ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
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Consumer control in Smart Grids
Second ELECON Workshop

Institute of Electrical Energy Systems – Otto-von-Guericke-University, Magdeburg, Germany,

October 28-29, 2014.

Consumption Management of Air Conditioning Devices for the Participation in Demand Response Programs

Fernando Barrias[a], Pedro Faria[a], Zita Vale[a,1]*

[a] *Polytechnic of Porto, R. Dr. Antonio Bernardino almeida, 431, 4200-072, Porto, Portugal*

Abstract

Demand Response has been taking over the years an extreme importance. There's a lot of demand response programs, one of them proposed in this paper, using air conditioners that could increase the power quality and decrease the spent money in many ways like: infrastructures and customers energy bill reduction.

This paper proposes a method and a study on how air conditioners could integrate demand response programs. The proposed method has been modelled as an energy resources management optimization problem. This paper presents two case studies, the first one with all costumers participating and second one with some of costumers. The results obtained for both case studies have been analyzed.

Keywords: Air Conditioners; Demand Response; Direct Load Control; Energy Resource Management.

1. Introduction

With the spread of distributed energy, and the increase of energy consumption by different types of consumers, demand response (DR) takes higher importance. This paper suggests using a DR program to reduce consumption by the air conditioner for a short period of time. It is therefore necessary to lay down certain rules that define where it will be reduced the energy consumption by air conditioner. It has been implemented an optimization problem for this, based on several variables, including the cost of energy consumed and of the produced energy and to their respective powers.

The present section makes the introduction to demand response programs, air conditioning consumption trends, and to the opportunities for the air conditioning to participate in DR programs.

1.1. Electric Energy Consumption Trends

Since electric power systems exists, the value of the energy consumed worldwide is increasing, thanks to various reasons like: increase population, better quality of life, increase of electrical equipment

* Corresponding author.
E-mail address: zav@isep.ipp.pt.

and others. World electricity generation increases by 93%, from 20.2 trillion kilowatt-hours in 2010 to 39.0 trillion kilowatt-hours in 2040 [1].

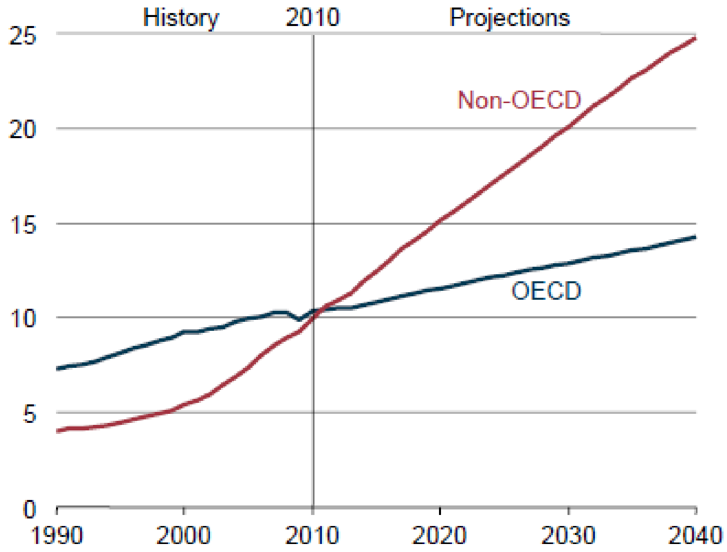

Fig. 1 Electricity generation by country in trillion kilowatt-hours (1990-2040) [1]

In fig. 2, one can see the electricity generation by sector, notice that the residential sector is the sector with the major increase of electricity consumption [2].

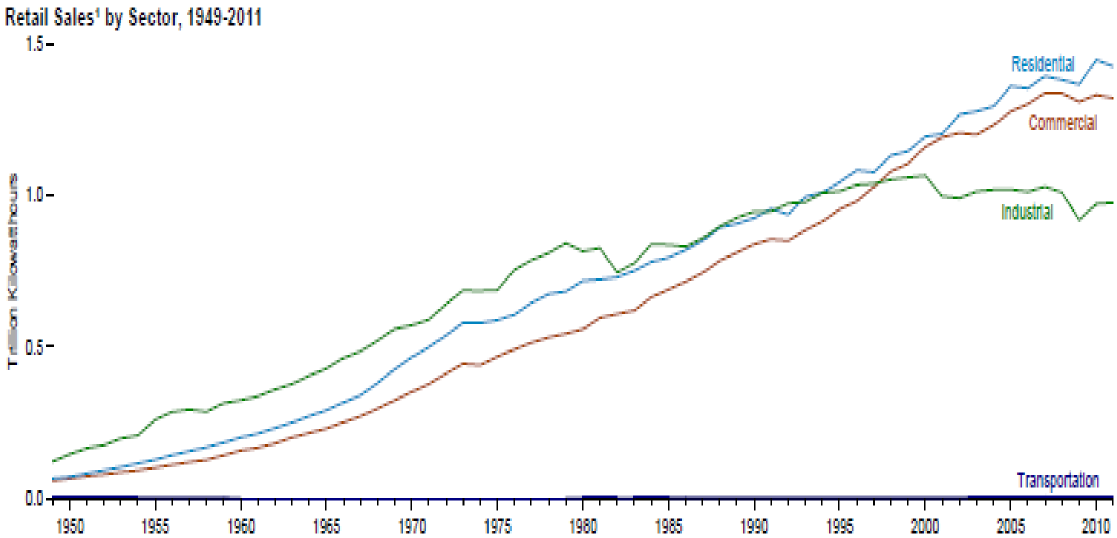

Fig. 2 Retail Sales by Sector (1949-2011) [2]

As for final, consumption by equipment, taking the example of housing, this has been changed over the years. Between 1993 and 2009, household appliances, lighting and heating are the equipment that has undergone major changes, having come to consume less and less energy, to the contrary, it has increased energy consumption are the handsets air conditioning [3].

The future trend in the residential sector between 2011 and 2040, is a continuation of what has been observed a reduction in lighting, water heating and appliances and a slight increase in air conditioning and ventilation [3]. The commercial sector will encounter a bit of what happens in the residential, except that here the air conditioning and ventilation, it is expected that tended to decrease in the period between 2011 and 2040, this decrease is the result of technological developments consequent increased energy efficiency of these devices, as seen in fig.3. [3].

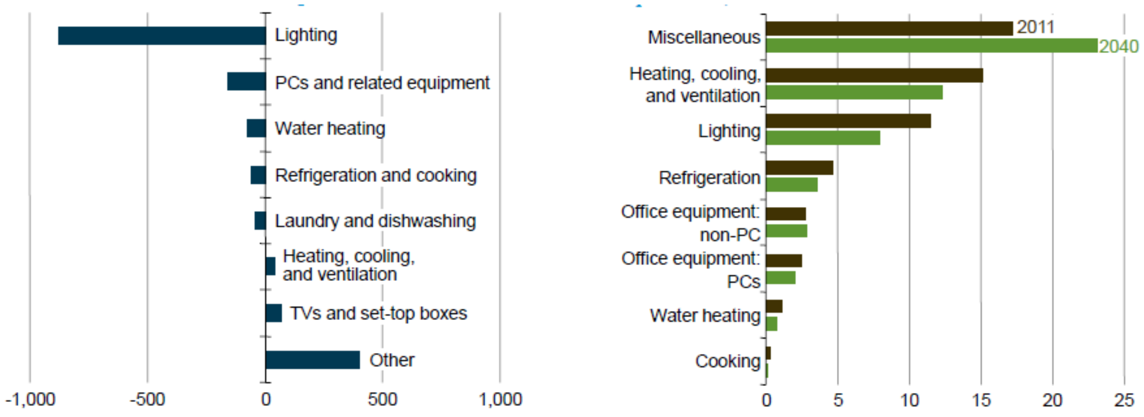

Fig. 3 . (a) Future trends in domestic houses, units kWh (2011-2040) [3] (b) Future trends in commercial houses, units btu (2011-2040) [3]

1.2. Demand Response programs

It's important for electric power systems, offering high reliability and lest there be power outages for consumers. When, for example, energy demand exceeds supply or when electricity costs are high energy provider asks and pays for the end customer help in reducing energy consumption. A good power management enables a lower cost and helps prevent service interruptions. [4 5]

There are several DR programs that have been developed over the years, as there are different environments from the production of energy by the type of customer, each DR program has better advantages when applied in the right [4] situation.

The DR programs can be divided into two distinct [4] categories: price-based or incentive-based. The programs are based on price-related changes in energy consumption by customers due to changes in its cost. These programs are [5,6]:

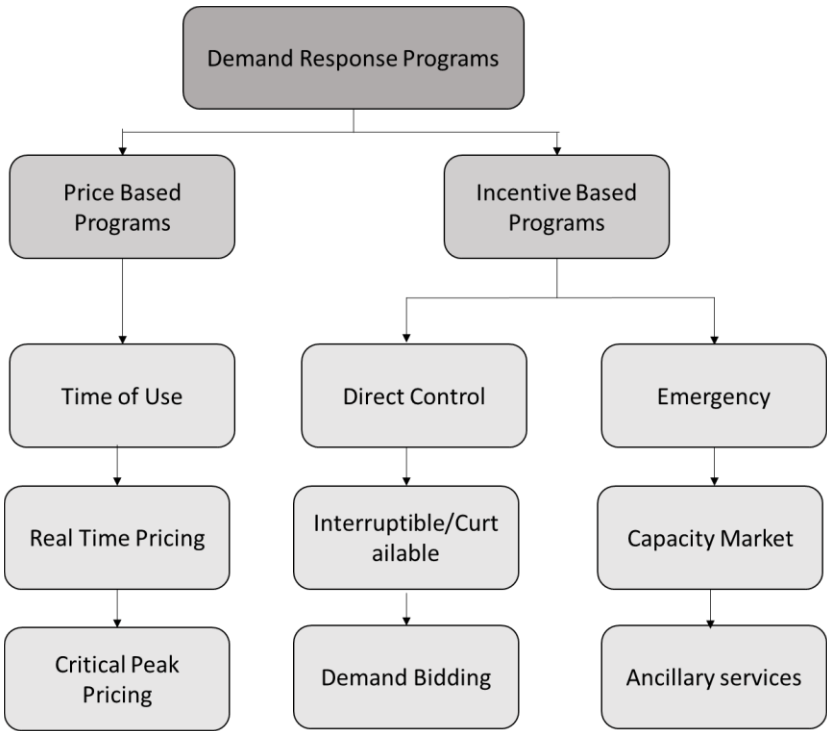

Fig. 4. DR programs classification [5, 6]

Price Based Programs

• Time Of Use (TOU): Different rates for each time period of the day.

• Real Time Pricing (RTP): The price is set for a given period of time, usually one hour.

• Critical Peak Pricing (CPP): It is a mixture of the two mentioned above, but with a price higher peak, which is used in specific situations.

Incentive Based Programs

• Direct Load Control (DLC): This is a program that remotely controls the electrical appliances, mainly used in homes or small trade.

• Interruptible / Curtailable Programs (ICS): It is based on the curtailment or interruption, reducing power consumption during periods of contingency. It is used in industries.

• Demand Bidding / Buyback (DBB): Customers who want to bid the cut. It is used in large power consumers.

• Emergency DR (EDR): On meeting with the programs and direct load control in Adjournment / Cutting Service, where the buffer becomes insufficient.

• Capacity Market (CM): load is cut to customers as the market for it is not necessary to power generation.

• Ancillary Service (AS): Similar to the bidding program, although only the market for auxiliary services.

1.3. Air conditioning and DR

With the increase of units of air conditioners, as can be seen in the graph of Fig 5 air conditioners becomes a possibility to integrate DR programs because there largest consumers of power they can be removed. Note that the application of a DR program of this kind could be more advantageous in some countries, especially where there are a greater number of AC unit and that they are used more frequently. In the fig. 5 only includes certain countries, for detailed consultation with all countries we suggests that you consult the reference [7].

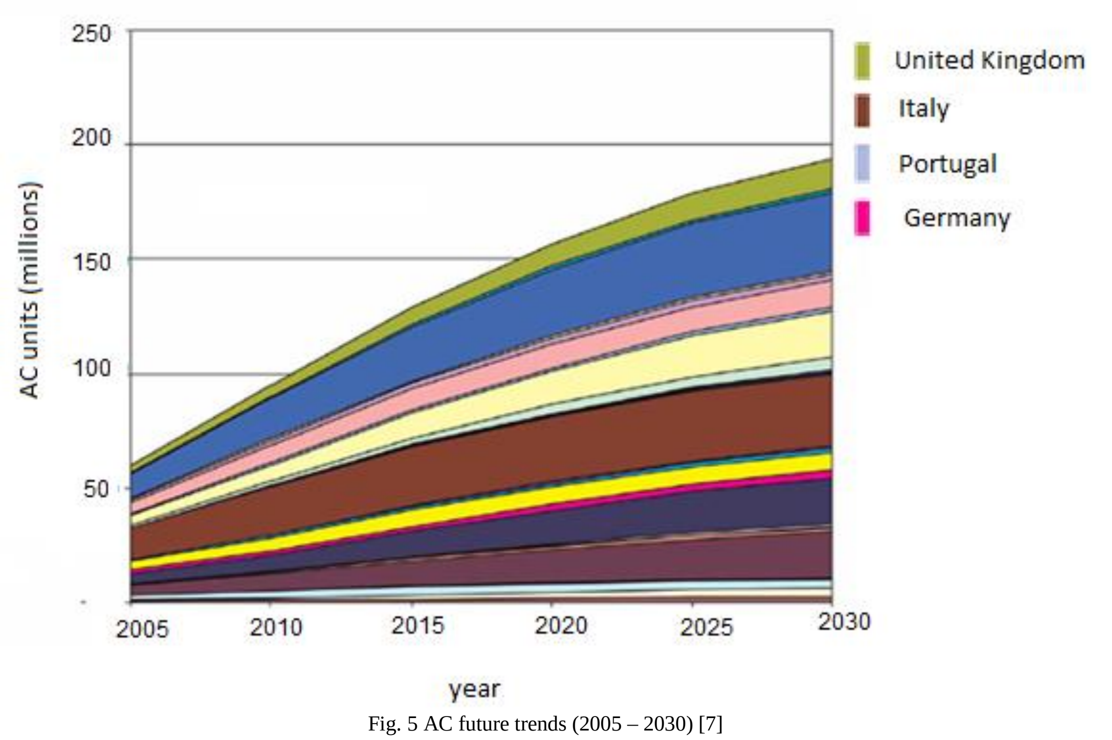

Fig. 5 AC future trends (2005 – 2030) [7]

The air-conditioned, offering good features to integrate in a DR program. Some of these features are the possibility of remote control to turn off or reduce the level of cooling can be turned off during periods eg 15 minutes without it materially affect the comfort of the people. Thus it is possible to control the air conditioners energy remotely, turning them off when necessary [8].

This time period may be increased or decreased according to some factors including the outside temperature or quality of isolation housing. Homes with good insulation can increase the period of time the air conditioner is switched off without affecting comfort, reducing energy consumption which turns into a decrease in the amount payable on the invoice to the distributor of energy. [9, 10]

For DR programs using the air conditioning, in general, do not yet exist in abundance. In Europe is still not present this type of programs related to air conditioning [11]. In the U.S.A. some distributor's mainly warmer zones are offering to the customers this type of DR programs.

2. Proposed resources management model

2.1. General Concepts

To do the management model, it took a few steps. Initially it was essential to obtain all data on the electric network. The data of the actual grid are: the price of energy per production technology, the type of consumer, the value of power consumption, the value of the power consumption of devices AC and the price of energy to the various types of consumers.

It is necessary to know the maximum possible power to be removed in AC per customer, as this is the maximum that can be reduced. Are also required to know the prices payable for each customer type for the optimization algorithm, minimizes costs to customers. The importance of power values generated their costs is also important for the production values are minimized and consequently the price is reduced by production technology. Known these values the next step was to apply them to an optimization problem, which in this case as aforesaid the software used was Matlab / Tomlab and Excel.

2.2. Optimization Problem

The strategy to use in solving the problem was with the optimization feature.

For the mathematical formulation first was necessary to understand and distinguish which are thr decision variables. Following the reasoning of the article studied [12] for the present study the variables that can be changed are the value of the power cut in AC and the power generated, these are the values obtained after the optimization problem solved, other costs and maximum possible powers to reduce initial and generated are fixed. With all the variables defined the next step was to identify the constraints and objective function of the problem.

The objective function and the constraints are:

Objective function:

$$\text{Min}\, C = \sum_{b=1}^{nb} (P_{MaxCut(b)} \times c_{Customer(b)} + P_{Gen(b)} \times c_{Gen(b)}) \tag{1}$$

Constraints:

$$\sum_{b=1}^{nb} (P_{\text{MinGen}(b)}) \leq \sum_{b=1}^{nb} (P_{MaxCut(b)} + P_{Gen(b)}) \tag{2}$$

$$P_{totalLoad} = \sum_{b=1}^{nb} (P_{MaxCut(b)} + P_{Gen(b)}) \tag{3}$$

Where:

$MinC$	Minimum cost (€/kWh)
$c_{Customer(b)}$	Customer energy cost (€/kWh)
$c_{Gen(b)}$	Generated energy cost (€/kWh)

$P_{MaxCut(b)}$	Maximum power cut in AC (kW)
$P_{Gen(b)}$	Power generated by the generators (kW)
$P_{MinGen(b)}$	Minimum power generated (kW)
$P_{\text{totalLoad}(b)}$	Power consumed by the load (kW)

The objective function (1) is to minimize the operation costs of the grid for both the production side and consumers.

The first constraint (2) requires that for a given bus at maximum cutting power in the air conditioning plus the power generated will have to be higher than the minimum generated power.

The second constraint (3) requires that the load power subtracted from the maximum cutting power must be equal to the power consumed by the load.

2.3. Management Model Diagram

As shown in the diagram of Fig. the first step is to obtain data on the network that are important to the application of the model, these are: the price of energy by type of production technology, solar, wind, hydro, biomass, etc.; energy prices for consumers; the generated power and the maximum power possible to reduce the AC. The price values are needed because as seen earlier are included in the objective function whose goal is to minimize costs, affecting both the producers and consumers, thus model will choose a final set of values with lower costs than the original. The values of powers are given to the moment before starting the DR program. Known these values are applied in optimization.

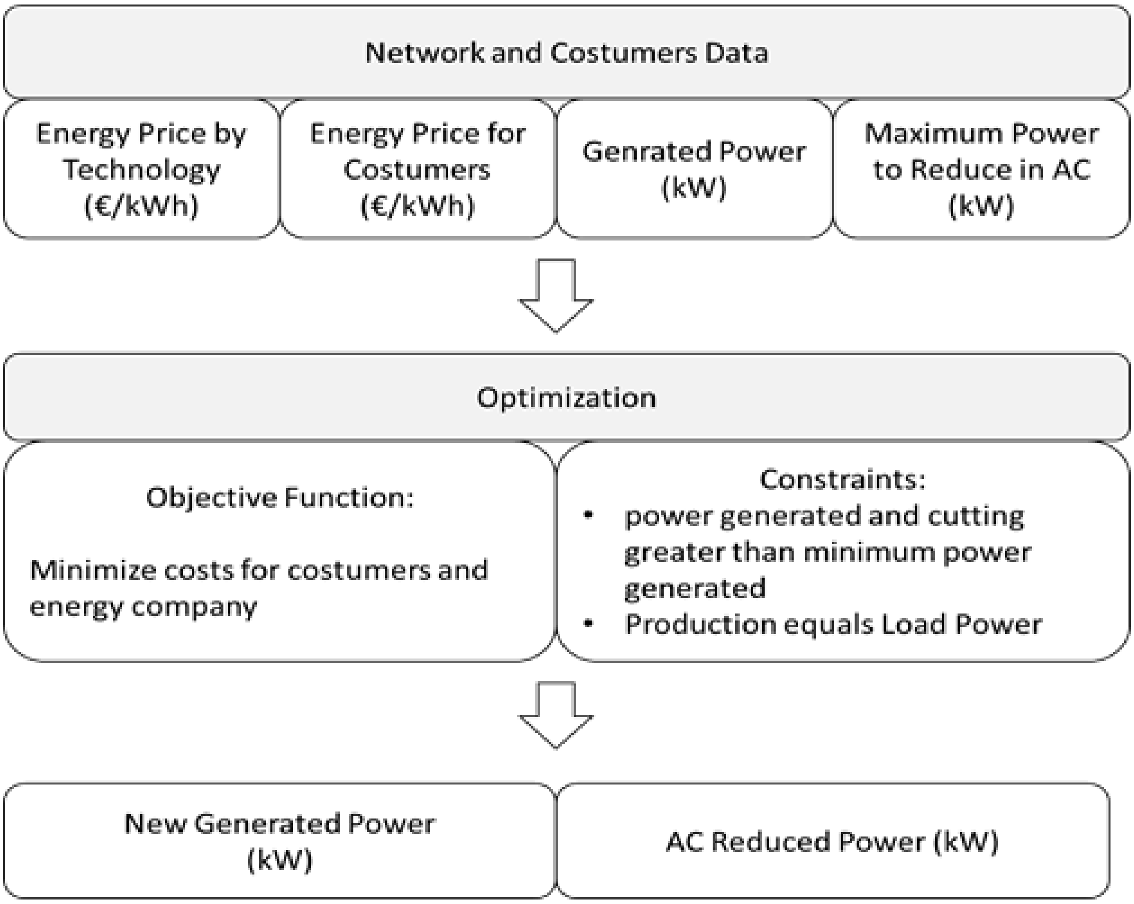

Fig. 6 – Implemented Model Diagram

In this paper we used *TomLab* to solve the optimization problem, the solver was cplex.

3. Case Study

3.1. Used Network

The presented scenario's is based on a distribution network used in [13], and showed in Fig.7.

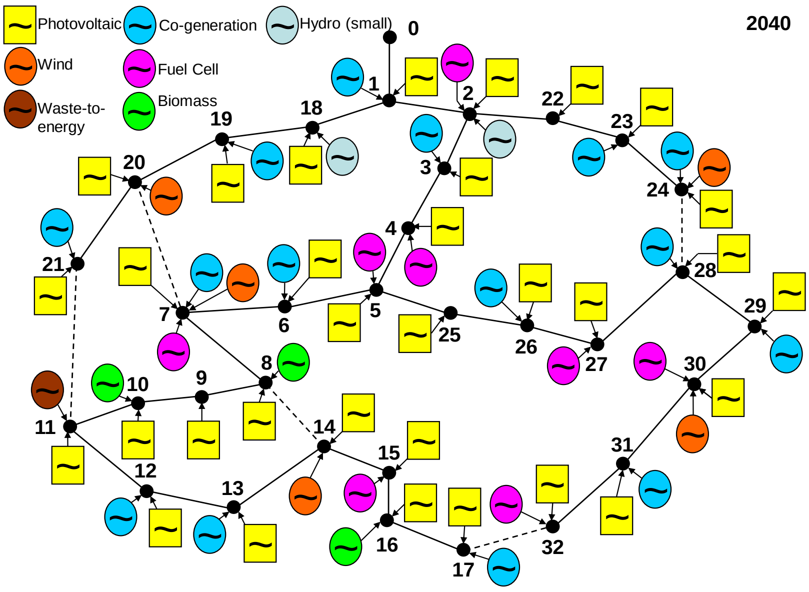

Fig. 7 – Distribution network [13].

There are 66 units of production. The total number of consumers is 218, and over the net present divided into the following classes: domestic (DM); small commerce (SC); medium commerce (MC); large commerce (LC); medium industries (MI) and large industries (LI).

As proposed in the model, we need to know electricity rates, energy costs (€ / kWh) for each type of consumer. These values are shown in Table 1. There are still more units power generation than those mentioned Fig.7, these are intended for special situations, such as a possible emergency, malfunction of any plant or even to consider the connection to the public distributor node 0 (Fig. 11). The value of production for these types of suppliers are followed by table 2-

Table 1 Price by consumer

Consumer type	Price (€/kWh)
DM	0,18
PC	0,19
MC	0,16
GC	0,20
MI	0,12
GI	0,14

Table 2 Additional suppliers

Source	Gen. Power (KW)	Price (€/kWh)
Supplier 1	1200	0,23
Supplier 2	800	0,24
Supplier 3	900	0,25
Supplier 4	1800	0,26
Supplier 5	800	0,26

Relying on these energy suppliers, the total energy when food was provided when the network was 8152.2 kW while consuming energy stood at 5827 kW.

To implement the management model is also necessary to get the AC portion of consumption on total consumption of a given installation. This value is the maximum value possible cut in AC. These percentages relating to the total consumption of AC consumption were obtained in accordance with the type of consumer, DM - Domestic consumers; SC - Small Commerce; MC - Medium Commerce, LC - Large Commerce, MI - Medium Industries and LI - Large Industries.

For the values of DM and SC had as the base document Annual Energy Outlook 2013 [3], where tables of energy consumption related to family dwellings and commercial buildings is described the amount and purpose of each type of consumption electric power, and the total consumption. These are values and annual btu units. Through these values we calculated the amount of energy consumed on the air conditioning using the values belonging to the cooling, these being 3.84btu and 1.77btu for DM and SC respectively.

$$DM = \frac{Space\ Cooling}{Total\ consumption} = \frac{3{,}84}{23{,}08} \cdot 100 \cong 16{,}6\%$$

$$SC = \frac{Space\ Cooling}{Total\ consumption} = \frac{1{,}77}{21{,}13} \cdot 100 \cong 8{,}37\%$$

Thus obtaining a value of 17% and 8% for DM for PC in 2040. The same process was followed for the remaining annual values 2010, 2020, 2030 and 2040.

Like the previous document did not contain the values for the remaining types of consumers, MC, LC MI and LI, these were extracted from a graph of this scientific article in the following bars: *A review on buildings energy consumption information* [14]. In the graph above listed consumptions hospitals, shopping centers and hotels, which are 30%, 42% and 41% respectively. Thus assigned them the values of the 30% MC and 42% of the LC and 41% for MI and LI.

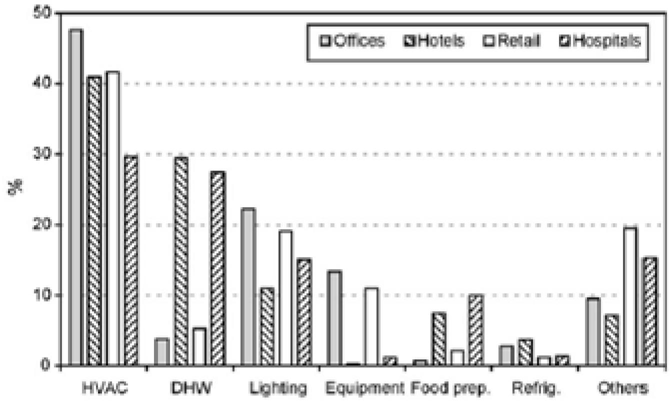

Fig. 8 Energy consumption by appliance

The values referred to in Article [14] correspond to the year 2003. Accordingly the values for the following years it was necessary from a criterion, this criterion was to make the extrapolation of values. As they were known for the 2003 MC LC MI and LI described above and removed from the graph of Figure 8, it was necessary to obtain the values of DM and SC in this year. These values were found in the *2003 Annual Energy Outlook 2005* document [15], these data from 2003 (MC and LC) is the extrapolation made by a simple rule of three for the remaining years, based on the trend of SC , example:

$$MC_{2010} = \frac{MC_{2003} \cdot SC_{2010}}{SC_{2003}} = \frac{30 \cdot 10}{8} = 37{,}5\%$$

$$LC_{2010} = \frac{LC_{2003} \cdot SC_{2010}}{SC_{2003}} = \frac{42 \cdot 10}{8} = 52{,}5\%$$

After these calculations for the necessary and consumers respective years made to Table 5, which summarizes the results of this small study on the consumption of AC in respect of all the appliances that installation of this type of consumer. In Table 5 are also marked as such values were obtained, directly or documents or by calculation.

Table 3 - Percentage of total consumption of AC equipment

Consumer type	2003	2010	2020	2030	2040
DM	10% a)	13% a)	14% a)	15% a)	17% a)
SC	8% a)	10% a)	8,8% a)	8,5% a)	8,4% a)
MC	30% a)	37,5% b)	33% b)	31,8% b)	31,4% b)
LC	42% a)	52,5% b)	46,2% b)	44,6% b)	44% b)
MI	41% a)	51,3% b)	45,1% b)	43,6% b)	43% b)
LI	41% a)	51,3% b)	45,1% b)	43,6% b)	43% b)

a) Obtained values from the document
b) Values obtained by extrapolation

3.2. Scenario 1

This first scenario under study concerns the application of the DR program referred to throughout this report. Briefly, it created a situation where the demand for energy by consumers was higher than supply, so as to maintain the operation of the power grid appealed to the DR.

For this case it was considered that all consumers actively participate in the DR program, ie all clients from small homes to large industries have subjected it to them to be removed from power air conditioners for a period of 15 minutes. Consumers to participate are as follows: DM, SC, MC, LC, MI and LI, where the percentage of maximum energy possible not to provide the apparatus is shown in table 3.

The network where the program was implemented is described in the previous section (3.1.). On the consumer side is not being made any changes to the maximum values that can be cut in AC. Overall consumption of the system at this time is 5827 kW. As part of the production was necessary to make a small change we changed the values in the designated power sources from different suppliers, keeping the same price, as shown in Table 4.

Table 4 – First scenario Supplier Values

Source	Gen. Power (KW)	Price (€/kWh)
Supplier 1	1200	0,23
Supplier 2	800	0,24
Supplier 3	200	0,25
Supplier 4	100	0,26
Supplier 5	0	0,26

This amendment was thus with a production value of 4952 kW, as consumption remained as originally found in the network, and its value 5827kW. With all the necessary values to the problem, namely: production values by generating unit and the appropriate price; maximum values of power cutting and respective consumer price tariff and total power consumed by the system, implemented in Matlab / Tomlab.

The graph in Figure 9 is intended to show the situation before application of the optimization problem, the bars are located production facilities by bus, and the two green lines the highest cutting power and other energy consumption.

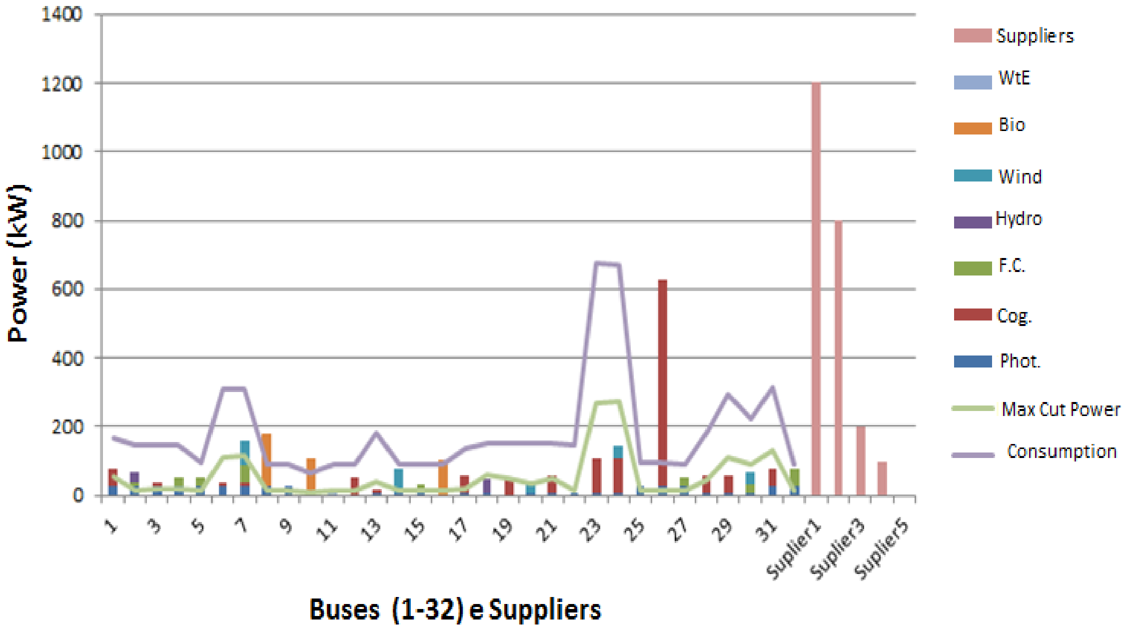

Fig. 9 - Graph summarizing the data input of the powers (scenario 1)

3.3. Scenario 2

This second scenario is around similar to the previous, the differences are that the value of output of suppliers have been increased, other changes were at the level of consumers to participate in the program, unlike the previous scenario, which all consumers actively participate in DR programs, now industrial consumers, MI and LI are not participating but domestic and commercial continue are actively participating.

All other output remained unchanged, with the total value of this production was 5252.2 kW, while consumption remained at 5827 kW just like scenario 1. For consumers the power that can be removed at the AC remained as in scenario 1 except consumer MI and LI as they do not allow them to be cut in AC power, ie they are out of the program.

Table 5 Second scenario Supplier Values

Source	Gen. Power (KW)	Price (€/kWh)
Supplier 1	1200	0,23
Supplier 2	800	0,24
Supplier 3	250	0,25
Supplier 4	200	0,26
Supplier 5	150	0,26

With this changes the total amount of power possible for them to be cut was 987.7 kW. This input data in the model, maximum cutting power and generated power are illustrated in Figure 10. Note that the line of green (maximum cutting power) gets lower values compared to the previous scenario in Figure 9.

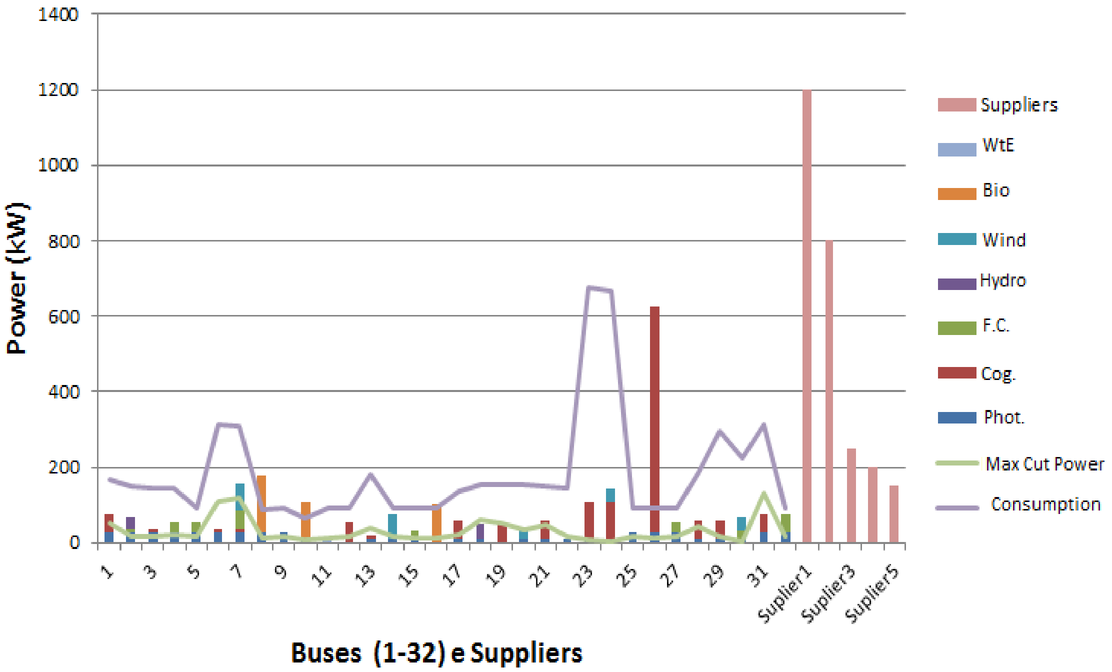

Fig. 10 - Graph summarizing the data input of the powers (scenario 2)

4. Results

4.1. Scenario 1 results

In the global consumer of each type, the amount reduced in power consumption can be seen in figure 11.

In Figure 12, here you can see the amount of energy that the AC was removed by client type and that would still be available for cutting.

It is noted that the cut occurs in the air conditioning for all consumers except those that have a higher value fare 0.20 €/kWh which are the LC, in all other consumers (DM SC MC MI and LI) see your AC to be turned off to them, it has energy value lower rate (tabela.1). This value cut, this is the maximum value ie the client is even without air conditioning for a short period of time. The total cutoff value was 1273.3 kW of a possible maximum of 1703.1 kW and calculating the difference obtains 429.8 kW value that could be cut if it were in a more extreme scenario.

Costs is also important for the distributor because with this model it is possible to be minimized. From the graph of Figure 12 you can see the difference between the costs of resorting to that DR program or not. The monetary value to pay for all plants was 702.7€ and the final value after optimization is 556.5€.

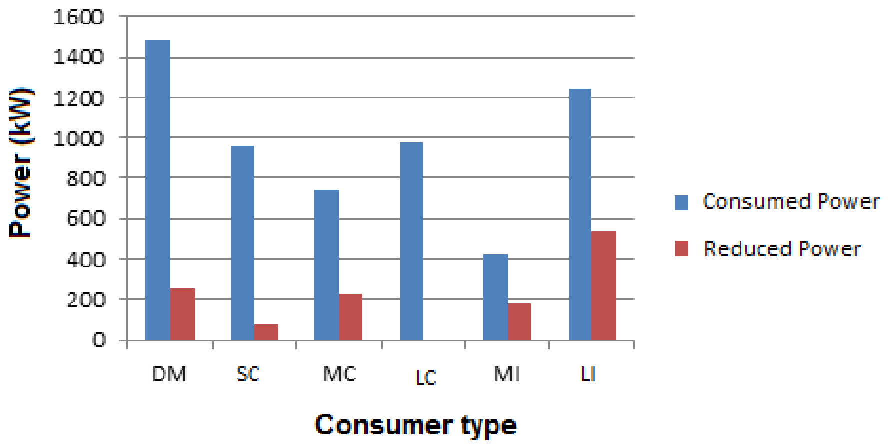

Fig. 11 - Power reduction by consumer type

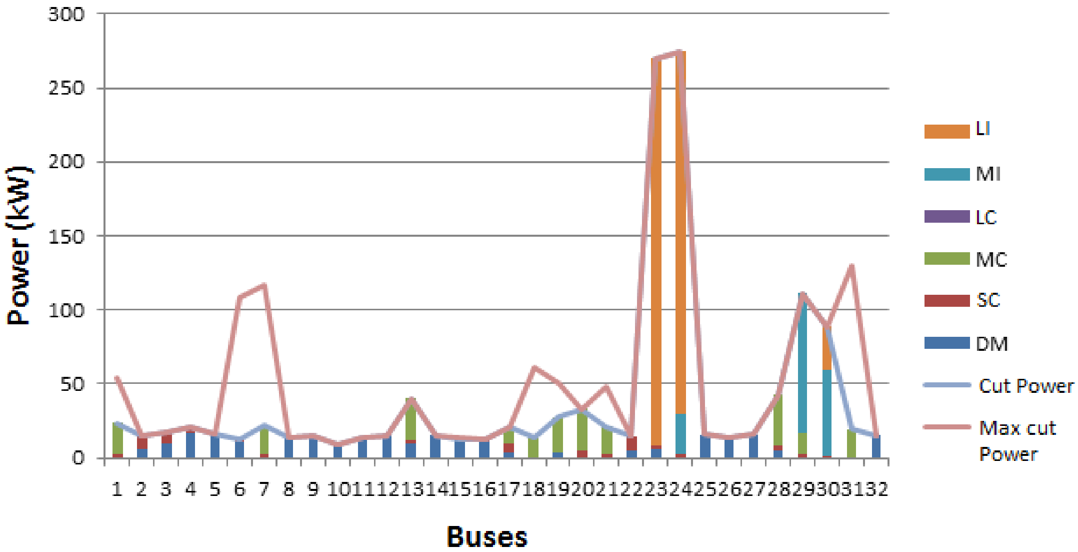

Fig. 12 - Values obtained from the consumer side

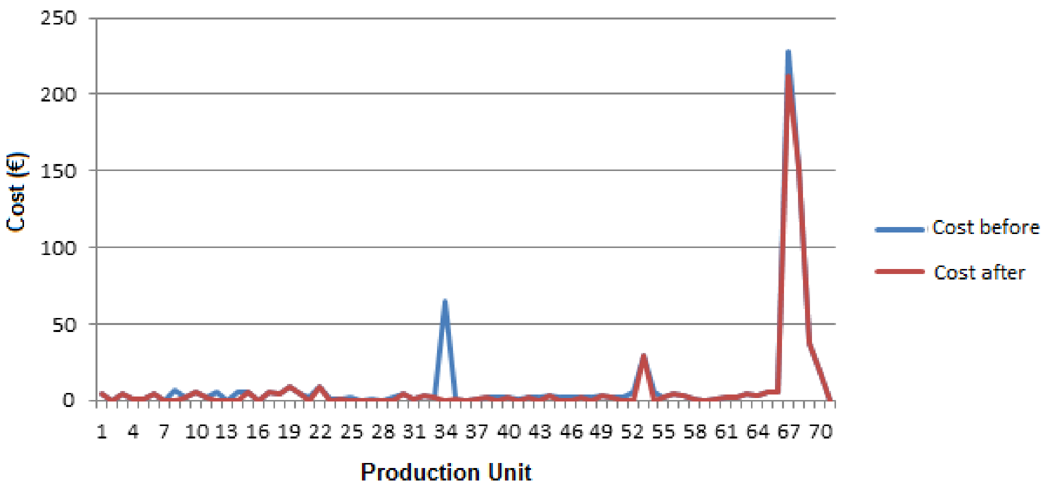

Fig. 13 – Production costs

Thus the initial scenario was that 4952.2 kW, that this power could not supply the load of 5827kW, with the DR program consumption is (5827kW minus 1273.3kW) equals 4553.7kW equalling output that has also become of 4553.7kW

The cutoff value in the AC was 1273.3 kW. The generator was producing 4553.7 kW and the costs of generating the total value was optimized before and after optimization € 702.7 € 577.8. On the customer side, before cutting the AC on full pay were going to pay 489.5€ with the AC cut will pay 96.5€.

4.2. Scenario 2 results

To this second scenario the amount reduced in power consumption can be seen in figure 14.

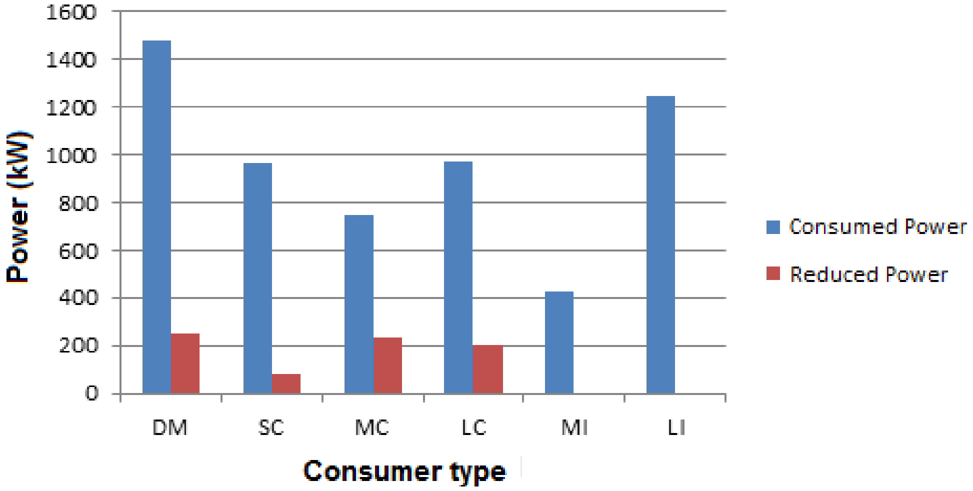

Fig. 14 - Power reduction by consumer type

In Figure 15, you can see the amount of energy that the AC was removed by client type and that would still be available for cutting.

In this scenario all clients, DM, SC and MC seen reduced the energy consumption of the plant, only cut the customers of type LC. This cut was 761.2 kW with a total of 987.7kW which was not necessary to use the total amount of power cut, the overall system cut in customers was 77.1%.

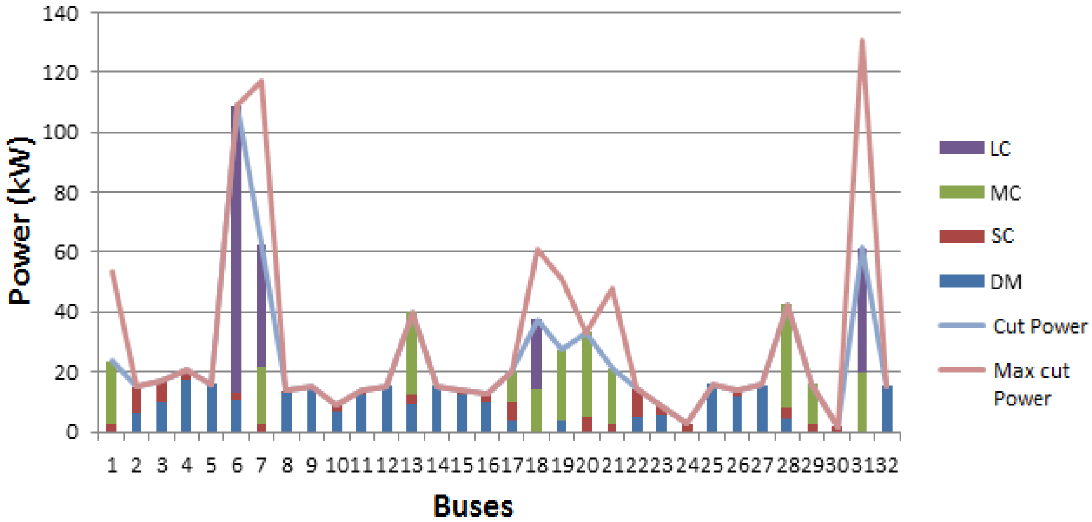

Fig. 15 - Values obtained from the consumer side

For the generating production from 5252.2kW to 5065.8kW which translates into a difference of 186.4 kW ie 96.5% compared to baseline. So with an initial load of 5827kW and a production of 5252.2kW insufficient to supply the load, 761.2 kW cut himself in charge getting equalling the value of production and consumption in 5065.8 kW.

The price paid for energy generated increased from € 759.7 to € 675.4, on the customer side in total had to pay 352€ instead of 489€. In this scenario the value of production was in 5065.8 kW against the initial 5252.2 kW. For consumers the total amount withdrawn from AC was 761.2 kW. The price to pay for power generated was € 675.4, customers paid in full € 352 (See Fig. 16).

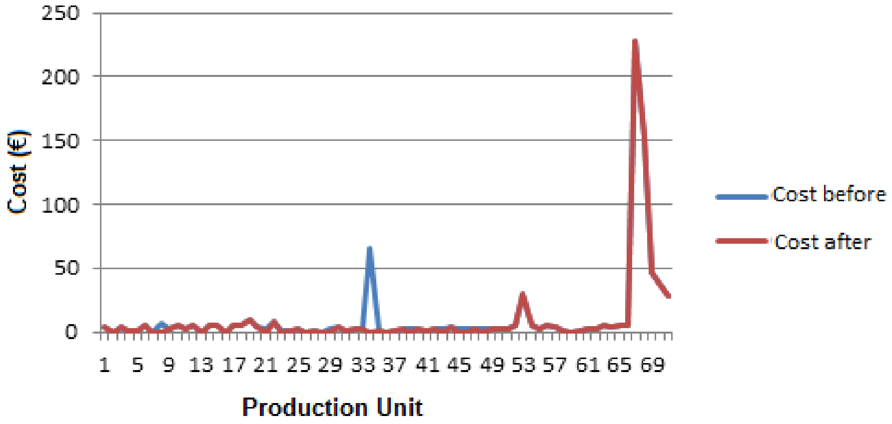

Fig. 16 - Production costs

4.3. Comparison of scenarios

Comparing the two scenarios in terms of the amount of cut, it is clear that in scenario 1 more power has been removed because it was no longer participating in the program and with great power available to cut. The Fig. 17 illustrates that even the difference between the two scenarios.

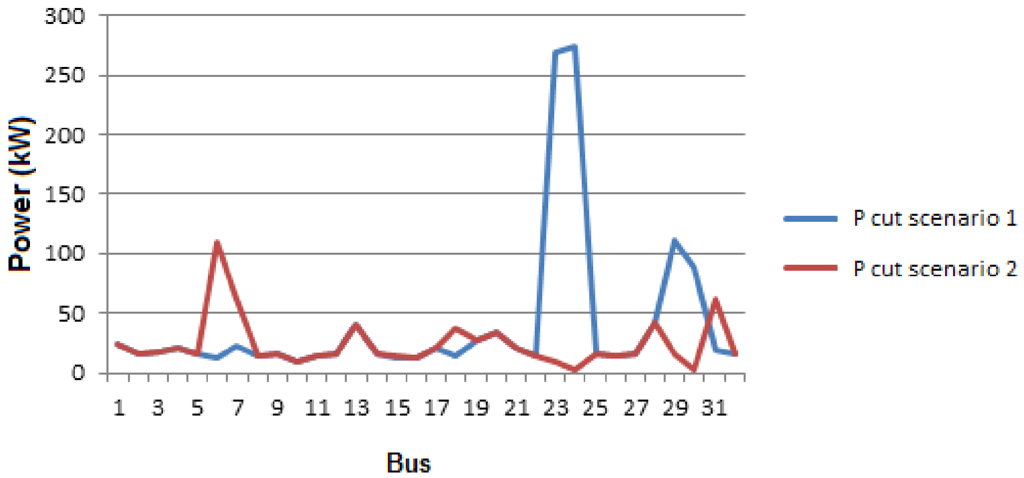

Fig. 17 – Cut power in both scenarios

As for generators, in the second scenario production from 5252.2kW to 5065.8 kW which was not such a marked reduction as in the first scenario, it should be that this second case broke a generated power exceeding and mainly because it was necessary to feed the air conditioning of the industries which has a significant consumption while in the previous case this had been curtailed (see Fig.18). In scenario 1, the generation level was 4553.7 kW while in scenario 2 it was 5065.8 kW.

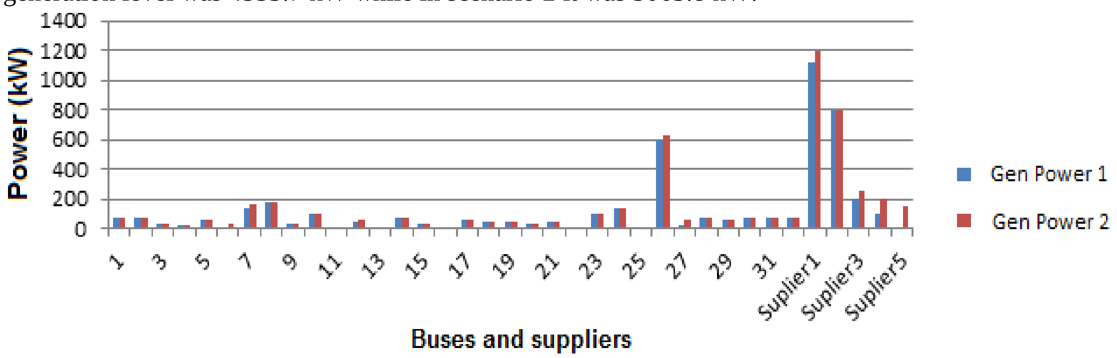

Fig. 18 Generated power comparison

5. Conclusions

The proposed methodology advantageous for both the consumer side and for energy utilities. The consumers has advantages in terms of price reduction and electric bill with a reduction in the air conditioning operation without a reduction in the comfort levels.

Analysing the presented scenarios, it is concluded that the ideal is that increasing the number of consumers participating in the DR program, makes possible to reduce the impact in the comfort levels. For networks with few customers, the implementation of this program will not only bring great benefits; possibly would succeed only in conjunction with other DR programs. It is very advantageous to use this type of program because customers can have savings while the network operator is able to increase the system reliability. This DR program is a good solution for the distribution companies to improve system reliability by increasing the quality of service and avoiding the need to invest in new infrastructure.

Acknowledgements

The authors would like to thank the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ for the support, under the project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912 (PIRSES-GA-2012-318912).

The authors also would like to thank the FEDER Funds through COMPETE program and the National Funds through FCT, by the support under the projects FCOMP-01-0124-FEDER: PEst-OE/EEI/UI0760/2014, and PTDC/SENENR/122174/2010.

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