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Virtual Power Producer and Consumer Agent Methodology for Optimal Management of Renewable Energy Resources

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ABSTRACT. This paper proposes a Virtual Power Producer and Consumer Agent as a methodology aiming to optimize the integrated management of distributed renewable energy resources and to improve control Demand Side Management (DSM) and its aggregated loads. The paper presents a proposed method to coordinate the power generation technologies, the different load types, and the storage system. This method uses a framework based on data-mining techniques to characterize the customers load curve. The optimal power generation technologies dispatching of the smallest equipment of renewable energy resources and storage system is formulated as mixed-integer linear programming problem, due to the presence of the binary and continuous variables in the optimization problem. The model is coded in General Algebraic Modeling Systems (GAMS) and solved by High-performance mathematical programming solver for linear programming, mixed integer programming, and quadratic programming CPLEX solver. The application of methodology to a real case study in an isolated electrical service area in Portugal demonstrates the effectiveness of this method to solve the optimal isolated dispatch of the DC micro-grid renewable energy park. The solution has been converged in 0.09 seconds and 30 iterations.

Keywords: Renewable energy optimization; micro-grids; smart-grids; virtual power producers**.**

1. INTRODUCTION

The power and energy systems have been subjected to significant changes all over the globe in general. Portugal is not exonerated from these changes. Common rules have been established for many countries as well for Portugal in its internal electricity market. In this market the customers can freely choose their own electricity company suppliers, obviously according to their interests. Symmetric market allows electricity buyers to act as important agents in a perfect competitive environment. This fact indeed, requires load aggregators to obtain relevant knowledge concerning load consumption patterns and demand side-management or even demand response program opportunities. Elasticity demand can be the key issue for taking advantage of opportunistic strategies in the market place.

Strategic behavior based on elasticity demand requires consolidated knowledge concerning electricity consumers' performance. Knowledge about load consumption patterns is very important for load aggregators and electricity company suppliers, as it provides the basis for agreements concerning electricity prices, and for defining marketing policies and developing innovative contracts and services.

The characterization of electricity consumers' behavior relies not only on past consumption data, but also on consumption trends and strategies [1]. Historic data can be used to extract knowledge about consumption behavior by using adequate data-mining techniques. Consumption categories can be determined by using this data, the knowledge of costumers' behavior, and information involving issues such as activity type code, hired power value through contracts, and consumed energy [2].

The integrated management of Distributed Energy Resources (DER) can be achieved by implementing the Virtual Power Producer (VPP) concept [3]. The aggregation of loads in the scope of VPPs creates a new market agent structure, the Virtual Producer and Consumer Agent Methodology (VPCAM). The VPCAM provides the means to optimize the aggregated Distributed Energy Resources (DER), such as generation and storage, and to improve the Demand Side Management (DSM) of their aggregated loads.

This paper proposes VPCAM architecture and its function-based organization. Within this organization, the VPCAM uses a framework developed to characterize Medium Voltage (MV) and Low Voltage (LV) consumers, as a decision-support tool supporting the active and strategic participation of loads in the new liberalized electrical environment.

This paper presents the results of the mathematical optimization model and some experimental tests using the proposed architecture and methodology in real-world situations and considering real electricity generation and consumption data in an isolated area in Portugal.

2. PERSPECTIVE ENERGY PRICE IN THE SCOPE OF THE PORTUGUESE POWER SYSTEMS

The Portuguese Power System changed the primary resources of electricity generation by introducing a combined cycle of natural gas and, more recently, implementing new wind farms (in 2008, new wind farms with 576 MW of power were installed, increasing the total power of Portugal’s wind farms to 2624 MW). In 2008, the production of the wind farms and the natural gas increased by 43% and around 20 %, respectively [4].

In contrast the production of coal thermal plants and fuel oil decreased by 11 % and 37%, respectively. Figure (1) shows the distribution of electricity production by technology and resource in Portugal. In 2008, two large photovoltaic plants were still in operation; the plant in the Amareleja region had a nominal capacity of 46 MW, and the plant in the Serpa region had a power output of 11 MW. As well, in 2008, a wave power plant with Pelamis technology and a power capacity of around 2 MW began operating in the Aguçadoura region. Electricity consumption is expected to increase by 1 %. To be prepared for this additional load, the Portuguese government is promoting an awareness campaign for an energy saving plan. This campaign has resulted in monetary saving and, therefore, has reduced in uncertain percentage of the government’s expenses.

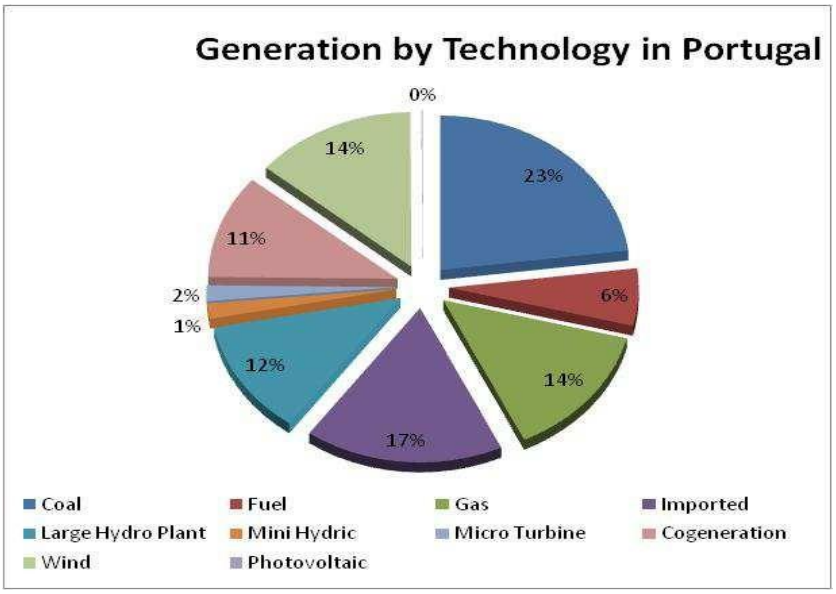

Fig. (1). Electricity production in Portugal by generation type.

Figure (2) shows the evolution of the monthly Portuguese consumption from 2006- 2008.

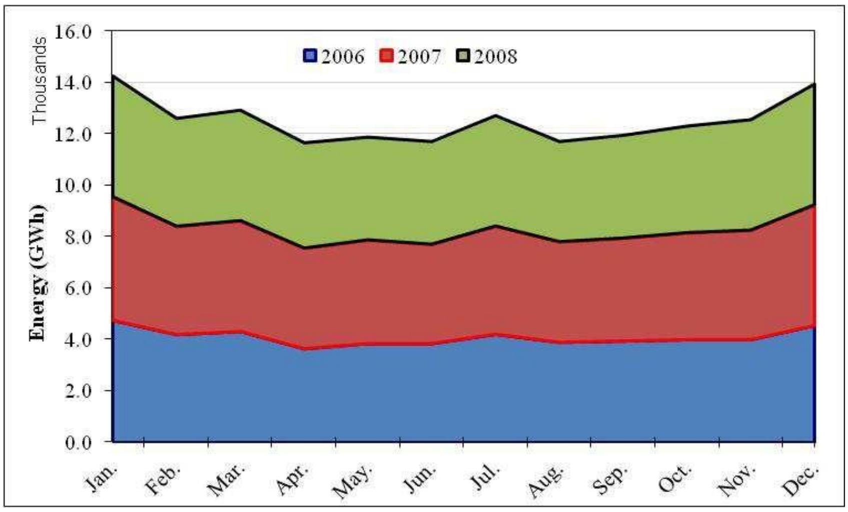

Fig. (2). Evolution Portuguese electrical consumption, 2006-2008.

The highest value of electricity power consumption was around 9 GW and occurred in the December of 2008.

The price of energy in Portugal is higher than the average price in the European Union countries, since the price of electrical energy in 2008 was 0.141 Eur/kWh for domestic consumers and 0.435 Eur/kWh for industrial clients [5].

Figure (3) depicts the evolution of the electrical energy prices in Portugal and 15 other countries in Europe.

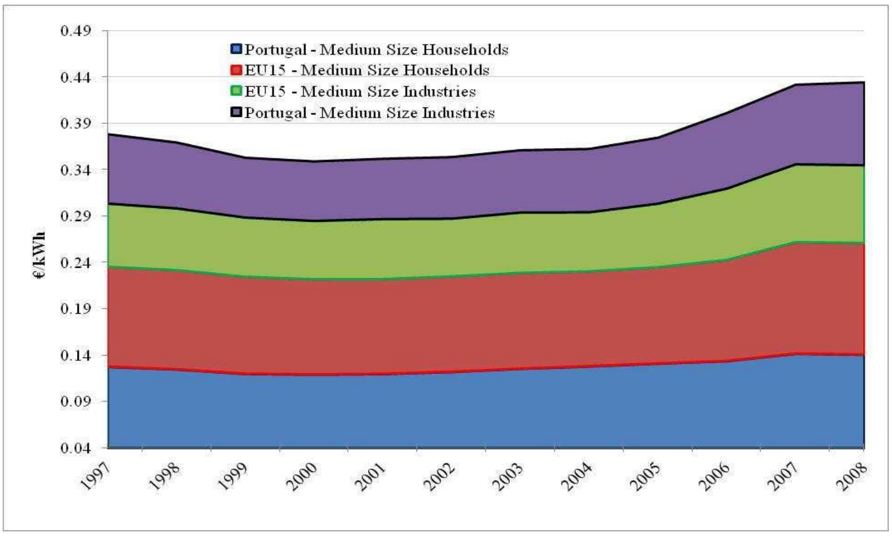

Fig. (3). Evolution of electric energy price in Europe, 1997-2008.

3. VIRTUAL PRODUCER AND CONSUMER AGENT METHODOLOGY (VPCAM)

With the liberalization of the power sector, electricity consumers can easily change their electricity-service contract from one electrical supplier to another. In this new environment, the market agents must provide new products and services offering attractive tariffs in order to take advantage of the competition opportunities. Choosing among several retailers could be a difficult task as contracts should be more flexible than they were previously, which can provide dynamic and therefore a fair contract management. Innovative and attractive contracts can provide different and flexible tariffs assuring a diverse quality of supply depending on the chosen tariff framework.

The electricity price is determined mainly by fixed costs, or the costs of generation, transmission and distribution, limiting retailer flexibility and the influence of customer behavior on electricity prices.

Currently, the Portuguese government and regional utility companies are working together to increase the influence of customers behavior and its impact on prices. An integrated vision of power generation and load demand, involving a set of power generation resources and loads, could provide the means to increase this influence positively.

The aggregation of distributed generation (DG) plants has resulted in a new concept: the Virtual Power Producer (VPP). VPPs are multi-technology and multi-site heterogeneous entities. VPPs can manage DG so that generators are optimally operated and the generated power has a good chance of being sold in the electricity market. Moreover, VPPs are able to commit to a more robust generation profile, raising the value of non-dispatched generation technologies.

In this context, VPPs can secure an environmentally friendly generation and optimal management of heat, cold and electricity together. They can also provide the means to ensure the optimal operation, the maintenance of generation equipment and, the electricity market participation. Aggregating loads as a consumer's agents to VPPs, resulting in a VPCAM, allows these entities to undertake the optimized integrated management of the aggregated DER and loads. Fig. 4 shows the VPCAM operation. The management of loads and power generation by the same entity allows new management strategies for DSM technique. With daily forecasting of power generation and consumption the VPCAM can coordinate several generation technologies and different load types and storage systems efficiently.

Another possibility for using VPCAM is in autonomous isolated systems disconnected from the main network. In these systems and in the isolated micro-grids, the power sources are limited to those inside the system, so that generation scheduling becomes increasingly important to satisfy the basic rule of the power system locally inside the isolated area [3].

In this system type, the most important power producers are the renewable energy sources, e.g., photovoltaic panels (PV), fuel cells, and wind turbines in combination with gas generators and cogeneration plants. These small power generations entity needs distributed and autonomous control for its correct performance. The use of small isolated power systems is also an attractive alternative for power utility companies, since these systems can help to improve the power quality and power supply flexibility and may increase reliability due to its availability in presence of faults. Also, they can provide a spinning reserve, ancillary services and reduce the transmission and distribution costs. Finally, these systems can be used to feed the customers in the event of an outage in the primary substation [6]. In order to characterize the consumers, the VPCAM should have an exact knowledge about when and how its clients consume electricity and their behaviors, as well as what electricity price has resulted from the market, and what generation has been forecasted in each considered time period.

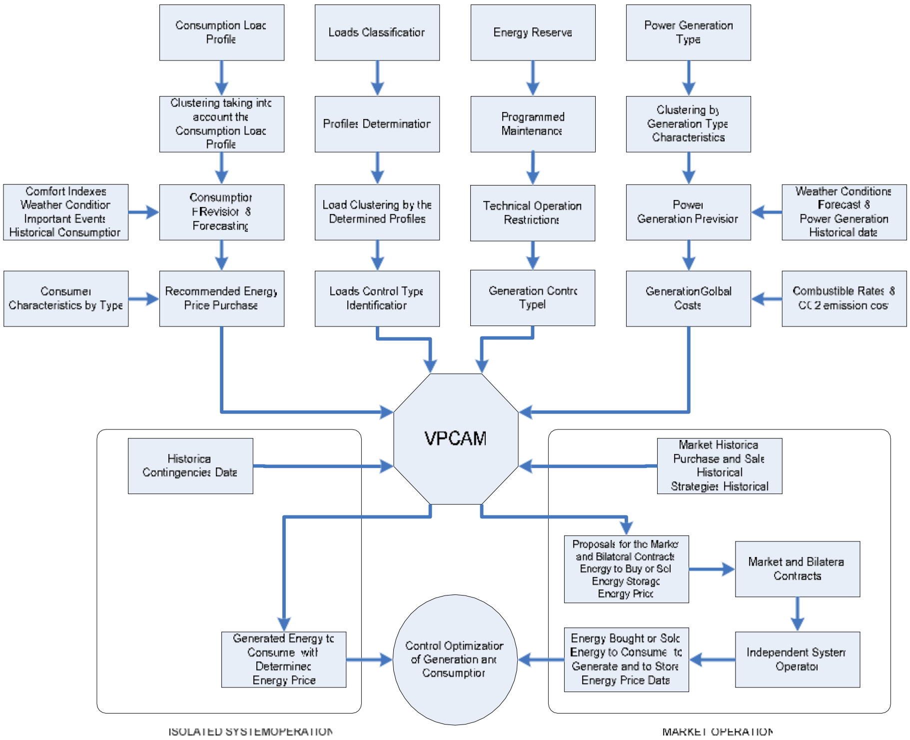

Fig. (4). Schematic representation of the functioning of a VPCAM.

The VPCAM should also identify the consumers who will be available to changing their electricity-consumption behavior taking into account the advantages which may be presented in term of price opportunities in the time period. A model can be used to determine the limited number of load profiles that are needed for resource management, as in cases of an energy shortage of determined loads. The major challenge here is the management for each considered time period the availability of the generated power during the considered time period, maximizing the reliability, so optimally handling the load curtailment decisions. Decisions must be based on the relevant knowledge of the consumers' behavioral characterization and its impact on the price in each time period.

4. CHARACTERIZATION PROCESS OF MEDIUM VOLTAGE CUSTOMERS

4.1 Customer clustering and classification

Figure (5) shows the study process for Knowledge Discovery in Databases (KDD) [7, 8, 9, 10].

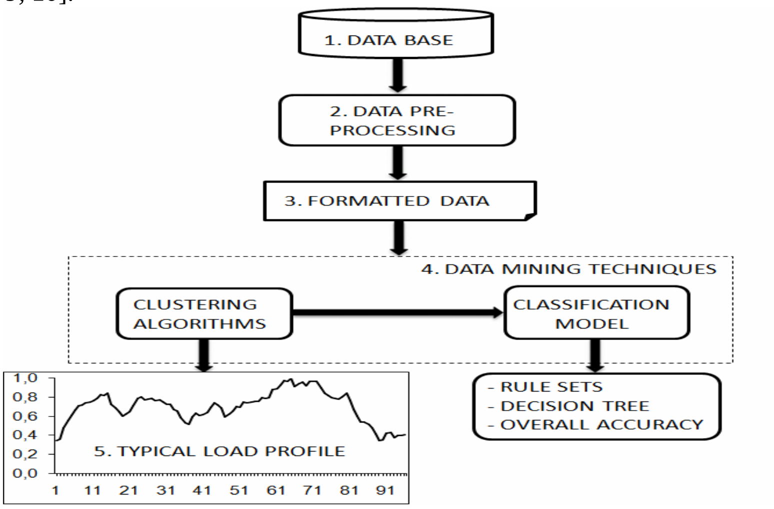

Fig. (5). MV consumer's characterization process.

The developed consumers' framework characterization used in this work is based on the process of Fig. 5. It includes several phases and uses Data Mining (DM) techniques in the calculation process. The framework is fragmented into different steps with different degrees of complexity: data and features selection, data preprocessing, formatted data, data mining techniques and the most important extracted knowledge.

DM techniques are used to characterize the typical customer profile, starting from an initial data set from a Portuguese utility [11]. The main goal of the consumer profiling is to group the data into classes so that the clusters of data in each class are highly similar and highly dissimilar to the clusters in other classes. With the new classification model, the new consumers can be placed in one of the known clusters according to their characteristics. By using a real data base released by the Portuguese distribution company with 229 MV customers, and collected during a period of 3 months in summer and the same period in winter for business days and weekends, the typical daily load curve of each customer was determined. Through data preprocessing action, 21 customers were discarded from the initial data, remaining 208 consumers to be analyzed. By using all the completed data, a representative load curve was obtained by averaging the daily load diagrams of each customer. Therefore, each customer is now represented by its typical load curve [11].

Figure (6) shows the representative business days load diagram obtained for each cluster, directly using the measured power [11].

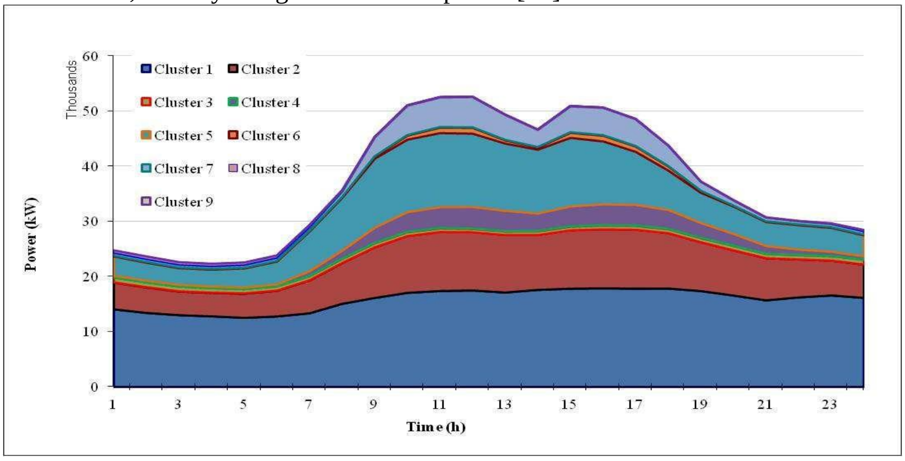

Fig. (6). Clusters obtained by using the two-step cluster algorithm for working days.

Each load curve depicts a cluster representing a customer group with the same consumption load pattern. Figure (7) shows the total amount of the electrical energy consumed by the 208 consumers considered in this case study.

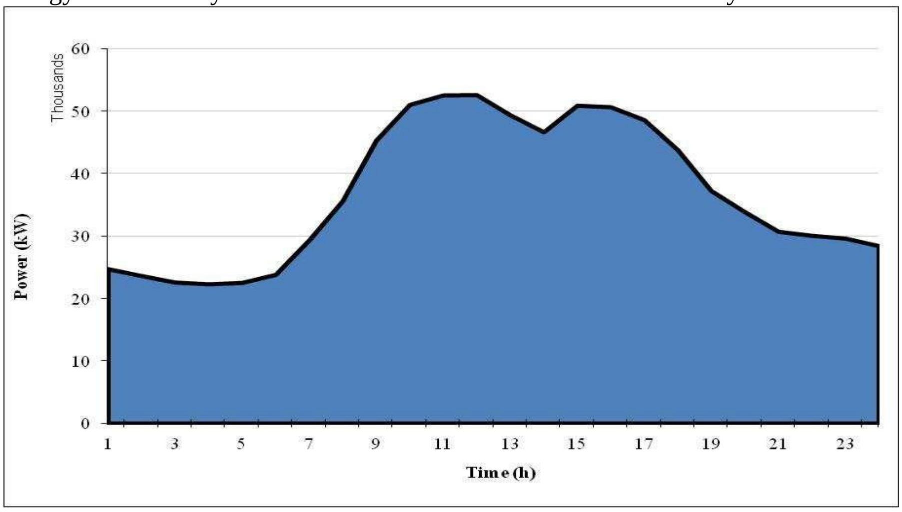

Fig. (7) . Total electrical energy consumed by the 208 consumers on work days.

4.2 Load Flexibility

Currently, the small isolated power systems are increasingly being used in the rural and remote electric service areas, instead of using only one centralized power generation system and its corresponding large networks that are necessary to feed the remote electric loads.

Although the advantages of using small power systems are considerable, these systems are based only on renewable energy resources, which require the use of storage capability due to the intermittence characteristics to increase their power availability. The VPCAM can explore dynamic pricing during the day to take advantage of the customers' load profile modeling. Dynamic pricing includes the price value variation during the day reflecting the highest cost of the peak electricity generation usage. VPCAM, power producers and consumers should not miss this opportunity, but to take advantage of it, the electricity consumers must be prepared to change their consumption habits following the dynamic electricity prices. Thus, the consumers who are available to changing their electricity-consumption behavior must be identified.

Let us consider four different typical load profiles that will permit, in some way, changes in their consumption habits:

- Profile 1: This load does not allow for any load curtailment, independently of the time of the day. This profile applies to vital industrial producing processes and to emergency infrastructures such as hospitals and military sites.
- Profile 2: The load can alter its schedule according to operational constraints (e.g., generation shortage). This profile applies to some tasks that can be done at any hour of the day (e.g., using a washing machine).
- Profile 3: The load can be partially curtailed under the same conditions. This profile may apply, for instance, to lighting, air conditioning and heating systems (which can be reduced by 1 or 2 degrees), compressed air (which can be reduce by 0.5-1 bar in air pressure), and escalators.
- Profile 4: The load can be curtailed at any time of the day. The contract specifies what electrical circuits can be curtailed.

By using this approach and knowing each load profile, a VPCAM can manage all generation units and consumers' loads in order to achieve the established goals, which might be diverse (e.g., to guarantee power system stability, to increase profits of power producers, to reduce consumers costs tariff, or to reduce the global costs).

4. RENEWABLE ENERGY RESOURCES AND LOAD MANAGEMENT

The VPCAM aims to optimally manage all the available energy resources and loads in order to achieve the established goals. In order to do so, it needs relevant information to define the amount of energy generated by wind energy, photovoltaic energy, fuel cell, mini-hydro, Combined Heat and Power (CHP), and the storage battery power charging and discharging. Decision making requires accounting for the following considerations:

- The wind power generation strongly depends on the weather conditions. To have enough precision, the generation capability can be estimated for a period of only 24 hours in advance.

- The photovoltaic generation can be forecasted precisely.
- For fuel cells and CHP, the total generated energy is determined by the amount of the fuel.
- Mini-hydroelectric plants have a limited quantity of stored water and low generator capacity.
- Storage battery power discharging is limited by the maximal discharging capacity and existing storage energy.
- The loads are forecasted by considering several aspects; however, most of the loads can be controlled under only certain limits (using DSM – Demand Side Management). For each cluster, the VPCAM knows the loads which can be totally or partially curtailed or moved to a different time slice.
- To ensure system power balance, the VPCAM can determine the terms of reserve. For example, the VPCA can limit the minimum reserve to 10% of the forecasted load. This reserve can be assured by using storage and fuel cells.

The main objective is to carry out an optimal dispatch accounting for all the available energy resources, the forecasted load, the load profiles, and the relevant considerations. The surplus energy is used for charging the storage battery system. The different generation units' costs are considered. The optimal schedule of the demand and generation can be made for the envisaged time horizon (e.g., 5 minutes, 1 hours, 1 day, 1 week, 1 month or 1 year). For solving this mixed-integer constrained portfolio problem, the CPLEX solver supported by the GAMS platform was used [12].

The constraints of the problem were elaborated while considering five different operation modes [13]:

- A surplus energy that can be stored is available (as in the case presented in Fig. 8).
- The generation is not enough to assure the supply of the total load; therefore, the battery is discharged.
- In case of a lack of generation based on renewable sources (wind, water and/or sunshine) the battery, CHP and fuel cell come into operation (as in the case presented in Fig. 9).
- In case of insufficient energy generation, the load must be shed.

The objective function of the mixed-integer linear model is the minimization of the total cost for a given period (T) as follows:

$$Minimize\ f=\sum_{t=1}^{T}\left[\begin{array}{l} C_{W,Ph,Hy,CH,Fc}^{(t)}\cdot P_{W,Ph,Hy,CH,Fc}^{(t)}+C_{SBd}^{(t)}\cdot P_{SBd}^{(t)}+C_{R}^{(t)}\cdot P_{R}^{(t)}+\\ P_{LMP}^{(t)}\cdot C_{LMP}^{(t)}+C_{LS}^{(t)}\cdot P_{LS}^{(t)}+C_{NSE}^{(t)}\cdot U_{NSE}^{(t)}-C_{SBc}^{(t)}\cdot P_{SBc}^{(t)}-C_{E}^{(t)}\cdot E_{E}^{(t)} \end{array}\right] \quad (1)$$

Where: T is the period study, which may be one day, one week, one month or one year. In this case T is for 24 period of the one day. The methodology is prepared to be applied from the one year scheduling. C is the cost coefficient of each power generation type during the considered time period t. P is the power generation type.

Subscripts W, Ph, Hy, CH, Fc refer to wind, Photovoltaic, Hydroelectric, Combined Heat and Power and Fuel Cell power generation respectively. Subscripts $SBd, R, LM, LS, NSE, SBc, E$ are Storage Battery discharge, Reduction, Load Shedding, Non Served Energy, Storage Battery charging and Excess respectively.

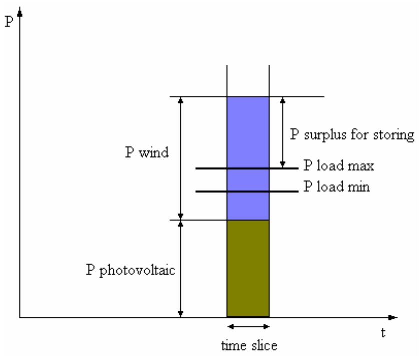

Fig. (8). Surplus of primary energy, adopted from [13]

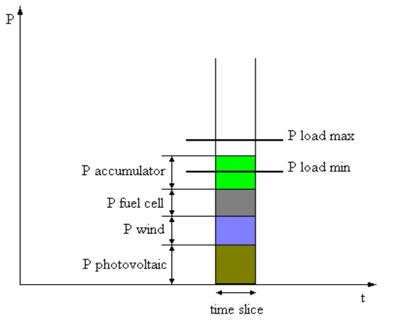

Fig. (9). The storage and the fuel cell in operation, adopted from [13]

Equation (1) is subject to the following technical constraints:

– First Kirchhoff Law or Power Balance

$$\sum_{t=1}^{T}\left(P^{(t)}_{W,Ph,Hy,CH,Fc} + P^{(t)}_{SBd} + P^{(t)}_{R} + P^{(t)}_{LS} + P^{(t)}_{LMP} + U^{(t)}_{NSE}\right) = \sum_{t=1}^{T}\left(Load^{(t)} + P^{(t)}_{SBc} + P^{(t)}_{LMV} + E^{(t)}_{E}\right) \quad (2)$$

Where: Subscripts LMP and LMV are the Loads that have to be moved from the peak load curve and Loads moved to the Valley of load curve respectively.

– Wind, Photovoltaic, Hydroelectric, Combined Heat and Fuel cell Power generation limits in each time period "t". This constraint can be stated for each power generation type.

$$P^{(t)}_{W,Ph,Hy,CH,Fc} \le P^{(t)}_{W,Ph,Hy,CH,Fc}(\lim it); \quad t = 1,...,T \quad (3)$$

– Storage battery limits in each time period "t"

$$P^{(t)}_{SB} \le P^{(t)}_{SB(Max)}; \quad t = 1,...,T \quad (4)$$

Where: SB and $SB_{(Max)}$ are the Storage Battery and the Storage Battery .maximum respectively

– Storage battery maximal discharge limits in each time period "t"

$$P^{(t)}_{SBd} \le P^{(t)}_{SBd\,(Max)} \cdot X^{(t)}; \quad t = 1,...,T\,; X = 0 \ \ or\ 1 \quad (5)$$

Where SBd(Max) Is the Storage Battery maximum discharge .

– Storage battery maximal charge limits in each time period "*t*"

$$P_{SBc}^{(t)} \le P_{SBc(Max)}^{(t)} \cdot Y^{(t)}; \qquad t = 1,...,T; \quad Y = 0 \ \ or \ 1 \tag{6}$$

– The battery cannot charge and discharge at the same time in each time slice "*t*"

$$X^{(t)} + Y^{(t)} \le 1; \qquad t = 1,...,T; \quad X \ and \ Y = 0 \ \ or \ 1 \tag{7}$$

– Storage battery maximal discharge limits in each time period "*t*" considering the battery state storage in time period t-1

$$P_{BD}^{(t)} - P_{B}^{(t-1)} \le 0; \qquad t = 1,...,T \tag{8}$$

– Storage battery maximal charge limits in each time period "*t*" considering the battery state storage in time period t-1

$$P_{BC}^{(t)} + P_{B}^{(t-1)} \le P_{BMax}^{(t)}; \qquad t = 1,...,T \tag{9}$$

Where the subscripts *BC*, *B* and *Bmax* are the Battery Charge, Battery and Battery Maximum capacity

– State balance of battery

$$P_{B}^{(t)} = P_{B}^{(t-1)} - P_{BD}^{(t)} + P_{BC}^{(t)}; \qquad t = 1,...,T \tag{10}$$

– Initial state of the battery

$$P_{B}^{(t=0)} = P_{B}^{0} \tag{11}$$

For the succeeding time slices, the constraints are the same. The existing stored energy is updated between time slices.

5. CASE STUDY

The proposed methodology was applied to a real case study. The following prices were considered: wind energy cost 0.4 Eur/kWh; photovoltaic energy cost 0.4 Eur/kWh; hydroelectric energy cost 0.4 Eur/kWh; CHP energy cost 0.6 Eur/kWh; fuel cell energy cost 0.9 Eur/kWh; storage energy discharging cost 0.7 Eur/kWh; energy storage charging cost 0.4 Eur/kWh; load energy moving for a different time slice cost 1.2 Eur/kWh; load energy reduction cost 1.3 Eur/kWh; load energy curtailment cost 1.4 Eur/kWh; undelivered energy cost 1.5 Eur/kWh; and the excess of the generated energy is with cost 0 Eur/kWh, due to the Portuguese legislation that does not permit any generated energy injection into the main grid in these time, but now is under study by the specialized governmental entity to be permitted in the near future.

To illustrate the generality and the effectiveness of the proposed methodology, a scenario involving several energy resources was created. The data for this scenario are presented in Table I. The VPCAM has detailed information about not only the consumption of all customers, but also the characteristics of their loads pattern and the industry's electricity needs. The real electricity needs of all consumers must be known and understood in order to adequately manage all the available resources, including the use of DSM.

Solving the optimization problem allows the VPCAM to obtain the optimal renewable energy generation dispatch by accounting for the cost of each generation technology. Several simulations were performed in order to demonstrate the importance of considering the different load profiles. Figure (10) presents the obtained results for the load supply in a situation where all the consumers do not allow for load shedding independent of the time of the day. Fig. 10 reveals that an amount of undelivered energy is present in time slices 10 to 18.

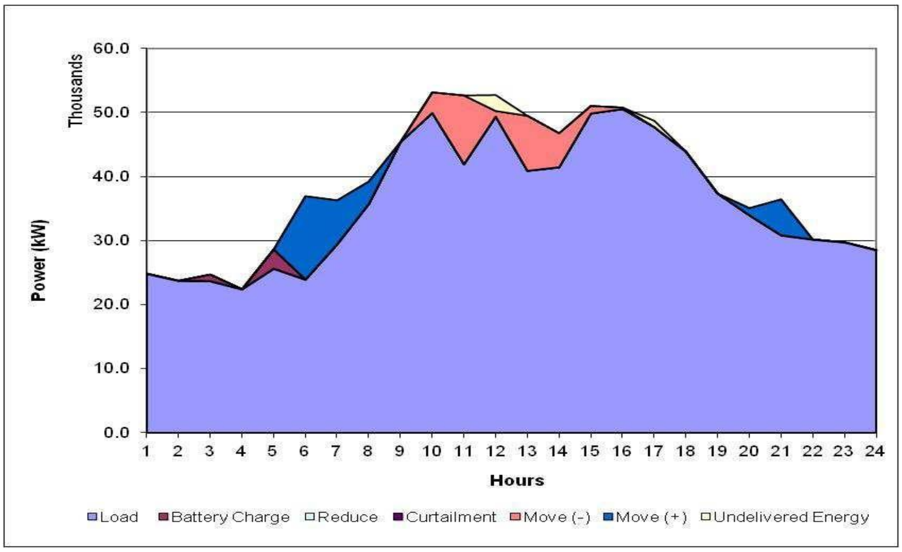

Fig. (10) . Energy consumption without consumption management.

Figure (11) shows the optimal generation scheduling for the same situation. By considering the contracts with all profile types, the VPCAM can manage the generation and consumption to reduce the undelivered energy to the important loads. For the same demand, the VPCAM will consider a set of contracts allowing for demand-side flexibility. By using the nine clusters obtained in Section III, the following profiles were considered:

- Clusters 2, 4 and 6 – Profile 1;
- Clusters 1 and 5 – Profile 1 and Profile 2;
- Clusters 3, 8 and 9 – Profile 1 and Profile 3;
- Cluster 7 – Profile 1 and Profile 4.

Fig. 12 shows the results for electricity consumption in this situation, revealing that the VPCAM was able to manage the resources so that no energy was undelivered for priority loads. Demand-side flexibility was achieved by moving a part of the load for off-peak periods and reducing and curtailing a part of the loads. The battery was charged in two periods.

Table (1). Estimated Power Generation and Consumption Forecast (kWh).

T.S	P_{W_1}	P_{W_2}	P_{W_3}	P_{PH}	P_{HYD}	P_{CHP_1}	P_{CHP_2}	P_{FC}	P_{S-1}	P_{SC}	P_{SD}	P_{CUT}	P_{RED}	P_{RED}	LOAD
1	6540	8760	8760	0	≤10000 Storage water to 60000	≤10000	≤3000	≤5000	1000	≤3000	≤1500	0	282	0	24778
2	7810	9780	9780	0								0	285	0	23674
3	8120	7690	7690	0								0	279	0	22632
4	9130	7560	7560	0								0	268	0	22349
5	10040	6830	6830	0								0	261	0	22575
6	9760	6350	6350	0								0	261	0	23863
7	10130	5490	5490	0								0	259	0	29380
8	10250	7980	7980	50								0	224	0	35690
9	9760	8150	8150	140								1041	171	0	45383
10	9570	8490	8490	280								1611	159	0	51122
11	8790	8670	8670	540								1628	153	17410*	52640
12	6540	9050	9050	770								0	144	30865*	52704
13	7130	9890	9890	850								0	148	29376*	49464
14	7430	10100	10100	890								0	153	11639*	46736
15	7800	10400	10400	840								0	150	12488*	50997
16	6430	8960	8960	790								500	161	11475*	50752
17	6580	7890	7890	450								489	165	0	48684
18	5900	8760	8760	320								370	168	0	43863
19	5670	7650	7650	240								0	172	0	37300
20	6490	6780	6780	110								0	185	0	33923
21	7830	7100	7100	40								0	179	0	30783
22	8120	7560	7560	0								0	181	0	30128
23	8340	7890	7890	0								0	203	0	29689
24	8760	8150	8150	0								0	238	0	28477

*- The consumption of the energy in a time slice can be moved to time slices 7 to 10h or 18 to 20h

Figure (13) shows the optimal generation scheduling for the same situation. In this simulation, the consumers with the most impact on the results were those that allowed some electrical energy to be moved during the off-peak hours. The other consumers were important for balancing the time slices with short difference between generation and consumption.

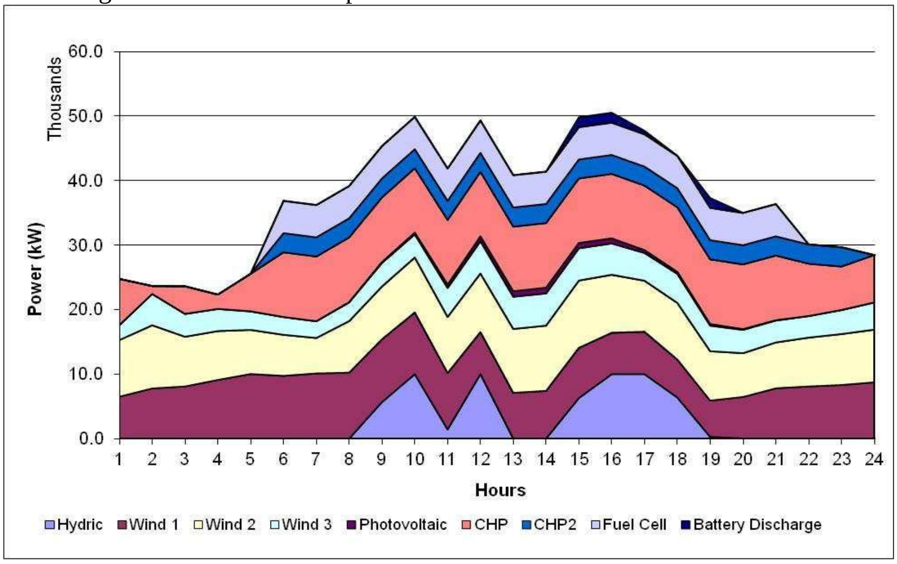

Fig. (11). Generation without consumption management.

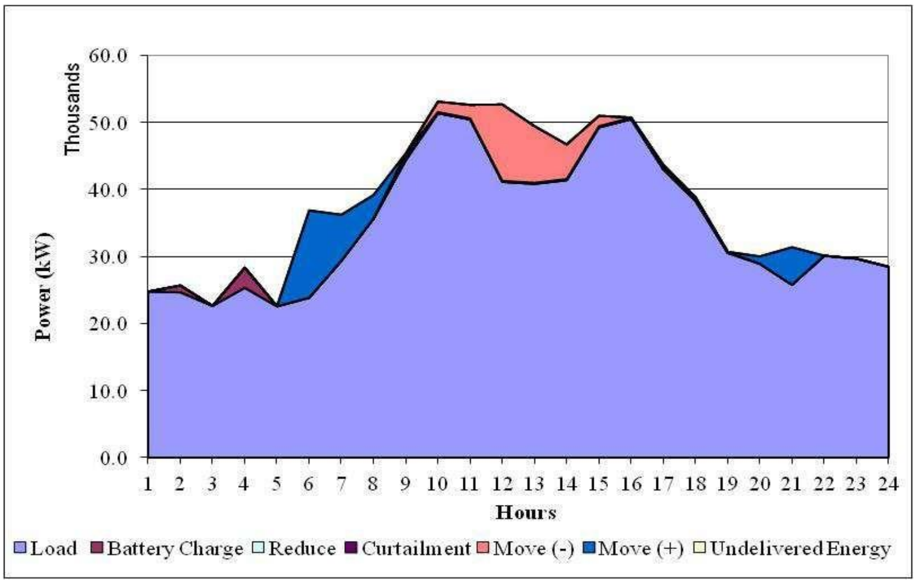

Fig. (12). Energy consumption by moving, reducing and curtailing some energy consumption.

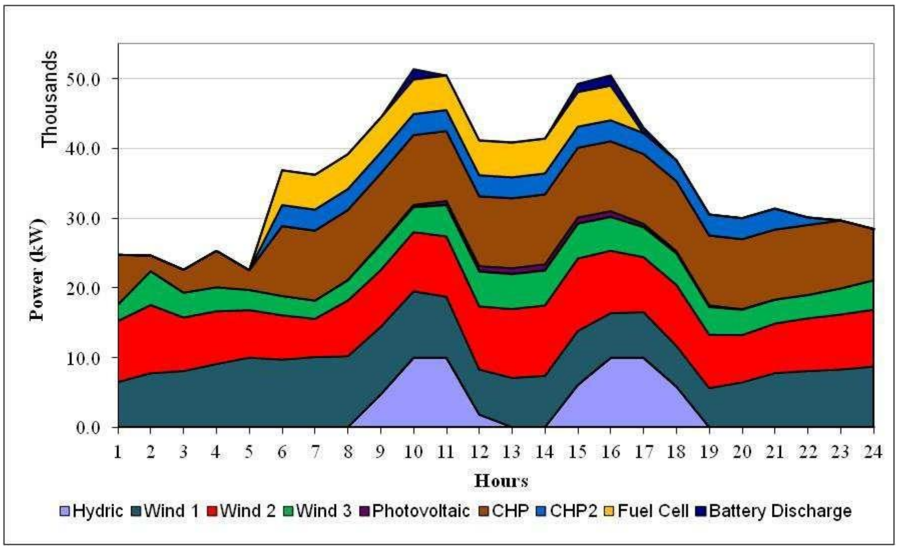

Fig. (13). Generation with moving, reducing and curtailing some electrical energy consumption.

6. CONCLUSION

This paper proposed a methodology to manage the operation of an isolated system by a Virtual Power Producer and Consumer Agent Methodology (VPCAM). The main goal was to minimize the total involved cost, which includes the generation costs, storage energy system charging and discharging costs, and demand-side flexibility use costs, subject to all the operational technical constraints. The VPCAM must assure a permanent balance between generation and consumption by undertaking the required load curtailment, when is necessary in an optimized way.

This paper presented the results of the application of the methodology to a set of real consumers' data. The dispatch was formulated as a mixed integer linear programming optimization problem and programmed and solved by using the GAMS platform and the CPLEX Solver, respectively. The obtained results demonstrate that the proposed methodology is effective and robust. It is also efficient as it requires only a brief execution time. The proposed method helps to minimize the operation costs by accounting all the available energy resources and the demand-side flexibility.

7. REFERENCES

[1] Praça, I., Ramos, C., Vale, Z., and Cordeiro, M., "MASCEM: A Multi-Agent System that Simulates Competitive Electricity Markets," *IEEE Intelligent Systems*, Vol. 18, (2003), pp. 54-60.

[2] Gellings, C. W., "Emerging Energy Customers of the Twenty-First Century," *CIGRE/IEEE Technical Session*, *IEEE Power Engineering Review*, (1998).

[3] Morais H., Kádár P., Cardoso, M., Vale, Z., Khodr H. M., "VPP Operating in the Isolated Grid," *IEEE PES General Meeting*, Pittsburgh, Pennsylvania, USA, 20-24 July, (2008).
[4] Redes Energéticas Nacionais (REN), "*Monthly Report Information – Power System Generation– Dec. 2008*", Portugal, Published (in Portuguese), January, (2009).
[5] http://epp.eurostat.ec.europa.eu (Eurostat).
[6] Milošević, M., and Andersson, G., "Generation Control in Small Isolated Power Systems," *37th Annual North American Power Symposium,* (2005).
[7] Figueiredo, V., Rodrigues, F., Vale, Z., and Gouveia, B., "An Electric Energy Characterization Framework based on Data Mining Techniques," *IEEE Transactions on Power Systems*, Vol. 20, (2005), pp. 596-602.
[8] Frawley, W.J., Piatetsky-Shapiro, G., and Matheus, C., "Knowledge Discovery in Databases: an Overview," Technical Report, (1995).
[9] Fayyad, U., Piatetsky-Shapiro G., Smith, P. J., and Uthurasamy, R., "From Data Mining to Knowledge Discovery: an Overview," *Advances in Knowledge Discovery and Data Mining*, AAAI/MIT Press, (1996), pp. 1-34.
[10] Chicco G, Napoli, R., Postulache, P., Scutariu, M. and Toader, C., "Customer Characterization Options for Improving the Tariff Offer," *IEEE Transactions on Power Systems*, Vol. 18, (2003), pp. 381-387.
[11] Ramos, S., Vale, Z., Santana, J., and Duarte, J., "Data Mining Contributions to Characterize MV Consumers and to Improve the Suppliers-Consumers Settlements," *PES GM 07– IEEE Power Engineering Society*, Tampa, Florida, USA, 24-28 July, (2007).
[12] GAMS Development Corporation, Washington, DC 20007, USA, "*GAMS-The Solver Manuals*," GAMS User Notes, (2001).
[13] Morais, H., Vale, Z., Faria, F., and Khodr, H. M., "Optimal Scheduling of a Renewable Micro-Grid in an Isolated Load Area Using Mixed-Integer Linear Programming," *Renewable Energy*, Vol. 35, (2010), pp. 151–156.

الإدارة المثلى لمصادر الطاقة المتجددة باستخدام منهجية منتج القدرة ووكيل المستهلك الافتراضي

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Ep٢١٠٢L ٢L٩ ¾,÷z1› 5se : p١١٠٢L ١١L٩٢ ¾,÷z1› p2eF

ملخص البحث‫ mi=2z2م zœ‫ z§›‫÷ gsa=c ã sa=¿ ‫›2¤,õ ووs=5 ‫mS=1g‹‹ ‫e¿é‫g ¸ xi.ض ‫£Q9ل
>1 ¸ ‫א-‫,õ 1âa ¸ QS,د, b,ãe c2i2õ a9ز<ã ،وzs‹‹ ½ms ‫=z3Q ¾ i-د‫,õ cãg ‫ð1¿ وaí,a› ‫ŞQ2ã،
و2;2Q=2 ‫ð.i¤ã <1 ¸ a¤¿ , ‹1=ms=@ i½ ;¤s=-,« ;9‹=2 ‫ð,ãe 9>=-,« ‫ae,ل ‫zS=1¤ã وaíQ ‫-z¿i¿‫
zœo ‫ð.i¤ã ;m=z2م bi,, >Q5 a§½ <1 ¸ wí,-¿ ;s¤=¿ ‫¿=§-,í,« ‹=z2i2 zsa=s-,« íل,a ‫mS=g1½3‫
و2¤› y g=-,s ã ma;›ã ui,د ‫-=z3Q ‫ae5ã i,w=z2‫م ‫zsã ‫?ð=ã ›<¿ ‫2<د ‫Q›z=zã ‫zS=1ðã، وذ›‹
و9c د a=yx‫« ذ‫« b§=2ã ma=Q.õ وísç ذ‫« b§=2ã ,eQ=ã is,¦=ã‫ وe2 y sczã ‫mS;›ã ,i,g=ً
م,aí ‫QSzcã ‫?ziã ‫2,aã ، و<1» i9w‫ðã <¿aã i.sã ذ‫« s¤,¥ô a.;¤2ã çgs, ui,د ‫£91ل mi§¿
‫2z=w,iم

‫1zsã ‫?ð=ã و i.sã ‫e<2‫د ‫Q›z=zã ‫zS=1ðã وíQi, ‫›z sã ‫›¿i=2=ã‫
و›¤2 ía‍g. ;ð§=@ ‫ð.i¤ã ›2,‫wã >,›ã >¤=¤=ã ¾ sað¤ã s2aã gs.i,¦=ã a2¿و›ã ¾ ‫›z;x,ل s¤,¥õ
>,=ã ¾ s2i2 ‫=÷x=5 و‫›=z3Q ›zy ş¤@ ‫e-‫א¥ ‫eaã5 ›=1‹‹ ‫÷§3ã ‫Qxyõ، و¤2› y ‫›9g9ل i9
‫s=-,¦¿ ‫Sã1 ¸ i22 ٣٠ >,وz ٩٠ a=11 ¸ i,í=ã‫