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Building Management Model Considering Demand Response and Occupancy Data

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Abstract

The recursive implementation of smart grid measures in the current energy systems, introduces demand-side resources to new concepts that require their active participation and management. However, these management systems often don't consider a human factor, i.e. the features that effect the personal comfort of each person, e.g. the lighting, air conditioning, appliances in a given space. In this way, the present paper proposes a methodology for dealing with locational sensor data, to perform the implementation of demand response programs. At the same time, the methodology addresses the scheduling of distributed generation and external suppliers to balance the consumer's load. The proposed methodology is tested on a case study involving the management of an office building, adapted to simulated sensor data.

Keywords: building management system, demand response, distributed generation, occupancy data

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1. Introduction

The increase in consumption over the years, suggests that consumers have not yet gain awareness over their electricity expenditures [1], [2]. Moreover, with the current existing technologies and respective solutions, promoting energy efficiency becomes accessible to consumers [3], [4].

Demand response programs arise to address the active participation of consumers in the energy systems operation, by supplying flexibility to whoever is managing it [5]–[7]. Demand response can be defined as the modification of a normal consumption pattern, in response to price signals or incentive payments [8], [9]. Although, this definition implies the presence of a manager entity that communicates with the consumer, demand response programs can also be applied by the consumer in its own consumption pattern with the objective of reducing its energy costs and to raise energy efficiency [10]. In this way, the consumer acts in its own interest, without receiving monetary incentives or price signals from a third party. There are several types of demand response applications, however, the main three are known as: load reduction, load curtailment, and load shifting [11]. In the first, consumers can reduce loads in an analog basis, allowing a continuous load adjustment. In the second, the contrary of the first type is applied, i.e. the consumption can be adjusted in a discrete basis, where step amounts are reduced. In the last, the load can be shifted from or to another period where it is more convenient to have consumption [12], [13]. Examples of where shifting load can be useful are: energy shortage, grid congestion, high electricity tariffs, amongst others.

The use of demand response programs in building management systems, can improve the overall energy efficiency of the building, and reduce considerably its operation costs [14], [15]. However, the use of demand response in buildings can affect the personal comfort of its users, since it influences the performance of loads, such as, lights, air conditioners, ventilation systems, equipment connected to sockets [16]. In this way, demand response must be implemented together with an informational system capable of providing additional data for the decision support of demand response implementation [17]. In this context, the knowledge about people's location allows an important asset for the decision of applying demand response, since the actuation in the loads can be made according to the presence or not of persons on their location [18]–[20].

Small capacity and stochastic generation of RERs are known as an obstacle for participation of these resources in energy and ancillary service markets. Therefore, the VPP has been defined as an entity for aggregating and planning of DERs (renewable or fossil based) with the acceptable overall capacity to facilitate participating in energy and ancillary service markets and also improving technical functionality of its distribution network with implementing appropriate management of DERs. Various types of generation and storage units can be integrated to form a VPP. The VPP combined DERs as a single power plant to take part in power market with defined hourly profit [2].

The present paper addresses the implementation of a consumer management system at an individual level, focusing on the usage of demand response programs, considering the influence of locational data related to the effect of people's preferences in the scheduling of a consumer's load. Moreover, it is considered that the management system can address the use of distributed generators and external suppliers to complement the consumer's scheduling.

In this section, it was introduced the context of the proposed methodology application, considering distributed energy resources concepts, mainly, demand response programs advantage regarding the isolated operation of consumers. In the next section, the proposed methodology is explained according to its objectives and features. In the third section, it is demonstrated the mathematical formulation of the proposed methodology, taking into consideration the demand response programs interpretation and the locational data considerations. In section IV, the case study to validate the methodology is detailed, and section V shows the results obtained. Finally, section VI presents the conclusions.

2. Proposed Methodology

In the present section, it is addressed the objectives, features, and considerations of the proposed methodology. The methodology can be separated in two phases: data acquisition, and resource's scheduling, as shown in Fig. 1.

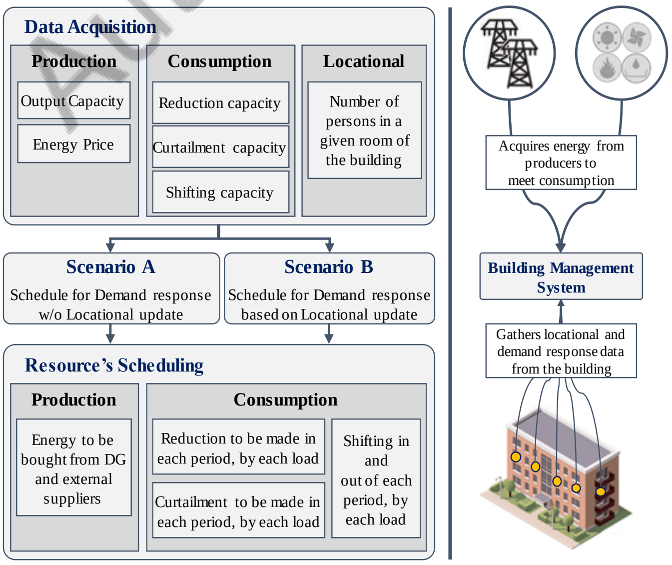

Fig. 1: Proposed methodology and implementation.

In the first phase, the building management system collects the information needed for the scheduling, which includes: current locational data (how many persons are in and where in the building), distributed generators capacity and price, external suppliers' capacity and price, and finally, the demand response available capacities (including load reduction, curtailment and shifting). The data sampling considered can be of several distinct time horizons, however, it is important to have a short sampling period, so that the building users are not affected by a decision concerning data from a previous distant instance. It is also important to represent the loads by equipment or aggregated type of equipment, thus ensuring that later on, the load modifications are applied to the correct devices.

In the second phase, the scheduling is performed taking into consideration the data acquisition. In this way, for several periods is possible to evaluate the actual conditions that the building has in terms of consumption and locational data. In other terms, for each period the building management system requests a data acquisition from the resources considered, gathering current data regarding the operation of the building (demand response and locational data) and external resources (distributed generators and external suppliers).

With this information, the building management system can optimize consumption levels and acquire energy to supply it in the form that minimizes the costs. At the same time, the system considers the presence of persons in each room, and thus can decide to reduce consumption in that room if there isn’t any people in it, taking into account the existing lighting and air conditioning loads. It can also propose a load shifting approach for equipment connected to sockets.

3. Mathematical Formulation

In the present section, the mathematical formulation for the resource’s scheduling is demonstrated. The optimization is classified as a mixed-integer problem, due to the several binary variables used to model the locational data and curtailment programs. In this way, the proposed methodology addresses a building management system that considers the use of distributed generation, external suppliers, and demand response programs, to minimize the operation costs of the consumer. Equation (1) shows the objective function considered for the scheduling optimization of resources.

$$MinOC = \sum_{p=1}^{DP} P_{(p,t)}^{DG} \cdot C_{(p,t)}^{DG} + \sum_{s=1}^{SP} P_{(s,t)}^{Sup} \cdot C_{(s,t)}^{Sup} \tag{1}$$

The consumer’s consumption management is similar to a usual scheduling from an operator or aggregator, however, at a much smaller size and complexity. Nevertheless, power balance must be attained at all moments making use of the available resources, as shown by equation (2).

$$\begin{gathered}\sum_{p=1}^{DP} P_{(p,t)}^{DG} + \sum_{s=1}^{SP} P_{(s,t)}^{Sup} = \\ \sum_{m=1}^{CM} \left[P_{(m,t)}^{Load} - \left(\begin{gathered} P_{(m,t)}^{DR\_red} + P_{(m,t)}^{DR\_cut} + \\ \sum_{d=1}^{T} \left[P_{(m,t,d)}^{DR\_shift} - P_{(m,d,t)}^{DR\_shift} \right] \end{gathered} \right) \right]\end{gathered} \tag{2}$$

To represent the locational data, it has been considered that the people inside the building can be identified as present or not present in each room (*r*), i.e. this type of system allows the management system to acknowledge the presence of a given person in a certain room belonging to the building. Thus, this feature can easily be represented by an integer variable that, for each room or space of the building, assumes the value 0 if it is detected presence, or 1 if empty, as demonstrated by equation (3) - $x_{(r,t)}^{DR}$. This information will later on allow the management system to apply demand response programs or not, in each room or space equipment based on the principle that $m \in r$.

$$x_{(r,t)}^{DR} = \begin{cases} \lambda_{(r,t)}^{DR} \geq 1, \, then \; 0 \\ \lambda_{(r,t)}^{DR} = 0, \, then \; 1 \end{cases} \tag{3}$$

The following equations (4) and (5) define the minimum and maximum output capacities of the available distributed generators and external suppliers. These reflect the power amounts possible to be supplied to meet consumption, by each producer, either distributed or not.

$$P_{(p,t)}^{DG\_min} \leq P_{(p,t)}^{DG} \leq P_{(p,t)}^{DG\_max} \tag{4}$$

$$P_{(s,t)}^{Sup\_min} \leq P_{(s,t)}^{Sup} \leq P_{(s,t)}^{Sup\_max} \tag{5}$$

In what concerns the demand response programs, it is considered that three types are made available: load reduction, load curtailment, and load shifting, as demonstrated by the equations (6), (7)-(8), and (9), respectively. The demand response programs provide the management system flexibility options to perform adjustments between production and consumption, facilitating the possibilities for cost minimization.

$$P_{(m,t)}^{min.red} \cdot x_{(r,t)}^{DR} \leq P_{(m,t)}^{DR\_red} \leq P_{(m,t)}^{max.red} \cdot x_{(r,t)}^{DR} \tag{6}$$

$$P_{(m,t)}^{min.cut} \cdot x_{(r,t)}^{DR} \leq P_{(m,t)}^{DR\_cut} \leq P_{(m,t)}^{max.cut} \cdot x_{(r,t)}^{DR} \tag{7}$$

$$P_{(m,t)}^{DR\_cut} = P_{(m,t)}^{max.cut} \cdot \lambda_{(m,t)}^{cut} \cdot x_{(r,t)}^{DR} \tag{8}$$

$$P_{(m,t,d)}^{min.shift} \leq P_{(m,t,d)}^{DR\_shift} \leq P_{(m,t,d)}^{max.shift} \tag{9}$$

Further detailing the load shifting program, it is imposed some limitations to the total amount of power that can be shifted from or into a given period, as demonstrated by the equations (10) and (11), respectively.

$$\sum_{d=1}^{T} P_{(m,t,d)}^{DR\_shift} \leq P_{(m,t)}^{shift\_out} \cdot x_{(r,t)}^{DR} \tag{10}$$

$$\sum_{d=1}^{T} P_{(m,d,t)}^{DR\_shift} \leq P_{(m,t)}^{shift\_in} \cdot x_{(r,t)}^{DR} \tag{11}$$

In equation (12), it is presented the limitation of reduction and curtailment demand response programs, for the actuation of lighting and air conditioning, as explained before. The equation demonstrates that both programs summed together, cannot affect an amount of consumption superior to the expected load to occur in each period.

$$P_{(m,t)}^{DR\_red} + P_{(m,t)}^{DR\_cut} \leq P_{(m,t)}^{Load} \tag{12}$$

In sum, this section approached the mathematical features of the methodology, presenting the resources representation, providing special focus in the use of demand response programs to provide flexibility of operation.

4. Case Study

In this section, it is presented the case study considered for the validation of the proposed methodology, detailed in the previous section. The case study is related to the study of a real building, using real consumption data regarding the day of 27th of October of the present year, however, production data is simulated. Firstly, in Fig. 2, it is shown the plant floor of the building, with the classification of each room.

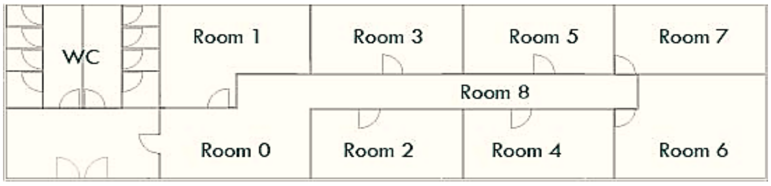

Fig. 2: Building plant and rooms designation.

The data used has a sampling of 15 minutes for a whole day, obtaining a total of 96 periods considered. Regarding consumption data, each of the rooms has three types of load that build up the total: lighting, air conditioning, and equipment connected to sockets. In the methodology, these are also approached this way, i.e. each room has three loads that represent the types mentioned. For load reduction and curtailment, it is considered that these can only be implemented in the lighting and air conditioning loads.

As for load shifting, it can only be applied in sockets load type, since per example, in the night or other times where no people are present in the building, there isn't a need to have lights or air conditioning on, and this is something that load shifting can provide to the management system. In this way, Fig. 3 presents the consumption and production values considered for the building's scheduling. The demand response programs are detailed in Table 1, however, the numbers presented are total values, since these, change amongst the rooms and periods considered. This allows a further parametrization of the rooms availability and user preferences from its person's occupancy. Also, production-side resources are shown in Table 1 according to their total operation values.

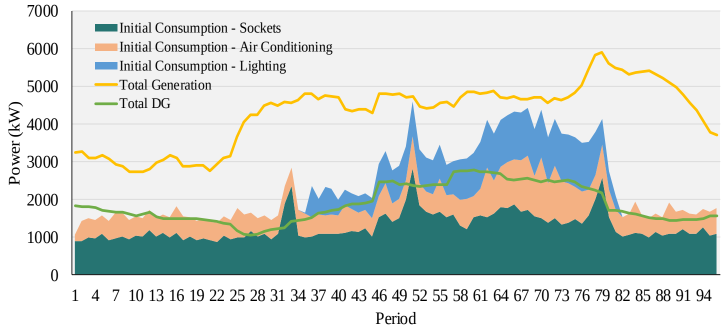

Fig. 3: Expected load consumption and available generation from producers and external suppliers.

Table 1. Resources' characteristics.

Type of resource	Total power capacity (kW)	Cost (m.u./kW)	# of	Owner
Load Reduction	66.752	0	18	Consumer
Load Curtailment	100.748		18	
Load Shifting	2 354.100		9	
Distributed Generation	180.020	0,06	6	Third Party
External Suppliers	231.970	0,1	4	

The case study is analyzed for two scenarios to evaluate the usefulness of the locational data. In this way, the following scenarios are considered:

- Scenario A – the locational data isn't available, and thus the demand response programs can only be used during the night periods, where no person is inside the building; From period 27 to 80, $x^{DR}_{(r,t)} = 0$
.
- Scenario B – locational data exists, and identifies the number of persons in each room, at any given period.

The locational data used in this scenario, is shown in Fig. 4.

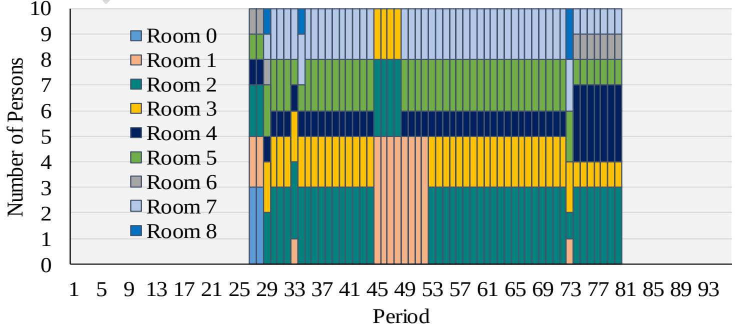

Fig. 4: Locational data data throughout the rooms, in the periods considered.

5. Results

In this section, it is presented the results obtained from the application of the proposed methodology in the previous detailed case study. As mentioned before, two scenarios are considered and evaluated: A – scheduling without locational data; and B – scheduling with locational data. In this way, the scenarios are analyzed considering their run time and total scenario cost (all periods) for the consumer.

A. Scheduling without Locational Data

In this first scenario, it is considered that the locational data is not existent, and therefore during the day periods (namely, from period 27 to 80) the use of demand response programs is not allowed. In this way, Fig. 5 shows the results obtained for the scheduling in the present scenario.

The results show a use of demand response programs only during the night where the number of persons inside the building is equal to zero. During the periods mentioned before the optimization performs the supply of consumption with production-side resources, namely, through the distributed generators and external suppliers.

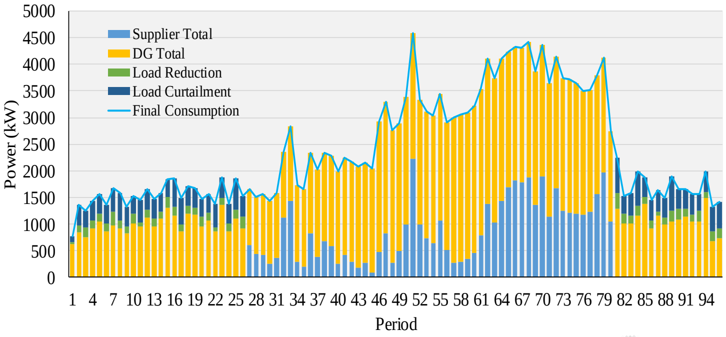

Fig. 5: Scheduling results for the consumer, in scenario A.

Regarding load shifting and its influences in the final consumer's scheduling, Fig.6 illustrates a detailed analysis. The results show a shifting activity during the night periods, mostly due to the fact that some of these periods present low production capacities, from both distributed generators and external suppliers. This causes the optimization process to buy more energy from the external suppliers (these present a higher capacity when comparing with distributed generators) in order to be able to supply consumption requirements. This is also possible to be seen in the total scheduling – Fig. 5.

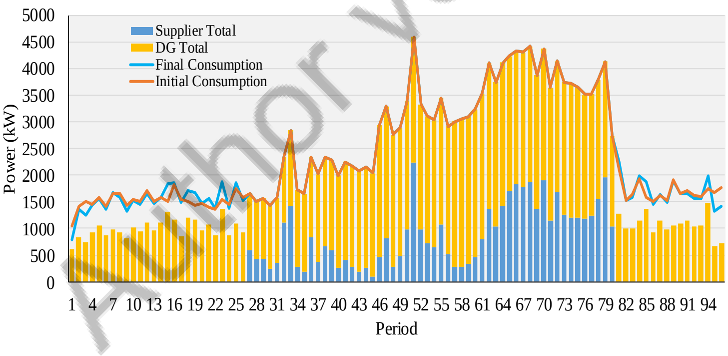

Fig. 6: Detail results for the consumer's final versus initial consumption, in scenario A.

B. Scheduling with Locational Data

The scheduling for the consumer demonstrates the management of the available resources and demand response programs implemented.

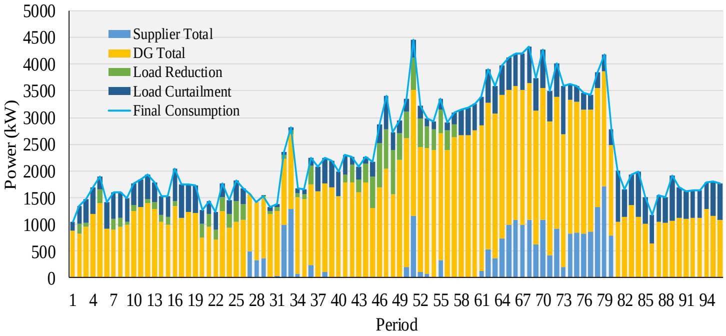

Fig. 7: Scheduling results for the consumer, in scenario B.

In Fig. 7, it is shown the scheduling with locational data. The results show a higher contribution of load reduction and curtailment regarding the during the day periods. Also, load shifting can occur during the day allowing more flexibility for the adjustment of load to production.

In Fig. 8, it is shown a detailed view of the load shifting program influences in the final scheduling of the consumer. In this way, the results from the optimization illustrate a shifting of load from the night periods (approx. 1 to 20 and 80 to 95) into the day periods. The movement of load is the optimization avoiding consumption in periods where production is lower, namely from the distributed generators. In this case, reaching the limit for demand response programs and distributed generators, the consumer would have to use energy from the grid (external suppliers), raising its operation costs due to a higher energy tariff.

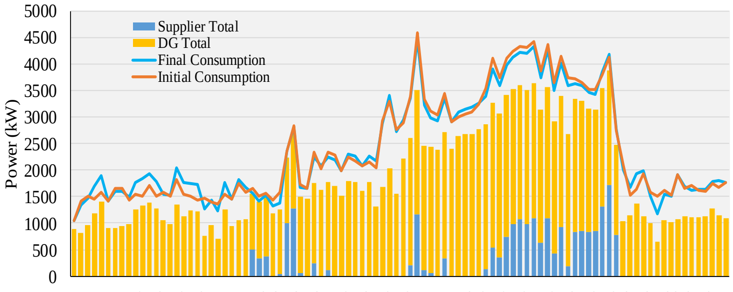

Fig. 8: Detail results for the consumer's final versus initial consumption, in scenario B.

C. *Scenario Comparison & Analysis*

In this subsection, the scenarios addressed before are compared in terms of their run time and total cost for the consumer. For this case, the total cost of the scenario is more important to the consumer rather than the run time of the optimization. In Table 2, it is presented each scenario results. The results show that the scenario without locational data in the scheduling during the day periods, causes a higher total cost for the consumer. In this way, it is noticed the importance of updating the information about the building inside activities, allowing the optimization to perform the cost minimization during all periods considered. Although the run time for the scheduling in scenario A is lower than in B, it is only less than half second faster. Considering the difference between the total cost in scenario A and B, this is considerably higher, namely, about 2.688 m.u.

Table 2. Scenarios' results summary.

Scenario	**Run time (s)**	**Total Cost (m.u.)**
(A) Without Locational Data	0,8750	14.314,04
(B) With Locational Data	1,3594	11.625,85
Variation values	0,4844	2.688,19

The features of demand response often imply that it occurs during times where user is not affected considerably by it. These times are mainly during the night or late hours, as intended by scenario A. The scenarios, based on the results, show that the usage of locational data from the building users allows a more efficient energy use, since it can reduce unnecessary consumption during the day and night, using demand response programs – Scenario B.

6. Conclusions and Future Work

In the present paper, it is proposed a methodology for consumer's consumption management, making use of distributed generators, external suppliers, and demand response programs (load reduction, curtailment, and shifting). The methodology performs the cost minimization for the consumer's operation, taking into considerations the available resource's characteristics, and based on the locational data of persons inside the building.

Three types of loads are considered, namely, lighting, air conditioning, and equipment connected to electricity sockets. The demand response programs are applied differently based on the type of load, i.e. load reduction and curtailment can be applied to lighting and heating type loads, whereas the load shifting is applied to the equipment connected to sockets. The case study presented, addresses the implementation of the proposed methodology based on real consumption data of an office building. The results show that the consideration of decision variables regarding the use of demand response along several periods, allows to obtain reductions in the total cost of operation due to the opportunities of reduction that it unveils, especially during the day.

For future work, it is intended to improve the proposed methodology by including the consumer's preferences of operation, for instance, in terms of lighting and air conditioning systems. In this way, demand response will act based on occupancy and other sensor data (e.g. temperature), considering the limitations imposed by the consumer. This will allow for a less intrusive approach of demand response in the consumer profile.

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