Dynamic Energy Management method with Demand Response interaction applied in an Office Building

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Abstract. The intelligent management systems of the end consumers are endowed with advanced functions being one of them the interaction with external entities through the automatic participation in demand response programs. The development of the intelligent management systems is to reduce the energy consumption based on internal information and on the interaction with an external entity. Moreover, the management approaches results in an active participation of the consumers in the operation of the smart grids and microgrids concepts. The paper developed presents the application of a dynamic priority method in SCADA Office Intelligent Context Awareness Management system to manage the energy resources installed in an office building. The intelligent management method allows the dynamic active participation of the office building in the DR events considering the real data of consumption and generation of one building in Polytechnic of Porto. The main goal of the methodology is to obtain a dynamic scheduling for all energy resources with little interference in the comfort of users. The results of dynamic management model in office building are discussed for the participation in 8 hours demand response event. The power limit of the scenario depends on the consumption and micro-generation power of an October day.

Keywords: Demand response, dynamic priority method, energy management, office building, energy resources

1 Introduction

Several approaches have been proposed to the consumers in view of an active participation in the operation of the Smart Grids (SG) and Microgrids (MG) with capability to manage their own energy consumption, generation and storage systems [1]. The main cause for the faster SG development requirement is the high penetration

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The present work was done and funded in the scope of the following projects: H2020 DREAM-GO Project (Marie Sklodowska-Curie grant agreement No 641794); EUREKA - ITEA2 Project SEAS with project number 12004; AVIGAE Project (P2020 - 3401); UID/EEA/00760/2013 funded by FEDER Funds through COMPETE program and by National Funds through FCT, and GECAD–EEA/00760.

of the distributed energy resources, making the energy management decision more decentralized, allowing the means for coordinating a wide range of players [2]. The players aggregated in small areas represent the MG that allows the management of several consumers, distributed generation and the connection with main grid [3].

With development of the SG and MG, it emerged the development of other systems: the smart meter, the smart home or smart buildings [4]. The smart home 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 and the interface with external operators, among others [5], [6]. A smart home include the internal communication network, intelligent control systems and home automation [7].

The advanced functions should be integrated on the House Management Systems (HMS) or on the Building Automation Systems (BAS) allowing the interaction with external entities through the automatic participation in Demand Response (DR) events [8], [9]. The HMS and BAS systems need to reduce the energy consumption based on internal information and on the interaction with an external entity according with DR events [10]. The development of sophisticated management systems has become the main goal of modern intelligent houses/buildings [9]. The actual developments of the HMS and BAS consider the management of the consumption, generation, electric vehicles and DR programs [11]. With this programs, it is possible to obtain a reduction of the electricity consumption without a substantial change in the comfort levels [12].The comfort level in the management of the HMS and BAS systems is so important and depends of each context, the minimum energy consumption and operation costs [13]. To the better management, the ability to autonomously acquire knowledge about the user’s behavior adjusting the consumer’s preferences arises as an essential role [14].

The present paper focuses in management of the energy resources installed in an office building of a university campus implemented by the SCADA Office Intelligent Context Awareness Management (SOICAM) system. The energy management of the building results by the application of an optimization algorithm developed for the SCADA House Intelligent Management (SHIM) platform to manage dynamically the active participation of the houses/buildings in the DR events considering, for the applied case, the loads, micro-generation and grid connection. The main contribution of the paper is the application of the dynamic priority method in real data of an office building from Polytechnic of Porto considering the consumption and generation. In the proposed methodology, the main goal is to obtain a dynamic scheduling for all energy resources presented in an office building from the university campus with little interference in the comfort of users.

After the introduction, Section 2 summarizes the simulation platform for energy management system and the dynamic priority method for the considered energy resources. For your side, Section 3 presents the SOICAM system and Section 4 describes the office building to implement the dynamic method. Section 5 shows the case study and the advantages of the model in the office building. The conclusions and contributions of the work are presented in last section.

2 SCADA House Intelligent Management System

The SHIM system has been developed in the Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development (GECAD), located in the Institute of Engineering – Polytechnic of Porto (ISEP/IPP), Portugal. SHIM is a testbed platform with the main goal of testing, simulating, and validating new algorithms and methodologies to apply into house/buildings' management.

The section presents an overview of SHIM system and a short description of the dynamic priority method developed for the SHIM including the optimization algorithm.

2.1 Energy Management Platform for Domestic Consumers

SHIM comprises real equipment such as several types of loads, micro-generation (photovoltaic panels, wind generator), and storage systems that allow the simulation of the electric vehicles behavior. The SHIM platform is presented in Fig. 1.

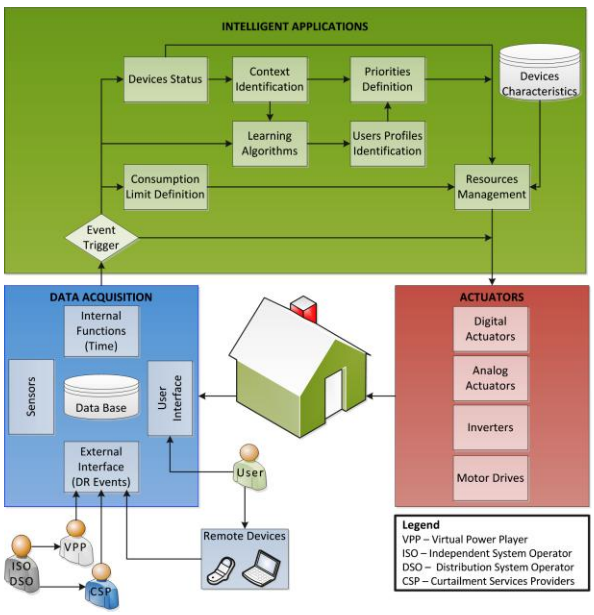

Fig. 1. Structure of the SHIM simulation platform [15].

SHIM is part of a large simulation platform based on multi-agents systems: Multi-Agent Smart Grid Simulation Platform (MASGriP) is a test platform that simulates a competitive environment in future power systems. SHIM platform comprises hardware equipment to control loads through programmable logic controller and the measurement of the power consumption through several power analyzers in the management system. The interface with the users is implemented for example, in a smartphone. For the complex scenarios simulation, SHIM is able to control real and virtual loads simulating the real data saved [16]. Different modules composing the

SHIM that are grouped into three parts: the Data acquisition, the Actuators, and the Intelligent Applications. The detailed information is presented in [15].

2.2 Resources Management Methodology

The dynamic method presented in [15] only considers the loads scheduling. To increase the capacities of the SHIM platform, the method was updated with more energy resources. The Dynamic Energy Resources Priority (DERP) method developed in [17] is summarized in this sub-section. The method, like in the work [15], focuses in an optimization problem to manage dynamically the domestic consumers in the DR events. The problem of the work was developed to be implemented in the SHIM system. The DERP method includes loads, micro-generation and grid connection. These different types of energy resources increase the smart home capacities to have a strong influence over the SG or MG operation in context with the grid and consumer conditions.

The objective of the optimization module of the dynamic model concerns in dynamic resources management. The detailed problem formulation and the respective nomenclature applied in the optimization process for every minute is presented in [17]. In this paper is only presented the objective function:

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

3 SCADA Office Intelligent Context Awareness

The SOICAM is implemented in real facilities also in GECAD research center located in the ISEP/IPP. The system is implemented in real facilities used by several researchers in a daily basis, aiming the energy monitoring and the energy management inside the laboratories. This system enables the test and use of several communication protocols [18], [19]. The section presents an overview of SOICAM system and a short description of the real office building.

3.1 SOICAM general structure

The SOICAM system is divided in two levels: the infrastructures (physical level) and the operational level where is used a Multi-Agent System (MAS) approach to represent, control and manage the 3 integrated facilities. The system includes a microgrid agent to aggregate the facilities, their services and energy resources [18].

For this reason, the SOICAM uses simulation in order to integrate more agents that otherwise cannot be placed in the system, for example, Houses 1, 2 and 3 are simulated facilities. Buildings I, N and F are ISEP/IPP buildings. The simulated facilities use real electrical energy consumption measurements, enabling the profile simulation of the simulated facility. More detailed information can be viewed in [19].

3.2 Energy resources description of the office building

The building is equipped with a system considering a programmable logic controller that communicates with five analyzers to read the data consumption of the several specific divisions. Also, the building has installed in the roof, a photovoltaic system with 30 panels (250 Wp for each one). The information of the building divisions is presented in Table 1. In the building information is indicated the type of the division, the loads presented and the quantity for each one, the total consumption for each load type, and the electrical circuit where each one is connected. The electrical circuit of the loads is divided in three types like presented in: P1 HVAC; P2 Lights; P3 Sockets (equipments connected in electrical sockets). Fig. 2 presents the consumption and generation data from October 22, 2015.

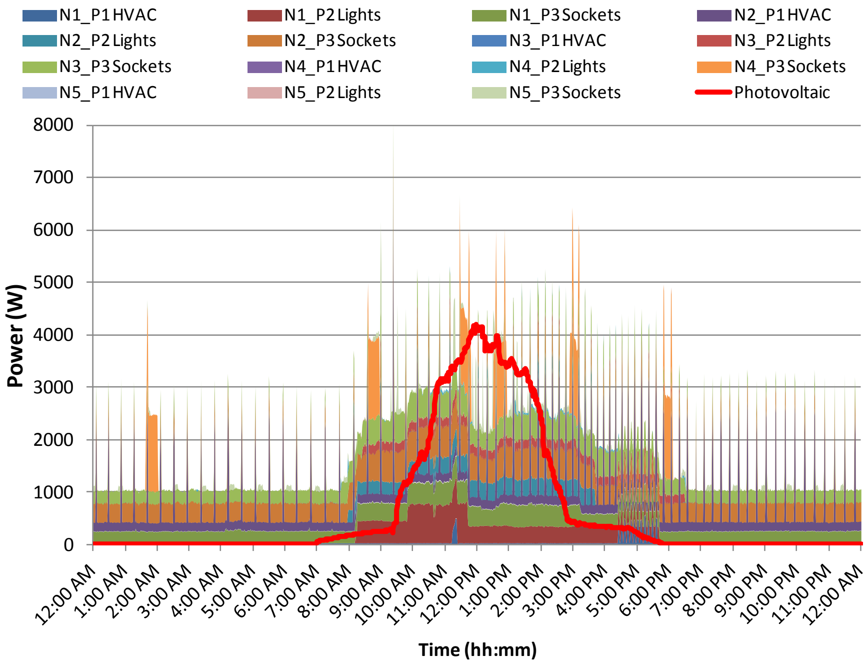

Fig. 2. Consumption and generation data of the office building.

The SOICAM data is stored in a SQL database. The register of the office building (building N) includes the consumption reaching more than 30 researchers daily and the generation. The consumption data register has started in July, 2014. The generation data register has started in October, 2015.

Table 1. Loads description for each analyzer of the office building.

Analyzer	Division	Type	Loads	Quantity	Total Power (W)	Electrical Circuit
N1	N101	Office	HVAC	1	1000	P1
			Fluorescent lamp	4	232	P2
			Compact lamp	2	36	P2
			Monitor	5	1357	P3
			Computer	2	950	P3
			Laptop	1	90	P3
	N102	Office	HVAC	1	1320	P1
			Fluorescent lamp	4	232	P2
			Monitor	8	2438	P3
			Computer	4	1900	P3
			Laptop	1	90	P3
	N103	Office	HVAC	1	910	P1
			Fluorescent lamp	4	232	P2
			Monitor	4	1311	P3
			Computer	2	950	P3
N2	N104	Support	HVAC	1	2500	P1
			Fluorescent lamp	2	116	P2
			Computer	1	475	P3
	N105	Office	HVAC	1	910	P1
			Fluorescent lamp	4	232	P2
			Monitor	6	1909	P3
			Computer	3	1425	P3
			Laptop	2	180	P3
	N106	Boardroom	HVAC	1	1320	P1
			Fluorescent lamp	4	232	P2
			Televison	1	345	P3
N3	N107	Office	HVAC	1	1320	P1
			Fluorescent lamp	2	116	P2
			Compact lamp	2	36	P2
	N108	Office	HVAC	1	910	P1
			Fluorescent lamp	4	232	P2
			Monitor	7	2231	P3
			Computer	3	1425	P3
	N109	Office	HVAC	1	1000	P1
			Fluorescent lamp	4	232	P2
			Monitor	2	713	P3
			Laptop	1	90	P3
			Printer	1	920	P3
N4	Hall	Common Services	HVAC	2	1920	P1
			Fluorescent lamp	4	232	P2
			Compact lamp	2	36	P2
			Water heater	1	1500	P3
N5	N110	Kitchen	HVAC	1	1000	P1
			Halogen lamp	2	50	P2
			Compact lamp	1	14	P2
			Refrigerator	1	130	P3
			Coffe machine	1	1300	P3
			Kettler	1	2280	P3
			Microwave	1	2250	P3

4 Case Study

The case study applies the methodology developed for the SHIM platform in the SOICAM system, contemplating the management of the consumption and generation resources. The methodology is applied for an office building described in Section 3 with several loads and one photovoltaic system. The results of the resources scheduling in the SOICAM system are presented in the following sections.

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.

The present case study is applied according with a DR event with 8 hours time duration, starting at 9:00 PM. Table 2 shows the values of the power limit that corresponds to the power supplied by the grid and depends on the conditions according with power consumption (P_{Load}) and power generation (P_{DG}).

Table 2. Conditions to the power limit in DR event.

Condition DR Limit	Power Limit (W)
$P_{DG} < P_{Load}$	$P_{Load} - P_{DG}$ - 100
$P_{DG} > P_{Load}$	0

4.1 Office building characterization in management system context

The case study section presents the data of loads and micro-generation that were used based on office building of the GECAD/IPP. The generation system is composed by 30 photovoltaic modules and the consumption represents 116 loads divided by three types: HVAC, Lights and Equipments like presented in Section 3.

The energy resources are characterized in the resources management module considering different characteristics that are presented and summarized in Fig. 3.

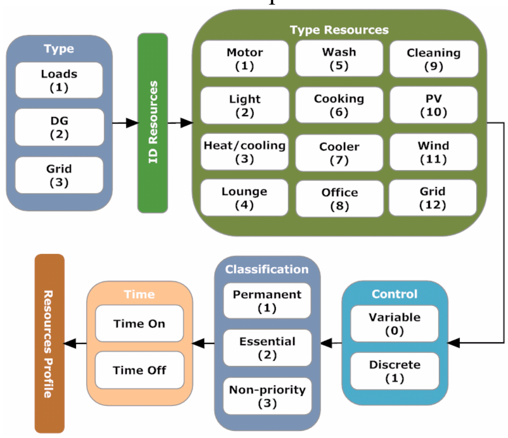

Fig. 3. Diagram to identify the characteristics of the energy resources [16].

According with Fig. 3, the resources information are presented and described in Table 3. For the three types of loads, the loads that allow the variable control of the consumption are the lights (fluorescent type) through the use of electronic ballasts, implemented and tested in GECAD laboratory. Others loads type are discrete loads.

Table 3. Energy resources information of the consumer.

Resource	Resources Type	Control	Classification	Ton	Toff	T	Maximum Power (W)
N1_P1 HVAC	3	1	2	6	4	10	3230
N1_P2 Lights	2	0	2	1080	360	∞	732
N1_P3 Sockets	8	1	1	∞	0	∞	8996
N2_P1 HVAC	3	1	2	6	4	10	4730
N2_P2 Lights	2	0	2	1080	360	∞	580
N2_P3 Sockets	8	1	1	∞	0	∞	4334
N3_P1 HVAC	3	1	2	6	4	10	3230
N3_P2 Lights	2	0	2	1080	360	∞	616
N3_P3 Sockets	8	1	1	∞	0	∞	5379
N4_P1 HVAC	3	1	2	6	4	10	1920
N4_P2 Lights	2	0	2	1080	360	∞	268
N4_P3 Sockets	8	1	1	∞	0	∞	1500
N5_P1 HVAC	3	1	2	6	4	10	1000
N5_P2 Lights	2	0	2	1080	360	∞	64
N5_P3 Sockets	8	1	1	∞	0	∞	5960
Photovoltaic	10	1	1	∞	0	∞	7500
Grid	12	0	1	∞	0	∞	7500

4.2 Energy resources scheduling results

The methodology applied in SOICAM system should manage a photovoltaic system with all loads of office building. According to the generation profile, the photovoltaic power has more generation between 10:40 AM and 2:00 PM. The results of the energy resources scheduling are presented in Fig. 4. The first figure shows the detailed scheduling for each type of load and compared with the initial consumption. The second figure presents the scheduling of the loads consumption and the injected power in the grid compared with the power generation of the photovoltaic system and the supplied power by the grid (that corresponds to the power limit).

The results show a reduction of the loads consumption in the moments when the consumption is limited only by the generation power, i.e., in moments when generation is higher than consumption ($P_{DG} > P_{Load}$). With application of the DERP in SOICAM, the management system reduces the power consumption when the generation is higher allowing higher power injection in the grid and consequently higher remunerations.

When the power generation is not enough to fulfill loads consumption ($P_{DG} < P_{Load}$), the DERP method limited the consumption owing to defined condition presented in Table 3: $P_{Load} - P_{DG} - 100$. The condition requires that the supplied power by the grid is reduced 100 W.

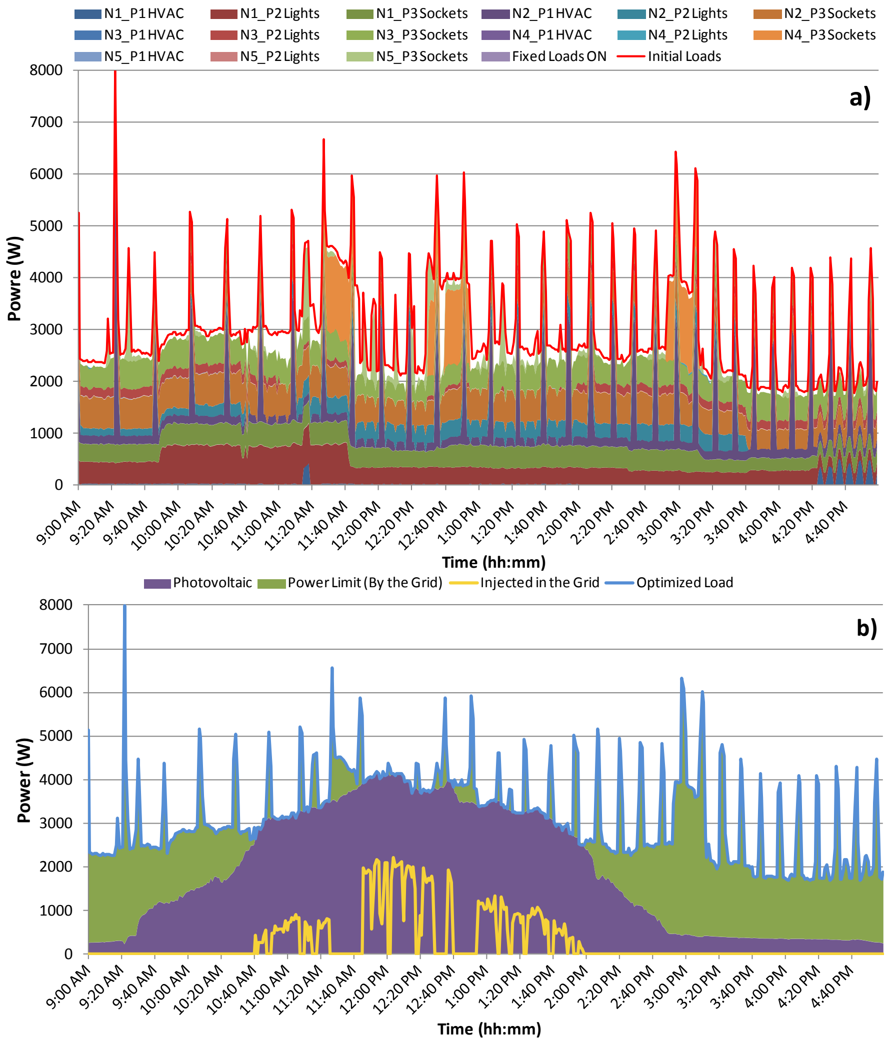

Fig. 4. Resources power results during DR event: a) detailed scheduling for each type of load, b) Scheduling for each type of energy resources.

The case study shows the applicability of the DERP method in the SOICAM system in both moments: overgeneration and overconsumption. In both moments, the capacity to reduce the consumption of the lights through the electronic ballast shows an important advantage of the system. Consequently, the capacity to reduce the power consumption has two different situations:

- When the generation is higher than consumption (overgeneration): the consumption reduction increases the capacity to injected power in the grid and increases the energy remunerations;
- When the consumption is higher than generation (overconsumption): the consumption reduction allows the reduction of the power supplied by the grid (reduce the energy costs) not compromising too much the comfort of users.

The main important result is the interaction between the SOICAM system and the grid through the power injected during the DR event. Thus, it takes advantage of the high generation and also, the consumption reduction obtained with lights and HVAC. With application of the DERP method is possible to reduce the consumption of the loads, in specific divisions of the building, sending energy to the grid or reduce the power supplied by the grid. Fig. 5 illustrates the consumption of each loads type in the analyzer N1 installed in the office building. The figure compares the initial consumption with the consumption obtained by the application of the DERP method in the SOICAM system.

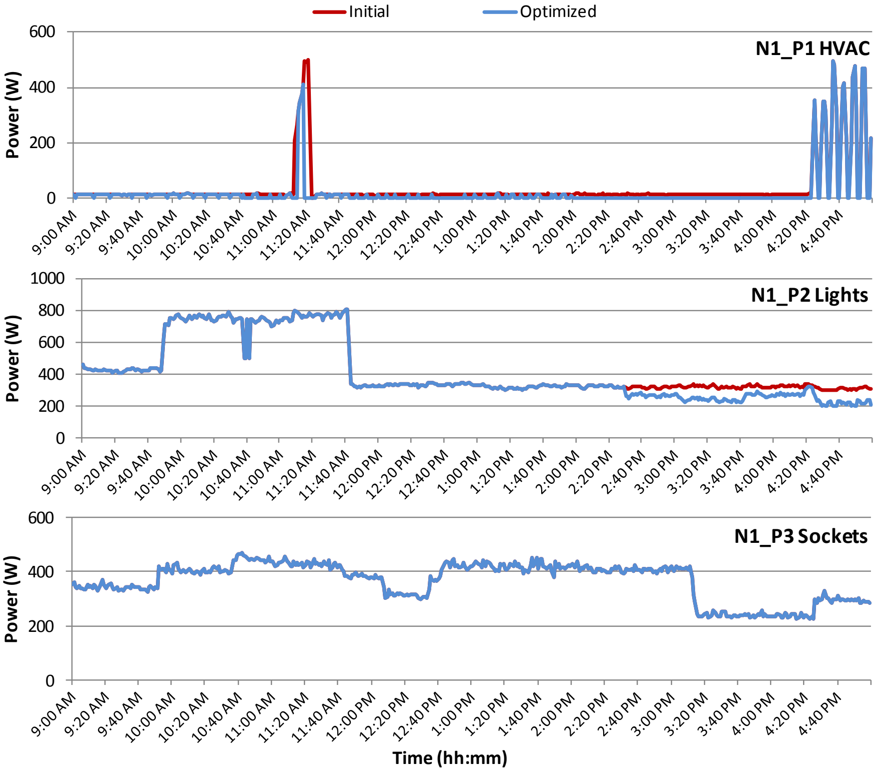

Fig. 5. Initial and optimized consumption for each loads type of the N1 analyzer installed.

The results show the sockets as the loads with higher priority for the office users' because the consumption is not modified. In the other hand, the HVAC and lights are the loads with less priority of the office users'. For example, between 2:30 PM and 4:59 PM, the consumption of the lights is reduced, but not completely turned off. This is possible with installation of the electronic ballasts for fluorescent lamps (the main lamps used in the office building). In the case of the HVAC system, this load type is turned off in some moments of the DR event.

According with the context of the day and the needs of the users, the comfort of the users is not affected so much. For example, the lights are reduced just slightly to minimize users' discomfort; and in the case of the HVAC, it is turned off in short periods of time to minimize the impact in the temperature comfort. The temperature comfort will be more affected if the HVAC is turned off for long periods according with others works developed in GECAD laboratories that involved HVAC systems.

5 Conclusions

The interaction between the end consumer and the grid operator is possible with application of an energy management system improving the effectiveness of the consumer‘s participation in a demand response events. In this context a SCADA system must support a decentralized structure to control, monitor and optimize all energy resources in any type of consumer.

The paper presents a method applied in SOICAM system to manage the consumption and generation used in an office building. The main goal of the Dynamic Energy Resources Priority method, developed in previous work for an energy management platform of the domestic consumer, is to change the resources priority during a demand response event through an optimization algorithm. It is considered the data saved in real time of the energy resources installed in an office building, and the resources scheduling obtained is analyzed to show the applicability of the dynamic priority method in a different type of consumer.

The novelty presented in the work consists in the application of the dynamic management method of the SHIM system in the energy management system of the office building, implemented in SOICAM, and contributes to the following advantages:

- DERP method applied in SOICAM system allowing better performances during a demand response event considering different types of energy resources in context of smart grids and micro grids operation, and obtains more flexibility by the interaction between the users and grid;
- In the building application, the resources scheduling is adapted every minute, ensuring the comfort levels needs, having the lights and HVAC systems an important role;
- With application of the DERP method, the case study shows that it is possible to reduce the consumption of the loads, in specific divisions of the building, sending energy to the grid or reducing the power supplied by the grid.

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