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Intelligent Management of a House Consumption according Photovoltaic Micro-Generation of Portugal and Brazil for Demand Response participation

Filipe Fernandes[a]*, Hugo Morais[a], Valdomiro Vega Garcia[b], Zita Vale[a], Nelson Kagan[b]

[a]*GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering – Polytechnic of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal*

[b]*NAPREI/ENERQ – Smart Grid and Power Quality Laboratory, Polytechnic School - University of São Paulo, Av. Prof. Luciano Gualberto, 380, 05508-010 São Paulo, Brazil*

Abstract

With increasing of the energy consumption in the last years, the residential sector represents an important part of the overall consumption in the developed countries. Several approaches have been proposed, with emphasis on Smart Grids and Microgrids concepts, to obtain an effective participation of the consumers. For the better management of domestic consumers, the Smart Home management systems have been developed in the scope of Smart Grids concepts. At the same way, Smart Home provides more adequate and efficient interaction between the network operator and the consumers allowing the monitoring and a better control of the appliances inside the house.

The paper presents an optimization algorithm to participate in DR programs considering the loads, micro-generation and grid connection. The method is applied in loads and real micro-generation profiles from University of São Paulo and from Polytechnic of Porto.

* Corresponding author.

E-mail address: fijgf@isep.ipp.pt.

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1. Introduction

In the new electrical networks operation paradigm, consumers will be seen as active resources with capability to manage their energy consumption, energy generation, and energy storage systems like presented in Figure 1. To implement this vision, several approaches have been proposed with the main focus on the concepts of the Smart Grids (SG) and Microgrids (MG) [1]. The high penetration of the distributed energy resources making the energy management decision more decentralized, allowing at the same time, the faster SG development [2]. The MG (players aggregated in small areas) allows the management of several consumers and distributed generation with the possibility to work in two ways: connected to the main distribution grid or to operate in islanded mode [3], [4].

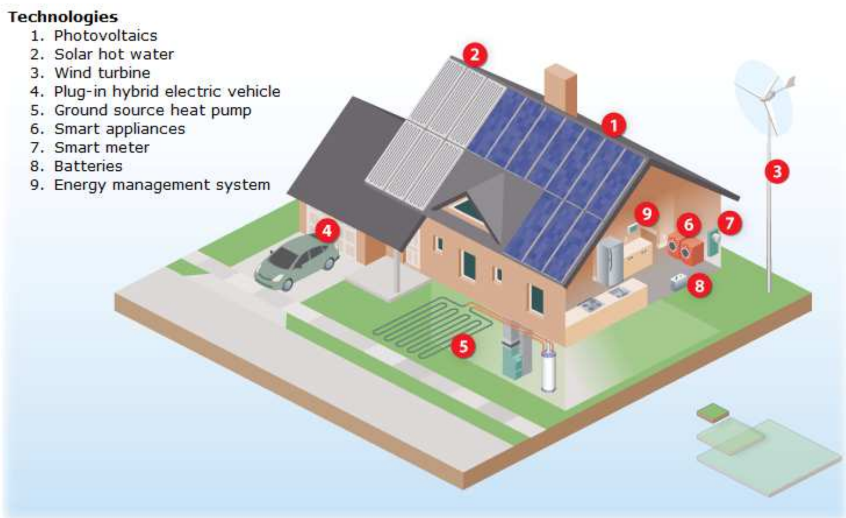

Fig. 1. House with energy resources integration [5]

The domestic consumers need to use the systems that allowing the management of the electrical consumption, the micro-generation units, the electric vehicles and the consumer participation in the Demand Response (DR) programs. All of this energy resources of the domestic consumer should be considers in a house management system. In the management of the electrical consumption are included all loads that user has in own house, some with consumption regulation (variables loads) and others On/Off tyoe (fixed loads). The distributed generations resources consider in the domestic consumer are in micro scale as, the wind generator, the photovoltaic panel and the combined heat and power unit (CHP) [6]. The electric vehicles consider can be conventional technology needing the charge of batteries or can be vehicle-to-grid (V2G) having the capacity to charge and discharge the batteries. The V2G type allows storing energy and making better use of renewable energy [7].

The development of the SG and MG requires the development of other new concepts such

as the smart meter or the Smart Home (SH). The SH can be defined as a house which comprises a network communication between all devices of the house allowing the control, monitoring and remote access of all application and services of the management system. The management system should include advanced functions, such as the management of electric vehicles, the interface with external operators, security functions, among others [8], [9]. A home to be considered smart should include three main elements: the internal communication network, intelligent control systems and home automation [10].

The present work focuses in an optimization algorithm to participate in DR programs considering the loads, micro-generation and grid connection. The method is applied in loads and real micro-generation profiles from University of São Paulo and from Polytechnic of Porto. The main goal of the method is to obtain a scheduling for all energy resources allowing the participation in DR programs.

After the introductory section, Section 2 presents energy management concepts used to develop the active participation of domestic consumers in SG. Section 3 shows the optimization model developed for energy management platform. A database of photovoltaic micro-generation profiles in Portugal and Brazil is presented in Section 4. Section 5 presents a case study based on Brazilian and Portuguese scenario considering different resources in domestic consumers. Finally, Section 6 presents the main conclusions of the work.

2. Energy management concepts

The present section includes some energy management concepts in the domestic consumers (sub-section 2.1) and the participation of domestic consumers in DR programs (sub-section 2.2).

2.1. Management systems in domestic consumers

Many advances were proposed in order to improve House Management Systems (HMS), such as the existence of integrated residential gateways [11] or the use of home internet network in HMS systems [12]. More features are proposed in [13], namely the use of wireless communication and the remote access to monitor and control house devices. The use of user location, user motion detection, and measurement/control devices in houses electricity sockets is proposed in [14], in order to determine the user´s consumption profile. Besides other features, this system allows turning off some devices when rooms are empty (without persons). Figure 2 show a structure of a SH to energy management of consumer.

Fig. 2. Energy management model in Smart Home context [15]

A HMS capable of joining the management of electricity and gas consumption is proposed in [16] and also addressed the user´s active participation and the contribution for a better performance/efficiency of the system. The electricity consumption profiles collected according to several factors which influence the consumption are analyzed in [17], such as the comfort levels or the weather.

Currently, several HMS solutions are proposed for companies and organizations. However, the massive use of HMS is still not a reality. Some barriers to the massive use of HMS keep, for example users don't have knowledge of the existing technologies; high prices of the solutions; and the weak users' interfaces proposed.

2.2. Participation of domestic consumers in DR programs

The present sub-section shows some examples of DR programs. DR programs can be an important energy resource in the future power systems. Large consumers (industry and large commerce) are the main focus of the actual DR programs, but the domestic consumers can provide more a flexible response. The management of DR events in the HMS is an important challenge for future HMS, in order to take monetary advantages from the participation in DR events. The future house management systems should be able to manage automatically DR events considering the consumers' point of view, regarding the consumption/prices off sets, and the loads preferences [18].

Several types of demand response are available being the Time-of-Use (TOU) programs the most popular. TOU encourage consumers to decrease the consumption in response to a higher electricity price [19]. The participation in DR programs can be managed by an

aggregator entity, for instance by the curtailment service provider (CSP). The CSP can manage the participation in demand response events of more than one consumer, making some guaranties to the system operators, and providing services to the consumers.

Figure 3 presents a system where is possible control some loads of a Smart Home through Energy Management Controller (EMC) considering DR programs. In this way it is possible to turn off the loads defined in Smart Home by the Direct Load Control (DLC).

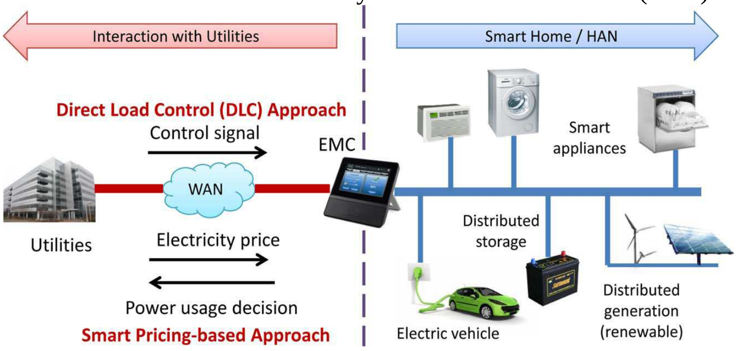

Fig. 3. Intelligent management system of a house with grid communication [20]

3. Optimization model developed for SCADA House Intelligent Management system

The present section explains the house management platform developed in Polytechnic of Porto (sub-section 3.1) and the optimization model to be consider in the resources management module of the SCADA House Intelligent Management (SHIM) system with main goal to manage the loads and micro-generation according with the context of the day (sub-section 3.2).

3.1. SCADA House Intelligent Management platform

The SHIM system has been developed in the Intelligent Energy Systems Laboratory (LASIE), located at the Institute of Engineering – Polytechnic of Porto (ISEP/IPP). SHIM is a testbed platform with the main goal of testing, simulating, and validating new algorithms and methodologies to apply into house/buildings' management. SHIM has real equipment such as several types of loads, distributed generation (photovoltaic panels, wind generator), and storage systems that allow the simulation of the electric vehicles' behaviour.

The SHIM platform is composed of different modules, being each module composed of different algorithms to be used in different situations. The modules are grouped into three different parts, namely the Data acquisition, the Actuators, and the Intelligent Applications (Figure 4):

- In the data acquisition part, four modules are included, namely the sensors, the user interfaces, the external communications, and the internal functions.
- A database was included to store all the information provided by other modules.
- The part of the actuators integrates all types of interfaces with real hardware, namely digital actuators, the analog actuators, inverters, motor drives, among others. This

module also includes the internal network management considering different protocols.

- The intelligent applications part integrates all the advanced functions in SHIM systems, namely the identification of the context, the definition of priorities, learning algorithms, the users' profiles identification, and the resources' management. The modules also need information on the equipment' functioning characteristics, and the actual status of each device.

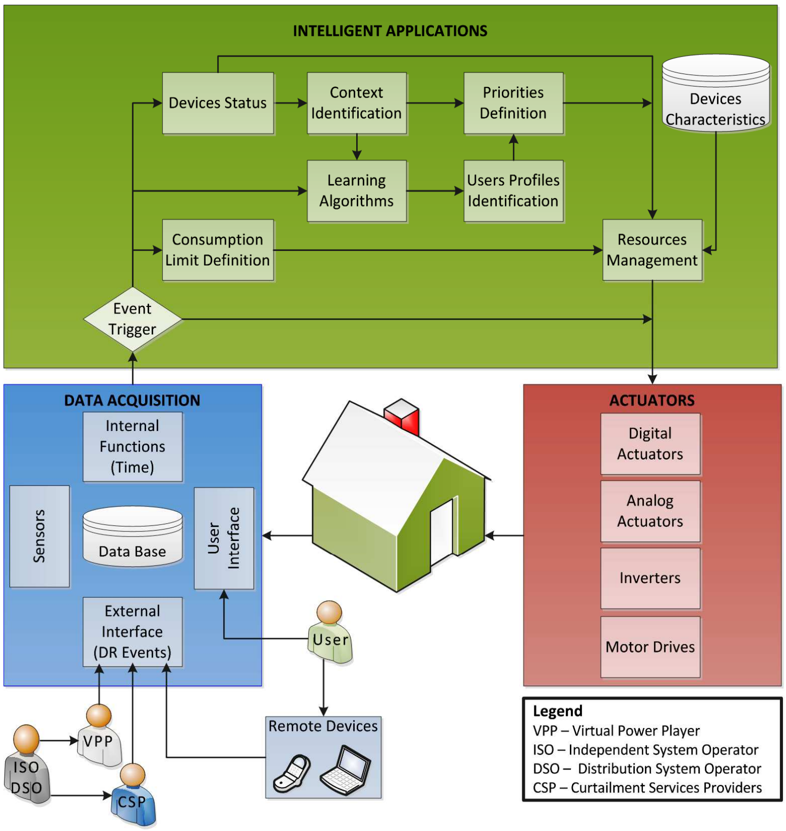

Fig.4. General diagram of SHIM platform [21]

3.2. Problem formulation of model

The present sub-section presents the problem formulation applied in the optimization for the participation in DR programs. The objective function to determine the resources that should continue in service is presented in Equation (1). The objective function depends of constraints and Equation (2) intends to determine the power balance. Equations (3) and (4) refer to the maximum and minimum limits of loads, respectively. If the load is discrete (On/Off), variable P_{Load}^{Max} is equal to P_{Load}^{Min}. In this case, the decision is imposed by the binary variable x_{Load}. Equations (5) and (6) refer to the maximum and minimum limits of micro-generation, respectively. In this case, the decision is imposed by the binary variable x_{DG}.

Equations (7) and (8) refer to the maximum and minimum limits of grid connection, respectively. In this case, the decision is imposed by the binary variable x_{Grid} , where the grid connection correspond to the power injected in the grid. Equation (9) imposes that the grid cannot supply and receive power at the same time. In this model, the power limit corresponds to the power supplied by the grid.

$$Minimize\ \ f = min\left\{\begin{array}{l}\sum_{Load=1}^{nLoad} \lambda_{Load} \times P_{Load} + \lambda_{Grid} \times P_{Grid} + \lambda_{Down} \times Reg_{Down} \\ -\sum_{DG=1}^{nDG} \lambda_{DG} \times P_{DG} - \lambda_{UP} \times Reg_{Up}\end{array}\right\} \tag{1}$$

$$P_{Limit} \geq \sum_{Load=1}^{nLoad} P_{Load} + P_{Grid} + Reg_{Down} + P_{FixedLoads} - \sum_{DG=1}^{nDG} P_{DG} - Reg_{Up} \tag{2}$$

$$P_{Load} \leq P_{Load}^{Max} \times x_{Load} \tag{3}$$

$$P_{Load} \geq P_{Load}^{Min} \times x_{Load} \tag{4}$$

$$P_{DG} \leq P_{DG}^{Max} \times x_{DG} \tag{5}$$

$$P_{DG} \geq P_{DG}^{Min} \times x_{DG} \tag{6}$$

$$P_{Grid} \leq P_{Grid}^{Max} \times x_{Grid} \tag{7}$$

$$P_{Grid} \geq P_{Grid}^{Min} \times x_{Grid} \tag{8}$$

$$x_{Grid} = 0 \quad if\ \ P_{Limit} > 0 \tag{9}$$

where:

λ_{DG}	Micro-generation priority factor
λ_{Down}	Regulation down preference factor
λ_{Grid}	Grid connection priority factor
λ_{Load}	Load priority factor
λ_{Up}	Regulation up preference factor
nDG	Total number of micro-generation units
$nLoad$	Total number of loads

x_{DG}	Micro-generation binary variable
x_{Grid}	Grid connection binary variable
x_{Load}	Load binary variable
DG	Micro-generation index
$Load$	Load index
P_{DG}	Active power micro-generation
P_{DG}^{Max}	Maximum micro-generation power
P_{DG}^{Min}	Minimum micro-generation power
$P_{FixedLoad}$	Total Consumption of non-controlled loads
P_{Grid}	Active power of grid connection
P_{Grid}^{Max}	Maximum injected power in grid
P_{Grid}^{Min}	Minimum injected power in grid
P_{Limit}	Limit power of grid by DR event
P_{Load}	Active power of load consumption
P_{Load}^{Max}	Maximum load consumption
P_{Load}^{Min}	Minimum load consumption
Reg_{Down}	Power Regulation Down
Reg_{Up}	Power Regulation Up

4. Photovoltaic micro-generation profiles in Portugal and Brazil

The present section illustrates the photovoltaic micro-generation profiles in two different countries, Portugal and Brazil, and for two different seasons of the year, winter and summer.

For the analysis of the micro-generation profiles, the ELECON makes electricity consumption data available whenever confidentiality and data property issues do not prevent their public use. The publication of these data is being made in the scope of the IEEE Working Group (WG) on Intelligent Data Mining and Analysis. For the present work, it is considers the photovoltaic generation data available in the public data sets in http://sites.ieee.org/psace-idma/data-sets/#pvge.

4.1. Characteristics of photovoltaic generation systems

The photovoltaic generation in Brazil and Portugal is compared in the case study according with two real and installed systems. From Brazil, the energy micro-generation data was acquired from the Smart Grid and Power Quality Laboratory at the University of São

Paulo (ENERQ/São Paulo), which is composed by ten photovoltaic fixed panels. From Portugal, the micro-generation data were acquired from the Intelligent Energy Systems Laboratory, at the Institute of Engineering – Polytechnic of Porto (GECAD/Porto). One of the three photovoltaic systems operating in GECAD is composed by two photovoltaic modules with solar tracker to increase the energy generation. The two systems have the general information presented in Table 1 and Figure 5.

Table 1. General information for photovoltaic installed systems in Portugal and Brazil

Detail	*ENERQ/São Paulo*	*GECAD/Porto*
Country	Brazil	Portugal
Region	Southeast	North Coast
Latitude	-23.555877	41.179346
Longitude	-46.729518	-8.608041
System Power	2550 Wp	400 Wp
Type	Fixed	Solar tracker

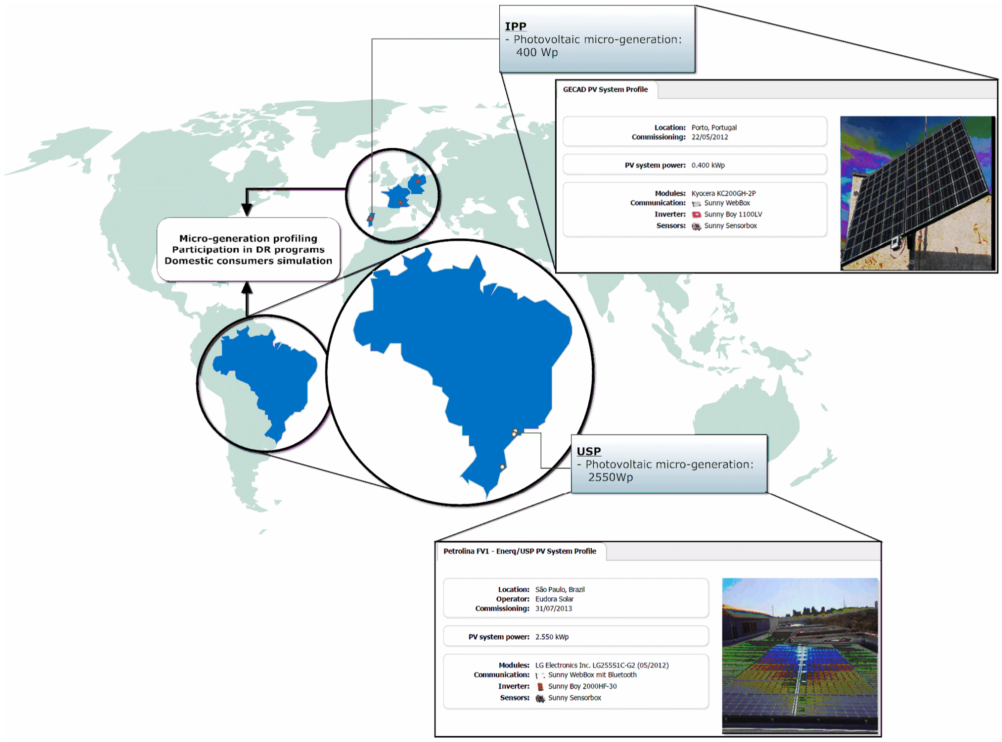

Fig. 5. Photovoltaic micro-generation systems for each country

4.2. Photovoltaic micro-generation for a winter season

In the Public Electricity Consumption Data of ELECON it is selected the PV generation for southeast of Brazil database a sunny and cloudy day for a winter scenario in the Brazilian case. The generation profiles for this case are presented in the Figure 6 and Figure 7.

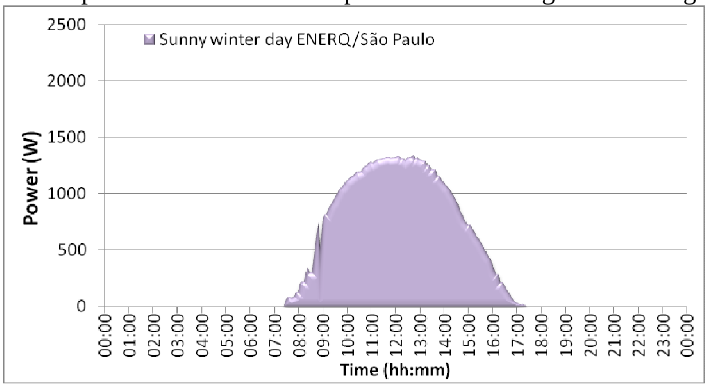

Fig. 6. Photovoltaic power generation for a sunny winter day in Brazil

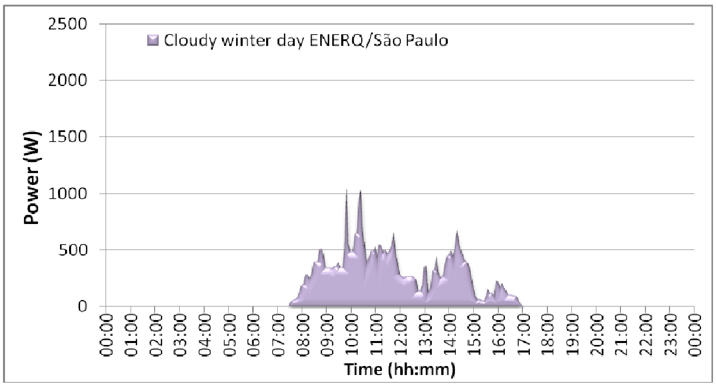

Fig. 7. Photovoltaic power generation for a cloudy winter day in Brazil

For the Portuguese case it is selected the PV generation of a sunny and cloudy day for a winter scenario. The generation profiles for this case are presented in the Figures 8 and 9.

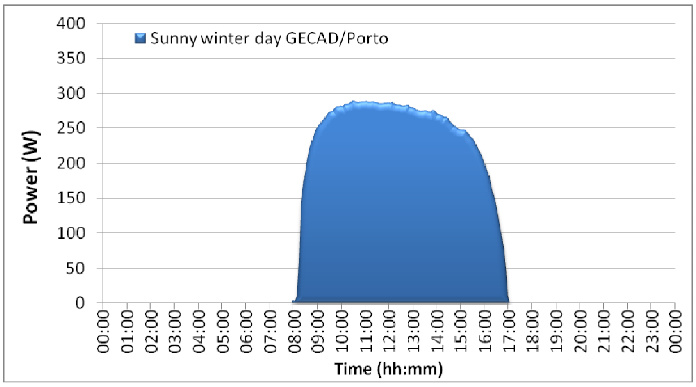

Fig. 8. Photovoltaic power generation for a sunny winter day in Portugal

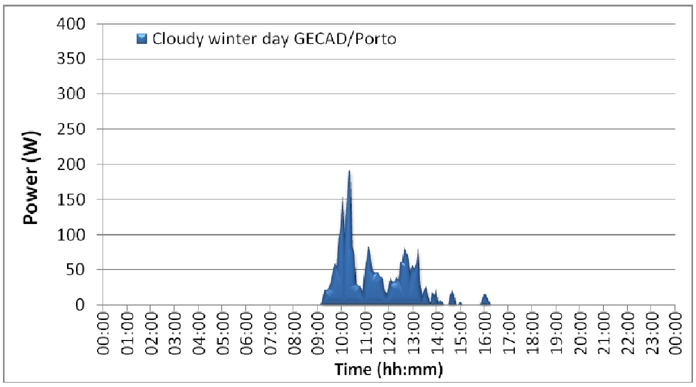

Fig. 9. Photovoltaic power generation for a cloudy winter day in Portugal

4.3. Photovoltaic micro-generation for a summer season

In the Public Electricity Consumption Data of ELECON it is selected the PV generation for southeast of Brazil database a sunny and cloudy day for a summer scenario in the Brazilian case. The generation profiles for this case are presented in the Figures 10 and 11.

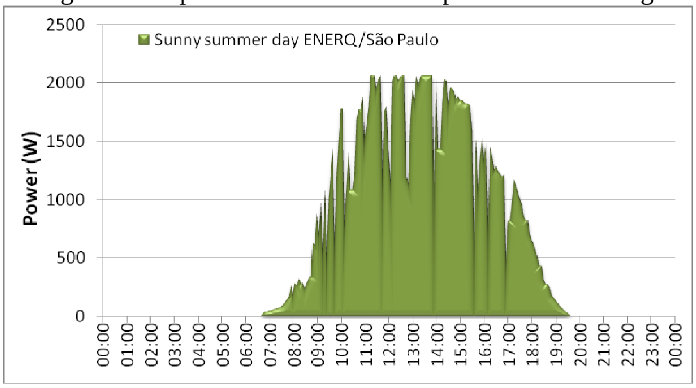

Fig. 10. Photovoltaic power generation for a sunny summer day in Brazil

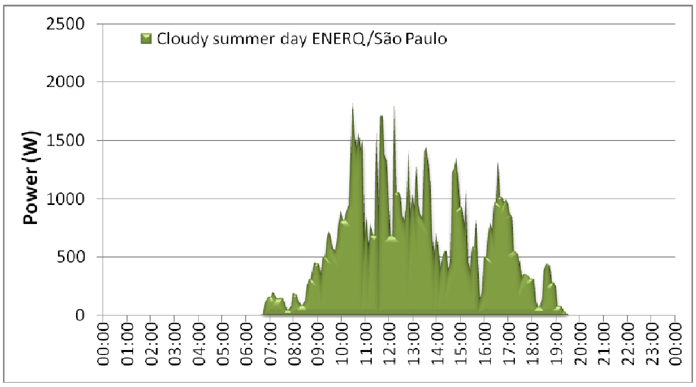

Fig. 11. Photovoltaic power generation for a cloudy summer day in Brazil

For the Portuguese case it is selected the PV generation of a sunny and cloudy day for a summer scenario. The generation profiles are presented in the Figure 12 and Figure 13.

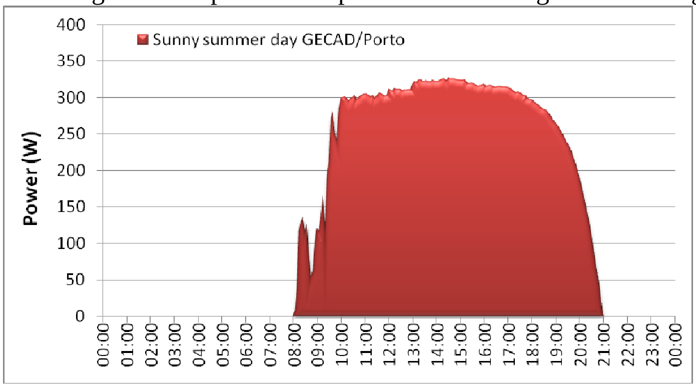

Fig. 12. Photovoltaic power generation for a sunny summer day in Portugal

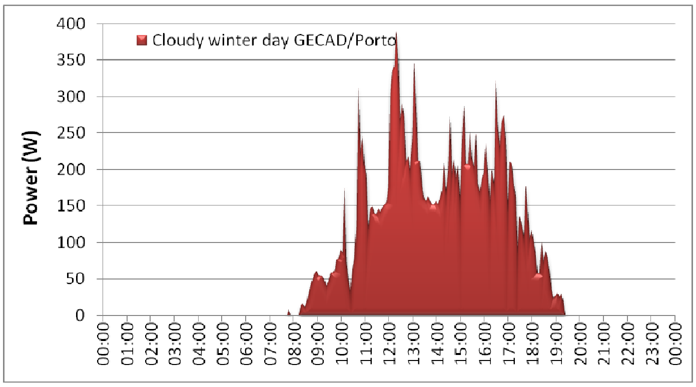

Fig. 13. Photovoltaic power generation for a cloudy summer day in Portugal

5. Case study

In the case study is presented the application of the optimization method to a domestic consumer considering the different generation and consumption profiles according with each country scenario (sub-section 5.1). The results of the case-study are presented for the Brazil case in sub-section 5.2 and for Portugal case in sub-section 5.3.

The case study was tested on a computer compatible with 2 processors Intel® Xeon® W3565 3,20GHz, each one with 4 Cores, 6GB de RAM and the operating system Windows Server 2007 64bits. The optimization module is implemented by a deterministic approach based on Mixed-Integer Non-Linear programming (MINLP) implemented on the *General Algebraic Modelling System (GAMS)* platform, interfaced with the computing tool MATLAB® R2009 64bits.

5.1. Scenario

The defined scenario is based in typical domestic consumers for one region of each country studied. In the case of Brazil, the loads are considered for a typical domestic consumer of the Southeast Region (São Paulo) [22]. In the case of Portugal, it is considers real and virtual loads in the same simulation for a typical domestic consumer of North Coast Region (Porto) and according simulation platform for energy management system developed in GECAD. The Table 2 presents all resources and maximum power for each one in domestic consumers for Brazilian and Portuguese cases.

Table 2. Resources information in domestic consumers for Brazil and Portugal scenarios

Brazilian Case		Portuguese Case	
Resource	Maximum Power (W)	Resource	Maximum Power (W)
Chest Freezer	100	Chest Freezer	100
Refrigerator	120	Refrigerator	120
Iron	1000	Iron	1000
Electric Shower	2000	Vacuum	2000
Computer	141	TV 1	138
TV 1	138	TV 2	124
TV 2	138	Microwave	991
Microwave	991	Kettle	1800
Kettle	1800	Dishwasher	2000
Washing Machine	400	Washing Machine	400
HVAC	500	HVAC	600
Water Bomb	300	Water Bomb	300

Light 1	120	Light 1	120
Light 2	60	Light 2	60
Light 3	100	Light 3	100
Light 4	60	Light 4	60
Light 5	60	Light 5	60
Photovoltaic	2550	Photovoltaic	400
Grid	2550	Grid	400

The main differences of domestic consumers consider in the case study are in some different loads, the micro-generation power capacity and consequently, the ability to inject power in the grid. Besides, the principal difference is in the profile and the context of each domestic consumer.

In the Brazilian case, the main differences in domestic consumer are in:

- Electric Shower with more use in the first hours of the day (between 5:00 AM and 9:00 AM) and in the end of the work (between 5:00 PM and 10:00 PM);
- Photovoltaic micro-generation with 2550 Wp of system capacity and the generations hours depends of the season and the state of the day (sunny and cloudy day).

In the Portuguese case, the main differences in domestic consumer are in:

- Dishwasher with more use in the hours after the dinner (between 8:00 PM and 11:00 PM);
- Photovoltaic micro-generation with 400 Wp of system capacity and the generations hours depends of the season and the state of the day (sunny and cloudy day).

5.2. Results of Brazilian case

The present sub-section shows the obtained results for Brazilian case. Table 3 presents the resources state and the priority for each resource. The resources state are considers for a sunny day and for a cloudy day in a summer season. According with a domestic consumer typical profile (represented by Initial in Table 3) for a summer day in Brazil, it is applied the optimization method of Section 3 at 6:00 PM with 4000 W of DR Limit. The optimization results are represented by Results in Table 3. The priority values change between 0 and 10, factor 10 being used for lower priority resources, and factor 0 for the highest priority resources. The red values represent the reduced loads or turned off loads.

Table 3. Resources states and priority values for sunny day and cloudy day in Brazil case

Resource	Sunny Day			Cloudy Day		
	Initial	Priority	Results	Initial	Priority	Results
Chest Freezer	100	3	100	100	3	100
Refrigerator	120	2	120	120	2	120

Iron	1000	9	1000	1000	9	1000
Electric Shower	2000	0	2000	2000	0	2000
Computer	141	6	141	141	6	141
TV 1	138	9	138	138	9	0
TV 2	0	8	0	0	8	0
Microwave	0	5	0	0	5	0
Kettle	1800	10	0	1800	10	0
Washing Machine	0	10	0	0	10	0
HVAC	500	3	500	500	3	500
Water Bomb	300	9	300	300	9	237
Light 1	120	9	120	120	6	120
Light 2	60	9	60	60	9	0
Light 3	100	9	100	100	6	100
Light 4	0	8	0	0	5	0
Light 5	0	8	0	0	5	0
Photovoltaic	651	0	651	318	0	318
Grid	0	0	0	0	0	0

The main results of the Brazil case are:

- Needed to turn off or reduce power in a higher number of loads in a cloudy day compared with sunny day due to the lower micro-generation power;
- Only the Kettle is turned off to guarantee the DR limit in the sunny day;
- Water Bomb power is reduced (not turned off) to guarantee the DR limit in the cloudy day. The Water Bomb continues to work with lower consumption;
- Electric Shower has the higher priority in both days and continues to work after optimization;
- The capacity to inject power in the grid (Grid) is not used because of overconsumption in both days.

The general results are presented in Table 4 and Figure 14 for each day type (sunny or cloudy).

Table 4. Power results with application of DR Limit compared with initial scenario in ENERQ/Sao Paulo case

Resource	Sunny Day		Cloudy Day	
	Without DR	With DR	Without DR	With DR
Consumption	6379	4579	6379	4318

Micro-Generation	651	651	318	318
Grid Supply	5728	3928	6061	4000
DR Limit	0	4000	0	4000

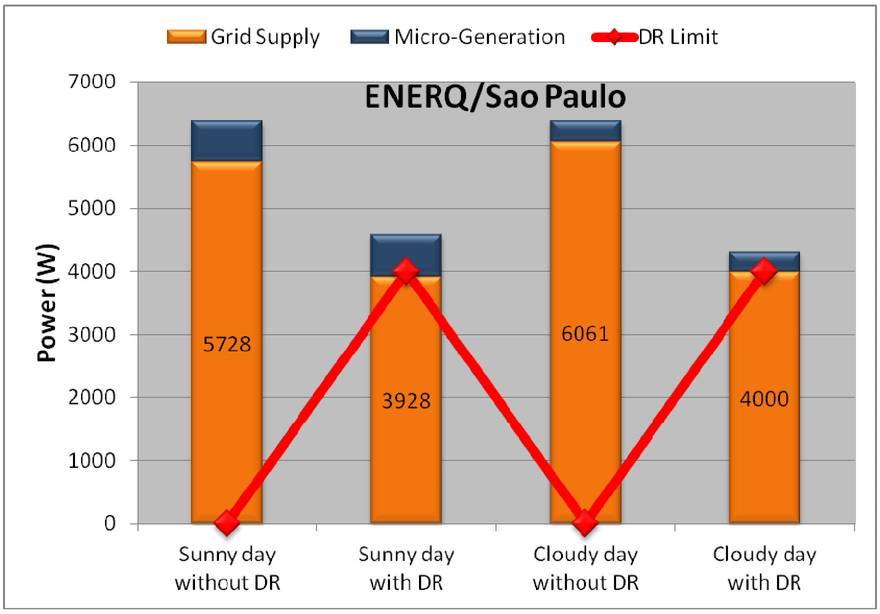

Fig. 14. Loads power consumption influenced by DR limit in ENERQ/Sao Paulo case

The results analyze shows in both cases that the system ensures the DR limit imposed at 6:00 PM in Brazilian domestic consumer, in the case 4000 W. Even more, in the Sunny day the optimization obtain a power of the Grid Supply (3928 W) lower than DR Limit (4000 W) allowing reduces the power value provided by the grid beyond the imposed DR limit. In the case of the Cloudy day the power of the Grid Supply is equal than DR Limit.

5.3. Results of Portugal case

The present sub-section shows the obtained results for Portugal case. Table 5 presents the resources state and the priority for each resource. The resources state are considers for a sunny day and for a cloudy day in a summer season. According with a domestic consumer typical profile (represented by Initial in Table 5) for a summer day in Portugal, it is applied the optimization method of Section 3 at 6:00 PM with 4000 W of DR Limit. The optimization results are represented by Results in Table 5. The priority values change between 0 and 10, factor 10 being used for lower priority resources, and factor 0 for the highest priority resources. The red values represent the reduced loads or turned off loads.

Table 5. Resources states and priority values for sunny day and cloudy day in Brazil case

Resource	Sunny Day	Cloudy Day

	Initial	Priority	Results	Initial	Priority	Results
Chest Freezer	100	8	100	100	8	0
Refrigerator	120	6	120	120	6	120
Iron	1000	9	1000	1000	9	1000
Vacuum	0	9	0	0	9	0
TV 1	138	9	138	138	9	0
TV 2	124	8	124	124	8	0
Microwave	0	5	0	0	5	0
Kettle	1800	9	1800	1800	9	1800
Dishwasher	0	6	0	0	6	0
Washing Machine	0	6	0	0	6	0
HVAC	600	10	0	600	10	0
Water Bomb	300	9	0	300	9	0
Light 1	0	8	0	0	5	0
Light 2	0	8	0	0	5	0
Light 3	100	9	14	100	6	100
Light 4	0	9	0	0	6	0
Light 5	0	9	0	0	6	0
Photovoltaic	296	0	296	106	0	106
Grid	0	0	0	0	0	0

The main results of the Portugal case are:

- Needed to turn off or reduce power in a higher number of loads in a cloudy day compared with sunny day due to the lower micro-generation power;
- Reduced power in Light 3 for a sunny day due to the lower priority compared with cloudy day;
- Needed to turn off the Chest Freezer, TV 1 and TV 2, due to the lower micro-generation power and the higher lights priority;
- The capacity to inject power in the grid (Grid) is not used because of overconsumption in both days.

The general results are presented in Table 6 and Figure 15 for each day type (sunny or cloudy).

Table 6. Power results with application of DR Limit compared with initial scenario in GECAD/Porto case

Resource	Sunny Day		Cloudy Day	
	Without DR	With DR	Without DR	With DR
Consumption	4282	3296	4282	3020
Micro-Generation	296	296	106	106
Grid Supply	3986	3000	4176	2914
DR Limit	0	3000	0	3000

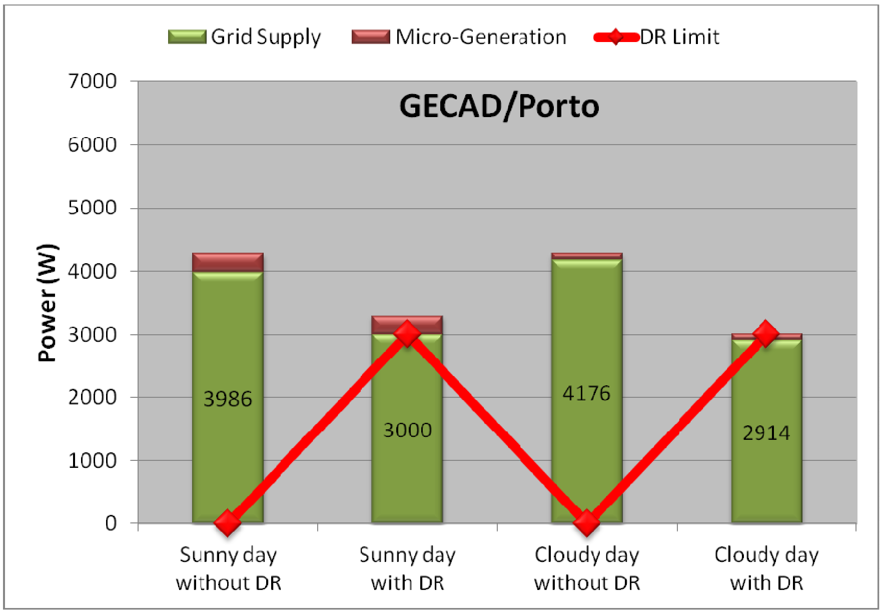

Fig. 15. Loads power consumption influenced by DR limit in GECAD/Porto case

The results analyze shows in both cases that the system ensures the DR limit imposed at 6:00 PM in Portuguese domestic consumer, in the case 3000 W. In the case of the Sunny day the power of the Grid Supply is equal than DR Limit. In the other hand, the results of Cloudy day show the Grid Supply power obtained (2914 W) lower than DR Limit (3000 W) allowing reduces the power value provided by the grid beyond the imposed DR limit.

6. Conclusions

The paper exposes an energy management concepts according with active participation of the domestic consumers through Smart Home application in Smart Grid context. The paper presents a methodology developed for the SCADA House Intelligent Management platform to manage the loads and micro-generation to participation in Demand Response programs. The work has a special focus in the photovoltaic micro-generation profiles in two different countries, Portugal and Brazil, presenting a database for each one to be applied in the methodology developed. The case study shows the methodology application for two different

scenarios, Brazil and Portugal case.

The proposed model is especially useful for energy resources scheduling when occurs a Demand Response event to limit the power consumption in two different contexts of domestic consumers.

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