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MV Producers and Consumers Agents Characterization with DSM Techniques

Hugo Morais, Sérgio Ramos, Zita A. Vale, *Member, IEEE* and H. Khodr, *Member, IEEE*

Abstract **– This paper consist in the establishment of a Virtual Producer/Consumer Agent (VPCA) in order to optimize the integrated management of distributed energy resources and to improve and control Demand Side Management (DSM) and its aggregated loads. The paper presents the VPCA architecture and the proposed function-based organization to be used in order to coordinate the several generation technologies, the different load types and storage systems. This VPCA organization uses a frame work based on data mining techniques to characterize the costumers.**

The paper includes results of several experimental tests cases, using real data and taking into account electricity generation resources as well as consumption data.

Index Terms **– Demand side management, electricity markets, load management, load profiles, micro-grids, virtual power producers.**

I. Introduction

The power sector, has been undergoing significant changes all over the world in general and in Europe in particular.. There are established common rules for the internal electricity market and customers can freely choose their own electricity supplier. Symmetric markets allow electricity buyers to act as important players in a competitive environment. This requires that load aggregators detain relevant knowledge concerning consumption patterns and demand side management opportunities. Demand elasticity can be the key to take advantage of opportunistic strategies, both in the market environment and in the scope of the aggregator.

Strategic behavior based on demand elasticity must be based on consolidated knowledge concerning electricity consumer's behavior. The knowledge about consumption patterns is very important for load aggregators and electricity suppliers, as it provides the basis for the accomplishment of agreements concerning electricity prices, and for the definition of marketing policies and innovative contracts and services.

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H. Morais, S. Ramos and Z. Vale are with GECAD – Knowledge Engineering and Decision-Support Research Center of the Engineering Institute of Porto – Polytechnic Institute of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal (e-mail: icp@isep.ipp.pt / hgvm@isep.ipp.pt / csr@isep.ipp.pt / zav@isep.ipp.pt / hmk@isep.ipp.pt).

The characterization of electricity consumers' behavior relies on past consumption data, but also on consumption trends and strategies. Historic data can be used to extract knowledge about consumption behavior using adequate data mining techniques. Consumption classes can be determined using these data and knowledge concerning real costumers behavior and information related with issues such as activity type code, hired power value, consumed energy, etc [1].

An integrated management of distributed energy resources (DER) can be materialized through the implementation of the Virtual Power Producer (VPP) concept [2]. The aggregation of loads in the scope of VPPs gives place to a new market agent structure, the Virtual Producer/Consumer Agent (VPCA). VPCA provide 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 a VPCA architecture and the respective function-based organization. Within this organization, VPCA uses a framework developed to characterize Medium Voltage (MV) and Low Voltage (LV) consumers is used as a decision-support tool, supporting the active and strategic participation of loads in the new liberalized electrical environment.

The paper presents the results of some experimental tests using the proposed architecture and methodology for real-world situations, considering real electricity generation and consumption data.

II. Virtual Producer/Consumer Agent

With the liberalization of the power sector, electricity consumers can easily change 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 advantages from the competition opportunities. Choosing among several retailers can be a difficult task as contracts should be more flexible and provide dynamic contract management. Innovative and attractive contracts can provide different and flexible tariffs and assure diverse quality of supply depending on the chosen tariff framework.

The electricity price is composed with a great predominance of fixed costs, namely generation, transmission and distribution, limiting retailer flexibility and making electricity prices not significantly dependent from customer behavior.

An integrated vision of generation and demand, involving a set of generation resources and loads can provide the means to

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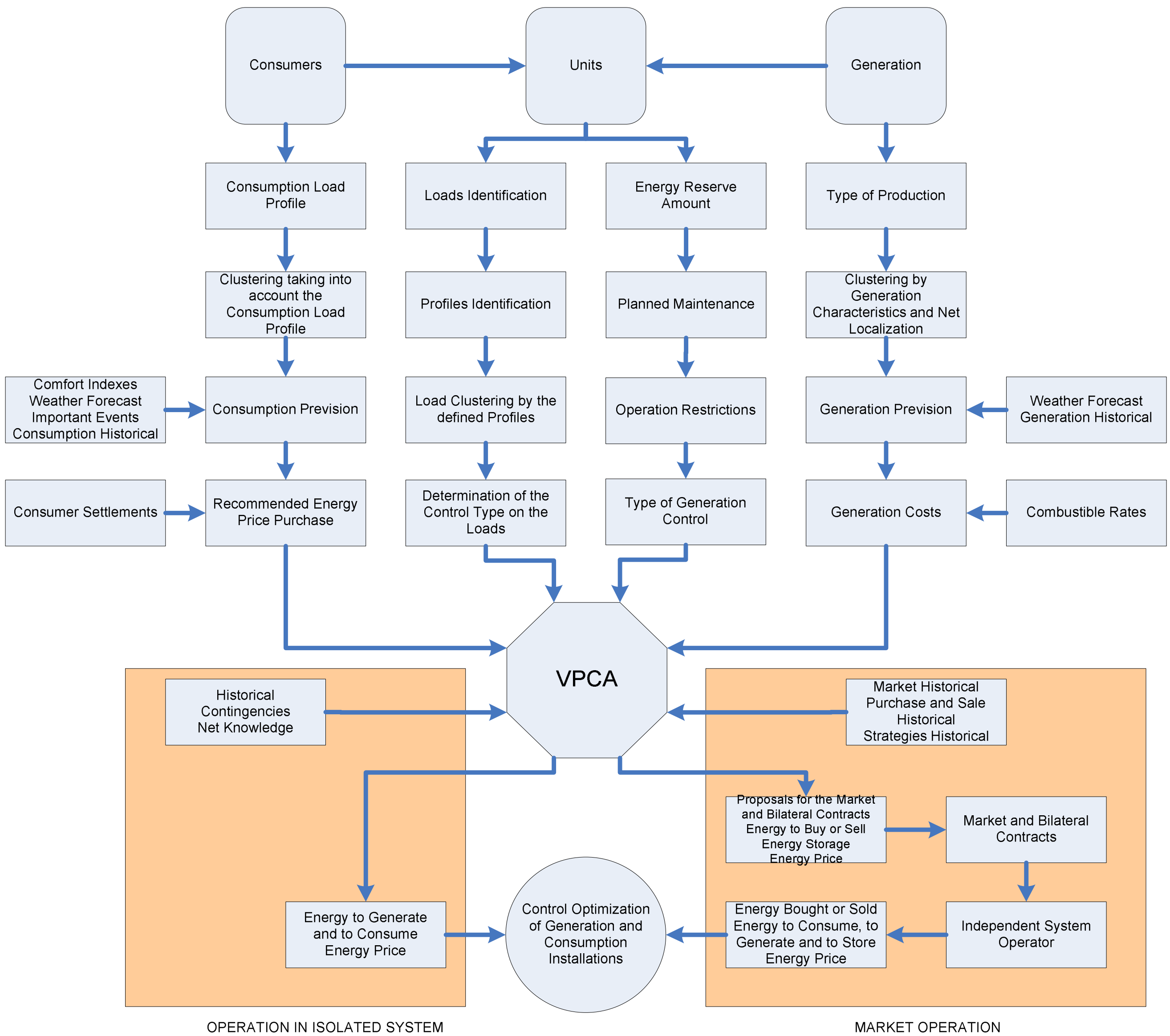

Fig. 1 – Schematic representation of the functioning of a VPCA

reflect consumer behavior on electricity prices in a more evident and advantageous away.

The aggregation of distributed generation (DG) plants gives place to 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 that the power has good chances to be sold in the market. Moreover, VPPs are able to commit to a more robust generation profile, raising the value of non-dispatched generation technologies.

Under this context, VPPs can ensure secure and environmentally friendly generation and optimal management of heat, cold and electricity. They can also provide the means to ensure optimal operation, maintenance of generation equipment and electricity market participation.

Aggregating loads to VPPs, resulting in a VPCA, allows these entities to undertake an optimized integrated management of the aggregated DER and loads. Fig. 1 shows the VPCA functioning.

The management of loads and generation with same entity allows new management strategies of DSM. With daily forecast of generation and consumption the VPCA can coordinate the several generation technologies and the different load types and also storage systems

Another possibility of VPCA actuation is in autonomous isolated systems, in this context and in the isolated micro-grids power sources are limited to the ones that exist inside the system, what makes generation scheduling increasingly important [2].

In this type of system the most important producers are the renewable energy sources (e.g, photovoltaic panels (PV), fuel cells, wind turbine etc.) in combination with gas generators and cogeneration. These small power generation networks need a distributed and autonomous control. Interest in small isolated power systems is also attractive for power utility companies, since they can help in improving the power quality and power supply flexibility. Also, they can provide spinning reserve and reduce the transmission and distribution costs, and can be used to feed the customers in the event of an outage in the primary substation [3].

In what concerns consumers' characterization, the VPCA should know exactly when and how their customers consume electricity as well as the electricity price that results from the market and the generation forecast. It is also indispensable to identify the consumers that will be open to change their electrical consumption behavior. This can be modeled determining a limited number of load profiles that are used for resource management, namely in cases of energy shortage. Then, the great challenge is to manage, in each instant, the available energy so the load curtailment decisions, when required, are based on the relevant knowledge related with consumers' characterization.

III. MV COSTUMERS CHARACTERIZATION

A. *Costumers clustering and classification*

Figure 2 shows the study process for Knowledge Discovery in Databases (KDD) [4], [5-7].

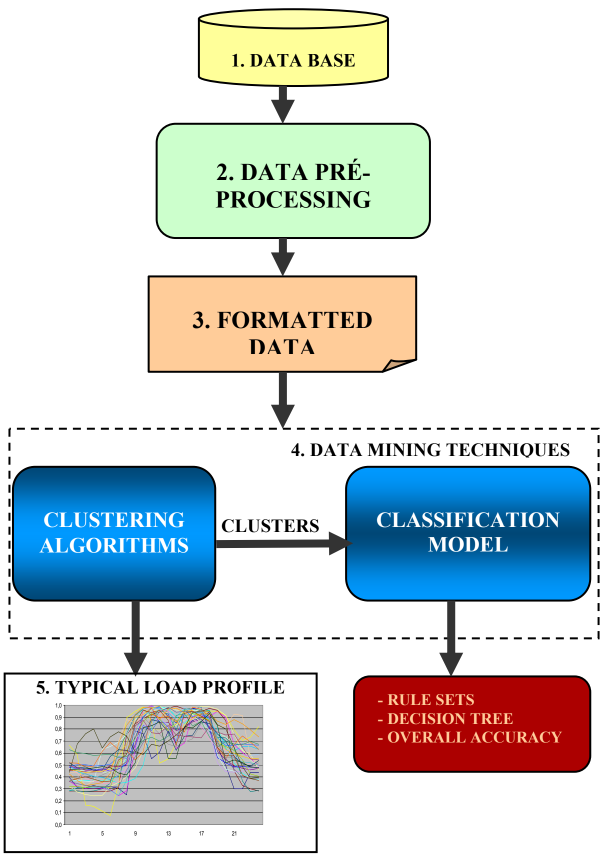

Fig. 2- Study Process Schedule framework of MV consumer's characterization

The framework developed for consumer characterization, used in the scope of this work, is based on this process. It includes several phases and uses data mining (DM) techniques. The framework is fragmented in different steps with different degrees of complexity, namely: data and features selection; data preprocessing; formatted data; data mining techniques and extracted knowledge.

Data mining techniques are used to characterize the typical customer profile, starting from an initial data set from the Portuguese utility [8]. The main goal of the consumer profiling is to group the data set in classes in such a way that the objects of a cluster should have a high similarity among them, and a low similarity with objects of others classes.

Using a classification model new consumers can be classified in one of the known clusters.

Starting from a real data base that was released by the Portuguese distribution company consisted of 229 MV customers, which was collected in a period of 3 months in summer and 3 months in winter for working days and weekends, the typical daily load curve of each customer has been determined. Through data preprocessing step, 21 customers were discarded from the initial data, remaining 208 consumers to be analyzed. With all data completed, a representative load curve has been obtained by averaging the daily load diagrams of each customer. Therefore, each customer is now represented by one typical load curve [8].

Figure 3 shows the representative working days load diagram obtained for each cluster, using directly the measured power [8].

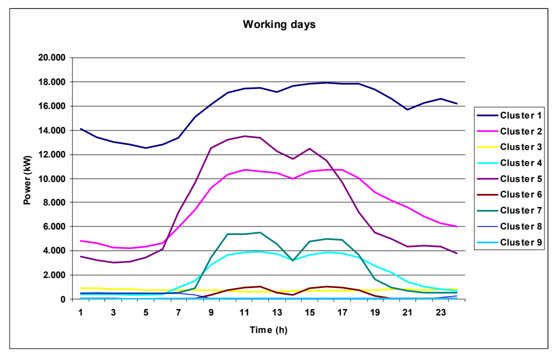

Fig. 3 – Clusters obtained by Two-step cluster algorithm for working days

Each curve represents a cluster that represents a customer group with the same consumption pattern.

Figure 4 shows the total amount of the electrical energy that was consumed by the 208 consumers considered in this case study.

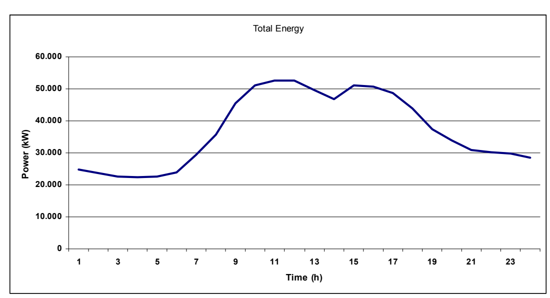

Fig. 4 – Total electrical energy consumed by the 208 consumers for working days

B. *Load Flexibility*

Nowadays there is an upward tendency for using small isolated power systems when regarding rural and distant places, against the idea of using only one central power producing system.

Although the advantages of using small power systems are considerable, the systems that are based only on renewable energy sources, require the use of storage capability to increase power availability.

The VPCA can explore dynamic pricing along the day to take advantage of the eventual modulation of their customers load profile. Dynamic pricing includes the price variation along the day that reflects the higher cost of electricity generation during peak hour's usage. This is an opportunity that VPCA, producers and consumers certainly should not miss, and for that the electrical consumers must to be prepared to change their consumption habits. So, it is indispensable to identify the consumers that are open to change their electrical consumption behavior.

We propose to consider 4 different typical load profiles that will permit, in some way, changing the consumption habits:

- Profile 1 – It does not admit any load curtailment, independently of the time of the day. This is for instance the case of vital industrial producing processes and of emergency infrastructures such as hospitals and military sites;
- Profile 2 – The load can alter its schedule according to operation constraints (e.g. generation shortage, incidents). This can apply to some tasks that can be done at any hour of the day (e.g. washing machine);
- Profile 3 – The load can be partially curtailed under some conditions. This may for instance apply to lightning, air conditioning and heating systems (reduction in 1 or 2 degrees), compressed air (reduction about 0,5-1 bar in air pressure), and escalators speed;
- Profile 4 – The load can be curtailed at any time of the day. The contract specifies to which electrical circuits this can be applied.

Using this approach and having knowledge about each load profile, the VPCA can manage all generation units and consumers loads in function of the established goals. These goals can be of diverse nature (e.g. to guarantee the power system stability, to increase the profits of producers, to reduce consumers costs, to reduce the global costs).

IV. Resource and Load Management

The VPCA aims at optimally managing all the available resources and loads in order to achieve the established goals. For this, it needs relevant information in order 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 charging and discharging. Decision making requires taking into account the following considerations:

- The wind power generation strongly depends on the weather. To have enough precision, the generation capability only can be estimated for a period of 24 hours in advance.;
- The photovoltaic generation can be forecasted in a precised way;
- 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 discharging is limited by a maximal discharging capacity and existing storage energy;
- The loads are forecasted considering several aspects; however most of the loads can be controlled under certain limits (using DSM - Demand Side Management). For each cluster the VPCA knows the loads which can totally or partially curtailed or moved to different time slice;
- To ensure system balance, the VPCA can settle terms of reserve. For example, the VPCA can limit the minimum reserve to 10 % of load forecast. This reserve can be assured by storage and fuel cells.

The main objective is to carry out an optimal dispatch taking into account all the available energy resources, the forescasted load, load profiles, and the referred considerations.

The surplus energy is used for charging the storage battery. 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)

For solving this continuous constrained portfolio problem we have programmed it in Cplex using GAMS plataform.

The constraints of the problem have been elaborated taking into consideration five different operation modes:

1. There is a surplus energy that can be stored (as in the case presented in Fig.5);
2. The generation is not enough to assure the supply of the total load, therefore the battery is discharged;
3. In case of lack of generation based on renewable sources (wind, water and/or sun shine) the battery, CHP and Fuel Cell come into operation (as in the case presented in Fig 6);
4. In insufficient energy generation case the load must be shed.

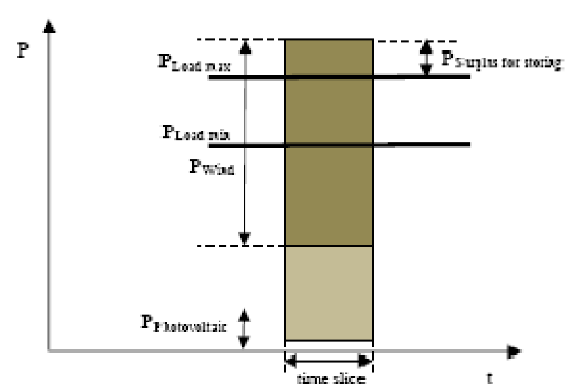

Fig. 5- Surplus of primary energy

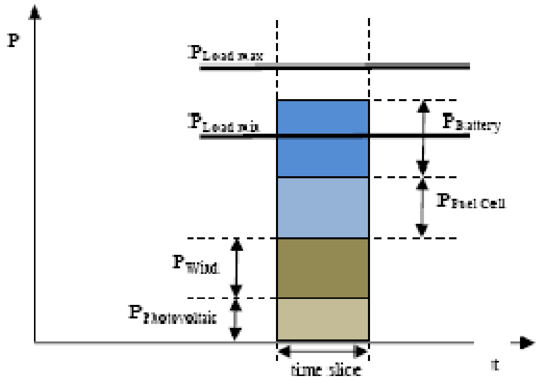

Fig. 6- The storage and the fuel cell are in operation

The objective function of the mixed-integer linear model is the total cost for a given period (T) and must be minimized:.

$$Minimize\ f =$$

$$Min\left[\sum_{t=1}^{T}\left(\begin{array}{l} P_{Wind\,(t)}\times c_{Wind\,(t)} + P_{Photovoltaic}\times c_{Photovoltaic\,(t)} \\ P_{Hydro\,(t)}\times c_{Hydro\,(t)} + P_{CHP\,(t)}\times c_{CHP\,(t)} \\ + P_{FuelCell\,(t)}\times c_{FuelCell\,(t)} \\ - P_{StorageBateryCharge\,(t)}\times c_{StorageBateryCharge\,(t)} \\ + P_{StorageBateryDischarge\,(t)}\times c_{StorageBateryDischarge\,(t)} \\ + P_{Reduce\,(t)}\times c_{Reduce\,(t)} + P_{Move\_m\,(t)}\times c_{Move\_m\,(t)} \\ + P_{Curtailment\,(t)}\times c_{Curtailment\,(t)} \\ + U_{ndeliveredEnergy\,(t)}\times c_{UndeliveredEnergy\,(t)} \\ - E_{xcessGeneratedEnergy\,(t)}\times c_{ExcessGeneratedEnergy\,(t)} \end{array}\right)\right]$$

Subject to a following constraints:
First Kirchhoff Law or Power Balance

$$\sum_{t=1}^{T}\left(\begin{array}{l} P_{Wind\,(t)} + P_{Photovoltaic\,(t)} + P_{Hydro\,(t)} + P_{CHP\,(t)} + P_{FuelCell\,(t)} \\ + P_{StorageBateryDischarge\,(t)} + P_{Reduce\,(t)} + P_{Curtailment\,(t)} \\ + P_{Move\_m\,(t)} + U_{ndeliveredEnergy\,(t)} = Load_{(t)} \\ + P_{StorageBateryCharge\,(t)} + P_{Move\_a\,(t)} + E_{xcessGeneratedEnergy\,(t)} \end{array}\right)$$

Wind generation limits in each period "t"

$$P_{Wind\,(t)} \le P_{WindLimit\,(t)};\quad t\in\{1,...,T\}$$

Photovoltaic generation limits in each period "t"

$$P_{Photovoltaic\,(t)} \le P_{PhotovoltaicLimit\,(t)};\quad t\in\{1,...,T\}$$

Hydroelectric generation limits in each period "t"

$$P_{Hydro\,(t)} \le P_{Hydro\_max}\quad t\in\{1,...,T\}$$

$$\sum_{t=1}^{24} P_{Hydro\,(t)} \le P_{StorageWater};$$

Photovoltaic generation limits in each period "t"

$$P_{CHP\,(t)} \le P_{CHP\,Max};\quad t\in\{1,...,T\}$$

Fuel Cell limits in each period "t"

$$P_{FueCell\,(t)} \le P_{FueCell\,Max};\quad t\in\{1,...,T\}$$

Storage battery limits in each period "t"

$$P_{Storage\,(t)} \le P_{StorageMax};\quad t\in\{1,...,T\}$$

10. Storage battery maximal discharge limits in each period "t"

$$P_{BatteryDischarge\,(t)} \le P_{BatteryDischarge\,Max}1500X_{(t)};$$
$$t\in\{1,...,T\};\ X\in\{0,1\}$$

11. Storage battery maximal charge limits in each period "t"

$$P_{BatteryCharge\,(t)} \le P_{BatteryCharge\,Max}Y_{(t)};\quad t\in\{1,...,T\};\ Y\in\{0,1\}$$

12. The battery can't charge and discharge at the same time in each time slice "t"

$$X_{(t)} + Y_{(t)} \le 1;\quad t\in\{1,...,T\};\ X\ and\ Y\in\{0,1\}$$

13. Storage battery maximal discharge limits in each period "t" considering the battery state storage in period t-1

$$P_{BatteryDischarge\,(t)} - P_{Battery\,(t-1)} \le 0;\quad t\in\{1,...,T\};$$

14. Storage battery maximal charge limits in each period "t" considering the battery state storage in period t-1

$$P_{BatteryCharge\,(t)} + P_{Battery\,(t-1)} \le P_{BatteryMax};\quad t\in\{1,...,T\};$$

15. State balance of battery

$$P_{Battery\,(t)} = P_{Battery\,(t-1)} - P_{BatteryDischarge\,(t)} + P_{BatteryCharge\,(t)};\quad t\in\{1,...,T\};$$

16. Initial state of the battery

$$P_{Battery\,(t=0)} = P_{Battery\,0}$$

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

TABLE I – 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								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	≤10000 Storage water to 60000	≤10000	≤3000	≤5000	1000	≤3000	≤1500	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 the time slice can be moved to time slices 7 to 10 h or 18 to 20 h.

V. CASE STUDY

The proposed methodology is applied to a simulated case based on real costumers data. The considered prices are the following: Wind energy 0,4 €/kWh; photovoltaic 0,4 €/kWh; hydroelectric 0,4 €/kWh; CHP 0,6€/kWh; fuel cell 0,9 €/kWh; storage discharging 0,7 €/kWh; storage charging 0,4 €/kWh; load moving for a different time slice 1,2 €/kWh; load reduction 1.3€/kWh; load curtailment 1.4€/kWh; undelivered power 1.5 €/kWh and the excess energy is 0 €/kWh.

To illustrate the generality and the effectiveness of the proposed methodology. Data for this scenario is presented in Table I.

The VPCA has detailed information not only about the consumption of all customers but also about the characteristics of their loads and of industry electrical needs. It is very important to have and understand the real electricity needs of all consumers. This knowledge is crucial for an adequate management of all the available resources, including the use of DMS.

Solving the optimization problem allowed to obtain the optimal renewable energy generation dispatch taking into account the cost of each generation technology. Several simulations have been done in order to understand the importance of the consideration of different load profiles.

Fig. 7 presents the obtained results for the load supply in a situation when all the consumers do not admit load shedding, independently of the time of the day. Analyzing Fig 7 it is possible to see that there is an amount of undelivered energy in time slices 10 to 18.

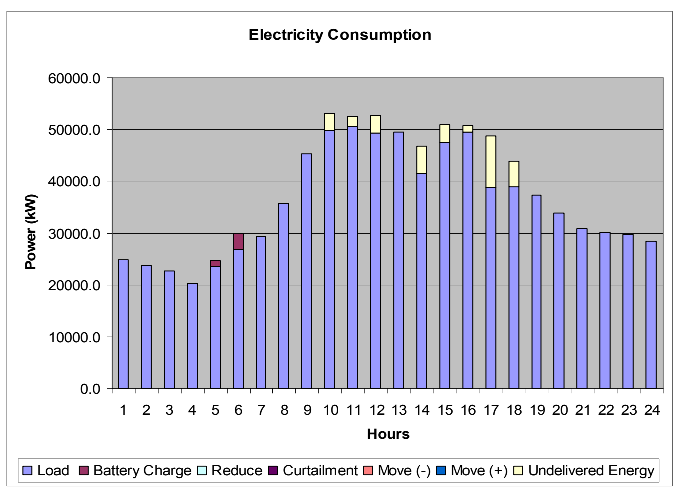

Fig. 7. Energy consumption Without Consumption management

Fig 8 shows the optimal generation scheduling for the same situation.

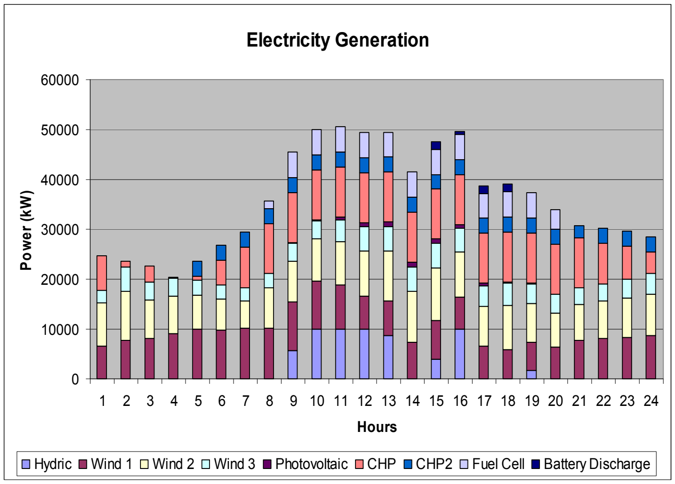

Fig. 8. Generation without Consumption management

Considering contracts with all profiles types, the VPCA can manage the generation and consumption to reduce the undelivered energy to the important loads. For the same demand, we will consider a set of contracts that allow to use demand side flexibility.

Considering the nine clusters obtained in section III, the following profiles are 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;
– Clusters 7 – Profile 1 and Profile 4;

Figure 9 shows the results for electricity consumption in this situation. It can be seen that the VPCA has been able to manage the resources so that there is not any undelivered energy for prioritary loads. Demand side flexibility is used by moving a part of the load for off-peak periods, reducing, and curtailing a part of the loads. The battery is charged in two periods.

Figure 10 shows the optimal generation scheduling for the same situation.

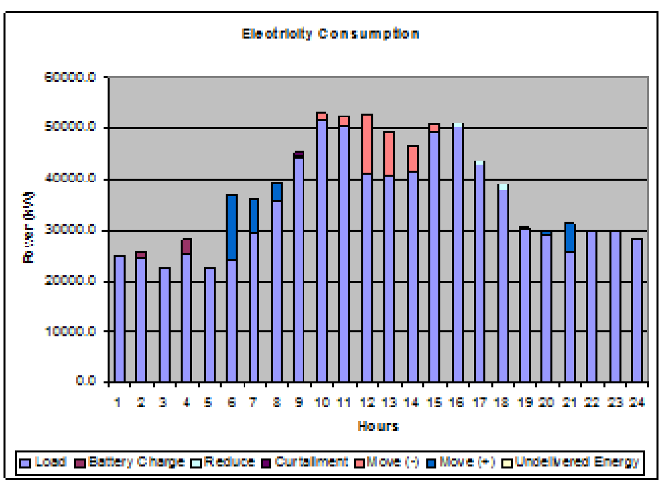

Fig. 9. Energy consumption with move, reduce and curtailment some electrical energy consumption.

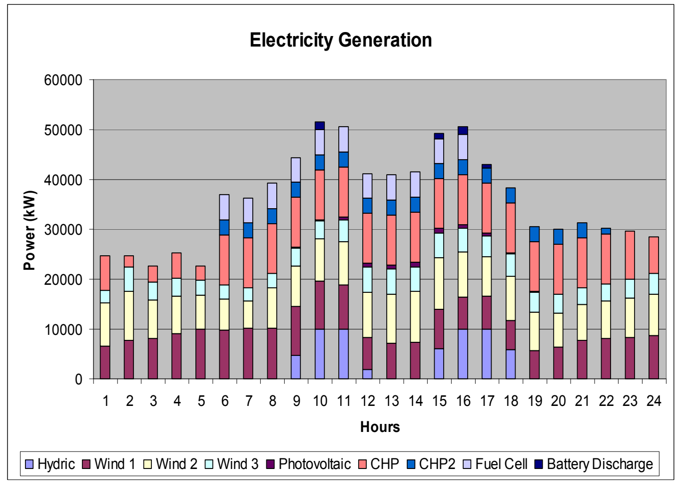

Fig. 10. Generation with move, reduce and curtailment some electrical energy consumption.

In this simulation the consumers profile with more impact on the results are the consumers that allow to move some electrical energy consumption for the off-peak hours. The other consumers are important to balance the time slices with short difference between generation and consumption.

VI. Conclusion

This paper proposes a methodology to manage the operation of an isolated system by a Virtual Producer/Consumer Agent (VPCA). The main goal is to minimize the total cost which includes generation costs, storage charging and discharging costs, and demand side flexibility use costs, subjected to all the operation technical constraints. The VPCA must assure a permanent balance between generation and consumption undertaking the required load curtailment, when this is necessary, in an optimized way.

The paper presents the results of the application of the methodology to a real consumers set. The dispatch has been formulated as a mixed integer linear programming problem and programmed and solved in GAMS platform using CPLEX.

The obtained results demonstrate that the proposed methodology is effective and robust. It is also efficient as it requires low execution time. The proposed method helps to minimize the operation costs taking into account all the available energy resources and the demand side flexibility.

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VIII. Biographies

Hugo Morais received the B.Sc. degree in 2005 from the Polytechnic Institute of Porto, Porto, Portugal. He is also a PhD student with the University of Trás-os-Montes e Alto Douro, Vila Real, Portugal and his research interests include distributed generation and future power systems.

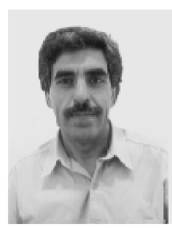
Sérgio Ramos graduated in the Polytechnic Institute of Porto in 1999 and received his MSc degree from the Instituto Superior Técnico (Lisbon-Portugal) in 2006.

He is currently an Assistant Professor of Electric Power Systems in the Polytechnic Institute of Porto. His research interests include competitive electricity markets, energy efficiency, load research and electrical installations.

Zita A. Vale is a Coordinator Professor of Power Systems at the Engineering Institute – Polytechnic Institute of Porto (ISEP/IPP), Portugal.

She received her diploma in Electrical Engineering in 1986 and her PhD in 1993, both from University of Porto.

Her main research interests concern Artificial Intelligence (A.I.) applications to Power System operation and control, Electricity Markets and Distributed Generation. She coordinates the Intelligent Energy Systems group at GECAD – Knowledge Engineering and Decision-Support Research Center.



H. M. Khodr (M´99) received the Ph.D. and M.Sc./Engineer degrees in Electrical Engineering from the José Antonio Echeverría Higher Polytechnic Institute (ISPJAE) in 1997 and 1993 respectively.
Former Associate Professor of Electrical Engineering at Simón Bolívar University, Venezuela. He was a Researcher at INESC porto, Portugal.
Presently, he is a Researcher at GECAD – Knowledge Engineering and Decision-Support Research Group of the Electrical Engineering Institute of Porto – Polytechnic Institute of Porto (ISEP/IPP). He has participated in a number of projects performed for the local industries. His current research activities are concentrated on planning, operation, and economics of electrical distribution and industrial power systems, power quality, grounding systems and optimization.