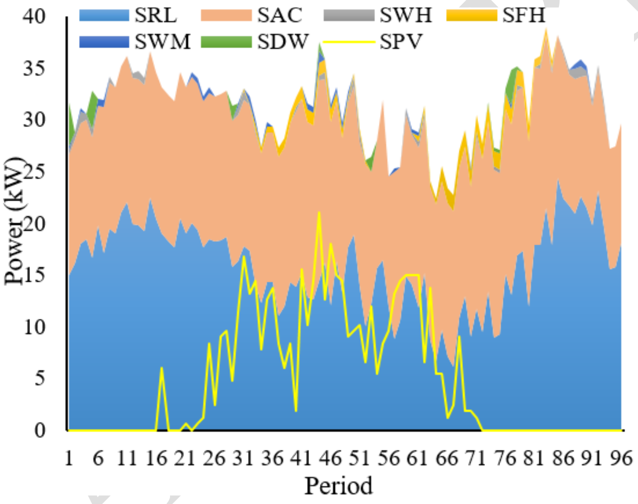

Fig.3. Behavior of the Appliances and PV on the Community.

V. RESULTS

Throughout this section will be presented and analysed the results of the study conducted to the proposed methodology in relation to the different cases.

Concerning Case 1, shown in Figure 4, this shows the initial total community consumption (SIL), where it consists of rigid load (SRL) and flexible load (SFlexL), in which the latter represents all equipment. The SFL is the total final consumption of the community that characterizes the expenditure after the application of cuts in the appliances, in due periods where it was intended to reduce the power consumed. On the other hand, the SPV represents the total production of photovoltaic power throughout the day, illustrating the points where there was greater sun exposure. Finally, the Grid, it represents the SIL after applying the cuts in the equipment and also the gains of the photovoltaic production. It is noteworthy that in the period 44, the Grid is 0 since the incisions in the apparatuses and the gains of the photovoltaic production were enough to annul the SIL. On the other hand, between periods 44-45, it is possible to verify that SPV is higher than SFL, which indicates that there is a photovoltaic excess that represents monetary benefits.

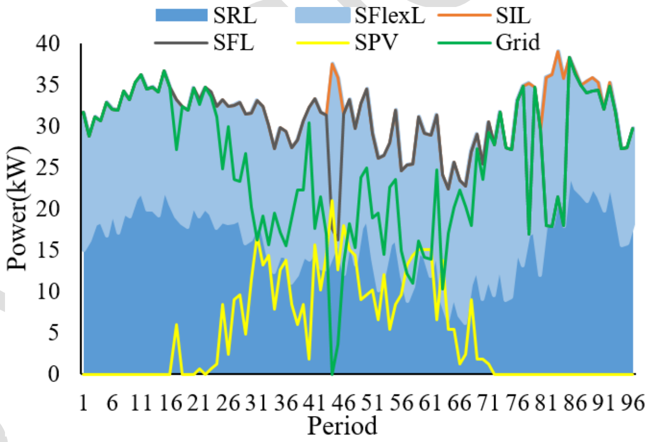

Fig.4. Initial and Final consumption from the Community, in Case 1.

With regard to Figure 5, this illustrates the cuts that have been applied to the respective equipment of each consumer, however, this only reveals the residential consumers, since in case 2, it treats the days of the weekend.

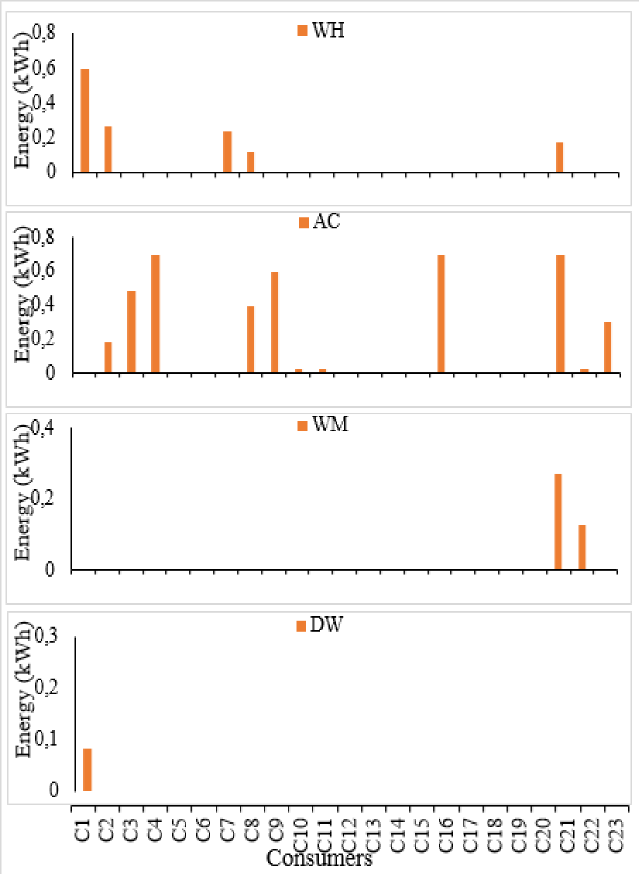

Fig. 5. *Cuts applied to each Consumer Load, in Case 2.*

On the other hand, these graphics do not present the FH device, since it is only installed in public buildings. With the analysis of the graphs, we can see that, in this case, a large part of the cuts were applied in the ACs, which we can conclude from this moment is that it causes more impact when applying the incisions. This figure also allows you to highlight which are the main participants who consume more but also can highlight, in a certain way, the amount of equipment they have or use in their daily lives.

Throughout Figure 6 and 7, it is intended to highlight the largest Residential and Public consumer, emphasizing in each one the total expenditure (IL) in one day, but also highlights the periods and the respective equipment where the incisions were applied.

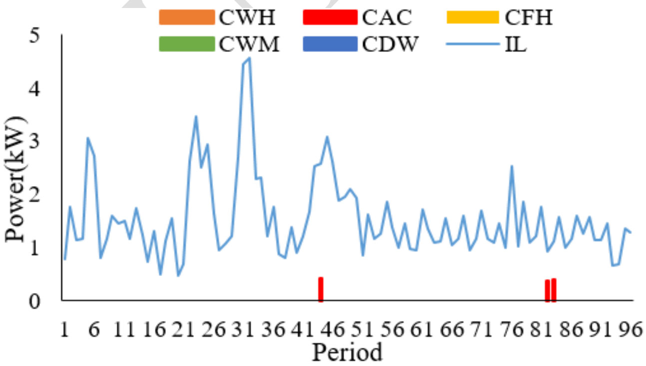

Fig. 6. *Largest Residential Consumer, in Case 3.*

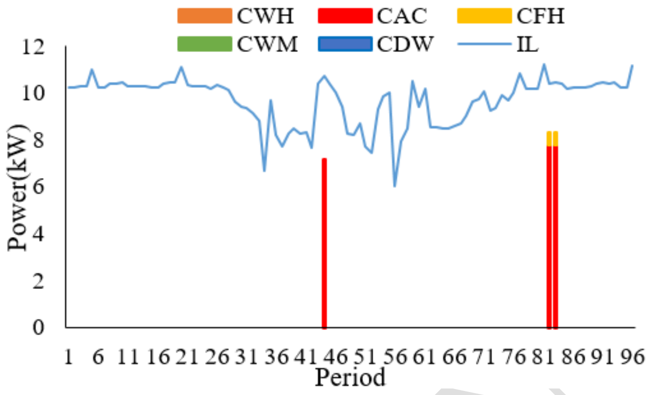

Fig. 7. *Largest Public Consumer, in Case 3.*

Through these figures, it is also possible to verify the difference between the level of consumption and the level of cuts between the two types of buildings, where the public is the predominant one.

Figure 8 illustrates the behavior of each case in various aspects. The first graph serves to show and highlight the decrease in consumption after the application of cuts in the respective equipment, in each case. In which the MaxIL, represented in blue, shows the highest value of IL verified during the 96 periods where the incisions will be applied, while the MaxFL, described in orange, illustrates the IL after the cut. It should be pointed out that in case 2 the decrease in consumption was lower than the others since public buildings do not participate in the implementation of the cuts in the weekend days.

Concerning the second graph, this is similar to the first one, highlighting through TIL, represented in blue, the total IL of the community in one day and with TFL, represented by orange, the total consumption after the cut. This graphic is intended to enhance the impact that incisions can cause to the community. As for the third graph, it serves to show, respectively, the number of consumers and varieties of equipment that contributed to the study.

Finally, the fourth chart emphasizes the remuneration attributed to consumers, where blue highlights the value that the public benefited from their participation, while the orange shows the amount that the houses have profited. It is noteworthy that in case 2, there is no remuneration for the public since in this case, they do not apply cuts for WE.

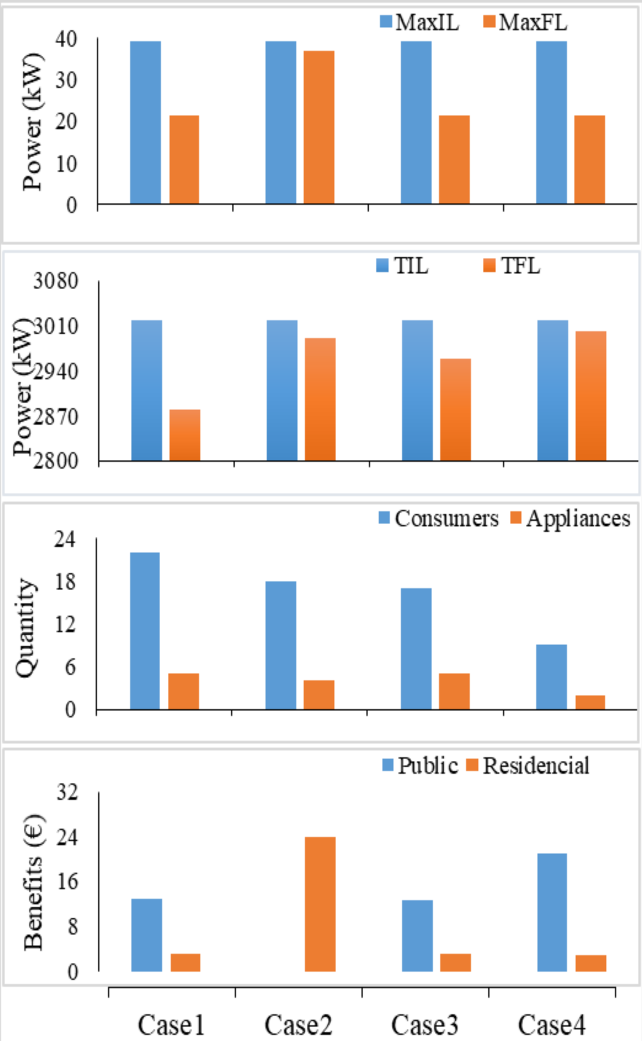

Fig. 8. Behavior of each Case.

In order to complete this paper, calculations are made on the remuneration of some consumers to see what the gain would be over a month. Through the compensations calculated for each of the consumers in each case, it is possible to prepare the calculation, where it will show the gain for the residential consumer that has the highest consumption and for the one that has the lowest use. Subsequently the same is done for the largest Public consumer.

If we consider that C1, C2, C3, and C4 are the remunerations of a consumer for each case, then the formula consists of practically multiplying them by a number of days of the month. Only in case 2, the number of days is fixed, since it represents the weekend, and since one month has four weekends, it multiplies by eight days. For the remaining cases, the days are distributed to create a possible scenario taking into account the season of the year, highlighting more the days where there is higher production of PV energy which, in turn, implies days with greater sun exposure. After calculating the remuneration, the values obtained for the Residences are:

Largest consumer: 54,11 €

Smallest Consumer: 8,27 €

For the public consumer, only the calculations are made for the largest consumer, where the result is: 198,45 €

VI. Conclusions

The work presented in this paper was made in the context of energy communities with PV generation and demand response programs available. The proposed methodology relies on the energy put into the grid by self-consumption units which are in public buildings so the obtained benefits are intended to be shared with all the members of the community.

During the daily operation of the energy resources in the community, demand response is used in order to reduce peak power. Then, the benefits of the self-consumption in public buildings are shared among consumers providing demand response, in the proportion of the share of the reduced energy consumption provided.

It was shown the amount of benefits that can be shared with different consumers providing demand response while it is a rather simple and fair remuneration scheme for demand response participation. The schedule and activation of individual appliances was also shown for each consumer in the community.

References

[1] R. Bucher, "Smart grid functionality for the high-voltage transmission grid: On the market readiness of Digital Substation 2.0 technology," *2017 Saudi Arab Smart Grid Conf SASG 2017*, pp. 1–4, 2018.

[2] A. Nur and A. Kaygusuz, "Load control techniques in smart grids," *4th Int Istanbul Smart Grid Congr Fair, ICSG 2016*, pp. 1–4, 2016.

[3] E. Espe, V. Potdar, and E. Chang, "Prosumer Communities and Relationships in Smart Grids: A Literature Review, Evolution and Future Directions," *Energies*, vol. 11, no. 10, p. 2528, 2018.

[4] P. Faria, J. Spínola, and Z. Vale, "Methods for Aggregation and Remuneration of Distributed Energy Resources," Appl. Sci., vol. 8, no. 8, p. 1283, 2018.

[5] C. Silva, P. Faria, and Z. Vale, "Assessment of Distributed Generation Units Remuneration Using Different Clustering Methods for Aggregation," 2018 IEEE Int. Conf. Commun. Control. Comput. Technol. Smart Grids, SmartGridComm 2018, 2018.

[6] O. Abrishambaf, P. Faria, and Z. Vale, "Participation of a Smart Community of Consumers in Demand Response Programs," *Clemson Univ Power Syst Conf PSC 2018*, pp. 1–5, 2019.

[7] A. Asadinejad, A. Rahimpour, K. Tomsovic, H. Qi, and C. fei Chen, "Evaluation of residential customer elasticity for incentive based demand response programs," Electr. Power Syst. Res., vol. 158, pp. 26–36, 2018.

[8] H. Yves and S. Teufel, "Prosumer communities: Electricity as an interpersonal construct", 2016 Int. Conf. Smart Grid Clean Energy Technol. ICSGCE 2016, pp. 89–94, 2017.

[9] O. Abrishambaf, P. Faria, and Z. Vale, "SCADA Office Building Implementation in the Context of an Aggregator," in 2018 IEEE 16th International Conference on Industrial Informatics (INDIN), 2018, pp. 984–989.

[10] M. Fice and K. Debowski, "Energy management in a semi off-grid prosumer micro system," *2016 Sel Issues Electr Eng Electron WZEE 2016*, pp. 1–6, 2016.

[11] A. Qureshi, I. Lymperopoulos, A. A. Khatir, and C. N. Jones, "Economic Advantages of Office Buildings Providing Ancillary Services With Intraday Participation," IEEE Trans. Smart Grid, vol. 9, no. 4, pp. 3443–3452, Jul. 2018.

[12] T. Mega, S. Kitagami, S. Kawawaki, and N. Kushiro, "Experimental evaluation of a fast demand response system for small/medium-scale office buildings," *Proc - 31st IEEE Int Conf Adv Inf Netw Appl Work WAINA 2017*, pp. 291–295, 2017.

[13] P. Faria, J. Spinola and Z. Vale, "Aggregation and Remuneration of Electricity Consumers and Producers for the Definition of Demand-Response Programs", IEEE Transactions on Industrial Informatics, vol. 12, no. 3, pp. 952-961, 2016