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Intelligent load management in local and wholesale demand response markets

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Proceedings of the Third DREAM-GO Workshop
Institute of Engineering - Polytechnic of Porto, Portugal, January 23-24, 2018

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Demand Response Cost vs Cost of Energy Purchased in the Wholesaler Market

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Abstract

With the increase of the production of electricity through renewable sources and the with the growing penetration of distributed production (decentralized production) as well as the implementation of the concept of Demand Response (DR), it is progressively possible to operate distribution networks autonomously. The aim of the DR concept it is to reduce consumption in exchange of an incentive or remuneration, when requested. This article studies the implementation of DR in a distribution network in order to verify what type of remuneration (tariff) suits best, from the point of view of the network operator.

Keywords: demand response, tariff, energy

1. Introduction

The growing technological evolution, the constant rise of the consumption of electric energy, the increase of the renewable power production and the alteration of the paradigm of the electric sector, all led to the creation of measures, which aim to rationalize consumption. Hence, a new concept called Demand Response (DR) emerged. It aims to reduce electricity consumption in certain periods (excessive consumption, possibility of not starting a generator, etc.) in exchange for remuneration [1], [2].

This concept is only possible due to the current technological evolution and allows that the customer, who usually has a passive role in the network to become an active customer, able to reduce consumption when requested. In this paper, we intend to study the profitability of the use of DR in a small electric network managed by an operator in an island concept.

In this paper, we will approach the case study, the methodology, followed by a brief explanation of the DR concept in point 4, and the analysis of the results, listing the conclusions drawn from this study.

2. Use Case (Analysis of the Tariff Adequate for DR)

In this use case, we propose an analysis according to the perspective of the network operator, about the best type of compensation to customers with DR contracts. Therefore, two different types of tariffs were defined for the remuneration of the network operator, whenever there is an underballast of loads.

After the definition of the tariffs, several scenarios were created. In each one, the request for DR was verified through the linking of aspects such as the quantity of energy discharged, the number of periods in which the request occurred and the remuneration paid to each type of customer. In this study, we chose the operator / Aggregator to be as self-sufficient as possible, thus we will also need to analyze the amount of energy not purchased as well as its cost.

2.1. Concept

To create this study, we will propose an analysis of an intelligent net, with distributed production (DP). An operator manages the whole network and, therefore, we will call it the aggregator. As presented in figure 1, this network consists of residential, commercial and industrial customers. Some of these clients have energy production in units, which enabled some of these customers to enter into energy sales contracts with the aggregator. The aggregator also has a wind farm and a solar park giving it a significant energy production capacity.

Where:

1) Command Aggregator Center
2) Wind Farm
3) Solar Park
4) Industry
5) Trade
6) Customer with Production
7) Customer with DR
8) Customer without production and DR

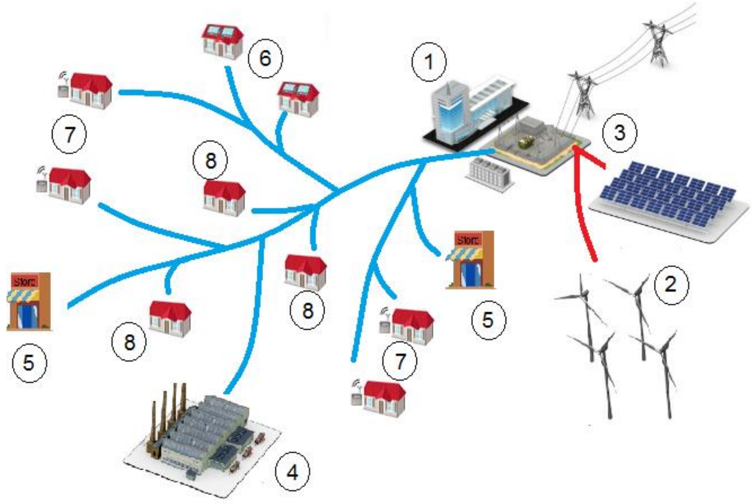

Fig. 1: Aggregator Smart Grid.

Due to the high productive capacity, the aggregator wants to become as self-sufficient as possible. Thus, it intends to incorporate a system of Demand Response (DR) so that in periods when production approaches consumption (but it is not enough to satisfy all demand) through DR, loads are underballasted, reducing consumption to levels equal to those produced.

When demand is higher than production, the aggregator will have to buy the necessary energy in the wholesale market through the Iberian market (MIBEL).

2.2. Methodology

In order to accomplish this study, it was necessary to acquire several consumption profiles (with and without production) [3] acquire production history through wind power plants and Photovoltaic [4] and acquire the historical energy prices in MIBEL [5]. The number of DR profiles, the number of groups per type and the amount of remuneration for each profile were also defined.

As can be seen in Figure 2 the analysis had two aspects. In the first there is no forecast of consumption or production and whenever there is possibility is done DR. The second aspect is considering the existence of forecasts in terms of quality of consumption, production and energy price in MIBEL (as it would be expected in a user operator in the energy market).

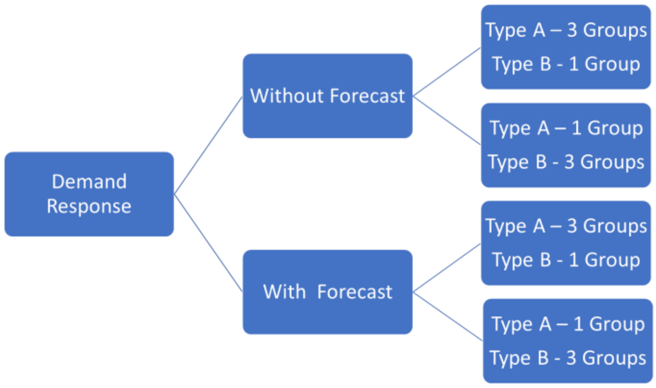

Fig. 2: Proposed scenarios.

Due to the number of clients, it was possible to create 4 client groups with DR contracts. Each group has the ability to blast up to 15 kWh for each 15-minute period.

The difference between the groups is the level of remuneration for the application of DR:

- Remuneration A
    - Have a fixe remuneration and for each request the remuneration adds 5%
    - If the underballast need does not reach 15 MWh in one period the DR can continue in the following period without any type of aggravation
    - Maximum of 5 requests per week
- Remuneration B
    - Have variable remuneration depending on the daily period
    - Drainage capacity is 15 MWh per period
    - Impossibility of being requested DR in two consecutive periods
    - Maximum of 5 requests per week

The remuneration value per kWh is presented in the following table because it is the magnitude that makes the most sense for the final consumer.

Table 1. DR Tariff.

DR Tariff						
Hour	Remuneration Type A with penalty					Remuneration Type B
	Normal	5%	10%	15%	20%	
00:00 - 01:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,035 €
02:00 - 06:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,030 €
07:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,035 €
08:00 - 10:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,045 €
11:00 - 13:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,055 €
14:00 - 18:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,045 €
19:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,055 €
20:00 - 21:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,060 €
22:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,055 €
23:00	0,045 €	0,047 €	0,050 €	0,052 €	0,054 €	0,045 €

For the analysis of the problem and in order to select a period of time that allowed the application of DR in load periods and emptiness periods, where the energy price in the MIBEL was lowest and higher, some monthly graphs were created with the consumption and production of energy and the price in the market. The week was then selected from 8 to 14 May 2017. Figure 3 shows the periods that were studied in this paper.

In a quick analysis of figure 3 we can see consumption is relatively constant and shows a slight decrease in the last 2 days (weekend). The production is very unstable due to the production through wind energy that in this system is considerable. Regarding the price of energy, there are some variations in equal periods of different days due to the variation of renewable production.

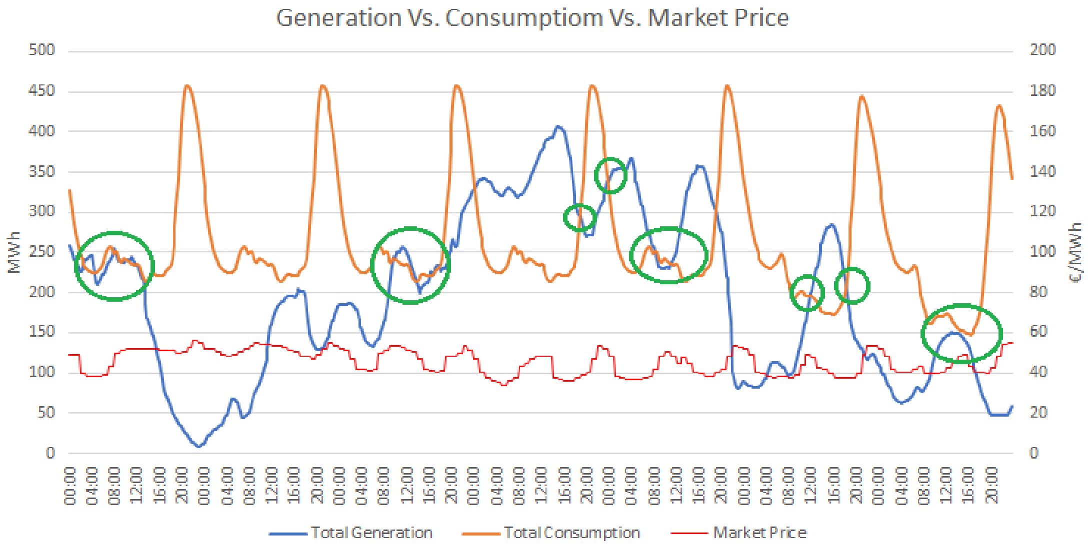

Fig. 3: Proposed scenarios.

Also in figure 3 it is possible to verify the possibility of applying DR in periods when the energy price in the market is low and high.

3. Demand Response

In an electrical system, in order for it to remain stable at all times, the production must match consumption. As energy storage is difficult and expensive, it is necessary to constantly adjust energy production to consumption.

With the evolution of the paradigm of the energy sector, new consumption rationalization technologies have emerged between them, the consumption management denominated Demand Response (DR).

The DR concept intends to manage demand for certain periods, during periods of peak consumption in order to not overload the networks and increase the production for a short period of time (the start-up of a generator set has high costs) calls for a reduction in consumption to consumers in return for monetary remuneration [6].

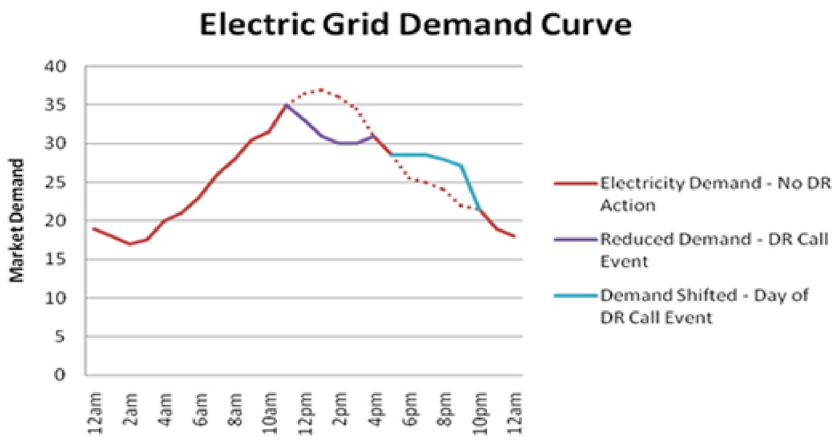

Fig. 4: Consumption profile with and without DR.

Figure 4 illustrates the profile of consumption of a consumer without DR and how would be the consumption with the application of DR.

The DR is defined / implemented through programs that may be price-based or incentive-based. There are several types of DR programs within [1] [8]:

- Programs based in prices
  - Time-of-Use (TOU)
  - Real Time Price (RTP)
  - Critical Peak Pricing (CPP)
- Programs based in incentives
  - Direct Load Control – DLC
  - Interruptible/Curtaible Service (IC)
  - Demand-Side Bidding (DSB)
  - Emergency Demand Response Programs (EDRP)

4. Results

The present section shows the results obtained in terms of scheduling of the appliances defined by the dependency vector and the energy bought from the network. In Fig..4 it is shown the total scheduling of the consumer's consumption, presenting the energy bought from the supplier, the initial demand before flexibility arrangement, and the final demand after flexibility implementation. Demand is divided into two categories, namely, fixed and dynamic, where the first represents the appliances that cannot be shifted, and the latter to the appliances that can be shifted to other periods. In this way there is a fixed cost for the consumer because of the fixed appliances, however, with dynamic appliances the energy management system adjusts their implementation to reduce the cost of it.

For this study was used 3 programs of DR:

- Time-of-Use (TOU) - with the implementation of a tri-hour tariff (empty periods, full and tips) promotes the reduction of peak consumption because it is the most expensive period.
- Direct Load Control - allows remote control of some devices (heater, AC, Fridge, etc.) in order to turn them off for short periods of time <15 minutes.
- Interruptible / Curtaible Service - consumer commitment to reduce the load, usually used in commercial and industrial environments.

As already mentioned in the methodology, it was created 4 different scenarios. The main differences between them are the existence of a forecasting system and the capacity (quantity of energy) discharged for each type of tariff as well as the remuneration of the tariff.

In this analysis, we discuss topics such as the number of requested dives, the amount of energy discharged, the cost of using DR and the cost of purchasing the energy in MIBEL. These results are mentioned in Table 2 and will be discussed below.

Table 2. DR Tariff.

Scenario	DR Application		Unused Energy (MWh)	DR Cost	Cos of energy in the MIBEL
	Type A	Type B			
1.1	15	5	198,14	9.006 €	8.343 €
1.2	5	15	198,14	8.037 €	8.815 €
2.1	12	5	201,35	9.296 €	9.453 €
2.2	4	15	203,64	8.137 €	9.436 €

Aggregator without forecast

In this part, it is assumed that the aggregator does not have any type of forecasting system so the DR is used as much as possible.

3 groups with tariff A and 1 group with tariff B

According to Table 2, DR requests were settled in all groups, in a total of 198 MWh of energy underballasted. With the application of DR the total cost amount was 9.000 € and was around 663 € more expensive if the aggregator bought the energy in the market. This event is justified either by the significant application of DR in periods of emptiness where the market price was below 40 € / MWh, or by the penalty for the request of the groups inserted in tariff A, causing the cost of the DR application to around 45.45 € / MWh.

We can also verify that DR was only applied during the first 3 days because the maximum number of requests was quickly reached.

1 group with tariff A and 3 groups with tariff B

In this scenario, the number of groups associated to tariffs was changed: only 1 group had the type A tariff and 3 groups had the type B tariff.

Similar to the previous scenario, we will have the maximum number of requests for all groups, the same amount of energy underballasted and the same cost of energy purchase in the market. These values are justified by the DR request occurring in the same periods of the previous scenario. The difference is in the remuneration since there are 3 groups with variable rates. In addition, the requests occur during periods of emptiness, allowing the application of DR to have a cost of 8.037 €, about 11% lower than the remuneration of the previous case. In this case there is a cost for the application of DR on average 40.45 € / MWh.

Aggregator with forecast

In this section, we will assume the aggregator has a forecast system with a high degree of certainty to predict the value of demand and production of energy as well as the market price. This system allows the aggregator to assertively manage the periods in which the DR application might be requested.

3 groups with tariff A and 1 group with tariff B

Analyzing first the request number of DR we can verify the type A requests did not reach the maximum, for each type A group only 4 DR episodes were verified, because due to the penalty the price of the fifth request for each group would be higher than the market price of energy in the same period.

Comparing point 2.1 with point 1.1 of Table 2 we can attest a smaller number of requests, however, the amount of energy lost is slightly higher, proving the use of forecasting makes the use of DR more profitable.

In this type of scenario we also verified the use of DR would have a lower cost of 157 € if purchased the same amount of energy in the MIBEL. In this case the average cost is 46.91 € / MWh with the application of DR to 47.71 € / MWh for purchase of energy in MIBEL.

This improvement is validated by the choice of the best periods to apply DR, which is only possible with the help of Forecast techniques.

If the remaining 3 utilizations of the tariff A were applied the savings no longer would exist and the average value of DR € / MWh would be equal to the cost of energy in the market.

1 groups with tariff A and 3 group with tariff B

After analyzing point 2.2 of Table 2, we verified that tariff A has not been fully utilized.

There is a reduction of 1.300 € in the use DR instead of the purchase of energy which translates to savings of around 14%. The average value of the DR application is 41.07 € / MWh and is significantly lower than 47.62 € / MWh in the case of the energy price in the MIBEL.

As a result, this scenario is the most appropriate because it gives the Aggregator the most savings.

5. Conclusions

Throughout the creation of this study, it was possible to acquire knowledge about DR and your applications.

We acknowledged that the DR application was a good solution for some network problems, not only for island networks but also for Operators that manage small networks, containing several types of clients and Production Park as the case of this study.

It has also been proven that the use of forecasting techniques in conjunction with the Demand Response application significantly increases the System's profitability.

Regarding the tariffs, we confirmed that the choice of the tariff and the number of customers affected by this tariff is of great importance, mainly because, as demonstrated in section 1.1, the use of DR was more expensive than buying the energy needed in MIBEL. It is important also to note that, while defining tariffs, the aggregator should take into account the periods in which it may be necessary to apply DR together with a historical market price of energy. In this case of use, tariff A was found to be inadequate, possibly due to the amount of the incentive or the amount of customers associated with this tariff.

In this case, we verified that the tariff B with a variable rate according to the period of the day is quite profitable, but the use of a fixed tariff should not be neglected for the periods in which the tip (more expensive).

Acknowledgements. This work has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 641794 (project DREAM-GO) and from FEDER Funds through COMPETE program and from National Funds through FCT, under the project UID/EEA/00760/2013.

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Intelligent load management in local and wholesale demand response markets
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Direct Load Control Demand Response Program for Air Conditioners

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Abstract

According to importance of demand response programs in last decades, many efforts have been made to change the consumption patterns of the users, and the use of renewable resources has also increased. Significant part of energy consumption belongs to the entire kinds of the buildings such as residential, commercial, and office buildings. In this context, the air conditioners can play an important role in demand response programs. Air conditioners can be as thermostatically controllable appliances for direct load control demand response program. In this paper, an optimization algorithm is developed to optimize the power consumption of air conditioners based on the user preferences to maintain the user comfort. The methodology of this work is proposed as a linear optimization problem that consider the generation of a renewable energy resource, which supplies a part of the energy consumption of the building. For the case study, the amount of the renewable energy generation, total consumption of building, and the consumption of the air conditioners in a real research building are considered and the optimization has been done based on the realistic data.

Keywords: demand response, direct load control, renewable energy, optimization

1. Introduction

Nowadays, the world is facing increasing energy consumption in many sectors like industrial, transportation, residential, and commercial [1], and this increment of using fossil fuels has led to many environmental problems [2]. The use Renewable Energy Resources (RERs), such as Photovoltaic (PV) and wind turbine, have been widely discussed, since they have no environmental impact [3]. In addition, RERs have more economic benefits for the users. For instance, the consumers are able to consume their own produced energy and sell the surplus of their generation to the energy market [4], [5]. Following this general increase of energy, electricity usage has a specific enhancement and the commercial and domestic buildings have a significant impact on the electricity consumption increment [6].

In this situation, Demand Response (DR) programs are very important in the topics of energy consumption. Programs with variable prices in the time, require a response from the customers that change their energy consumption pattern according to the price variation over time [7]. The different types of the DR program can be mentioned as, Direct Load Control (DLC), Interruptible/Curtailable Service (ICS), In Demand Bidding/Buyback (DBB) programs, Emergency Demand Response (EDR), Capacity Market (CM) programs, and Ancillary Services Market (ASM) [8].

In this context, the Air Conditioners (AC) have a significant power consumption in the buildings and can play a key role in participating in DR programs [9]. The regulation of the DR in ACs is made by the actuation in the AC. Thus, this type of DR program is called DLC, because there is ACs that can be considered as thermostatically controllable appliances [10].

This paper represents an optimization based model for optimizing the consumption of the AC system of an office building with interference of RERs, specially a PV system that supplies part of power demand of the building. The building consists of the several laboratorial and commercial equipment and instruments, such as several Programmable Logic Controllers (PLCs) and several energy meters, which enable the system to have real implementation of the optimized data.

This paper is proposed in four sections. After this introductory section, the optimization problem is presented in section 2. Section 3 demonstrates the case study, and its obtained results. The conclusions of this work are presented in Section 4.

2. Optimization Model

The proposed model regarding the optimization of consumption of AC and in reducing the total cost of the energy consumption in the building is based on the priority of them. In this way, the maximum consumption reduction for each air conditioner has been considered. The overall architecture of the presented optimization problem is illustrated in Fig. 1.

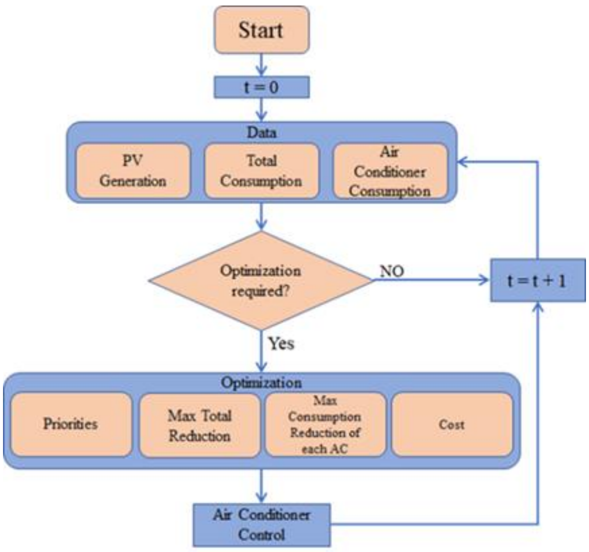

Fig. 1: The flowchart of the proposed optimization model.

As you can see in Fig. 1, the optimization model starts with definition of input data including generation of the PV, total consumption of the building, and the detail of the total consumption of the air conditioning system. After checking these values, if the desired power consumption is met, the optimization process is not required and should check the values again as long as the system is in the high consumption level. Then, the program starts to optimize the consumption of the AC to fulfil the system goal. For this purpose, priorities are defined in the program. This means each air conditioner of the building has a priority based on its location and user preferences. After that, the required power reduction of whole air conditioning system and the maximum consumption reduction of each air conditioner is defined, as well as several constraints for the proposed optimization problem. This methodology is run for a single period, however, the optimization process depends on the input values of the system. Equation (1) demonstrates the objective function of the optimization problem:

$$Minimize\ EB = \sum_{t=1}^{T}\sum_{d=1}^{D}((P_{red_{(d,t)}} * W_{(t,d)}) + P_{total} - PV) * Cost_{(t)} \quad (1)$$
$$\forall\, t\ \in\ \{1, \ldots, T\}$$
$$\forall\, d\ \in\ \{1, \ldots, D\}$$

Where P_{red} is power consumption reduction of each air conditioner, and W is abbreviation of weight of the priority of each air conditioner that depends on the user and situation of the room. D and T represent the total number of devices that mean the AC and number of time periods respectively. Moreover, P_{total} represents the total power consumption of the building, PV indicates the generation of Photovoltaic system in the building, and *Cost* is the electricity energy cost in each period. Moreover, the model constraints are shown by equations (2)- (4).

$$0 \leq W_{(d,t)} \leq 1 \tag{2}$$

$$Maximum\ Reduction: \sum_{t=1}^{T}\sum_{d=1}^{D} P_{red(d,t)} = P_{total} - PV \tag{3}$$

$$P_{red(d,t)} = \{0, P_{red(d,t)}^{Max}\}\ \forall 1 \leq t \leq T; 1 \leq d \leq D \tag{4}$$

The equation (3) indicates that the required consumption reduction of the system. Actually, the process of optimization depends on the input data. As it illustrated in Fig. 1, total consumption of the building and the generation of the PV, are the values that specify the required reduction for the system, and equation (4) shows that consumption reduction for each device is limited to maximum consumption reduction of each device.

3. Case Study

This section represents the case study used for verifying the proposed optimization model. As it was mentioned, the main purpose of this section is to optimize the consumption of the air conditioning system in an office building (The office building is a part of GECAD research centre located in ISEP/IPP, Porto, Portugal). This building consists of 9 offices and a corridor as Fig. 2 shows. Daily, the building has more than 16 researchers working inside. The control of the AC was made by developing an infrared emitter to transmit the air conditioner signals to turn on/off or to regulate the desired temperature and operation mode. The infrared emitter is connected to a PLC that receives orders using a Modbus/TCP connection and then send the desired signals to each air conditioner.

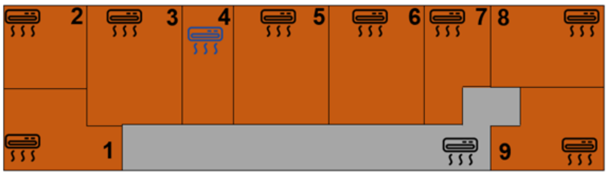

Fig. 2: Plan of GECAD office building.

As it was previously mentioned, the optimization is based on the weight of the priority of the AC and the cost of electricity in each period. The order of priority is the importance of each device for the user or for the building rules. For instance, the air conditioner placed in office number 4 has the highest importance as its placed in the server room, so they should be always on.

The time period used in this case study is one minute, within a total period of 24 hours. Two situations should consider for defining the required reduction value: periods that the generation of the PV is more than the power consumption of the building (that requires a reduction with a negative value), and periods of the day where the power consumption of the building is higher than PV generation (where the optimization must reduce the consumption). Fig. 3 illustrates the results of the optimization for entire building.

As it is clear in Fig. 3, most of the optimization periods are in the working hours of the office building where the total power consumption is more than the PV generation.

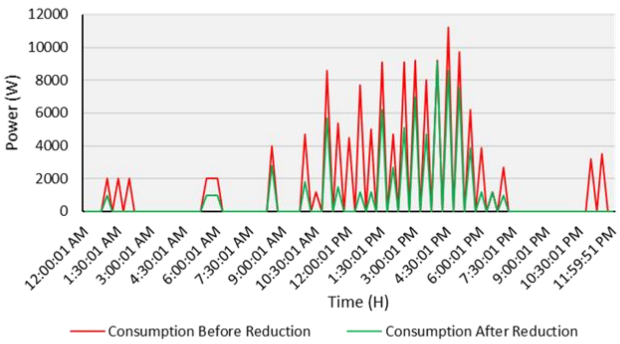

Fig. 3: Comparison of the power consumption before and after the optimization.

4. Conclusions

This paper presented an optimization algorithm for optimizing the power consumption of air conditioners of an office building based on the user preferences. Renewable generation were considered on the algorithm, which it supplies a part of building consumption. The optimized data has been implemented in the building using several programmable logic controllers and energy meters.

The results obtained show that optimization of the air conditioning consumption in the buildings can effectively reduce the final energy consumption and keeps the preferences and comforts of the users by specifying priority to each device. In this way, the use of renewable energy can be increased in residential, commercial, and office buildings, since it can benefit both sides of the network. The demand side can benefit by reducing their electricity bills, and the grid side will be benefit by reducing the generation in critical periods.

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Intelligent load management in local and wholesale demand response markets

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Real-Time Demand Response Program Implementation Using Curtailment Service Provider

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Abstract

Nowadays, electricity network operators obligated to utilize the new concepts of power system, such as demand response program, due to peak shaving or reducing the power congestion in the peak periods. These types of management programs have a minimum capacity level for the consumers who tend to participate. This makes small and medium scale consumer incapable to participate in these programs. Therefore, a third party entity, such as a Curtailment Service Provider, can be a solution for this barrier since it is a bridge between the demand side and grid side. This paper provides a real-time simulation of a curtailment service provider that utilize real-time demand response programs for small and medium consumers and prosumers. The case study of the paper represents a network with 220 consumers and 68 distributed generations, which aims at the behavior of two small and medium scale prosumers during a real-time demand response program.

Keywords: real-time simulation, hardware-in-the-loop, demand response, aggregator, curtailment service provider.

1. Introduction

Demand Response (DR) programs and Distributed Generation (DG) are two concepts that widely discussed in the state of the art [1]. DR programs are efficient tools for both sides of the network, since it can reduce the electricity bills of the demand side consumers, and also provides flexibility for the grid operators [2]. Briefly, DR program is referred to the change of electricity consumption profiles of the demand side consumers in order to response to the electricity prices changes or the incentives paid by the DR managing entities [3]. All DR programs are classified into the two categories of price-based and incentive based [4], [5].

It is clear that if the use of DR programs integrated with the DG, it enables the network operator to have more flexibility in the energy management [6]. However, both DR and DG units should have adequate capacity in order to have a significant role in the grid management. According to [7-9], the minimum capacity of reduction for the demand side consumers in order to participate in DR programs are 100 kW. Therefore, this is a barrier for the small and medium scale consumers and prosumers to participate in the DR programs individually [10]. Curtailment Service Provider (CSP) can be considered as a third party entity, which aggregates the small and medium scale consumers and prosumers and participate them in the electricity market negotiations as a unique resource [11-13]. However, before the massive implementation of CSP, it should be well tested and validated in order to identify future problems [14]. The simulation of an electricity network by computational resources, would be non-affordable and the results may be far from the reality [15]. Real-time simulation methods using Hardware-In-the-Loop (HIL) can be a verified methodology in this context, since it merged the results of both reality and simulation environments [16].

This paper represents a real-time simulation of a CSP that consists of 220 consumers, and 68 DG. The focus is given to the reactions of small and medium prosumers, while the CSP is managing the resources in real-time including DR programs and DG units. The small and medium prosumers are the ones that cannot participate in the DR program individually since they do not have adequate reduction capacity for the DR, and they established a contract with the CSP. The CSP model is executed in real-time digital simulator, and both prosumers are emulated by the real and laboratorial hardware equipment.

The rest of the paper is organized as follow. Section 2 describes the CSP model and DR programs. The real-time simulation model developed for the CSP is represented in Section 3. Section 4 concerns about the case studies considered for the developed model and its results are described in the same section. Section 5 provides the main conclusions of the paper.

2. Curtailment Service Provider

In this section, the theory of CSP and its operation in a real-time DR program will be proposed. The CSP demand response procurement model presented in this section is adapted and improved from [13]. Generally, if a particular customer has an adequate amount of energy to attain the minimum required reduction of a DR event, then it can establish a direct contract with the DR program managing entity (which usually is an ISO). On the other hand, players that are not able to provide the sufficient reduction by themselves can make a contract with the CSP to be aggregated and participated in DR events. In this model, it is considered that the players are equipped with the Renewable Energy Resources (RERs) and Energy Storage System (ESS), and they are capable to store their own generation in the ESS as well as inject energy to the main grid. When a contract is made between a prosumer and the CSP, the prosumer should specify three specific values. These values are ordered in below based on the incentives paid by the CSP to the prosumers:

• Regular reduction – is the amount of energy that the prosumer can reduce it in real-time (cheapest reduction from CSP stand point);

• Renewable use – is the real-time amount of RER generation, that the prosumer should inject it to the grid, and it is not allowed to store it in ESS;

• Direct Load Control (DLC) – is related to the loads that CSP is able to directly control (most expensive reduction from CSP stand point).

During a DR event, the CSP has a specific time to achieve the amount of consumption reduction mentioned in the contracts. This specific time is called ramp period. If the proposed event is a real-time DR program, the prosumers should transmit their regular reduction values and the amount of renewable use to the CSP at the beginning of the event. Fig. 1 illustrates the procedure done by CSP during the ramp period of a real-time DR program.

As Fig. 1 shows, the procedure done by CSP during the ramp period of a real-time DR program consists of six steps. In the first step, the CSP informs the prosumers from the DR event. After that, in the second step, the prosumers transmit both values of regular and renewable energy. In the third step, the CSP evaluates the amount of the regular reduction. If the regular reduction cannot provide the minimum reduction for the event, the CSP evaluates the amount of renewable use. In the fourth level, the CSP transmits the final decisions of the evaluation to the prosumers. If both regular and renewable use are not adequate for DR reduction, in fifth level, the CSP estimates the DLC reduction, and evaluates the three mentioned resources (Regular + Renewable + DLC). Finally, in the last step, the CSP decides concerning the players that can participate in the DR event or not, and the players that cannot provide the sufficient reduction, will be excluded from the DR event.

In fact, the minimum reduction for a CSP to participate in a DR event always should be a value higher than the defined minimum DR reduction. For example, if the DR program managing entity defines the minimum reduction as 100 kW, the CSP should consider 120 kW in order to overcome the possible failures.

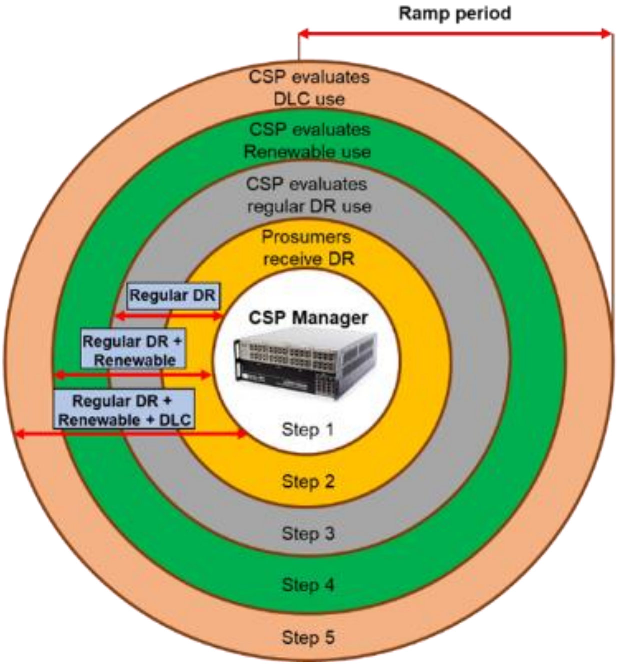

Fig. 1: CSP procedure during the ramp period of a real-time DR event.

3. Real-Time Simulation Architecture

In this part, the real-time simulation model and the network (with their hardware structures) proposed for the CSP will be demonstrated and explained in detail. The main core of the CSP model is OP5600 (www.opal-rt.com), which is a real-time digital simulator. In the presented model, the OP5600 is the main controller of the CSP, and is based on MATLAB^{TM}/Simulink. Moreover, the Hardware-In-the-Loop (HIL) capability of the OP5600, enables the model to integrate and control the real hardware resources from the Simulink environment.

The power distribution network presented for the CSP is a 33 buses distribution grid with 220 consumers and 68 DG units (including RERs) [17]. This distribution network was implemented in the MATLAB^{TM}/Simulink, in order to be compatible with the OP5600. Fig. 2 illustrates the developed distribution network.

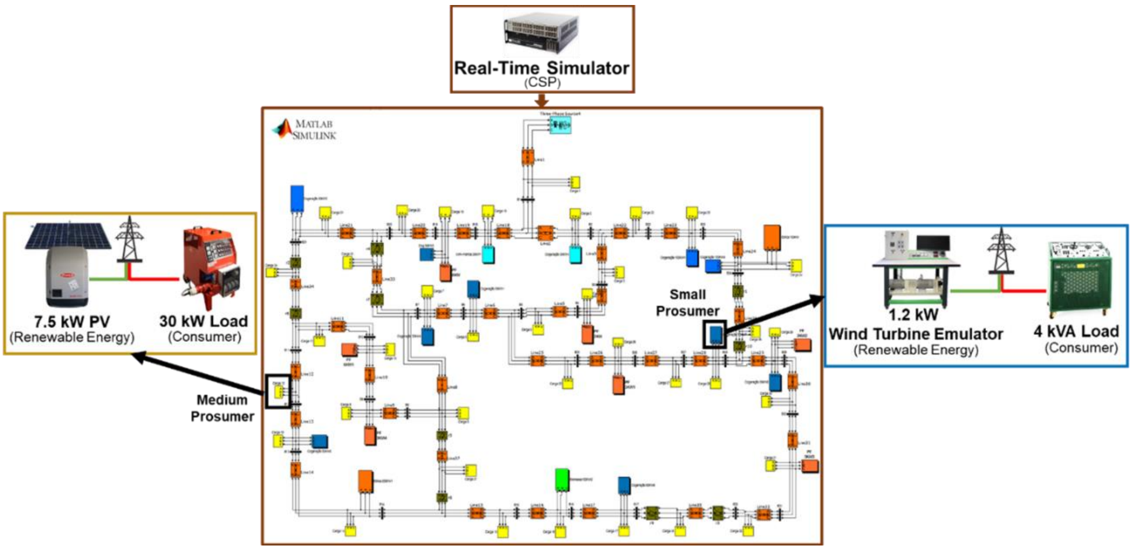

Fig. 2: Real-Time simulation of CSP using real hardware resources.

As it was mentioned, the main focus is to survey the behaviour of the small and medium prosumers while they have been aggregated by the CSP in order to participate in the DR event. For this purpose, bus

#10 and #24 of the distribution network are dedicated respectively to a medium and a small prosumer. As Fig. 2 shows, the medium prosumer consists of a 30 kW resistive load emulating the consumption of the player, and a 7.5 kW PV unit as a renewable energy producer. Additionally, the small prosumer includes a 4 kVA load and a 1.2 kW wind turbine emulator.

The hardware equipment used for small and medium prosumers simulator are physical equipment connected, in real-time, with the real-time simulator (OP5600) by the HIL methodology. Fig. 3 and Fig. 4 illustrate the details on how these medium and small prosumers have been integrated in the OP5600. From the CSP stand point, these prosumers are capable to deliver the produced energy to the grid, and also, they can store it in the ESS.

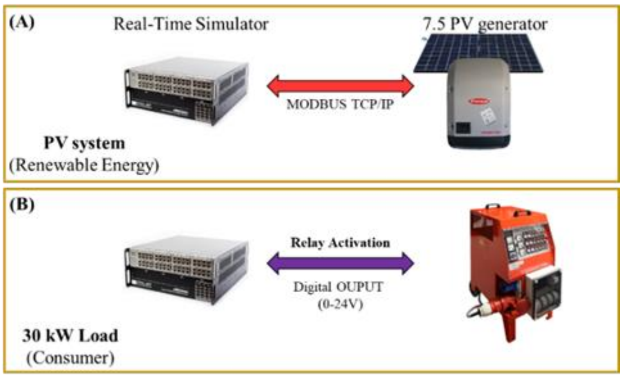

Fig. 3: HIL methodology for medium prosumer.

As it is clear in Fig. 3-(A), for acquiring and monitoring the real-time generation data from the PV system to OP5600 and Simulink model, Modbus/TCP protocol has been used. Also, for the 30 kW load, (Fig. 3-(B)), the OP5600 applies several Digital outputs in order to activate the related relays installed on load [16].

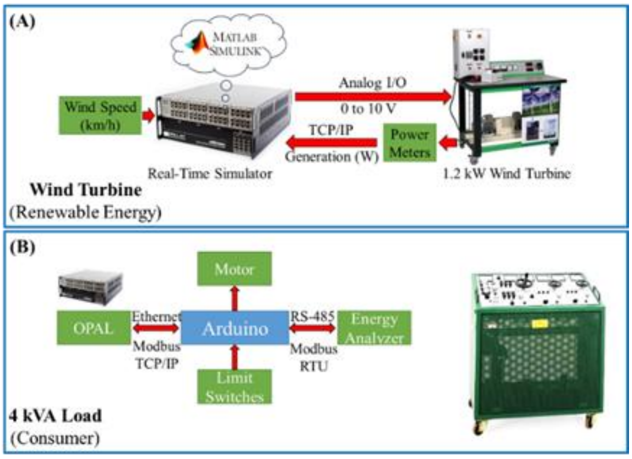

Fig. 4: HIL methodology for small prosumer [16].

As Fig. 4-(A) shows, for controlling the wind turbine emulator of the small prosumer, the analog input terminal of the speed controller unit has been integrated to the analog output board of the OP5600. Then, the wind speed data have been converted from km/h to a value in the range of 0 to 10 V, provided to the analog output board of the OP5600. The computations of this conversion have been done in the Simulink environment. In the last stage, the related power meter of the wind turbine emulator has been connected to the OP5600 via Ethernet interface, with Modbus/TCP protocol. Moreover, for the consumption of the small prosumer, the 4 kVA load is used. The 4 kVA load consists of three independent parts: resistive, inductive, and capacitive. The resistive part is automatically varied through a controlling process that is illustrated in Fig. 4 (B), using a 12 V DC motor to control the motion of the resistive gauge. Therefore, by controlling the direction of the rotation in this small motor (clockwise or counterclockwise) the resistive gauge can be moved upward or downward in order to increase or decrease the load consumption. Moreover, a power meter was used for measuring the real-time consumption of the 4 kVA load. An Arduino®

(www.arduino.cc) equipped with an Ethernet shield and a Relay module has been employed for controlling the 4 kVA load [16].

4. Case Studies

In order to test and validate the system capabilities, three case studies are designed to be applied in the CSP developed model. For all the case studies, it is considered that the medium prosumer is a small factory equipped with the PV arrays, and the small prosumer is an office building with small-scale wind turbine.

The consumption and generation profiles regarding these two players during 17 periods of one minute each are demonstrated in Fig. 5. The consumption profile of the factory (Fig. 5 – (a)) has been adapted from GECAD database, and its generation profile is the real production curve of the PV system installed in GECAD research centre, ISEP/IPP, Porto, Portugal. Moreover, the consumption pattern of the office building (Fig. 5 – (b)) is the real consumption profile of the GECAD research centre, and the wind speed data for the wind generation profile were chosen from ISEP meteorology. Also, the established contract between the two presented prosumers and the CSP is shown on Table 1. For the case studies, we considered that the CSP receives a real-time DR program from the DR managing entity, such as ISO, for 15 minutes with the minimum reduction capacity of 100 kW. Therefore, the CSP considers 120 kW as the minimum reduction in order to overcome the possible failures.

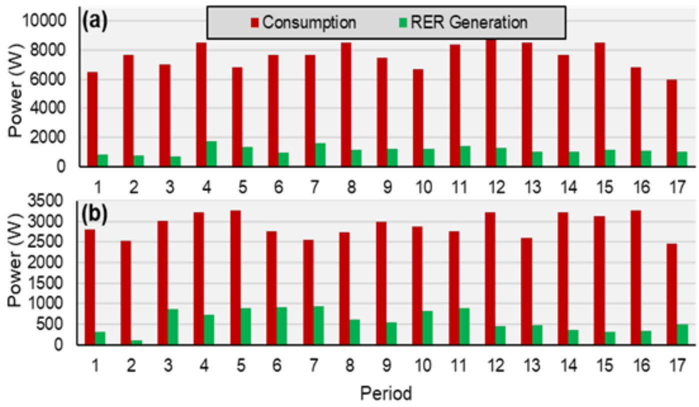

Fig. 5: Consumption and generation profiles of: (a) factory - (b) office.

Table 1. CSP information during the DR events in the case studies (All values are in kW).

	Case Study 1			Case Study 2			Case Study 3		
	Reg	***RER***	***DLC***	***Reg***	***RER***	***DLC***	***Reg***	***RER***	***DLC***
Factory	3	~1	1	3	~1	1	3	~1	1
Office	1.5	~0.5	0.2	1.5	~0.5	0.2	1.5	~0.5	0.2
Others	124.5	~20.4	9	88.3	~40.9	13	88.3	~24.3	13
Total	129	~21.9	10.2	92.8	~42.4	14.2	92.8	~25.8	14.2
	161.1			149.4			132.8		

4.1. Case Study 1

In this case study, it is assumed that the factory player has 3 kW capacity in the regular reduction (Reg. in Table 1), and it can provide around 1 kW renewable use (RER in Table 1) to the CSP, and finally, 1 kW capacity in the DLC reduction (DLC in Table 1). Moreover, the office player has 1.5 kW capacity in the regular reduction, around 0.5 kW renewable use, and 0.2 kW capacity in the DLC reduction. Additionally, the other players available in the CSP provide 124.5 kW in regular, 20.4 kW in renewable use, and 9 kW in the DLC. These values are transmitted from the players to the CSP during the ramp period (as Fig. 1 showed), consequently, the CSP can achieve the minimum required reduction by the regular reductions provided by the players, which is the cheapest one.

The behaviours of the factory and office building during the DR event are illustrated in the Fig. 6. The results shown in Fig. 6 are for 1020 seconds (17 periods, one minute per period), provided by the real-time simulator (OP5600) in MATLAB^{TM}/Simulink. As Fig. 6 shows, the DR event starts from 60 to 960 seconds, which is period 2 to 16. In Fig. 6 – (A), the consumption profiles of the factory are emulated by the 30 kW load, where the red line is the consumption before the reduction, and the purple line indicates the consumption after the reduction. The difference between these two lines demonstrates the regular reduction (3 kW). Also, in Fig. 6 – (B), the consumption profiles of the office building are emulated by the 4 kVA load, and the difference of the red line (consumption without DR event), and the purple line (consumption during DR event) indicates the amount of the regular reduction by the office building (1.5 kW).

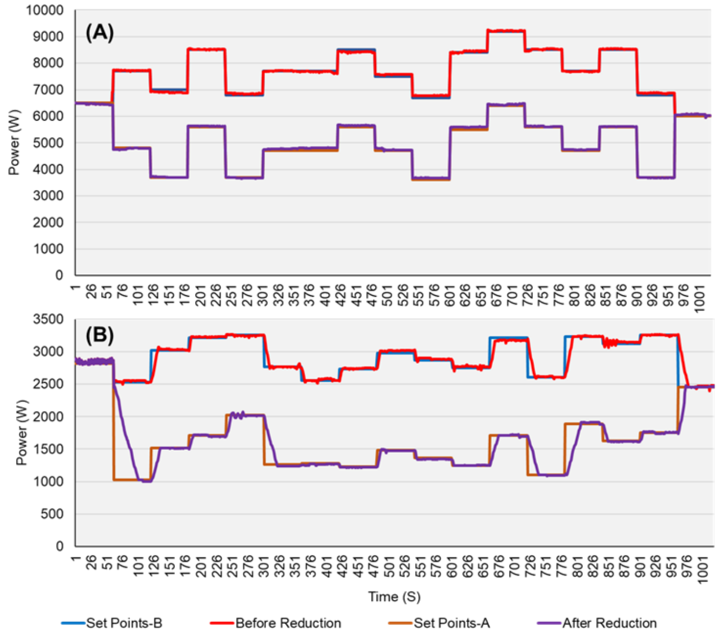

Fig. 6: The reactions of the two CSP prosumers in the case study 1: (A) factory - (B) office building.

The blue and brown lines in Fig. 6 are related to the real-time simulation and HIL methodology. In other words, these lines are the values that OP5600 transmits from the Simulink to 30 kW and 4 kVA load with one minute time interval, and the red and purple lines are the real-time consumption values transmitted by the devices to the Simulink environment with one second time interval.

4.2. Case Study 2

In the second case study, it is considered that all the conditions explained in the case study 1 will be equal, except the amount of reductions that the other players of the CSP will provide. As Table 1 shows, for the case study 2 it is assumed that the other players provide 88.3 kW in the regular reduction, 40.9 kW in the renewable use, and 13 kW in the DLC. In this moment, the CSP computes the provided reductions in the ramp period, and since the sum of regular reductions are not sufficient for participating in the DR event, it decides to use the second reduction resource, which is renewable use. Therefore, by using both reduction resources (Reg. + RER in Table 1), the CSP achieves the minimum reduction with 135.2 kW, and there is no need to use the DLC resource. In the next step, the CSP transmits its decision to the players, which is reducing their consumption until the regular reduction, and do not storing their produced renewable energy in the ESS, however, inject it to the main grid. While the players inject their own produced energy to the main grid, the CSP will see a reduction. The reactions of the factory and the office building during the DR event in this case study are shown on Fig. 7.

Similar to the case study 1, in Fig. 7 the DR event starts from the period 2 to 16, which is 60 to 960 seconds. The amount of reduction in both prosumers is the same as the case study 1, which is around 3 kW and 1.5 kW in the factory and office respectively. However, in this case study, all CSP players including these two prosumers are bounded to inject their own produced energy to the grid.

The generation profile of the factory is related to the real PV production of GECAD research centre, with one second time interval. Also, the generation profile of the office building is related to the generation of the wind turbine emulator, somehow the OP5600 transmits the real-time wind speed data with one minute time interval to the emulator, and the emulator produces power and transmits the real-time generation data to the OP5600 with one second time interval.

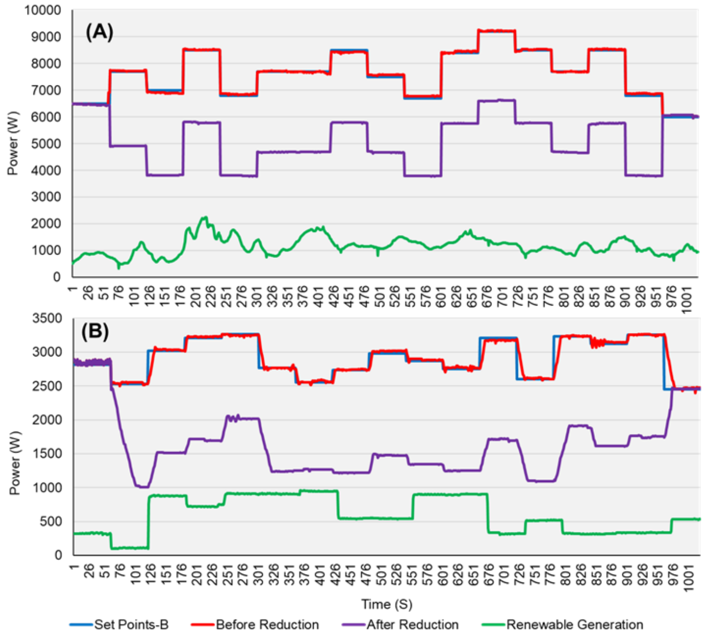

Fig. 7: The behaviour of two CSP prosumers in the case study 2: (A) factory - (B) office building.

4.3. Case Study 3

In the case study 3, we considered that the CSP encountered with significant reduction in the RER generation by the players. Therefore, as Table 1 showed, the regular reduction and renewable use will not be adequate for the CSP to achieve 120 kW reduction. Consequently, the CSP should use the DLC contracts, which enable the CSP to directly turn off the loads that are involved in the contract. Fig. 8 illustrates the final results of the case study 3. As it is clear in Fig. 8, the CSP utilizes its DLC reduction, which is the last and most expensive resource, in order to reach the minimum reduction capacity for participating in the DR event.

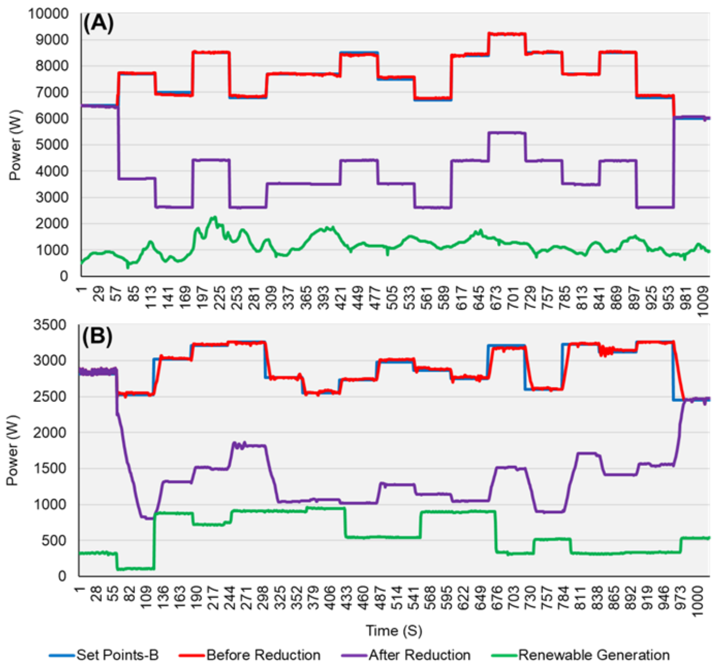

Fig. 8: The reactions of the two CSP prosumers in the case study 3: (a) factory - (b) office building.

During these three case studies, the energy that the CSP sold to the two prosumers is illustrated in Fig. 9, and also the voltage variations during the real-time simulation of the three case studies are shown on Fig. 10.

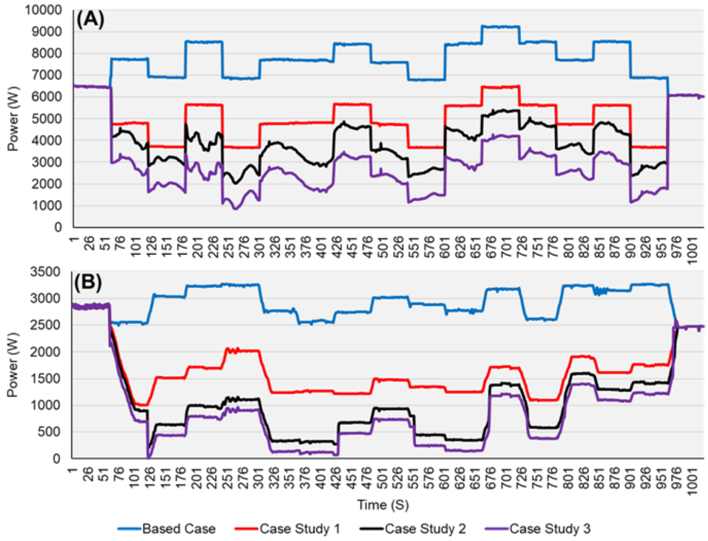

Fig. 9: The energy consumption of the two prosumers during the three case studies from the CSP stand point: (A) factory – (B) office building.

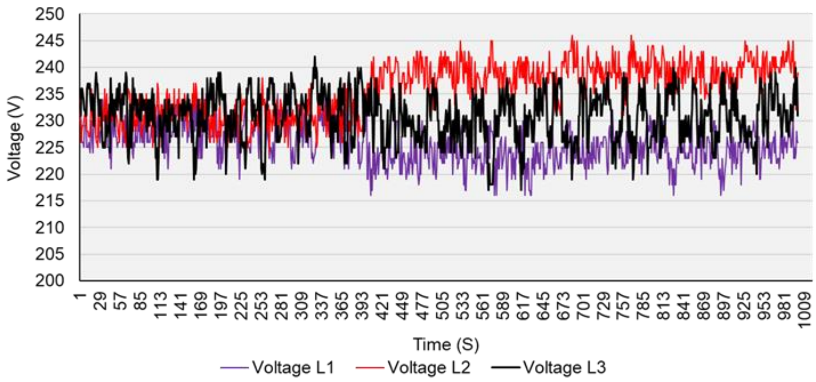

Fig. 10: Voltage variations during the real-time simulation of three case studies.

As you can see in Fig. 9, the blue line indicates the consumption of the prosumers while there was no DR event. When the DR event starts, in the case study 1, the transmitted energy from CSP to the prosumers is reduced based on the regular reduction. Also, in the case studies 2 and 3, by the involvement of the produced renewable energy by the prosumers, the CSP sold less energy to them. Therefore, it sees a reduction in the consumption and consequently, the CSP was able to participate in the DR event. The most important novelty showed by the case studies, is when the load schedule is changed, the actual and real consumption devices take a while to reach the desired consumption level. This is the fact that was not considered in the electrical network simulation models, and has been addressed by the real-time simulation test bed using HIL methodology.

5. Conclusions

This paper represents a real-time simulation of a Curtailment Service Provider consisted of 220 consumers, and 68 distributed generations, which supports decision making for demand response programs testing and validating. The presented model executed by a real-time digital simulator (OP5600) using several real and laboratory hardware resources by Hardware-In-the-Loop methodology.

In the case studies, the reactions of a small and medium prosumers have been investigated while the CSP makes various decisions for participating in a real-time DR event. The results of the case studies are the real measured data from the loads and generators, which validate the concepts of the CSP by enabling the small and medium prosumer to participate in a DR event. Also, the results demonstrated that whenever the rate of consumption changed, the loads require some times to reach the desire consumption rate. This is one of the main differences between the experimental works and simulation works, which in simulation environment the consumption rate changed immediately, however, in real world all consumers need a period to adapt and reach the desired consumption.

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Intelligent load management in local and wholesale demand response markets
Third DREAM-GO Workshop
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Definition of Remuneration in an Aggregator Using Clustering Algorithms

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Abstract

Currently, the use of demand response programs and renewable energy resource are a reality in the power distribution network. Therefore, an efficient and optimal energy resource management is required for fully benefit from these new concepts of power system as well as avoiding energy wasting. In this paper, a methodology is represented in order to support the aggregator activities, with the aim of participation in the electricity market negotiations using aggregated distributed energy resources and demand response programs. Moreover, the presented model demonstrates the benefits of aggregator participation while promoting their inclusion. Additionally, a case study will test and validate the proposed methodology, which considers a university campus distribution network as aggregator network including 20 consumers and 26 renewable producers.

Keywords: aggregator, demand response, energy managemet system, clustering, optimization, smart grid

1. Introduction

The Distributed Renewable Energy Resources (DRERs), when managed by an aggregator, are represented as a unique resource with characteristics that reflect the aggregated resources [1], [2]. An aggregator managing a given number of resources or region, implies a simplification of processes to the operators, since the number of resources to be considered is reduced and energy negotiation and trade can be made [3]. Also, if Balance Responsible Parties (BRPs) exist, the activities developed by the aggregator can also provide useful services to the BRPs [4]. In fact, several countries of the European Union (EU) have introduced and accepted the concept of aggregators operating in their energy systems providing service mainly to consumers, and the usefulness of an aggregator is specially seen as a flexibility provider, through the gathering of active consumers that can participate in the aggregator's demand response programs [5].

Regarding production-side resources, the aggregator assumes the role of a virtual power plant, as referred before [6], [7]. These resources often belong to the consumers who can also produce (called Prosumers) and have small capacity of generation. This means a third party entity, namely aggregator, is required in order to aggregate these kinds of small and medium scale resources and participate them in the electricity market negotiation as a unique resource [8].

An aggregator model is also responsible for Demand Response (DR) programs [9]. DR program is defined as the modification of electricity consumption patterns in the demand side in order to response to the price changes or incentive payments, which can be due to any economic or technical reasons [10]. In this context, aggregator should gather all small and medium scale consumers who intend to participate in DR programs, and represent them as one DR resource. This means the aggregator can be considered as a flexible network player, which brings flexibility to the network by establish bidirectional contracts with end-users for DR programs to manage consumption resources [11].

This paper presents an optimization based aggregator model for small and medium scale DRER and DR management. Moreover, a methodology is provided to support the aggregator in its activities, with focus on the participation of aggregated DRERs and DR in energy markets, and on how the aggregator can benefit from this participation while promoting their inclusion. The presented methodology utilizes clustering algorithm in order to define remunerations.

After this introductory section, section 2 represents the model for aggregator and remunerations by focusing on the mathematical formulation of scheduling optimization problem. Section 3 provides the details regarding the case study, which contribute the developed model in a realistic distribution network of a university campus, and its results are illustrated in the same section. Finally, the main conclusions of the work are presented in Section 4.

2. Presented Model

In this section, the proposed methodology is explained and all its components, regarding the scheduling, aggregation, and remuneration activities performed by the aggregator will be demonstrated. The proposed methodology is shown in Fig. 1. At the end of the methodology, the output results are the energy and cost of each group of resources made, according to the specifications of the aggregator. With this information, the aggregator can negotiate in the market by bidding the available energy amount at a given price. However, the selling price must be equal or higher than the cost of each group to obtain profits or at least recover what was spent on distributed resources. The activities of the aggregator are divided in two types: upper-level and bottom-level activities.

The scheduling of resources considers external suppliers and two types of DRERs, namely, renewable resources and active consumers. For the production-side resources, the methodology considers a linear cost function for both distributed generators and external suppliers. Regarding active consumers, it is considered that these can be enrolled in three different types of DR, namely, load reduction, curtailment, and load shifting. In this way, only the reduction and curtailment energy amounts obtained are considered by the aggregator to be scheduled and therefore negotiated in the energy market. The load shifting model is based on [12]. In the case of the demand-side resources, the cost considered is also linear for reduction and curtailment, while load shifting is free.

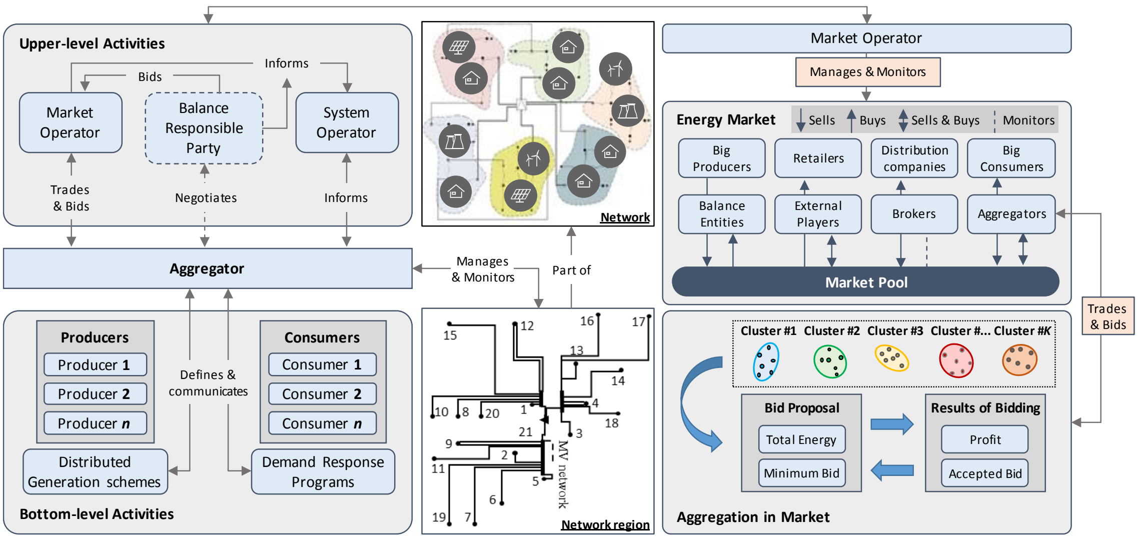

Fig. 1: Overall architecture of the proposed methodology [13].

Aggregation of resources is made using K-Means clustering algorithm, considering the observations of the energy scheduled and the discriminated cost of that scheduling. It is important to notice that the aggregation is only made considering the resources with participation in the scheduling, i.e., if the resource is not affected by the scheduling of the aggregator, then it is not considered in the aggregation process. The remuneration of resources is computed after the aggregation, since the groups need to be made to define a group tariff, i.e. the resources belonging to a given group are remunerated at the same price. In this case, it is considered that the maximum price in the group, which corresponds to the group tariff, will result in paying the most expensive consumers a fair amount, and the least expensive an incentive to participation since the payment is superior to their initial expected price. This ensures that most of the consumers are encouraged to participate in the aggregator's schedule.

In sum, each of the formed groups will represent a bid made by the aggregator in the energy market (seen as a bid group), considering the energy obtained from the resources within that group, and the respective group tariff as the minimal acceptance rate for the aggregator. The energy in each group corresponds to the sum of the scheduling obtained for the distributed resources in that same group. This type of analysis facilitates the activities developed by the aggregator, namely, by providing a simple decision strategy based on the financial balance computation of its participation in market.

The scheduling optimization reflects a Mixed-Integer Linear Problem (MILP), since it involves continuous and discrete variables. In this methodology, it is not considered that the aggregator is responsible for the technical verification of the network, i.e. this is assumed to be the operator's role. Equation (1) presents the objective function implemented for the aggregator's cost minimization. The resources considered for the objective function are: the energy bought from the external suppliers ($P_{(s,t)}^{Sup}$), the energy obtained from distributed generators ($P_{(p,t)}^{DG}$), and the demand flexibility (reduction - $P_{(c,t)}^{Red}$, curtailment - $P_{(c,t)}^{Cut}$, shifting -$P_{(c,t,d)}^{Shift}$.

$$
\begin{aligned}
MinOC = & \sum_{s=1}^{S} P_{(s,t)}^{Sup} \cdot C_{(s,t)}^{Sup} + \sum_{p=1}^{P} P_{(p,t)}^{DG} \cdot C_{(p,t)}^{DG} \\
& + \sum_{c=1}^{Cs} \left[\begin{array}{l} P_{(c,t)}^{Red} \cdot C_{(c,t)}^{Red} + P_{(c,t)}^{Cut} \cdot C_{(c,t)}^{Cut} \\ + \sum_{d=1}^{T} P_{(c,t,d)}^{Shift} \cdot C_{(c,t,d)}^{Shift} \end{array} \right] \\
& \forall t \in \{1, ..., T\}
\end{aligned}
\tag{1}
$$

The constraints of the proposed optimization problem consist of:

- The energy balance to assure the consumers are supplied according to their consumption needs;
- Technical generation limits of the external suppliers and distributed generators;
- Technical limitations of demand response programs;
- Limitations regarding the maximum amount of energy shifted out and into a given period;
- Maximum price of the resources belonging to each group.

Therefore, the key components of the proposed methodology, regarding the scheduling and remuneration of resources managed by the aggregator have been presented. In the next section, it is detailed the case study used to validate the present methodology.

3. Case Study

This section presents the description of the case study used to validate the proposed methodology. The considered network is composed by 21 buses, representing a university campus, as described in [14]. The network has 20 consumers classified by their average consumption, and 26 production generators classified by type of source.

The energy cost of both distributed generation and external suppliers, is considered constant in all periods. All producers, except the external supplier, can participate in aggregation for energy markets. Regarding the consumers, these are divided into five types: Domestic (DM), Small Commerce (SC), Medium Commerce (MC), Large Commerce (LC), Industrial (ID). This type of assignment is performed based on their average daily consumption. Fig. 2 presents the consumer's details considering their linear cost, by type of resource. The maximum reductions are 6% of the initial load for reduction, and 10% for curtailment and shifting.

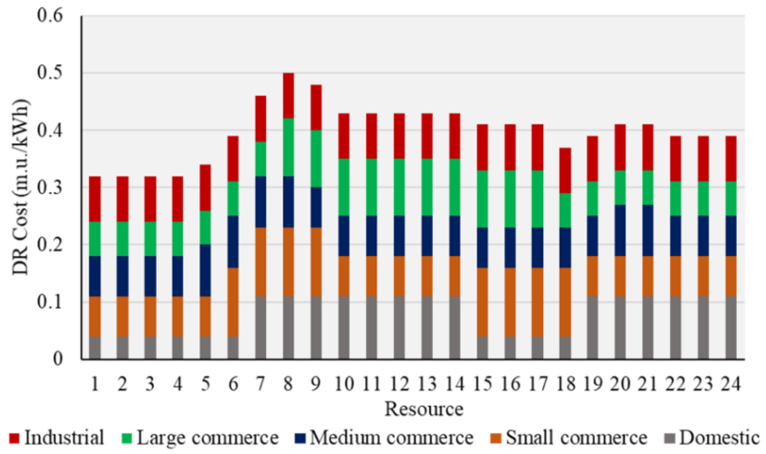

Fig. 2: Linear cost for load reduction and curtailment.

To simulate the participation in the energy market by the aggregator, a market place must be considered. A market pool ensures that several entities can propose energy bids, including aggregators. This kind of market ensures competition between participants, and therefore improves the outcome from the consumer's perspective. Therefore, a summary of the results obtained for the scheduling, aggregation, and remuneration processes is described in below, and more detailed information is available on [13].

The results concerning the market negotiation are focused on describing how the aggregator can use the results obtained to present a bid. First, the scheduling results for generation are presented in Fig. 3. It is considered an energy shortage from the external suppliers in the first 4 periods, being these able to support only 10% of their capacity, around 50 kWh.

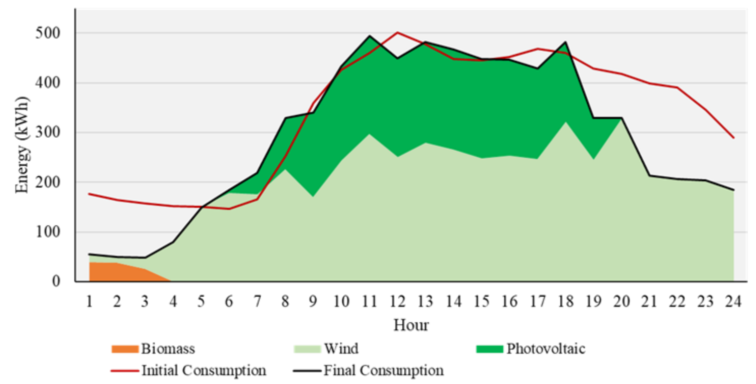

Fig. 3: Generation scheduling with initial and final consumption.

This causes the aggregator to apply DR programs that can balance the difference between production and expected consumption, in the periods where it is needed considering the minimization of costs. The scheduling shows a high penetration of distributed generation, expectable since the cost of it is lower than the cost of the external suppliers. The differences between initial and final consumption are related to DR actuation, namely, load reduction, curtailment and shifting.

The demand side management adjust the remaining energy differences between production and consumption when distributed generation is not sufficient. Moreover, during the periods of energy shortage from the distributed generators, load shifting is used to move consumption from those periods to more favorable ones, thus avoiding the buying of energy from the grid, which is more expensive. Moving on to the energy market's results, in Table 1, the results for the aggregation and remuneration of the resources are shown, regarding period number 12. The total energy and number of resources are outputs of the aggregation process, while the minimum bid tariff is from the remuneration process.

Table 1. Remuneration and aggregation results.

Bid group	**1**	**2**	**3**	**4**	**5**
Energy in DR groups (kWh)	6,09	9,49	4,04	17,18	3,55
Number of DR resources	1	1	1	2	1
Group tariff (m.u./kWh)	0,05	0,05	0,05	0,05	0,05
Energy in DG groups (kWh)	30,73	250,58	16,02	37,72	114,21
Number of DG resources	2	3	4	2	7
Group tariff (m.u./kWh)	0,03	0,05	0,06	0,03	0,05
Total Energy	**489,62**				

The results presented in Table 2 show that the aggregator could profit from the distributed resources energy sell in the energy market of around 489,62 kWh, a total of 24,10 monetary units. It is possible to conclude if a higher energy amount were sold, the aggregator would be able to rise considerably its profits from the negotiation. It is also relevant to notice that this evaluation is for a single period, for example, a given hour of the day as the case study presented suggests. Again, the profitability of the aggregator is also dependent of the offers and capability of negotiation in the energy market by the aggregator and existing competition. Using the proposed model, the operation of the aggregator becomes profit, from its market participation, even with a small-size region (20 consumers and 25 distributed generators). By controlling a larger region or number of resources, the aggregator gains more energy capacity for clustering, and as mentioned before, market negotiation.

Table 2. Financial balance for the aggregator.

Parameter	**Value**
Total costs using distributed resources (m.u.)	24,94
Market clearing price (m.u./kWh)	0,0976
Revenues obtained from market sell (m.u.)	47,78
Profit obtained by the aggregator (m.u.)	22,84

As mentioned before, the aggregation was made considering only the resources that participated in the aggregator's scheduling in each of the periods. Each period's aggregation therefore, considers the characteristics and scheduling of the resources in that time. Further on, a comparison is made regarding the influence of load shifting in the costs. The comparison is made between the total costs of the aggregator in the current scenario (WS), and in one when instead of load shifting availability, there is enough energy available from the external suppliers (WOS). In Table 3, the results of the scenarios comparison show that the influence of load shifting availability affects considerably the total costs of the aggregator, since these are mostly balanced by the contributions that distributed generators and external suppliers provide for the scheduling. In the scenario without load shifting the generation from external suppliers is raised in 50 kWh in the first four periods, obtaining a total of 100 kWh. This is performed so that energy balance can be obtained without load shifting.

Table 3. WS and WOS comparison.

Scenario		**Value**	**Total**
WS	Total costs using distributed resources (m.u.)	286,41	286,41
	Total costs using external suppliers (m.u.)	0	
WOS	Total costs using distributed resources (m.u.)	279,87	300,27
	Total costs using external suppliers (m.u.)	20,40	

4. Conclusions

This paper provided an optimal model for an aggregator who is responsible for managing small and medium scale distributed energy resources and demand response programs. A methodology was represented to support the aggregator activities that aims on the participation of its aggregated resources in the electricity market negotiations. Moreover, the developed methodology applied a clustering algorithm for remunerations of resources that participated in demand response programs.

The results obtained from case study showed that the aggregator can perform the scheduling according to the resources contribution, that has been applied through different programs such as demand-side resources. Therefore, the aggregator would be able to perform network balance and the participation of each resource. Moreover, the aggregation and remuneration results proved that the developed methodology affect the outcome of benefit for the aggregato. However, the aggregator can obtain the operation balance and a fair usage of distributed energy resources for its activities by using this methodology.

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Two-stage algorithm for the management of distributed energy resources included in an aggregator's activities

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Abstract

The growing number of distributed energy resources in power systems, leads to the appearance of new entities and roles for the existing ones that affect the operation of the network. One of these entities with more relevance, is the aggregator, either independent or represented by public organizations. An aggregator manages small-size distributed energy resources, creating a virtual amount of energy flexibility that can be used by it, to enable participation in energy markets and capitalize the integration of distributed energy resources. This paper proposes a two-stage optimization methodology for the operation of an aggregator regarding distributed energy resources. In a first stage, the network part managed by the aggregator is scheduled, meaning at a macro perspective, while in the second stage, it is assumed that the distributed energy resources are also scheduled considering their operation. It is assumed that this second stage is enabled due to an aggregator's communication infrastructure and interconnected management systems.

Keywords: aggregator; demand response; distributed generation; optimization

1. Introduction

In Europe, renewable energy sources have been installed by several consumers at their location, in response to promoting schemes implemented by the national entities of each country. This represents a goal of the European Union to reduce greenhouse gases emission in a global consideration of 20% by 2020 [1]. In 2014, much of greenhouse gases emission, comes from fuel combustion and fugitive emissions from fuels (without transportation), namely, 55.1% [2]. The use of fossil fuels in electricity generation greatly contributes for this percentage, and thus, efforts must be made towards a more sustainable future using other generation sources. In this way, renewable energy sources were the main solution considered by the European Union, and since then, promoting schemes have been implemented to support the installation of these resources, both in a small and large scale in terms of capacity [3], [4]. In the first approach, legislation was made to enable the installation of renewable energy sources of small capacity by consumers or individuals, being implemented a business case that clearly benefits the installer in a way that remuneration is attractive considering the energy consumption price. These consumers that besides their consumption, have also generation, are named prosumers [5], [6]. In the latter case, auctions and tenders of large wind and photovoltaic farms are implemented to obtain a responsible entity for its construction. These farms consider several units of renewable energy sources to obtain a large amount of energy generation with a high level of operation flexibility [7]. Renewable energy sources provide flexibility to the system in a less expensive way, since it is cheaper to stop a wind turbine than a traditional power station.

The number of prosumers in nowadays power systems, reflects a growth of interest in distributed energy resources (DERs), and represents a trend regarding a sustainable future of energy consumption [8]. The average consumer does not take much interest in its consumption, however, it is known through several studies that the existing potential of energy savings is high and can avoid the continuous construction of new generation facilities [9]. This can be achieved through an elastic demand that can adjust to the current operation of the power system, instead of the classical model where generation adjusts to an inelastic demand. Both prosumers and consumers can provide flexibility to the power system through their consumption profile, namely, by adopting demand response measures [10]. Demand response is defined as the modification of load profile in exchange for monetary incentives or in response to price signals. The demand response concept is associated to the elastic demand, in a way that can be adjusted to the operation context. Additionally, this strategy has been gained popularity in recent years by being associated with the terms: energy management systems, energy efficiency, smart grids, and intelligent consumption.

All concepts referred above, are interconnected by their complementarity between each other and between them and the smart grid implementation. In this scope, new tools must be developed so that a more facilitated integration of these DERs and related concepts can be achieved, considering both technical and social environments. In the first feature, these tools must comprehend the necessary concepts for the management of electricity consumption, considering the adequate exhibition of the information that is more relevant for this action. In the second feature, these tools must be capable of being adjusted to different operation contexts and consumer behaviors, implementing the best strategies that are in line with the interests of the user. In a more legal approach, it must be considered that these tools are developed accounted for the current legislation, data privacy, and data security.

In addition to the appearance of new tools that facilitate the integration of DERs, new managing entities and/or roles to existing entities, must be implemented in power systems to complement the progress made by the tools. In this case, the role of aggregators is focused. Aggregators are entities capable of grouping several small-size DERs, such that a virtual energy amount is obtained that enables market participation and the uncovering of flexibility potential [11], [12].

DERs are often spread geographically from each other, although their characteristics may be similar. In this way, the aggregator can either manage these individuals without considering the network operation, or act as a system operator, and manage a given region of the network. The interaction between the aggregator and the other upper-level entities responsible for the network operation, is essential for the successful implementation of DERs to complement the operation of power systems in a benefic way [13], [14]. Nowadays, most aggregators focus their activities in the ancillary services market, providing operation flexibility to the power systems by using DERs, both distributed generation (composed of prosumers and/or other small generating units) and demand response (composed of prosumers and/or consumers) [15]. Also, in Europe, the interruptible load programs are the most popular, while in the United States, emergency demand response programs are most often available for load participation. The activities developed by the aggregator can cover several levels of actuation, in Figure 1 and as follows:

- **Upper Level** – stage where the aggregator manages resources considering a global perspective of grid operation, providing them a scheduling that these can adopt, that benefits both the aggregator and the resource in their operation;
- **Lower Level** – stage where the aggregator can provide management systems that complement its global scheduling, and reflects the resource's assets and interests.

This two-stage approach is representative of the real business models implemented by aggregators operating in Europe or United States, and has been the subject of some literature [16]. These consider that the aggregator, besides managing their resources to enable market participation in an upper level perspective, often provide energy management systems to allow a facilitated communication structure from their control center to the resource's assets and location. This process is sequential, since the lower-level adjusts to what is obtained in the upper-level, considering the resource's constraints and interests. These management systems provide real-time information for the aggregator, that can help support its scheduling decisions and better evaluate possible operation scenarios. This paper presents a methodology that implements the activities of an aggregator, implementing distributed generation and demand response resources.

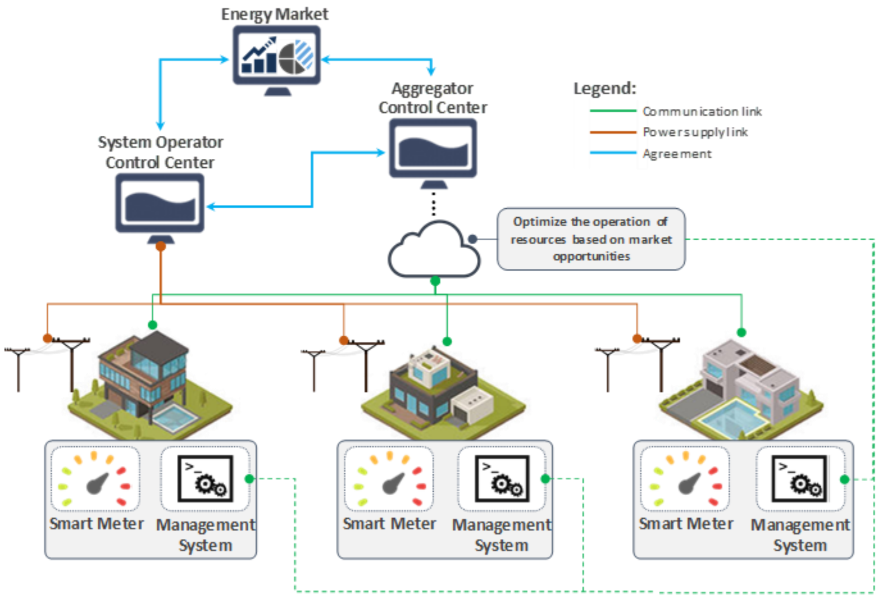

Fig. 1: Action levels of an aggregator.

This is performed using a two-stage algorithm, where in the first stage the resources are scheduled in an upper-level approach, and the in the second stage, an individual scheduling of the resource's assets is made. This allows the aggregator to unveil opportunities to improve energy efficiency of the resource's operation, and consequently, provide the aggregator more negotiation capacity in the energy market. The present paper is structured in the following way. After this introductory Section, the next Section details the main components of energy management systems, approaching their advantages, concepts, and opportunities that these can provide. In section 3, the methodology is explained and its considerations that represent the aggregator's activities. Section 4 presents the case study and results obtained to verify the usefulness of the proposed methodology, while finally, Section 5 shows the main conclusions.

2. Proposed Methodology

The proposed methodology is detailed in this section, considering its overall structure and sequence. It is important to notice that the second stage receives a data that is an output of the first stage, namely, the energy schedule. Based on this data, the second stage can complement the aggregator's activities with an adequate schedule of a consumer's inner operation, regarding the schedule obtained in the first stage. The first scheduling, due to the complexity that involves, is adequate to be in a day-ahead approach. This provides enough time for the aggregator to perform and analyze the operation optimization of the network. As for the second scheduling, the consumer's processes are adjusted in real-time, based on the signals transmitted by the aggregator related to what is obtained from the first scheduling.

The aggregator can perform the optimization of its activities given certain operating conditions, based on its interests in a first stage, and in the consumer's interests in a second stage. It is assumed that the resources belonging to the aggregator's portfolio, have a communication structure and the necessary equipment for the interconnection between the first and second stage of the proposed methodology. The second stage is related to the operation of three types of distributed energy resources, namely, generators, consumer, and prosumers. In this way, being one of these three types, a resource belonging to the aggregator's network and portfolio, can participate in the aggregator's market participations, by providing generation or load reduction/shifting.

3. First Stage – Aggregator's Resource Scheduling

In this section, it is presented the first stage of the proposed methodology, addressing a macro perspective for the resources scheduling. The aggregator considers the technical constraints imposed by the network, simulating the aggregator's role when acting as an operator. Additionally to considering the operation costs for the usage of resources to network balance, the objective function, demonstrated in equation (1), includes the revenues obtained from the sale of energy supply to consumers, and the remuneration obtained from market participation with the flexibility scheduled. In this way, the objective function addresses the interests of the aggregator whether in terms of reducing the operation costs of the usage of resources, and the capitalization of revenues obtained from consumer's supply and market participation.

$$Minimize = Cs - (R^{load} + R^{market})$$
$$= \sum_{t=1}^{T} \left[\begin{array}{l} \sum_{p=1}^{P} P_{(p,t)}^{DG} \cdot C_{(p,t)}^{DG} + \sum_{s=1}^{S} P_{(s,t)}^{sup} \cdot C_{(s,t)}^{sup} \\ + \sum_{c=1}^{C} \left(P_{(c,t)}^{red} \cdot C_{(c,t)}^{red} + P_{(c,t,d)}^{shift} \cdot C_{(c,t,d)}^{shift} \right) \\ - \sum_{c=1}^{C} \left(\begin{array}{l} P_{(c,t)}^{load} - P_{(c,t)}^{red} \\ - \sum_{d=1}^{T} \left[P_{(c,t,d)}^{shift} - P_{(c,d,t)}^{shift} \right] \end{array} \right) \cdot C_{(c,t)}^{load} \\ - \left(\sum_{p=1}^{P} P_{(p,t)}^{DG} + \sum_{c=1}^{C} P_{(c,t)}^{red} \right) \cdot C_{(t)}^{market} \end{array} \right] \quad (1)$$

As mentioned before, the aggregator must perform the analysis of the network when acting as an operator. Moreover, the aggregator performs the resource's scheduling/dispatch based on this approach. In this paper, it is considered the AC power flow model with only active power to guarantee that the optimization reflects the technical limitations of the network. In this way, equation (2) demonstrates the AC power flow method for active power based on the injected power of each bus, represented by equation (3).

$$P_{(i,t)}^{inj} = \sum_{j=1}^{B} V_{(i,t)} \cdot V_{(j,t)} \cdot \left[\begin{array}{l} G_{(i,j)} \cdot \cos\left(\theta_{(i,t)} - \theta_{(j,t)}\right) \\ + B_{(i,j)} \cdot \sin\left(\theta_{(i,t)} - \theta_{(j,t)}\right) \end{array} \right]$$
$$\forall i \in \{1, ..., B\}, \forall t \in \{1, ..., T\} \quad (2)$$

$$P_{(i,t)}^{inj} = \sum_{p=1 \in i}^{P} P_{(p,t)}^{DG} + \sum_{s=1 \in i}^{S} P_{(s,t)}^{sup}$$
$$+ \sum_{c=1 \in i}^{C} \left[P_{(c,t)}^{red} + \sum_{d=1}^{T} \left(P_{(c,t,d)}^{shift} - P_{(c,d,t)}^{shift} \right) - P_{(c,t)}^{load} \right] \quad (3)$$
$$\forall i \in \{1, ..., B\}, \forall t \in \{1, ..., T\}$$

Moreover, the technical limits imposed by the power flow equations shown before, are reflected by the levels of voltage magnitude and angle, expressed in equation (4). These variables may change over time and by bus of the network, according to the balance of energy. In this way, the aggregator guarantees the security of operation to both the network's equipment and resources regarding energy quality.

$$V_{(i,t)}^{min} \le V_{(i,t)} \le V_{(i,t)}^{max}$$
$$\theta_{(i,t)}^{min} \le \theta_{(i,t)} \le \theta_{(i,t)}^{max} \quad (4)$$
$$\forall i \in \{1, ..., B\}, \forall t \in \{1, ..., T\}$$

Previous equations are related to the physical limitations of the network. The resources that belong to that network also possess operation constraints, namely, in terms of output generation (in the case of generation units) and load reduction (in the case of consumers and prosumers) capacity – equations (5) and (6), respectively.

$$P_{(t)}^{\min sup} \leq P_{(t)}^{sup} \leq P_{(t)}^{\max sup} \quad \forall t \in \{1, \ldots, T\} \tag{5}$$

$$P_{(p,t)}^{\min DG} \leq P_{(p,t)}^{DG} \leq P_{(p,t)}^{\max DG} \quad \forall p \in \{1, \ldots, P\}, \forall t \in \{1, \ldots, T\} \tag{6}$$

Regarding demand response programs, two are considered in this stage by aggregator to be applied to consumers: load reduction and load shifting. These two programs allow the aggregator to obtain more energy flexibility from the resources, in this case, consumers. The limit of each consumer in each time step, for the load reduction program, is expressed by equation (7). This program reflects the capacity of a consumer or prosumer, in a continuous form, reduce load of their operation.

As for the load shifting program, it considers that load can be shifted between periods for either benefit the aggregator or the consumer in their operation. In a similar way to the load reduction program, equation (8) represents the limits of load transfer amongst periods for the consumers and prosumers. Moreover, equations (9) and (10) limit the total amount of load shifted to or from other periods, by a given consumer.

$$P_{(c,t)}^{red} \leq P_{(c,t)}^{max\_red} \quad \forall c \in \{1, \ldots, C\}, \forall t \in \{1, \ldots, T\} \tag{7}$$

$$P_{(c,t,d)}^{min\_shift} \leq P_{(c,t,d)}^{shift} \leq P_{(c,t,d)}^{max\_shift} \quad \forall c \in \{1, \ldots, C\}, \forall t \in \{1, \ldots, T\} \tag{8}$$

$$\sum_{d=1}^{T} P_{(c,t,d)}^{shift} \leq P_{(c,t)}^{max\_shift-out} \quad \forall c \in \{1, \ldots, C\}, \forall t \in \{1, \ldots, T\} \tag{9}$$

$$\sum_{d=1}^{T} P_{(c,d,t)}^{shift} \leq P_{(c,t)}^{max\_shift-in} \quad \forall c \in \{1, \ldots, C\}, \forall t \in \{1, \ldots, T\} \tag{10}$$

This section presents the mathematical formulation of the first stage of the optimization model, representing the macro perspective of the aggregator. The resource's scheduling is based on the grid's constraints and limits, insuring the adequate technical operation of the network and resources. In the next section, it is detailed the second stage of the proposed methodology regarding the operation of a given prosumer that belongs to the network managed by the aggregator.

4. Second Stage – Prosumer Scheduling

In the second stage of the optimization methodology, it is considered the operation of a consumer given the received schedule from the aggregator in an upper level. In this way, the objective function, equation (11), defines the interests of the consumer which are the minimization of operation costs. This objective function considers the use of on-site generation and of the demand-side management capabilities of the prosumer or consumer.

$$Minimize\ Costs = Cs - R^{agg}$$
$$= \sum_{t=1}^{T} \left[\begin{array}{l} P_{(t)}^{Agg} \cdot C_{(t)}^{load} + \sum_{g=1}^{G} P_{(g,t)}^{DG} \cdot C_{(g,t)}^{DG} \\ + \sum_{a=1}^{A} \left(P_{(a,t)}^{red} \cdot W_{(a,t)}^{red} + P_{(a,t,d)}^{shift} \cdot W_{(a,t,d)}^{shift} \right) \\ - \sum_{a=1}^{A} \left(P_{(a,t)}^{red} \cdot C_{(a,t)}^{red} + P_{(a,t,d)}^{shift} \cdot C_{(a,t,d)}^{shift} \right) \end{array} \right] \tag{11}$$

The prosumer needs to maintain the balance of operation based on the request of the aggregator for a certain level of load, obtained in the first stage of the proposed methodology, expressed by (12). The balance of the consumer's operation is based on the usage of on-site generation and, load reduction and shifting of appliances. The consumer has an energy contract with the aggregator, being him the one that supplies the consumer, expressed by (12).

$$\begin{array}{l} P_{(t)}^{Agg} + \sum_{g=1}^{G} P_{(g,t)}^{DG} - P_{(a,t)}^{red} \\ - \sum_{d=1}^{T} \left[P_{(a,t,d)}^{shift} - P_{(a,d,t)}^{shift} \right] = P_{(a,t)}^{loadStage1} \\ \forall t \in \{1,...,T\} \end{array} \tag{12}$$

As in the first stage, and because of the energy contract with the consumer, this second stage consider the technical limits of the resources, both for the aggregator supply and the use of on-site generation. This is represented by equations (13) and (14), respectively. It is also considered that the prosumer may have multiple on-site generators, being this implemented in the mathematical formulation.

$$\begin{array}{l} P_{(t)}^{\min Agg} \le P_{(t)}^{Agg} \le P_{(t)}^{\max Agg} \\ \forall t \in \{1,...,T\} \end{array} \tag{13}$$

$$\begin{array}{l} P_{(g,t)}^{\min DG} \le P_{(g,t)}^{DG} \le P_{(g,t)}^{\max DG} \\ \forall t \in \{1,...,T\}, \forall g \in \{1,...,G\} \end{array} \tag{14}$$

The demand response programs that the consumer can adopt are the same as the ones considered in the first stage for the macro perspective of the aggregator. The limits of their implementation are modelled by equations (15) and (16). The demand response differs from the first stage, only in terms of costs, that are replaced by the consumer preferences through weights.

$$\begin{array}{l} P_{(a,t)}^{\min red} \le P_{(a,t)}^{red} \le P_{(a,t)}^{\max red} \\ \forall t \in \{1,...,T\}, \forall a \in \{1,...,A\} \end{array} \tag{15}$$

$$\begin{array}{l} P_{(a,t,d)}^{\min shift} \le P_{(a,t,d)}^{shift} \le P_{(a,t,d)}^{\max shift} \\ \forall t, d \in \{1,...,T\}, \forall a \in \{1,...,A\} \end{array} \tag{16}$$

The second stage considers the scheduling of the consumer's operation, using demand response programs and on-site generators. The consumer's scheduling intends to minimize the costs and raise the revenues, accomplishing the objective of load set by the first stage of the proposed methodology.

5. Conclusions

This paper has proposed and discussed a methodology for an aggregator to manage the existing distributed energy resources. This method is divided in two phases for an improved accuracy of the consumers response to demand response events. Further work will include a large scale case study in order to demonstrate the effectiveness of the proposed methodology.

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Intelligent load management in local and wholesale demand response markets
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Household occupancy detection based on electricity consumption

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Abstract

Through monitoring the power consumption of a house, it is possible to establish if someone is on it at a particular time. Currently there are several approaches to determine the occupation of a home. There are works that ad-dress the use of intrusive systems that require user interaction, while other works address the non-intrusive use of sensors for presence detection. In this article, we propose the use of a sensor network for measuring the electricity consumption of a family home. In particular, the use of a multi-agent system is proposed for the intelligent management of the data generated by the deployed sensor network. Through non-intrusive occupation monitoring algorithm, it can be determined when a house is occupied by users and when it is empty.

Keywords: demand response, load shiting, home energy management system, smart grid

1. Introduction

Occupancy detection techniques have been a widely studied field in recent years. This topic has awakened the interest of the scientific community, since knowing if there is human presence in a certain building, has a large number of applications.

Perhaps, the main area where presence detection has been most applied, is the re-duction of energy use [1]. For instance, heating, ventilation and cooling (HVAC) and lighting systems could take advantage of the presence information of a building, inasmuch as they could automatically operate in real-time, so the energy consumption could be reduced, contributing to enhance the building energy efficiency [2]. By applying this techniques not only energy could be saved, but the occupants comfort could be better, by obtaining a comfortable temperature when the inhabitants are at home [3]. Likewise, regarding the reduction of energy use, the occupancy patterns can be useful for incentivized-based forms of Demand Response (DR) [1]. DR systems aim to modify the consumption patterns in response to (i) the electricity price over time or (ii) to incentive payments designed to induce lower electricity use at times of high wholesale market prices [4]. Another field where occupancy detection data has been widely applied is health monitoring, we can find several examples where elders or hospital patients behavior is studied in order to improve the different health-care services that are offered to them [5][6].

Otherwise, the concept of Smart Grid is booming. It can be defined as “the use of sensors, communications, computational ability and control in some form to enhance the overall functionality of the electric power delivery system” [7]. There are many initiatives to ensure the implementation of this kind of technologies on the part of the European Union and the United States, like the European Electricity Grid

Initiative -which is within the framework of the Strategic Energy Technology Plan- [8] or the Energy Independence and Security Act [9]. Consequently, in the near future it is expected that all the households will be provided with new intelligent meters. For this reason, the load curve data will be accessible for smart metering operators.

As exposed in [10], load curve analysis can be an illuminating praxis to take into account in day-to-day operations, system reliability and energy planning. The analysis of this data acquires a greater relevance in a particular area: the demand side management (DSM) of smart grids. However, this kind of data can reveal additional information; non-intrusive appliance load monitoring (NILM) techniques are able to disaggregate a household's electrical consumption into particular data [11]. Following the lines of this area of the load curve analysis, household occupancy can also be studied according to its electrical consumption. There are some previous works regarding this area [12], but we consider that they suffer from certain weaknesses, so some improvements can be done. For this reason, we purpose a multi-agent system for the detection of presence in the home based on electricity consumption. Specifically, the deployment of a sensor network based on the Cloogy project [13] for consumption monitoring is proposed. Thanks to the data collected by the sensor net-work, through the occupancy algorithm presented in this work, it is possible to infer the occupation or not of a home in which the proposed system is deployed.

The paper is organized as follows. In Section 2 a review of the current state of the art in occupancy detection techniques is performed, from the sensor-based systems those which do not make use of sensors, emphasizing on the ones which analyze the households load curve. Section 3 presents the proposed system, describing both the theoretical and the practical details. Section 4 shows up the results which have been obtained. In closing, Section 5 sets out the main conclusions drawn from the analysis of this work.

2. Background

There is a wide number of studies where occupancy monitoring is performed. The prevailing method to accomplish this target is the use of sensors. There are many different approaches in this area, the first distinguishing feature, is the use of a single sensor, or many sensors. It is common to opt for the second choice, since the fusion of several information sources improves the performance of the diverse occupancy detection methods. The second distinguishing feature among these studies, is the kind of sensor or sensors which are used. In [14] we can find a survey of the cur-rent approaches for real-time building occupancy estimation with sensor networks, which is summarized in Table 1, where the groups have been grouped by: (i) meth-od: terminal or non-terminal based, attending to the need of use of a terminal which is carried by the user, (ii) function: defines the ability of the system to detect, identify and track individuals in the environment, (iii) infrastructure: where it is established a distinction between explicit and implicit infrastructures, depending if the purpose of the infrastructure is just the occupancy detection, or if the occupancy detection is inferred from certain data sources.

Table 1. Classification of occupancy detection systems [14]

	Method		Infrastructure		Infrastructure	
Sensors	**Terminal**	**Non-terminal**	**Individualized**	**Non-individualized**	**Implicit**	**Explicit**
CO2 sensors	X	√	X	√	X	√
PIR sensor	X	√	X	√	X	√
Ultrasonic sensors	X	√	X	√	X	√
Image sensors	X	√	X	√	√	√
Sound sensors	X	√	X	√	X	√
EM Signals	√	X	X	√	√	√
Power meters	X	√	X	√	X	√
Computer App	X	√	X	√	√	√
Sensor fusion	√	√	√	√	√	√

Notwithstanding, the use of this kind of approach involves the intrusion of all these sensors into the environment; the installation of this devices might be bother-some for the house inhabitants, or in some cases, the household itself cannot support the installation of a sensor architecture. This is why a non-sensor dependent, and therefore non-intrusive alternative is sought.

As we have previously introduced in Section 1, many initiatives and investments are being done from part of the governments in order to get smarter grids, so the number of houses which have smart meters at hand is increasing exponentially. The data registered by these devices can be analyzed to investigate if there could be certain consumptions that imply human activity and thus presence in the household in a non-intrusive way.

In Fig. 1 we can see the common architecture of a smart metering system. The main necessary components that conform a smart metering system are [15]: (i) smart metering devices -smart meter (SM) -: responsible for calculating in detail the electrical consumption, they are able to communicate this information through a network; (ii) a data gathering device -data concentrator (DC) -: in charge to gather the data provided by SMs. Frequently, this devices act as a master node of a communication subnetwork conformed by itself and a group of SMs; (iii) a communication system, where quality, time and security of the data flow must be guaranteed, and (iv) a centralized management and control system, -control center (CC) - which will store and process all the received data.

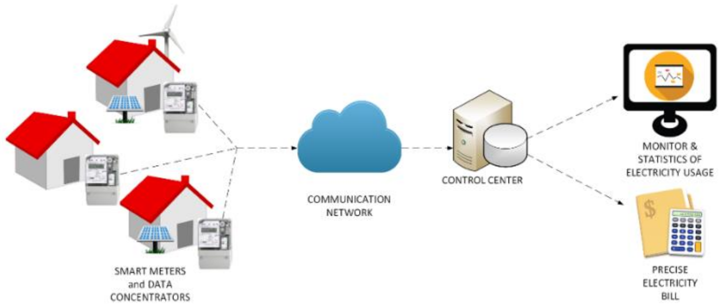

Fig. 1: Smart metering system architecture

3. Proposed system

The architecture proposed in this work is detailed below. Each of the elements that make up the system will be explained in detail. The diagram in Fig. 2 shows the main elements that make up the proposed system. For the design of the architecture, the PANGEA platform [16] has been chosen, which facilitates the creation of virtual agent organizations and their integration into different light hardware devices. Different virtual organizations are in charge of carrying out tasks such as data collection and management or coordination and security tasks.

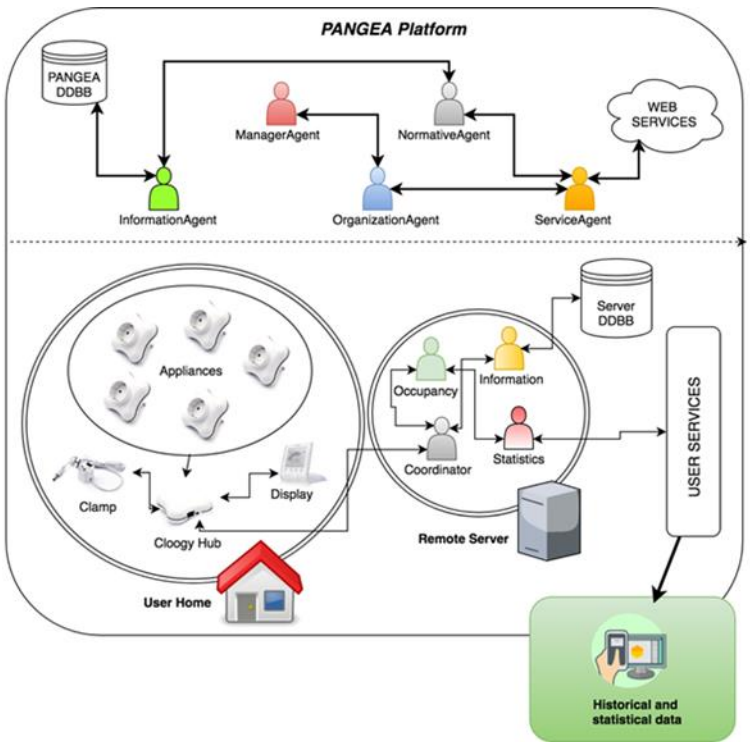

Fig. 2: General diagram of the proposed architecture for the detection of occupancy based on electricity consumption.

The first element present in architecture is the organization of the user's home. Within the housing, all the sensors involved in the non-intrusive occupancy detection system are displayed. These commercial sensors of the company VPS (Virtual Power Solutions) [17] are available through the web of the Cloogy project [13] and are simple to install in the domestic electrical network.

First and as a central element of the system deployed in the user's home is the Cloogy hub, this device is responsible for receiving data from each of the nodes of the system. The clamp is the device responsible for recording the data of the whole household electricity consumption from the electrical panel. The display is responsible for displaying information on the consumption of the house in real time. Final-ly, the smart plugs are responsible for monitoring the electrical consumption of any individual household appliance, obtaining its consumption independent of the rest of the equipment. All data processed by the deployed sensor network is sent in real time to the central server of the system.

The remote server organization has the following roles: Coordinator, statistics, information and occupancy. The agent with coordinating role is in charge of managing the information that comes from the sensor devices. The agent whose role is information is responsible for storing all recorded data, while the agent with role statistics is responsible for collecting and displaying the data and statistics obtained in the system to users of the platform. Lastly, the agent with an occupancy role is in charge of analysing the data generated by all load reading devices and then deter-mine the occupancy or not of the house.

3.1 Occupancy agent

The main task of the occupancy agent is to determine the human presence or absence in the household based on the readings of all available reading devices (clamp and smart plugs). In order to accomplish this objective, several preprocessing tasks must be done previously with the collected information.

The algorithm carried out by this agent includes the use of a minimal setup of at least a clamp for the whole load consumption reading and 0 to N smart plugs installed in different appliances of the house. As it will be described later, the accuracy of the occupancy detection will be increased depending on the setup of smart plugs in the household.

At the time of smart plug installation, the web page will ask to the user the kind of appliance connected to the smart plug from a list of possible appliances, although this could be tedious for the user it can be automated with appliance classification [18][19]. We have classified this devices in two types of appliances: Human Interaction Appliances and Non-Human Interaction Appliances (HIA and NHIA). On one hand, HIA require, as their name points out, a human interaction to change from one of their possible power states to another, for instance a television needs an Human Interaction Event (HIE) to be powered on. On the other hand, NHIA do not require human interaction to change their power state. As one of the assumptions of this method, we excluded that cases where the user establishes to timer for change the power state of their HIA.

Therefore, as is displayed in the Fig. 3, a distinction is performed between HIA and NHIA. The data collected by HIA will be processed in order to search HIE which implies directly human presence, that events will be used later to increase the accuracy of the occupancy algorithm applied to the whole household consumption. In addition, the load coming from monitored NHIA will also discarded in the occupancy algorithm since this load is not related with human presence.

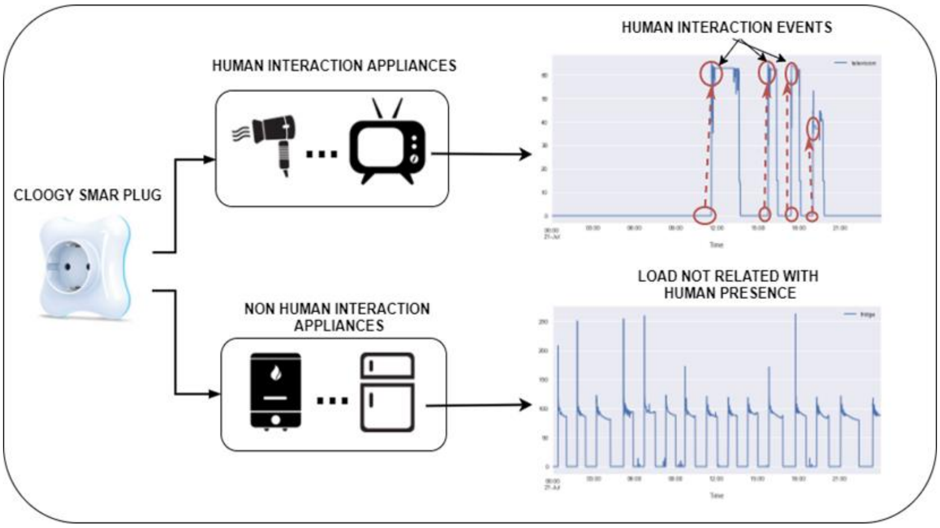

Fig. 3. Human Interaction Appliances and Non-Human Interaction Appliances

The occupancy algorithm performed by the occupancy agent is displayed in the Fig. . This algorithm is based in the algorithm of Dong Chen et al. NIOM [12] but in this case we intend to increase their performance and solve their drawbacks using additional information coming from smart plugs.

The occupancy algorithm performs the following steps: (i) collection and subtraction of the load coming from NHIA to the whole load. (ii) perform NIOM algorithm to the whole load previously processed (iii) aggregation of HIE to the results of NIOM algorithm and occupancy values correction. After this process the inferred occupancy state is stored.

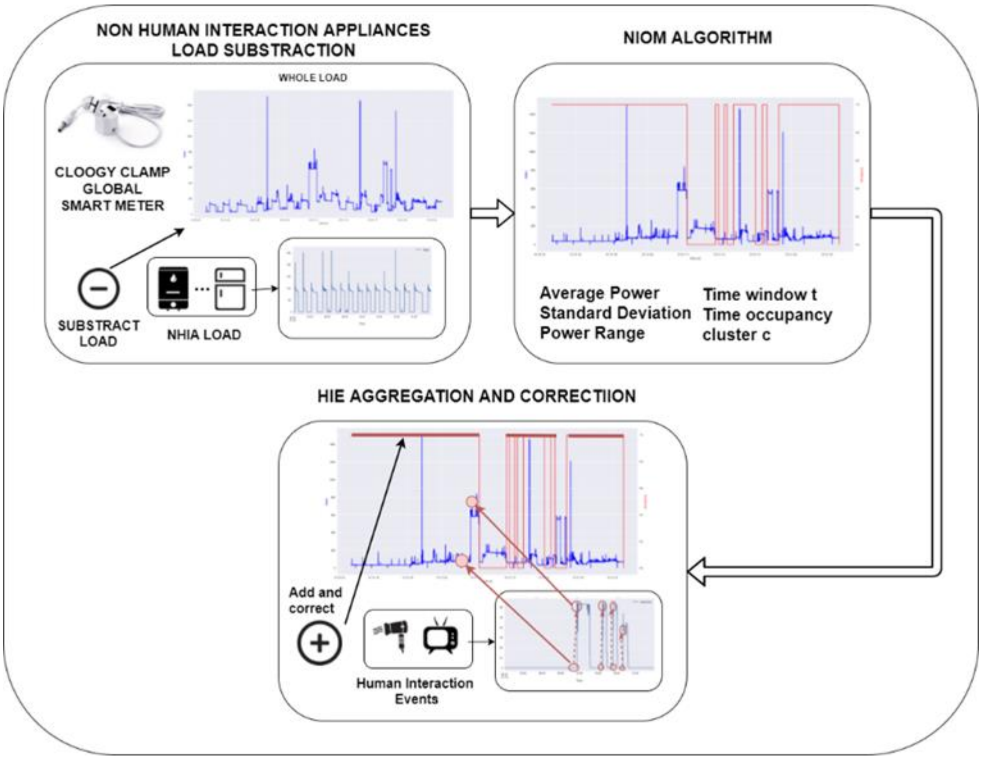

Fig. 4. Algorithm flowchart process

One of the most relevant drawback of NIOM algorithms it is their sensibility to NHIA loads, this generate false positive in the occupancy results. Thanks to the exclusion of NHIA load in the algorithm we will improve the accuracy of the algorithm. Another drawback in the NIOM algorithm is related with the sensibility of the start of human occupancy in the household, with their algorithm it is necessary a great change in the load consumption to change the state from non-occupancy to occupancy and that will be worst when it is masked with NHIA loads. The inclusion of HIE within the exclusion of NHIA load improves the accuracy in that situations.

4. Results

In order to test and evaluate the performance of the proposed platform, DRED dataset [20] has been used. Dredd is an open-access, publicly available dataset from The Netherlands which includes data from several sensors measuring electricity, occupant's occupancy and ambient parameters in a household over a 6 months period. Since this dataset provides occupancy data, the performance of the occupancy detection system can be measured. First, the evaluation of the system is done with the total household consumption, while different HIA and NHIA data is progressively included in the in the subsequent evaluations of the algorithm. In this process, it has been demonstrated that both the subtraction of the NHIA, and the use of the HIA as an occupancy indicator, have improved the results of the NIOM algorithm. Fig. 5 shows a snapshot of the visualization tool used to visualize both the household electrical consumption and the algorithm output.

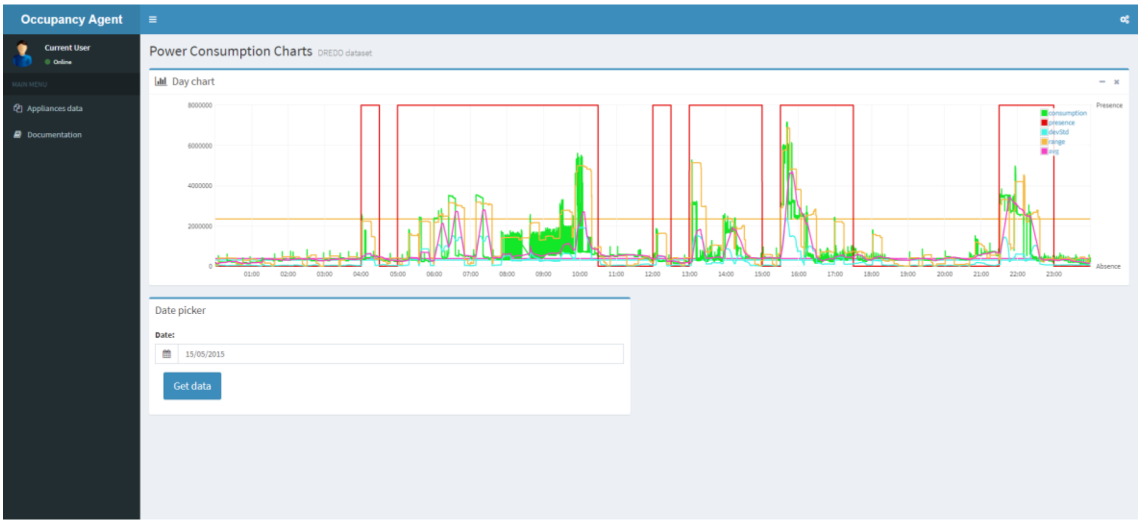

Fig. 5: Visualization tool.

5. Conclusions

Knowing if there is human presence in a certain building, has a large number of applications, so this topic has awakened the interest of the scientific community. In the near future it is expected that all the households will be provided with new intelligent meters. For this reason, the load curve data can be a useful data in order to induce human presence in a household. There are several state-of-the-art algorithms that have been developed in this line of research. In this way, the present proposed system arises as a possible improvement of NIOM algorithm by the inclusion of individual appliances consumption data.

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Intelligent load management in local and wholesale demand response markets
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Radio-Frequency communication in a SCADA system for the monitoring and control of intelligent building and office blocks

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Abstract

The efficient use of electricity and how people approach it, is a topic that has a big impact on the environment and society. The consumption management will be improved by the monitoring and the controlling of electrical installations. Communication is a key part in this process and that is why the improvement of data transmission is very important to obtain a controlled process. Transferring data is achieved by sending an electromagnetic signal by means of different types of communications channels. This paper presents a connection between a superior network and an external one to create the possibility of monitoring and controlling devices linked to the networks in a research institution (GECAD). The communication devices used are modems which use radio waves to make the transmission. A program has been created to access the data of an energy meter to obtain knowledge on how to implement analyzers in a SCADA system to improve monitoring of an electrical installation. This assignment will achieve a better understanding of the different protocols and operation modes.

Keywords: Intelligent building; SCADA system; MODBUS TCP/IP; ARM-SE; radio transmission

1. Introduction

In recent years the concern about energy consumption and its energy sources is growing since they may have environmental impacts. Renewable energy resources are a solution in order to overcome this barrier..

The buildings are one of the biggest energy consumers, somehow there is no efficient management on the use of energy. With increasing the population of communities, it is important to make buildings more efficient, and the use of smart devices and software that analyze several parameters, which allows a more reliable energy consumption management. This electrical system is known as a smart grid and uses the information of the installation to manage and improve energy consumption.

The industrial sector is important to integrate these intelligent systems. It is projected that in 2040 industry will consume more than half of the global delivered energy. Fossil fuels are still the biggest energy supply however the nuclear and renewable energy are growing fast. This means that the use of these energy sources has a big impact on the development of systems to control the energy consumption. As an example, solar panels contribute during the day but depend on the weather and other factors. This create an inconsistent source of energy that needs to be controlled and managed for an efficient use.

Besides of residential and commercial, the industrial and transportation sector are also major consumers. When talking about smart buildings it can easily be extended to smart cities on a larger scale. The smart grid is the base of the intelligent controlling of systems and actively managing of the consumption [1].

Connectivity and management are the pillars of the intelligent systems to reflect on the consumption in the different sectors. It is important to react where necessary to create an efficient consumption with an environmentally friendly focus. Intelligent algorithms are designed to access the information needed to manage the installation. These algorithms are created to be integrated easily in a process because they are flexible and can be wirelessly connected to an operating system. The use of a SCADA system make it possible to collect, process, display and manage information for the intelligent buildings.

The assignment is creating the ability to control and monitor an extern network to manage production and the consumption in the future using a new radio modem that GECAD has bought. The aim is to establish data transmission, creating a link between two separated networks and retrieve usable data. The focus is on the connectivity and creating an own SCADA system to monitor and manage an extern installation [2] [3].

There are many ways to achieve data communication to reach connectivity of intelligent buildings such as Ethernet, LAN, Wi-Fi, serial communication, etc. Avoiding hardwiring is often useful because of its substantial costs or when it is not geographically possible. But sometimes it is the cheapest way to create the communication.

Wireless communication has many advantages which are created by applying new techniques to improve the quality of the radio bridge. The first requirements are the transfer distance which has increased drastically over the years with decreasing probability of failure. Capacity and speed of the transfer are also important to send as much information as needed. Furthermore, the geographic aspect and the costs of an installation are also influential aspects. The combination of all these factors is determining for the type of communication channel fits best for a specific data transfer.

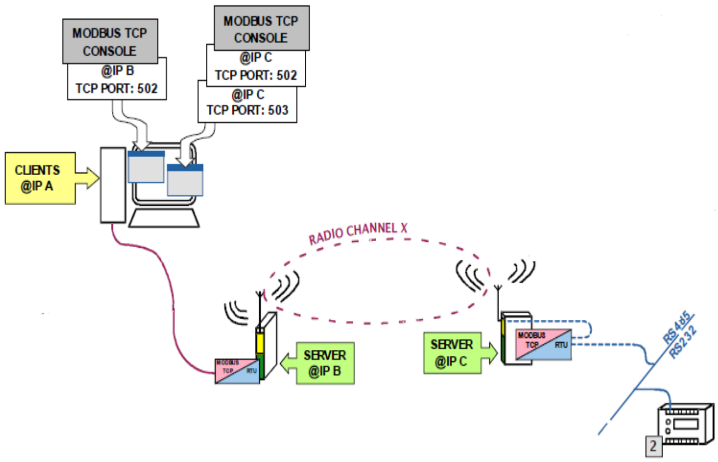
2. System Implementation

This chapter contains all the information about the equipment and the implemented system used during this assignment. The equipment and the topics that have been used in this system are:

- *ARM-SE* – The ARM, (Advanced Radio Modem), using a license-free high-frequency band located between 863MHz and 870MHz, suitable for industrial, medical and scientific applications. ARM-SE can operate with serial ports RS232 and RS485 or Ethernet as an alternative of Wi-Fi as the communicator with the network. The largest power is around 500mW which can reach over 5 km of range [4].
- *ANT868-BZ* – The antenna used in the test set up which is an omnidirectional antenna, especially designed for mast fitting.
- *PM130 PLUS Power Meter* - The PLC is connected to 3 PM130 PLUS energy meter for monitoring real-time energy consumption.
- *SCADA System* - Abbreviation of Supervisory Control And Data Acquisition (SCADA) is a system that is integrated into the industrial sector because it creates an easy visualization and exchange of data for an operator. SCADA communicates with Ethernet RS232 or RS485 and the software, downloadable from the site has a customizable interface which can operate a machine by writing data to the control unit. In this system, several PLC have been used in order to implement the SCADA system.
- *MATLAB* – This software is used by GECAD to retrieve data through Modbus. The system that serves as the SCADA system for this assignment can be reproduced as a program developed in MATLAB®.
- *Modbus* - The protocol has become a common tool for transmission between various kinds of electrical devices. Modbus protocol operates between a client and a server however it can also be interpreted as master and slave. The client and master have the same function as server and slave for Modbus which can create confusion.
- *Modbus TCP/IP* - TCP stands for Transmission Control Protocol while IP stands for Internet Protocol. Modbus TCP/IP is just an RTU command with an Ethernet TCP/IP wrapper. A Modbus TCP/IP frame fabricated for a transaction is called the ADU, (Application Data Unit), which exists in two parts: the protocol data unit and the Modbus application header. Both parts create the message for the transaction.
- *Modbus RTU* - The similarity with the TCP frame is obvious but the differences are the 1 byte slave ID in front of the frame and the two bytes CRC at the back. The slave ID is to identify the slave so it needs to be the same value as the ID of the slave [5] [6].

A connection between two or more modems can be achieved by two main configurations, which are both described below. During this assignment, both configurations were tested but the accentuation is on the principle that allows a larger number of devices to communicate. There are only two modems available to test these principles but it can be enlarged to communicate between lots of different industrial devices [7].

- *Point to Point (P2P)* - This configuration is the simplest way to communicate between the modems because the data just has to go from one point to another. There are no other devices and modems involved besides the two original modems.
- *Point to multipoint* - The 'point to multipoint' configuration is split between two main functionalities, the access point and the clients. The Access point can interact with each client, together or separately, while the clients can't communicate with each other. This principle is used to monitor different devices on one network which can be used in the industrial sector. In this assignment, there is only one client given the lack of more modems but it still can be a presentation of reality when using more devices.
- *Alerts* - The webpages provide a system that can alert the person who uses the modem in case of emergency. The tab 'Alerts' gives the opportunity to detect an error and to warn the operator. Watchdogs are an integrated function that measures the time that no data are transferred to see if an error occurred. It also compares the number of bad packages compared to the total number of packages sent to analyze the quality of the signal during an operation. With the tab 'e-mailing' the status of the watchdog can be sent to an e-mail address when certain triggers are activated.



- Fig. 1: Diagram of the used operating system

The main focus of this paper is to implement a connection between two buildings, which enables the SCADA system to integrate the real-time data of another building in its information. The Figure 2 shows the flowchart of this process, including how the energy meters data reach to the SCADA network. The modems on the Modbus gateway operation ensure the communication with energy meters

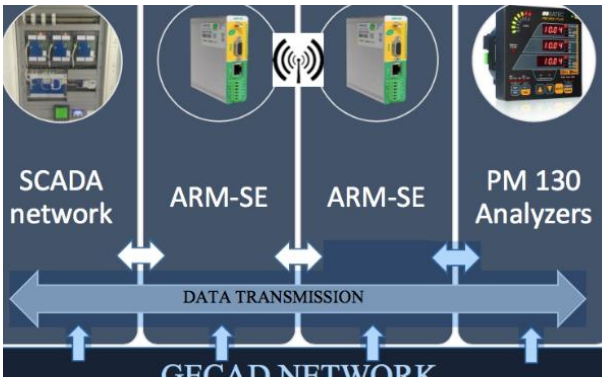


Fig. 2: Flowchart of SCADA process

Using this process, creates the possibility to monitor the energy meter in another building. The SCADA system will monitor all the necessary data by sending requests continuously. The response will be translated and monitored to control the installations.

The last step in the process is to access the data response trough a PLC in the GECAD laboratory with the computer to create the SCADA system. In the software of the PLC is shown which accesses the data and send it to a SCADA webpage, created by the PLC.

To create a link with the PM130 energy meter the request described in the previous paragraph needs to be transformed, despite the fact that both energy meter use the same protocol, the settings are different (e.g The messages send to the PLC are made out of 16 or 32 bits which is more than the 8 bit request of the energy meter).

Not only need the settings to be modified but also the amount of registers that will be accessed, are increased. Instead of collecting data from one register, this program needs to collect all of them and display them in graphs. This means the period and interval need to be chosen carefully to collect all the data so no error can occur. If there are too many requests in a small time-lapse the data will not be received anymore or it will lead to data corruption.

3. Case Study

The main aim of this report is to use the ARM-SE to integrate the data of an external building into the SCADA system in the GECAD laboratory. This means, creating a data transmission between the research lab and PM130 energy meter located in another building to monitor the installation. The energy meter are connected to a PLC and measure the electrical installation of the building. The modems want to retrieve that data to monitor the building. The PLC is situated in the F-building and can be reached using an antenna and the client modem. The most suitable modes and parameters have been selected in view of achieving the best transfer. First the created program in described in 0 is used to extract data of the power energy meter to check the quality of the transmission. Subsequently the energy meter is changed with the connection of the PM130 energy meter of the PLC to fulfil the assignment by collecting data of the electrical installation [8].

The research lab of GECAD is located in the N-building on the most southern point of the campus of ISEP. The access point modem is installed at this location. The PLC is located on the 4th floor of the F-building which is located next to the lab. At both locations, the modem and antenna are installed and tested to verify that a connection is possible. The only obstacles are the threes located between the two buildings that can hinder a transmission.

Before the actual installation the antennas are placed in both buildings and the test needs to be successful before it is possible to transmit data between the two locations. The test consists of a request to the client using the Modbus Gateway mode. If the access point receives the requested data, this indicates that the antennas are in the right place. As described before, the request and the corresponding response were generated successfully from the energy meter indicating a successful connection. This test is executed with the energy meter as this is the most efficient way to retrieve data.

The modem located in GECAD needs to be connected to the network to be accessible in the whole laboratory. In Figure 3 is a ground map of the two buildings and the antennas are also indicated with the symbol. It is noticeable that the trees can have an influence in the communication between the two modems.

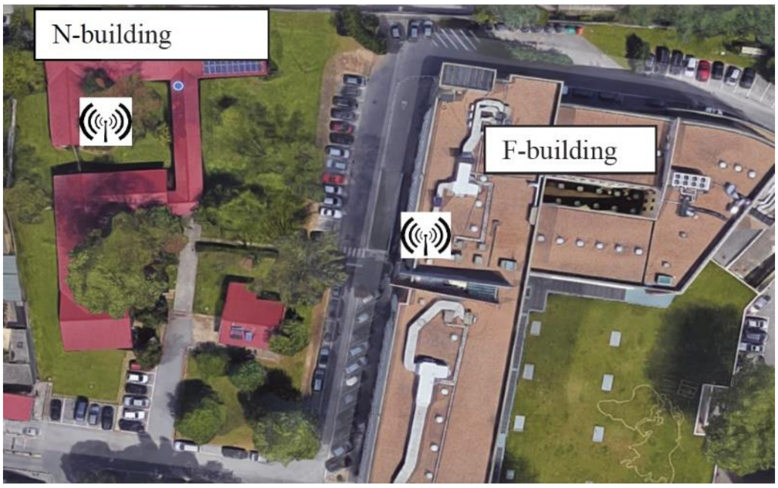


Fig. 3: Location of the antennas on map

The antenna is placed on the roof of the N-building and connected to the building using a cable. The modem will be installed on the wall and connected to the network of the GECAD-building to enable everyone to have access to the data by making the connection with the IP-address using the MATLAB® program.

The antenna of the client is attached close to the window to have a good reach while still being located close to the PLC. The modem itself will be installed next to the PLC to enable it to take power from the controller which is also 24V. The IP-address of this modem does not require corrections.

Modbus is a serial communications protocol which makes it compatible to communicate with the serial operation mode of the ARM-SE. The Modbus gateway is using the Ethernet cable while the serial operation mode uses RS485 or RS232. The PLC is compatible with the serial operation mode since the device has the Modbus protocol. This means that the energy meter can be connected to the RS485 of the client modem. The access point modem can run on the Modbus gateway operation mode which makes it accessible using the MATLAB® program. The reason for choosing Modbus TCP/IP and not Ethernet is the purpose of the design. Modbus is especially used to transmit data while Ethernet is used for other purposes. The Modbus TCP/IP protocol is used on an Ethernet layer but it can be found on other networks as well and can be used like a SCADA system, as mentioned before.

The energy meter can be connected to the modem which makes the choice for Modbus and serial obvious. There is a port available above the PLC with RS485 connection where the cables can be connected.

. After succeeding the connection with the power analyzer and successfully creating the graph, it is time to connect the modem to energy meter which are connected to the PLC. It is very important that the RS485 connection of the PLC itself is disconnected from the analyzers. Otherwise there are two different masters asking data of the analyzer, the PLC and the modem in GECAD through the client in the F-building. If this occurs the data cannot be transmitted to the modem which will indicate 'remote problems' on the webpages.

If one of the energy meter is connected with the modem independently of the PLC and the registers are known, a program is needed. Instead of using a new program, the data can directly be implemented in the SCADA system of GECAD to collect data of all the energy meter. Thereby the system can fluently extract data of energy meter over the antennas for a self-chosen amount of time and create a graphical form.

4. Results

After receiving the right data of energy meter, the data can be send to the self- created webpage of the PLC. It is shown below in Figure 4 how the voltages can be monitored. On the y-axis the values are between 2000 and 2600 but it needs to be divided by 10 to reach the exact value of the voltages.

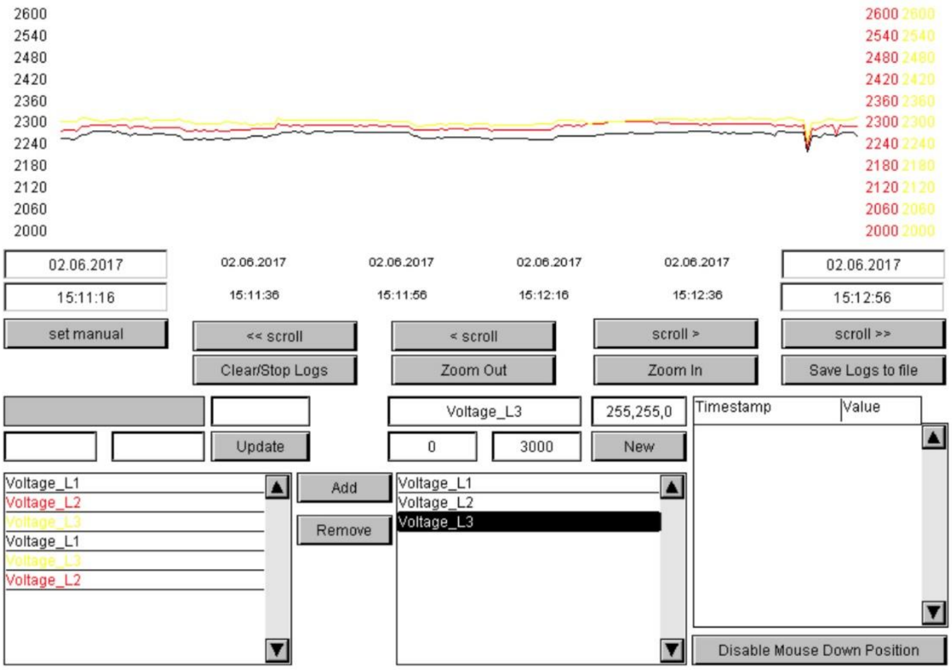


Fig. 4: SCADA webpage of the three phase voltages

This graphical form can be created with all the other registers of the energy meter. This shows the great purpose of a SCADA system that can access all the data and displays it clearly to make monitoring possible.

Other measurements cannot be displayed because, at the moment the analyzers only measure the voltage and frequency. The energy meter do not measure any current which indicates there is no consumption. When they are reconnected to the whole grid of the F-building the SCADA system will be able to display all the parameters of the installation.

The communication time between the SCADA system and the energy meter fluctuates between 500ms. This gives an indication that the radio waves can create a small distortion in the data transmission. This was also the case for the communication time of the CIRCUTOR but it does not create a big influence in the received data.

The response time between both modems is very fast which is perfect when integrating in a SCADA system.

In this case it is impossible to use this parameter to analyze the quality of the transmission because there were only two possible outcomes during this assignment. If the modems could communicate with each other, there were never packages lost.

All tests, were executed with a perfect signal where no packages were lost. But from time to time, it could occur that the signal got lost and no data could be retrieved

5. Conclusions

ATIM, the manufacturer of the ARM-SE modem, created a useful device to execute a data transmission using radio communication with different protocols. They managed to make the modem compatible with many operating systems and developed a system to create a fluent way for usage.

At the start of this assignment the modems were successfully configured and the different operation modes and protocols were tested. The tests of the various possible modes showed that there would be many complexities in the process. The first was to create an interface to display the response of any energy meter. This was only possible using the mode of the Modbus Gateway because it was integrated in the webpages. The interfaces for other operation modes were established using an Arduino, simply Modbus and Matlab®, which indicates the great variety of the modem. Ethernet was the only operation mode that was not tested with an external system because there were none available. The only way to test this mode was by using the command prompt on the computer for multiple Ping-Pong tests. The use of these different protocols in this research of the ARM-SE has shown all the possibilities of the modem. It created a clear view on how radio transmission and data transfers are realized.

All the various approaches to retrieve data between two modems, enabled to select the best way to connect the network of GECAD to energy meter of a PLC in an extern building. By connecting the networks energy meter a SCADA system can monitor the electrical installation. The energy meter used during the tests of the different operation modes can connect to the modem the same way an energy meter can be connected. This is why the MATLB® program was designed first for the energy meter so it became clear how to access the energy meter. The chosen operation modes for the modems have also been selected in function of the MATLAB® program and SCADA system. This means that the access point modem located in GECAD uses Modbus gateway and the client in the F-building uses the serial mode with RS485.

The program designed in MATLAB® can find the IP-address using the Modbus TCP/IP and generates a request in function of generating a response of the energy meter or PLC. These responses are recalculated and transformed into decimal values that in turn are displayed in a graphical form showing the fluctuation of the measurement over a specific period of time. When the energy meter were connected to the network of GECAD, the PLC could be configured easily because of the knowledge gained by the MATLAB® program. At the end of this assignment the SCADA system was able to reach the data of the PM 130 analyzers to monitor the electrical installation.

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Intelligent load management in local and wholesale demand response markets

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Laboratorial Microgrid Emulation Based on Distributed Control Architecture

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Abstract

Power systems worldwide are complex and challenging environments. The increasing necessity for an adequate integration of renewable energy sources is resulting in a rising complexity in power systems operation. Multi-agent based simulation platforms have proven to be a good option to study the several issues related to these systems. This paper presents an emulation of a laboratorial microgrid based on distributed control architecture. The proposed model contains real consumption and generation resources, including consumer load, photovoltaic, and wind turbine emulator. Also, a web-based graphical interface has been designed in order to monitor and control the microgrid. In this system, there are four main agents, which are connected by means of a communication network capable of sharing and exchanging information to achieve the overall system's goal. The performance of the distributed architecture is demonstrated in order to observe the applicability of the agents and their collaboration abilities. The results of the paper show in practice that how a distributed control based microgrid manages its resources, and how it reacts if there is a fault or no activity on them.

Keywords: demand response, load shiting, home energy management system, smart grid

1. Introduction

Nowadays, according to the daily increment of electricity demand, the utilization of Distributed Renewable Energy Resources (DRER) is an opportunity to assist the power distribution network [1]. DRER, such as Photovoltaic (PV) system and wind turbine, are moving the current power grid toward the elimination of centralized power plants [2]. DRER have several benefits for the power grid, namely, they decrease the greenhouse gas emissions, relieves the grid congestion, and decrease the costs related to the electricity production [3]. However, the integration of DRER into the current power grid, leads to have network management and stability problems [4]. The ability of dividing the whole power distribution network into the several subsets, has widely investigated by the research societies to overcome these drawbacks. Therefore, they have come up with a new concept called "microgrid" [5]. Microgrid is referred to a single controllable entity, which operates with respect to the main grid, and consists of several distributed energy resources and local loads [6]. The microgrid is considered as one of the interesting context of the future smart grids, since it can manage the amount of consumption and generation of the local resources [7]. The microgrids can operate in two manners [8]:

- Grid-connected: The microgrid has been connected to the main power grid, which means the local loads can be supplied from the main grid in the case of low generation in local energy resources. In

the case of high energy production, the energy resources can inject the excess of produced power to the grid;
- Islanded-mode: There is no energy transaction between the microgrid and the main grid. The local resources are responsible for feeding the local loads.

Concerning the management of microgrid, two methods can be proposed. The centralized control where a powerful central controller unit and communication between this unit and each single component of the microgrid is required. This is an expensive method and in the case of failure in a component, all of the microgrid may be affected [9]. The second scheme is the distributed control, where the decisions take place in the local controllers based-on the real-time data acquired by the other components [10]. The distributed control method is preferred when comparing with centralized control, since, if microgrid is operating in islanded-mode and a fault occurs, the faulty agent can be easily eliminated and microgrid is able to continue its operation [11]. Additionally, distributed control is more cost-effective [12], tolerant, adaptive, and flexible for microgrid management [13]. Before the massive implementation of business model related to the distributed control for microgrid, the need of laboratorial simulations and survey the behaviour of each components is evident. Intelligent methods such as multi-agent simulations are satisfying for conveying the complex models with dynamic interactions [14].

This paper proposes an implemented laboratorial model of a microgrid based-on distributed control architecture. This model employs several real hardware resources, such as a medium consumer load, a PV arrays, and a wind turbine emulator, that each of which are interconnected to each other as well as the power grid through the four transmission lines. The presented model employs four Programmable Logic Controller (PLC) in order to implement the multi-agent modelling and distributed control. In this microgrid model, all of the agents are conveying information in real-time, and all of controlling decisions are taken place locally. Furthermore, a web-based graphical interface has been designed for monitoring and controlling the microgrid. In this paper it is attempted to survey the controlling decisions of each agent and investigate the behaviour of the microgrid, if there is a fault or no activity (consumption or generation) in the resources. At the end, a case study will be demonstrated in order to test and validate the system capabilities.

The rest of paper is structured as follows: the model description including the implementation, operation, and proposed distributed architecture, is presented in Section 2. In Section 3, the developed web-based graphical interface model will be presented. Section 4 concerns about the case study and the obtained results, and finally, the conclusions are presented in section 5.

2. Distributed based Microgrid Implementation

The model provided in this paper is referred to a laboratorial microgrid simulator based-on distributed control. This system employs several real hardware resources available in GECAD research center ISEP/IPP, Portugal. The model consists of a 30 kW resistive load playing the role of a consumer in the grid, a 7.5 kW PV arrays and a 1.2 kW wind turbine emulator representing the role of renewable energy resources. All of these resources are connected to each other and to the power grid by several transmission lines. The proposed model employs several automation ideas implemented in these resources in order to be managed by one or more controller units. Fig. 1 illustrates the overall view of the system.

The 30 kW resistive load has a switchboard on the front view to control the consumption from 1 kW to 30 kW. In order to implement a fully automated system, four relays have been embedded on this resource. These relays enable the controller unit to automatically control the consumption of the 30 kW resistive load. More details about this process are available in [15].

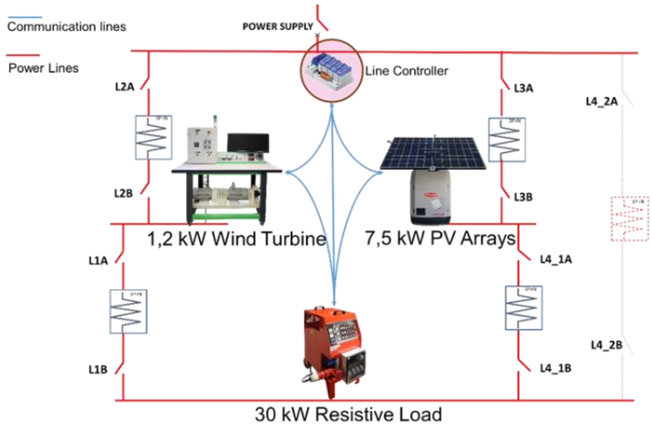

Fig. 1: Overview of the implemented microgrid.

The first renewable resource of this microgrid model is a PV unit with maximum generation capacity of 7.5 kW. Currently, this unit is installed in the GECAD laboratory and its produced energy supplies a significant part of GECAD building's consumption. The data related to the production of this renewable unit is monitored in real-time and also stored in a database using RS-485 interface with MODBUS RTU protocol. According to this information, there are some moments during the day that not only this renewable resource supplies all of the energy demand, but also it injects the rest to the utility grid. Therefore, we can conclude that this unit is an adequate solution for the microgrid model in order to operate in islanded-mode during the day while there is a significant amount of generation. The second renewable resource of this microgrid is a wind turbine emulator with maximum generation capacity of 1.2 kW. In this emulator, there is a three-phase asynchronous motor coupled with an inductive three-phase generator. A speed controller unit is responsible for controlling the speed of motor. Actually, the motor emulates the blade of the wind turbine, which its speed is managed by the speed controller. In this machine, the generator can inject the produced energy to the utility grid, or supply the local loads. More information about this emulator and its automation can also be found in [15].

In the last section of the model, there are four transmission lines responsible for flowing the energy between the system players and the power grid. In each transmission line there are two circuit breakers, one at the beginning and one at the end of the line. Additionally, two energy meters are installed in each line in order to measure and monitor the energy transactions between the system players. As it is demonstrated in Fig. 1, line 1, 2, and 3 have constant position, however, line 4 has two possibilities for its position, the first one is between the consumer and PV unit (L4_1), and the second one is between the consumer and the power grid (L4_2). This enable the microgrid to take appropriate decisions for feeding the consumer unit on critical periods. If, for instance, there is no energy production in the renewable resources, the system supplies the consumer from the power grid by interrupting the line 3 and altering the position of line 4, from L4_1 to L4_2.

Fig. 2 presents the overall system architecture deployed in a distributed fashion. There are four main agents namely, Load, PV, Wind Turbine and Line agent. As also shown in Fig. 3, each agent is equipped with a PLC in order to perform decision making locally and communicate with other agents to fulfil the overall system's goal. The main purpose of the line agent is to supervise the circuit breakers in the transmission line. If, for instance, one of the energy generator agents does not supply energy, it will be interrupted. Moreover, energy meters reside in this agent as well. Suppose that, the load agent broadcasts a message to the agents that its consumption changed to 8500 W. PV agents responds that it can supply up to 5000 W based on its current output power. The rest of the required energy will be provided from the main power grid since there is no wind and hence no energy supplies from the wind turbine agent. Moreover, Fig. 3 presents the deployment diagram which addresses the static realization of the system. In this figure, each agent is represented by its corresponding representation in UML deployment diagram called node.

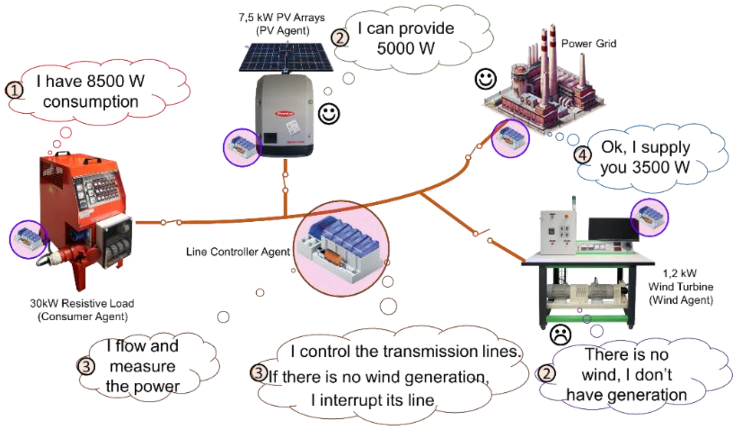

Fig. 2: Distributed control architecture.

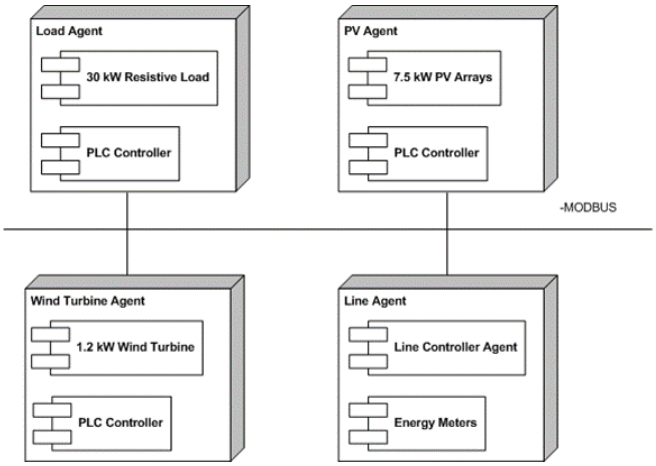

Fig. 3: Agent-based deployment diagram.

A node consists of several components which are the instances of the components shown in Fig. 2. The nodes are communicated via Ethernet interface, with MODBUS TCP/IP protocol. The agents constantly exchange messages in order to share their latest status in the network. This will reduce the response time to any changes in the load agent and hence improve the adaptability. On the other hand, flexibility and reconfigurability are two main important characteristics that an agent-based system offers. For instance, any faulty machine or agent can be easily repaired and replaced without any disruption in the overall system's task. The faulty agent will be registered in the line agent and the system will be reconfigured accordingly.

3. Graphical Interface

Fig. 4 presents the graphical interface designed and implemented in this paper. The overall scheme of this web page consists of four main nodes. The first node is related to the grid connection, which connects the microgrid resources to the utility grid. In this node, there is an energy meter, which measures the energy transactions between the utility grid and microgrid. The second node has owned by the 30 kW resistive load. The interface controls this resource in "Auto" or "Manual" modes. While "Auto" button is ON (green), the real-time consumption of the GECAD building is transmitted to this player, and it attempts to match its consumption with the received value. However, while the "Auto" button is OFF (yellow), the user can manually insert the desirable amount of consumption that intends to be simulated by the 30 kW resistive load.

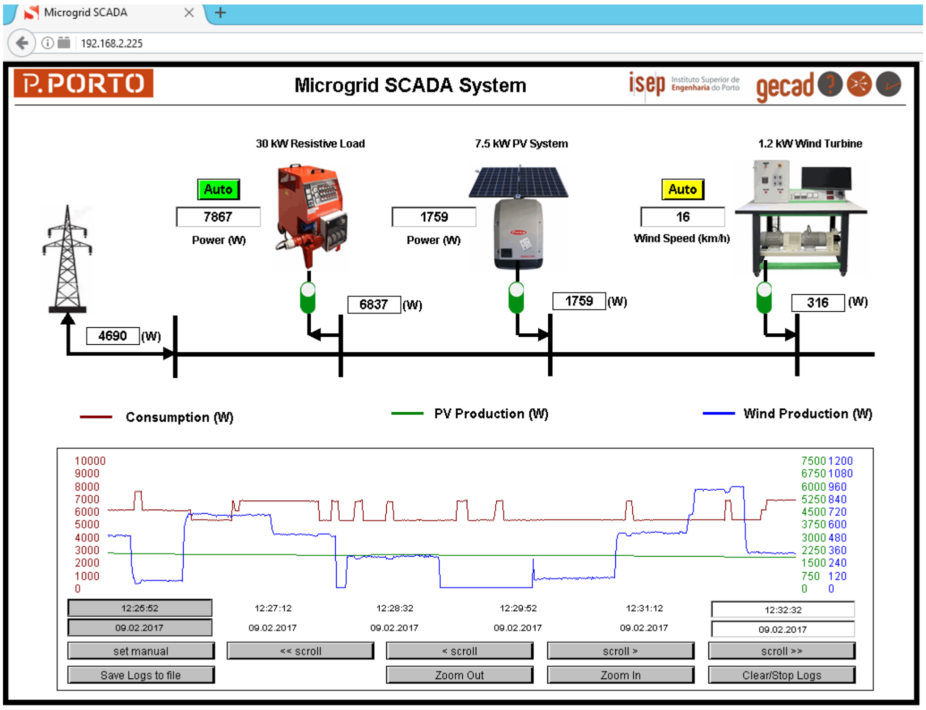

Fig. 4: The graphical interface designed for microgrid control and monitor.

The third node is related to the 7.5 kW PV system. There is no control on this resource, and the system only monitors the real-time amount of generation. The last node is connected to 1.2 kW wind turbine emulator. This energy resource follows the same method as the 30 kW load. However, the difference is when the "Auto" is selected, the real-time wind speed data provided by [16] is transmitted to this resource, and the emulator starts to generate energy regarding to the real-time data. Moreover, the user can turn off the "Auto" button and manually insert the favourable wind speed data. For each one of these nodes, a toggle button has been considered in order to interrupt them from the grid. These buttons are connected to the circuit breakers available in the transmission lines. At the bottom of the interface, there is a trend, which plots the profiles of the consumption and generation of microgrid resources in real-time.

4. Case Study

In this section, a case study will be implemented on the microgrid model provided in this paper in order to test and validate the features and capabilities of the system. For this purpose, the real consumption data of GECAD building has dedicated for the consumer part of this microgrid. The GECAD building is one floor office building including 16 offices, meeting rooms, server rooms, a kitchen, and two bathrooms. In this case study, firstly, the real-time consumption data of the building is provided to the load agent via Ethernet interface, with MODBUS TCP/IP protocol. Afterward, the agent takes several controlling decisions locally in the 30 kW load for matching its consumption to the received value. Regarding the PV agent, the real-time generation profile has been considered for this agent since the PV system is already installed on the GECAD building and it is generating energy now.

In order to provide a complete case study, real-time wind speed data acquired from ISEP Weather Station, Porto, Portugal [16] is transferred to the Wind turbine agent during the case study. For this purpose, a micro-controller unit (Arduino® - www.arduino.cc) has been deployed, which acquires the wind speed data in JavaScript Object Notation (JSON) format, converts it to an integer value, and finally conveys to the Wind turbine agent through Ethernet interface, with MODBUS TCP/IP protocol. While the agent receives this input, it starts generating power according to the real-time wind speed data.

In this case study, the load agent broadcasts it consumption to other agents per second, and simultaneously, the renewable agents (PV and Wind) also broadcast their real-time amount of generation. Therefore, the load agent is aware that how much energy is supplied by the renewable resources and how much energy should be purchased from the power grid. In the meanwhile, the line agent supervises on the power flow and interrupts the line of the faulty agent or the resource that have no activity on the system.

The final results are illustrated on Fig. 5. This case study has executed on a winter day during working hours (10:00 AM to 17:00 PM).

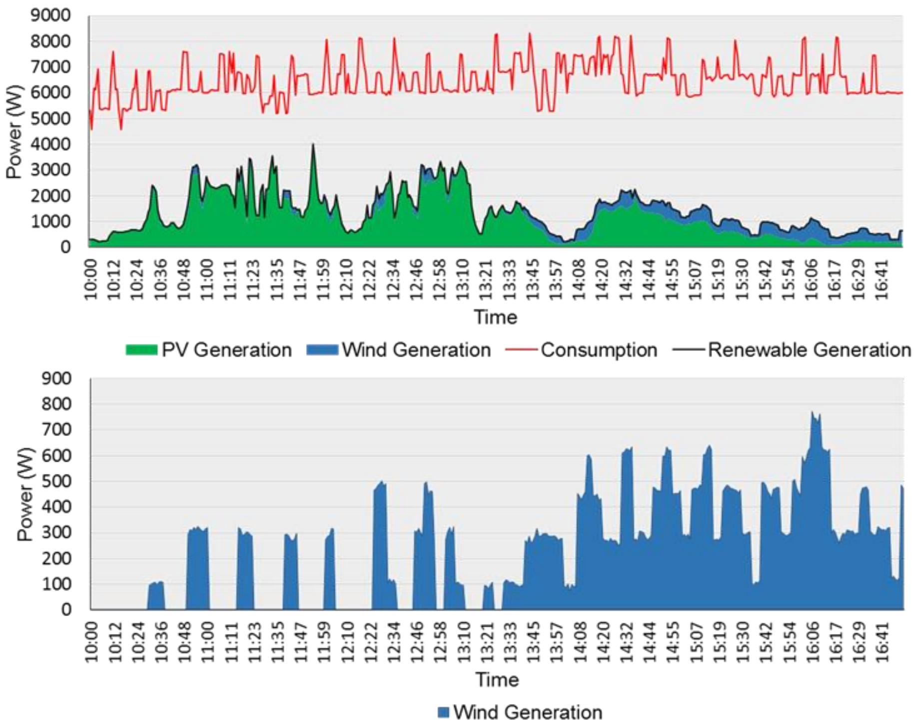

Fig. 5: Consumption and generation profiles of the microgrid simulation during a day.

As it is clear in Fig. 5, the red line stands for the real-time consumption of the GECAD building simulated by the load agent, the green areas refer to the real generation profile of PV arrays mounted on the building, and the blue areas are for the wind generation profile emulated by the wind turbine agent based-on real-time wind speed data. Additionally, the black line is the aggregation of renewable energy production. In another word, the black line is the part of consumption that has been supplied by the renewable energy resources. Moreover, the area between the red and black lines is the power purchased from the utility grid.

5. Conclusion

In this paper, a real-time microgrid simulation based on distributed control architecture has been presented. The system is located in the GECAD Lab, ISEP, Portugal where consists of four main agents. All the agents have their own programmable logic controller in order to process and make decisions locally. One of the agents continuously monitors the status of the all other agents to analyse the overall system's generation and consumptions. If any fault occurs in one of the resources, or system detects there is no activity on that resource, the related agent interrupts it from the system and connects it back while the resource would like to start its activity. Furthermore, a web-based graphical interface was designed and developed, which enabled the microgrid operator to have control and monitor the resources.

The results of this paper demonstrate in practice that distributed control model reduces the response time to any changes in the agents and hence improve the adaptability of the system. Additionally, flexibility and reconfigurability are two main important characteristics that an agent-based microgrid offers. For instance, any faulty machine or agent can be easily repaired and replaced without any disruption in the overall system's task.

Acknowledgements. This work has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 641794 (project DREAM-GO) and from FEDER Funds through COMPETE program and from National Funds through FCT, under the project UID/EEA/00760/2013.

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Intelligent load management in local and wholesale demand response markets

Third DREAM-GO Workshop

Institute of Engineering - Polytechnic of Porto, Porto, Portugal, January 23-24, 2018

Virtual to Reality Emulator for Electrical Loads

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Abstract

The test and validation of demand side management systems are a priority before installing this systems in real environments. This paper presents a load emulator that acts as an energy analyzer. This emulator enables its installation in physical environments, fooling the metering systems. This capability allows the placement of the emulator in a physical metering system while emulating a load that is not there. In a R&D center the emulator can be used to create buildings by placing several emulators for load emulation and using a real and physical metering system to read the consumption data while demand side management algorithms and techniques are used. Using the proposed emulator, the gap between research and real implementations can be fulfill in the laboratories to test and validate demand side management systems. The paper presents the emulator and its results.

Keywords: energy analyser, load emulation, metering

1. Introduction

The change of paradigm in power systems enables the active participation of small and medium players in the smart grid environment [1]. The integration of Demand Side Management (DSM) systems in end-consumers is also enabled by the new paradigm and it will allow end-consumers to manage their energy [2]. Therefore, the design, development, test and validation of DSM systems should be done fast in order to implemented them, in near future, in end-consumers houses and buildings.

There are a vast variety of DSM research works that try to provide valid solutions for DSM systems, some examples are [3], [4], [5], [6], [7] and [8]. However, the majority of these research works lack of real implementations to test and validate their solutions in uncontrollable environments.

The main contribution of this paper is the load emulator proposed. The Virtual to Reality (V2R) emulator enables the emulation of loads, in an hardware device, that can replace an energy analyser. This enables the placement of V2R in a RS-485 network with other energy analysers, fooling the system.

By using the proposed load emulator, is possible to build a building in laboratory to test DSM systems. The ability of V2R to work as an energy analyser enables the integration with real monitoring and control systems. Therefore, the laboratory can build a building using three layers: load emulators, a physical monitoring and control system, and the DSM solution to be tested and validated. With these three layers the monitoring and control system and the DSM solution think that they are dealing with real loads, approaching the solution to a real implementation.

After this first introductory section, the V2R emulator will be presented in Section 2. Section 3 will present some of emulation results. While Section 4 will present the main conclusions of this work.

2. Virtual to Reality Emulator

The main contribution of this paper is the test and validation of Virtual to Reality (V2R) emulator [9]. V2R was designed and developed to solve a problem in most of the power system R&D centres: the lack of residential electrical loads. It is important for R&D centres to test machine learning techniques and optimization algorithms. Therefore, the use of residential loads can benefit the test and validation of solutions regarding demand side management.

Fig. shows the V2R architecture. The emulator works as a common energy analyser. Therefore, the architecture was designed to enable the emulator to communicate using Modbus/RTU through RS-485. This way, V2R is able to be connect to a Programmable Logic Controller (PLC) similar to energy analysers. The real-time clock enables real-time emulations, and the data storage is used to store the data and information that V2R must emulate. For configuration and database connection, V2R has a TCP/IP block that enables the users to configure the emulation and enables the V2R to store the emulation data into a database.

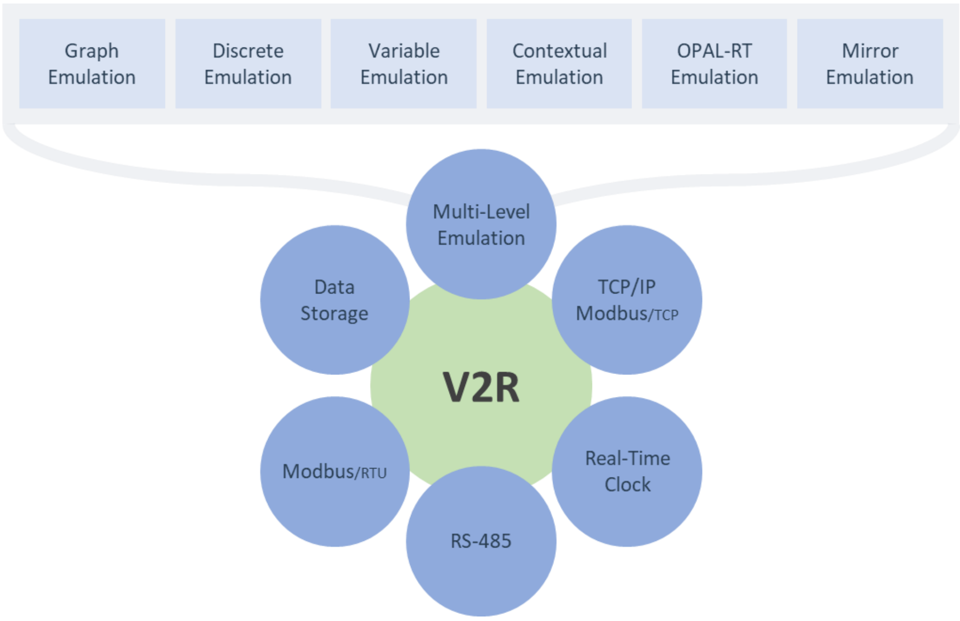

Fig. 1: V2R architecture

Regarding emulations, V2R was designed to provide a total of six emulations with a total of sixteen subvariations of emulations:

- *Graph Emulation* – the graph emulation emulates a load based on a real load profile using real readings taken in the past. For example, is possible to measure a refrigerator during a 24 hours period and then order V2R to emulate that refrigerator. The refrigerator data is stored in the data storage block. This type of load allows the emulation to run in real-time (following the hours of the real data) or in emulation time (following the hours of the emulation);
- *Discrete Emulation* – the discrete emulation emulates a discrete load built by the user, this is a load with only two states: on, and off. The user must set the load consumption when the load is off (usually set to zero), and the load consumption when the load is on. Also, the user can define if the initial state of the load is set to on or off;
- *Variable Emulation* – this emulation is similar to the discrete emulation. However, in this emulation the load has more than two working states, it can have multiple working states with different consumptions levels or a range of states with a range of consumption – for instance, a dimmer lamp;
- *Contextual Emulation* – the contextual emulation was provided to emulate loads with working cycles. Imagine a washing machine that has a working program with a specific consumption profile, the contextual emulation receives the consumption profile and emulate it every time the load is set to on, when the profile finishes the load is automatically set to off;

- *OPAL-RT Emulation* – for more detailed emulations, V2R is able to work together with OPAL-RT [10], using real-time simulations. The benefit of V2R with OPAL-RT is the ability to put the consumption values generated by OPAL-RT into an energy analyser emulator;
- *Mirror Emulation* – the mirror emulation enables V2R to mirror the consumptions of another energy analyser using Modbus/TCP communication between V2R and energy analyser. This enables to put the consumption of on building or load in a different geographic region without the need of dislocations.

Beside all the emulations available, V2R has the possibility to apply a random variation into emulations, excluding only the OPAL-RT and Mirror emulations where this option is disabled. The randomness emulates the variation of consumptions that occurs in energy analysers where the voltage, current and power has small variations in time. The random variations in V2R are applied each second and according to the user definition.

Fig. 2 shows the implementation of V2R used in this paper. The implementation used an Arduino and Arduino Shields for the components in order to simplify its development. The only component that was not used in a Shield format was the MAX485. The board of MAX485 was handmade following the connection schema provided in the datasheet.

a) b)

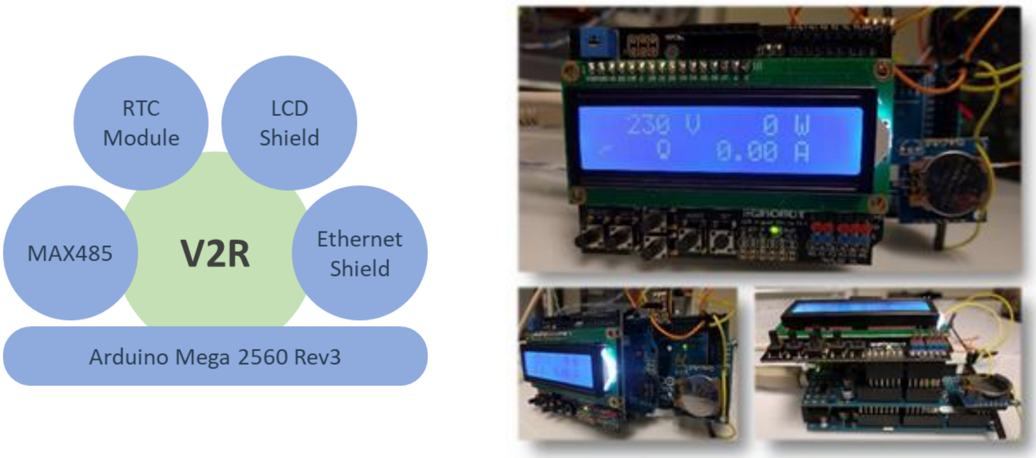

Fig. 2: V2R implementation using an Arduino: a) Used components, b) Final implementation

V2R has a simple architecture that enables the emulation of a common energy analyser. The emulation is accomplished using Modbus/RTU protocol through RS-485 serial communication. It is possible to connect the V2R to any RS-485 master device. Table shows the readable Modbus/RTU registers available in the V2R. The values of registers are represented in IEEE Standard for Floating-Point Arithmetic (IEEE 754).

Table 1. V2R Registers Addresses

Address (hex)	Size (bytes)	Data Type	Description
0x01	4	IEEE 754	Voltage
0x05	4	IEEE 754	Current
0x09	4	IEEE 754	Power consumption

Using a LCD Shield, basic information is displayed to the user. The buttons, available in the LCD Shield, controls a menu with the following options: server IP, publishing status, RS-485 slave identifier, V2R IP address, and V2R unique identifier.

Fig. 3 shows the configuration website of V2R for a discrete emulation. V2R integrates a TCP/IP communication layer for remote configuration, monitoring and control. For configuration is needed the IP address of V2R that can be found in the device menu.

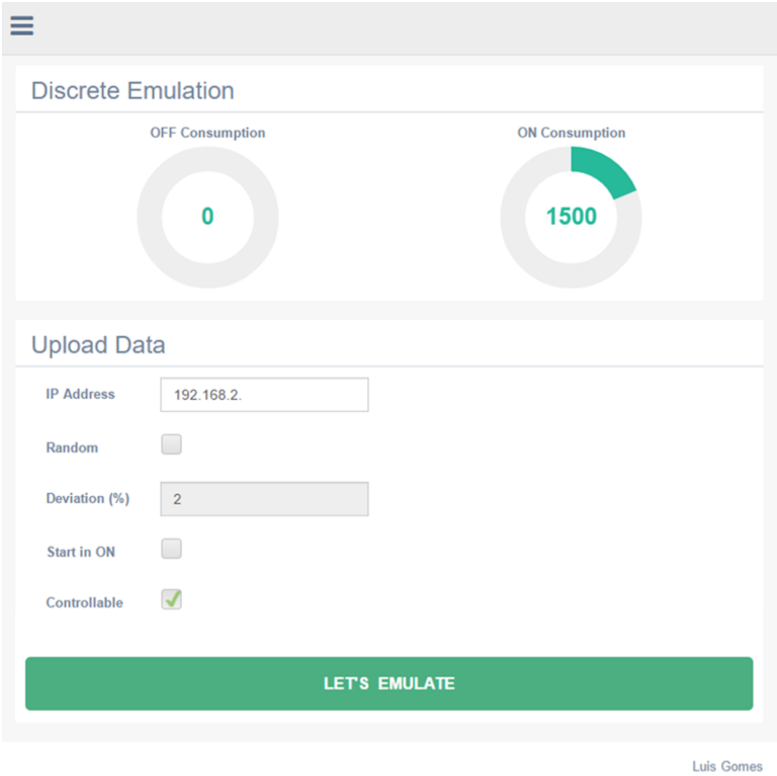

Fig. 3: V2R configuration webpage for discrete load

During the configuration is possible to define a random value to be applied in the emulation. The value is a percentage of randomness that will be applied to the consumption emulated by V2R. This gives the illusion of the variation founded in real load measurements made by energy analysers. The random value is applied each second during the emulation execution. The random variation is also applied when the emulated load is turned off, in this case the random variation is applied in the voltage value.

The values of emulation can be sent to an external server to save de data in a database. For this work is used a SQL Server database to store the data. The period of data storing was set to one second, and the values stored are: *arduino_id*, date, voltage, current and consumption. The TCP/IP block of V2R also enables the remote control of the emulation. Fig. 4 shows the webpage where is possible to remotely control a V2R emulator, the IP address can be found in the emulator's LCD menu.

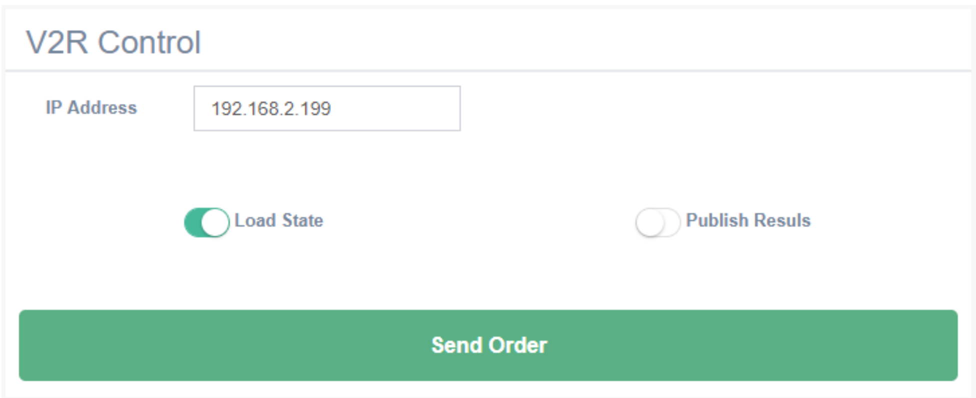

Fig. 4: V2R remote control

The capability of V2R to mimic an energy analyser gives the possibility to place V2R in monitoring and SCADA systems fooling the system. The SCADA will read V2R and see a consumption load, that do not exist in reality. This enables the integration of unavailable loads in physical monitoring and SCADA systems to test and validate the management of new loads. This feature of bringing emulations to physical systems and the versatility of V2R provides the R&D centres with the means to build residential homes or office buildings in their laboratories without the need of buying and acquiring consumption loads.

3. Results

For this paper, four emulations were executed in V2R and the results are presented below. These demonstrations of V2R use the discrete load and graph load emulations with and without random variation. The presented values were taken using a PLC that measures energy parameters in an office building and save them to a database. The PLC is a master in its RS-485 network and is responsible for the storage of energy analysers measurements. The PLC communicates with V2R in equal form that it communicates with the energy analysers, the PLC do not know that V2R is an emulator and not a real load.

A. Discrete emulation

For this example, it was emulated an industrial heater of 3.2 kW. Because the idea was to control the emulation manually, the discrete emulation was chosen without any random variation. The manually control was made using the LCD Shield buttons and the webpage provided by the TCP/IP connection of V2R. Fig. 5 shows the results from the PLC, regarding the measurements read by the PLC.

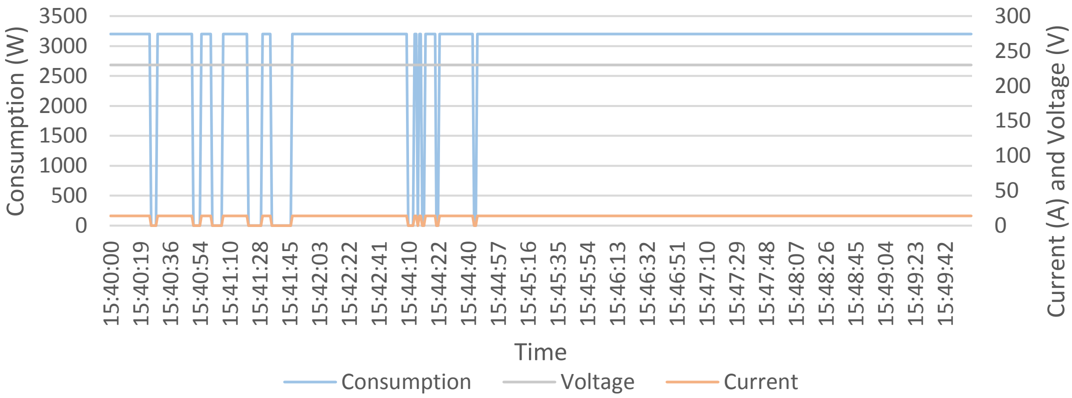

Fig. 5: Discrete emulation of an industrial heater

B. Discrete emulation with random variation

To show the possibilities of the random variation, the emulation of the previous section, regarding an industrial heater, was run again using a random variation of 2%. The results are shown in Fig. 6. By comparing Fig. 5 and Fig. 6 is possible to see the impact of the random variation, the consumption measurements appear to be more real with random variation.

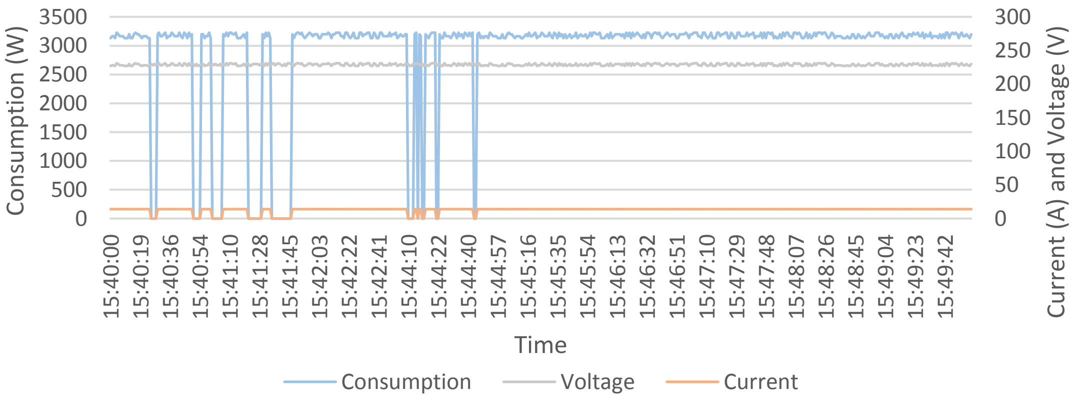

Fig. 6: Discrete emulation of an industrial heater with a random variation of 2%

C. Graph emulation in emulation time

As seen before, the graph emulation is ideal to emulate load profiles that cannot be controllable. This example shows a graph emulation using a refrigerator profile. The emulations will not apply any random variation and it will run using the emulation time, this means that at the start of emulation the profile will read from midnight to midnight – from the beginning of the profile file till its end. Fig. 7 shows the results of this emulation during a three-hour period.

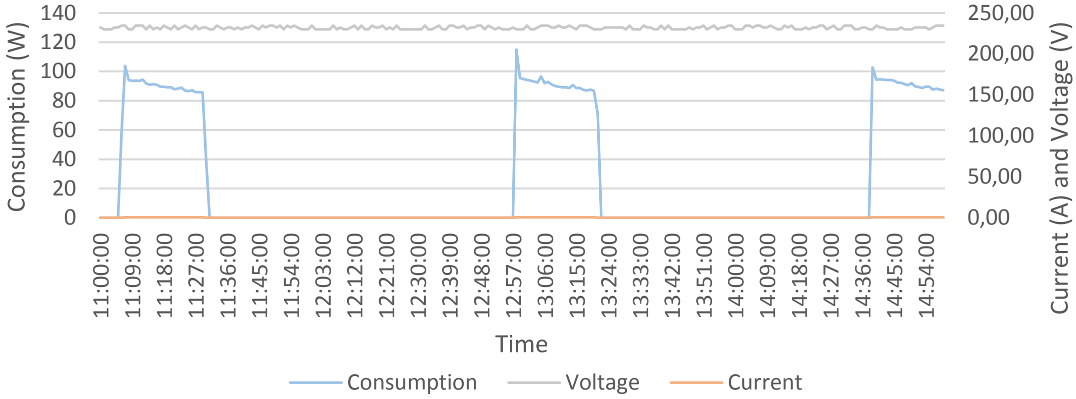

Fig. 7: Graph emulation of a refrigerator

D. Graph emulation in real-time with random variation

This example uses the same profile of previous section but using a random variation of 2% and using real-time. This means that the profile will be executed using the timestamp of the data file – for instance, at 08:00 a.m. it will be shown the values measured in refrigerator at 08:00 a.m. Fig. 8 shows the results of this emulation. The three-hour period used in Fig. 7 and Fig. 8 are the same but the consumption profile is not. This happens because the first emulation, of Fig. 7, uses emulation time and the data of the graph corresponds to the midnight of the refrigerator profile – beginning of the data file. In Fig. 8 is used real-time, meaning that the timestamp of the graph is equal to the timestamp of the profile data. And because is launch time, is possible to see two openings of the door, one at 12:37 and the other at 13:37. Because this emulation uses a real consumption profile, that has intrinsic variation on the consumption data, the random variation is not visible in the results

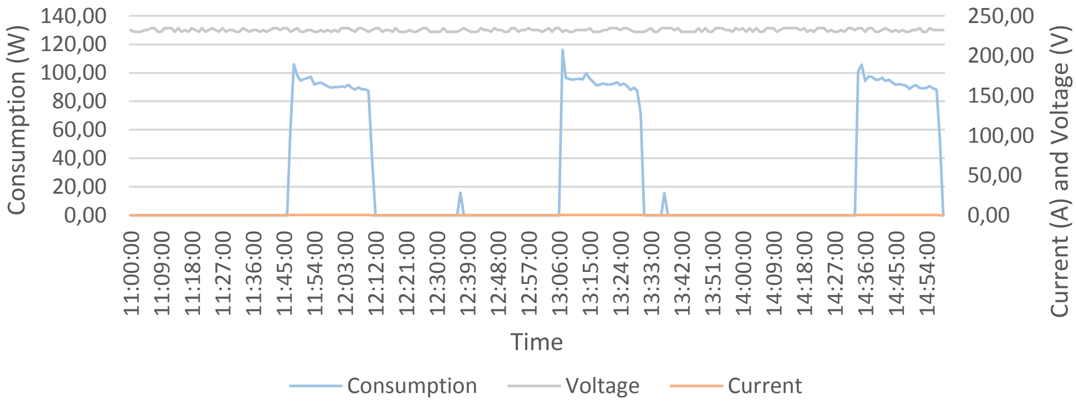

Fig. 8: Graph emulation of a refrigerator with random variation and using real-time

4. Conclusions

This paper presents a load emulator that acts as an energy analyser and for this reason it can be installed in a physical metering, monitoring or SCADA system. The emulator architecture is presented as well as the necessary components to build the emulator.

The results of several emulations were measured using a metering system of an office building. This metering system had a RS-485 network where the emulator was installed. The metering system treated the emulator as an energy analyser and was able to read the consumptions data and stored it in its database.

The obtained results were a success and prove the capabilities of the proposed emulator. The emulator can be used in physical systems and act as energy analysers, fooling the system. This enables the test and validation of demand side management systems using loads that are not available in the buildings.

Acknowledgements. This work has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 641794 (project DREAM-GO) and from FEDER Funds through COMPETE program and from National Funds through FCT, under the project UID/EEA/00760/2013.

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Intelligent load management in local and wholesale demand response markets
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Applying a Bio-inspired Paradigm to Manage a Domestic Electric System

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Abstract

In the domestic environments, the connection of devices is essential for saving energy and money. Therefore, a wide number of optimization models have been developed for the management of energy, such as fuzzy logic, linear programming or bio-inspired algorithms. The present approach intends to solve an energy management problem in a domestic environment by applying a specific bio-inspired algorithm, namely, artificial immune system (AIS). It is performed a specific case study with a domestic environment system in order to demonstrate the success of an artificial immune system to find optima that satisfy the problem constraints.

Keywords: demand response, load shiting, home energy management system, smart grid

1. Introduction

Over the last decade, home buildings have been involved in electrical grids as active players [1]. They ar also part of the smart grids (SGs), and are also involved in the optimization process of energy [2] . Therefore, Home Energy Management Systems (HEMS) are entities capable of improving the economy and the energy saving through computational approaches.

There are different strategies that optimize the scheduling of home power usage. Several approaches make use of statistical models, such as, [3], where the loads are influenced by weather conditions by applying a Markovian approach. In [4], a classical methodology is developed for demand response program through the controllers and the appliances controlled under uncertainty of outdoor temperature and electricity price. [5] solved three electrical systems with an Markovian process which reduces the domestic energy costs in the time-varying electricity price market.

Additionally, different paradigms contains potential solutions optimization problems, like the bio-inspired algorithms. These models imitate biological behavior to find solutions too expensive to be obtained. Among them, we can highlight artificial neural networks, genetic algorithms and swarm intelligence [6], which have been widely applied in smart grids. [7] addresses through a particle swarm optimization (PSO) an energy service model. In [8] , a multi-objective genetic approach is proposed to solve a domestic load scheduling. In [9], an hybrid approach between an Artificial Neural Network and a Genetic Algorithm (ANN-GA) is developed to optimize a smart appliances scheduling.

Artificial immune systems (AIS) have been successfully applied in different fields. There are some preliminary achievements in energy management, such as the energy dispatch problem-solving [10], or electrical reconfigurations [11]. [12] develop an AIS for the thermal control in domestic environments and [13] makes use of the AIS to optimize a wind-thermal generator. However, the application of AIS for energy issues has been scarce.

Therefore, AIS is involved as a new paradigm to optimize a domestic energy management problem. In particular, we use a specific version of AIS called opt-aiNet [14]. We aim to demonstrate that Opt-Ainet can be successfully applied to electric management problems in domestic environments.

We present a preliminary domestic electrical system with the following different devices connected; a PV panel, a battery system, a space heater, a storage water heater, as well as must-run services. Our main goal is to optimize the schedule for the next 24 hours to maximize the electrical profit between the energy sold and the energy that we have to buy in order to maintain all these devices running correctly.

In order to evaluate the optimization process of the AIS, we propose two strategies for two different electrical situations. In Strategy 1, the domestic building manages the electrical scheduling maintaining the home's electrical load through electrical energy produced by the PV system but without any store device. Strategy 2 aims to supply the electrical demand autonomously whenever possible. Therefore, the surplus of the PV power generation is stored in a battery to be able to provide energy to the grid when required. In this case, when the battery does not provide all the energy needed, the system will take power from the grid.

We have adapted the opt-aiNet algorithm to include complex constraints in the optimization problem and to work efficiently with a considerable number of parameters. Three case studies have been designed to compare AIS with a classical genetic algorithm (GA) approach, analysing the advantages of Strategy 2 against Strategy 1, and considering the behaviour of the system in different situations with the battery. All the results validate the AIS as a proper algorithm for DEMS optimization.

This paper is structured as follows. Section 2 describes the electrical environment considered in the paper. In Section 3 we summarise our case studies and results. Finally, the conclusions from our research are presented in Section 4.

2. Domestic Electrical Environment

The considered electrical context represents a domestic electrical system, where some appliances are connected (Figure 1).

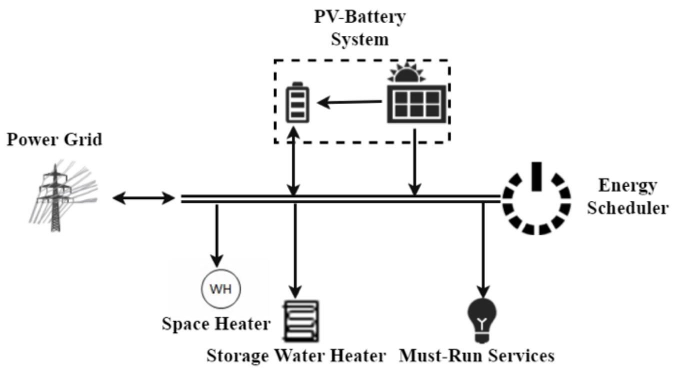

Fig. 1. Schematic image of domestic electrical system.

Our domestic grid considers on appliances that provide energy loads to the DEMS (PV system and the battery), and appliances that consumes energy load, which includes the space heater, the storage water heater, and the must-run services. The appliances are connected to a power grid which can provide electrical load when the system requires so. The scheduler is in charge of balancing the profit of energy services, considering the PV, the power grid and the battery as providers of energy, and the rest of devices connected as consumers.

The problem aims to maximize the profit of energy services provided in a domestic energy management system. Equation 1 expresses the term, *OF*, that is the objective function to optimize.

$$OF = \sum \lambda_{sold}(t)P_{sold}(t) - \lambda_{bought}(t)P_{bought}(t) - \sum (VOLL_j L_j^{shed}(t) - V_{pv}^{s} S_{pv}(t))$$

This function consists of four terms that should be designed. First part, $\lambda_{sold}(t)P_{sold}(t)$, represents the revenue of selling energy produced by PV panels to the power grid. The total cost of electrical energy that is bought from the network, $\lambda_{bought}(t)P_{bought}(t)$, is represented in the second term. The value of electrical energy which is not served is stated in the third part, $(VOLL_j L_j^{shed}(t)$. Finally, the energetic costs of PV generator, $V_{pv}^{s} S_{pv}(t)$, is encoded through the last term.

We want to highlight the fact that the battery is used to charge and discharge load in the DEMS. We also aim to provide the domestic electrical demand locally. In this case, the surplus of the PV power generation is stored in the battery. Then, the DEMS will send the energy load to the external energy net if the battery is charged completely. However, the battery system discharges if the electrical demand is more than the power generation of the PV. The rest of appliances in the domestic system have been modelled following the approach in [15].

3. Case Study and Results

To assess the performance of the proposed DEMS, the physical system from [7] is applied with some modifications. The maximum power produced by the PV system is 2-kW. The battery can store between 0.48 and 2.4 kWh. Maximum heating power of the Space Heater (SH) equals 2 kW to maintain the temperature of the house within ±1 of desired temperature (23ºC). The thermal resistance, R, of the building shell is equal to 18ºC/kW, and C equals to 0.525 kW/hºC. The energy capacity of the Storage Water Heater is 10.46 kW per each hour, with 2 kW of heating element. The values for the predicted data have been taken from [16]. Table 1 and 2 show the maket prices of the system, VOLL, and the energetic costs of the PV generator.

Table 1 Price of the Energy loads

Time	Price ($/MW) λ_{sold}	Price ($/MW) λ_{bought}
23-7	2.2	0.0814
8-14	2.2	0.1408
15-20	2.2	0.3564
21-22	2.2	0.1408

Table 2 VOLL and Spillage prices

Time	VOLL ($/MW) Space Heater	VOLL ($/MW) Storage Water Heater	VOLL ($/MW) Must-Run Services	Spillage Cost ($/MW) PV Panel
0-23	1	1	2.2	4

The data are essential to model the domestic system. Opt-aiNet aims to maximize the function given in Equation 1. For this purpose, opt-aiNet generates an initial population which accomplishes the constraints considered in the electrical management problem. The steps to follow by our specific AIS are detailed below:

- Initiate *N*-individuals in the population which accomplish with the constraints of the model.
- Evaluate each individual according to the *OF*.
- For each individual, create N_c-clones. The elements of each clone should be slightly changed. This mutation procedure guarantees that the constraints are respected by all the clones.
- For each cell or antibody, select the clone with the best fitness value according to the *OF*.
- If the mean fitness of the last iteration and the present one is below a limit, then we suppress similar individuals, according to a threshold t_s that measures the distance (similarity) between two antibodies.
- If we suppressed some individuals, then we have to add new random population

- This cycle is repeated until convergence criterion (maximum number of iterations).

With the appropriate parameters, the AIS obtains one or more individuals with an optimum objective value. We should balance the values to set the number of clones, the mutation process, how the clones can be suppressed and the maximum number of iterations upon convergence.

Firstly, N_c can bias the final results of AIS. If we set N_c with a very low value, we can delay the convergence criterion, as we cannot find enough diversity to select better individuals for each cell. Otherwise, if we generate too many clones, the time upon convergence might be longer than expected. Secondly, the mutation process can also be an element that should be balanced. If it is set to a very high value, the individuals can be randomly mutated, as the fitness values are not influenced by the mutation process. Otherwise, the individuals are very strongly mutated, which can make our final results biased. The suppression constant can also influence the execution time of the AIS. If it is set to a very low value, the list of similar individuals can be largely reduced and the population can augment exponentially, which influences the time upon convergence. Otherwise, if t_s is very high, the population can decrease exponentially and render a false convergence upon a false optimum value. Finally, the convergence can be influenced by the iterations of the algorithm and the population N. If we set a few iterations or if the initial population N is very low, the algorithm might not converge correctly and give false optima values. Otherwise, the time cost can be very high and not desirable for our problem.

In order to evaluate AIS in different situations to highlight its usefulness to solve such kind of problems, two different strategies have been followed. We optimize the profit when the battery is not considered (Strategy 1). Moreover, we consider the whole system with the battery (Strategy 2). In this last strategy, two different situations can happen: the battery is available, meaning that it can be filled and used when necessary, or unavailable, when the battery is full and cannot be charged or discharged under any circumstances. Given both scenarios, we aim to balance the parameters of the AIS by considering the time elapsed to find the optima and the maximum fitness value that allow us to obtain the best results.

Therefore, we empirically set the AIS parameters (Table 3), which gave the optima results according to the fitness values and time.

Table 3. Optima values for the AIS parameters

	N	N_c	Number of generations	t_s	Mutation parameter
Strategy 1	250	12	250	10	100
Strategy 2	250	18	300	3	10

With the optima parameters set, we can simulate the AIS behaviour with the DEMS. The evaluation will follow three different paths. Firstly, we aim to demonstrate that AIS obtains positive results for optimization problems in smart grids through a comparison between a classical approach (i.e. Genetic Algorithms) and the AIS. A second goal is to study how the strategy can impact in the energy management. Finally, we want to demonstrate the impact that the battery can have in getting a maximum profit from the domestic environment. Therefore, we design three case studies:

- Case Study I: Comparative Study between GA and AIS in Strategy 1.
- Case Study II: Comparison between Strategy 1 and Strategy 2
- Case Study III: Analysis of Strategy 2 when the battery is disconnected or connected

3.1. Case Study I

In Case Study I, it is achieved a comparison between a genetic approach and the opt-AiNet algorithm. The goal is to predict the optimum values for each variable for 24 hours, following Strategy 1. We applied the linear constraints proposed in the electrical model, and we measured the objective function for the optimized variables.

The GA contains some parameters that can be set for an optimal operation. In this preliminary study, we set the mutation to 0.3, the cross-over rate to 0.8, the selection function is Roulette and the number of generations is 3000. With these values, we execute the AIS and the GA and compare the values of *OF*. GA obtained a value of 23.55 against to AIS which obtained a value of 23.86. AIS can get better results in this particular problem, however, we would like to deepen in this analysis in a future work.

3.2. Case Study II

In this section, two proposed strategies for the energy environment proposal are evaluated. As outlined before, maximizing the home's energy profit is the main goal of the first strategy. However, the second strategy intends to maximize energy profit and act as an autonomous energy system. In this section, the battery system is not considered.

Table 4. Comparative values between Strategy 1 and Strategy 2.

	Strategy 1	Strategy 2 (without battery	Strategy 2 (with battery)
OF	23.861	5.11	12.31
Energy Sold	14.22	4.64	6.22
Energy Bought	45.66	26.53	10.47

Table 4 represents the optimization values for Strategy 1 and Strategy 2. Strategy 1 has higher values, which means the Strategy 1 maximizes the energy profit in the DEMS. Moreover, Strategy 2 shows that the energy difference of the domestic environment and the grid is lower, due to the autonomous management of energy that the strategy 2 pursues.

3.3. Case Study III

The impact of a battery system on the objective function and exchanged energy are assessed based on Strategy 2. Table 4 shows that the battery improves the objective values (columns 3 and 4). That means the battery increases the amount of electrical energy sold from the smart home to the grid, and it decreases the amount of home's electrical energy bought from the network.

4. Conclusions

Residential buildings influence greatly the energy scheduling, and the optimization process of this problem could be addressed in multiple ways. In this work, an specific Artificial Immune System called Opt-aiNet [14] is fully adapted and tested to include complex constraints and set some parameters like clonation, mutation or suppression thresholds in the optimization problem.

From an electrical point of view, a DEMS with several appliances connected is modelled. Subsequently, we design three different case studies. Firstly, we demonstrated of the AIS by comparing it with an optimal configuration of a genetic algorithm. Secondly, we compare two strategies to analyse the autonomy process to sell and buy energy. Finally, we highlight the impact of the battery to show its importance in a home building.

As a future work, we propose to present a more complex case with non-linear constraints as well as considering the uncertainty of predicted variables to encourage the use of different evolutionary computing and make a comparison between them.

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Intelligent load management in local and wholesale demand response markets
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MAS-based Energy Management and Control System of Smart Homes for Local Energy Transacting

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Abstract

Power systems worldwide are complex and challenging environments. Integration of renewable energy sources rises complexity of the energy management problems in the power systems. Multi Agent Systems (MASs) make this opportunity to model and study several issues related to the complex systems. In a smaller scale, a residential energy management system would be effective for the both sides of the network. It can reduce the electricity costs of the demand side, and it can help the power grid to be more robust in peak times. This paper represents a multi-agent approach to model the smart home's energy system. In the proposed case study, smart home can exchange energy with the upstream operator in distributed power system, and manage its own energy consumption autonomously.

Keywords: demand response, energy management system, local market, multi agent system, smart home.

1. Introduction

Recently, increment of the renewable energy resources in the distributed power systems decreases the power transaction costs in the distributed power system and increase the reliability of the power grid in the distributed level [1]. Moreover, they decrease the greenhouse gas emissions [2]. However, the integration of these intermittent energy resources leads to have stability problems in the power system cause of they are not dispatchable, and they uncertainty energy resources inherently [3-4]. In a smaller scale, a Residential Energy Management System (REMS) enables the domestic customers to manage their consumption to minimize the electricity costs. For implementing a REMS, several infrastructures are required, such as sensors for real-time monitoring and actuators for controlling the equipment [5]. The centralized control where a powerful central controller unit is an expensive method and in the case of failure in a component, all the system may be affected [6]. This way, the MAS approach, where the decisions are made in the local controllers based on the real-time data acquired by the other components [7-8]. The MAS method is preferred when comparing with centralized control, the system can continue its operation in a decentralize way [9].

In this paper, A virtual MAS-based platform for Smart Home Energy System (MASHES) is introduced. The MASHES includes different agents each of whom have different tasks in the system. Also, our REMS manages electrical energy inside the home independently, and it can transact energy with the distributed power grid operator to maximize its expected profit.

2. Residential Energy Management System

The task of the REMS is to make optimum decisions in the MASHES. In this section, the Residential Energy Management (REM) problem is modelled as a two-stage problem. The first stage is called Day-Ahead (DA) stage, and the second stage is called the Real-Time (RT) stage.

Objective Function, Here, the objective is to maximize the Expected Profit (EP) of energy services in the DA and RT stages, simultaneously. In this work, the PV system is the only Distributed Energy Resource (DER) that is considered. EV exists as an Energy Storage System (ESS) in the MASHES. Also, Electrical Loads (ELs) consist of Space Heater (SH), Storage Water Heater (SWH), Pool Pump (PP), and Must-Run Services (MRSs).

$$EP = EP^{da} + EP^{rt} \tag{1}$$

Day-Ahead Stage obtains optimum decisions for the system in day d-1. Hence, the EP for the DA stage is represented as Eq. (1). However, EP^{rt} consisting of five parts. The first part represents the revenue for selling energy produced by the PV system in the real-time stage. The total cost of electrical energy that is bought in the RT stage is represented in the second part. The third part expresses the profit due to selling the stored electrical energy of the EV in the RT stage. Also, the charging cost of the EV is represented in the forth term. The Value of Lost Load (VOLL), $VOLL_j$, is stated in the fifth part. Finally, the spillage cost of the PV system is represented in the last part.

$$EP^{da} = \sum_{t=1}^{N^t} (\lambda'_t P^{da}_{pv,out_t} - \lambda_t P^{da}_{net_t}) \tag{2}$$

$$EP^{rt} = \sum_{t=1}^{N^t} (\lambda_t \big(P^{rt}_{pv,out_t} - P^{da}_{pv,out_t}\big) + \lambda_t P^{rt}_{dis,out_t} - \lambda_t P^{rt}_{ch_t} - \sum_{j:\{ELs\}} VOLL_j L^{shed}_{j\;\;t} - V^{s}_{pv} S_{pv_t}) \tag{3}$$

It is noticeable that electrical loads consist of loads that can be controllable and/or shiftable. The space heater provides the indoor temperature at the desired temperature. The space water heater is in charge of storing the heat in the water tank. The pool pump should not run more than specific hours in a day. Finally, ,must-run services include the loads that should be provided quickly - e.g. lighting, entertainment, etc.

3. MAS-based Hardware Implementation

The electrical loads considered for this system have been categorized in three main types:

- Controllable loads: This category includes the loads that their consumption can be reduced or curtailed;
- Shiftable loads: This category consists of the electrical loads that their consumption can be shifted from a period of time to other certain periods, without any reduction or curtailment;
- Must-run loads: This group contains such electrical loads that their consumption cannot be controlled, shifted, or curtailed.

In this system, a space heater is considered as a controllable load. The space heater is related to a home appliance, which provides the indoor temperature at the desired temperature. The maximum capacity specified for this load is 5.525 kW. Storage water heater and pool pump are the other electrical loads considered as shiftable loads. The storage water heater is in charge of storing the heat in the water tank, and the pool pump is a part of swimming pool installations. The energy capacity of the storage water heater is 10.46 kWh (180 L), which has 2 kW heating element. The rated power of the pool pump is 1.1 kW, and it is considered that it can operate for a maximum of 6 hours during the day. Additionally, several types of loads, such as lighting, or entertainment, are considered as must-run loads. The maximum energy produced by the PV system is 2.5 kWh. Furthermore, an EV is propounded for the system playing the role of an ESS. This ESS unit can store energy between 1.77 and 5.9 kWh, and its maximum charging/discharging rates are 3 kW. Besides, charging and discharging efficiencies are 90%. Fig. 1 represents the overall system architecture. In this system, the PV and EV can supply the local demand, and while there is more generation than the local demand, the system is able to inject the excess of the produced power to the utility grid.

As Fig. 1 shown, there are five main agents namely, PV, EV, Water Heater, Space Heater, and Pool Pump agent. As also illustrated in Fig. 1, each agent is equipped with a Programmable Logic Controller (PLC) in order to perform decision-making locally and communicate with other agents to fulfill the overall system's goal.

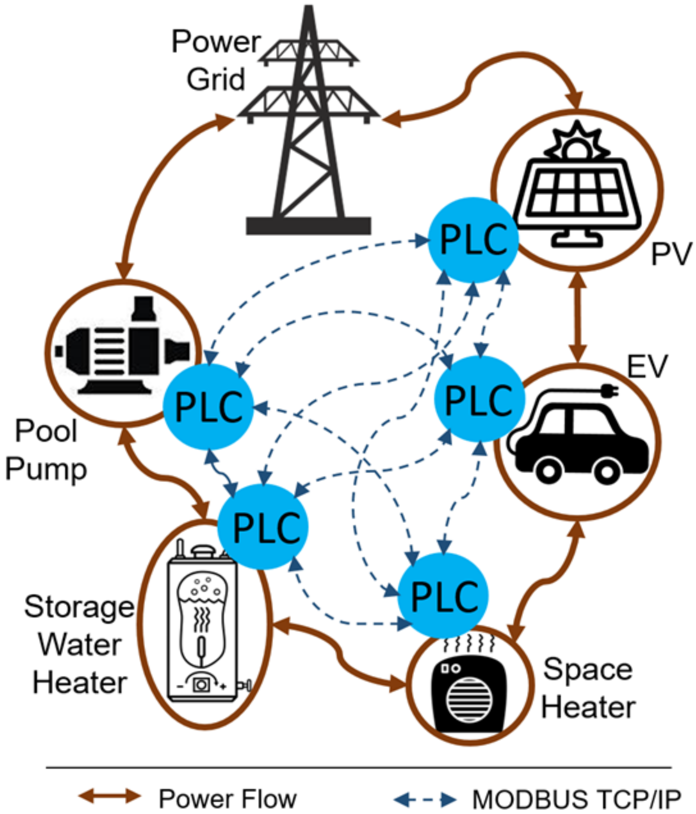

Fig. 1: Proposed MAS architecture for the system control [4].

4. Results

The impact of the EV is assessed in two scenarios in this section. In Scenario 1, EV is available in all hours in the MASHES, and plays as the battery in the system. In Scenario 2, EV is out of home in period 6-17. Also, it is assumed that the EV should be full of charge at 6, and it has the minimum capacity at 17. Moreover, worst case is considered in this section. As seen in Table 1, the expected profit of the system in Scenario 1 is more than Scenario 2 because the EV is completely available at home in Scenario 1. Besides, there is no any constraint to force the state of charge of the EV in some specific times in Scenario 1. On the other hand, the bought electrical energy from the local market is less in Scenario 1. However, Scenario 1 increases the sold electrical energy to the local market.

The effect of the Demand Response Program (DRP) on the EPs and the smart home's electrical energy that is sold/bought to/from locale electricity market is assessed. Here, time-of-use program is used. As seen in Table 2, DRP causes the positive effect on the amount of total objective function on the REMS. In other words, while EP^{da} is increased when DRP is not considered in the system, EP^{rt} is decreased dramatically because electrical loads are not flexible when DRP is not considered in the REMS. Furthermore, considering DRP decreases the amount of electrical energy that a smart home buys from the local market, because the main purpose of applying DRP is to eliminate the need of electrical energy by shifting the electrical load in the energy management time-period, and to reduce the electrical loads in some situations.

Table 1. Impact of EV on the total expected profit, the bought/sold energy from/to the local electricity market.

	EV		
	EP	E^{rt}_{bought}	E^{rt}_{sold}
Scenario 1	11.598	34.791	14.909
Scenario 2	9.962	36.510	13.538

Table 2. Impact of PV power generation uncertainty, EV, and demand response program on day-ahead, balancing, and total objective functions.

	Worst case			Best case		
Scenarios	EP^{da}	EP^{rt}	EP	EP^{da}	EP^{rt}	EP
with uncertainty	4.836	6.613	11.449	49.232	2.475	51.707
without uncertainty	49.232	2.386	51.618	49.232	2.386	51.618
with battery	4.836	6.613	11.449	49.232	2.475	51.707
without battery	4.232	5.553	10.389	49.232	1.416	50.647
with DRP	4.836	6.613	11.449	49.232	2.475	51.707
without DRP	6.063	0.723	6.786	50.459	-2.087	48.372

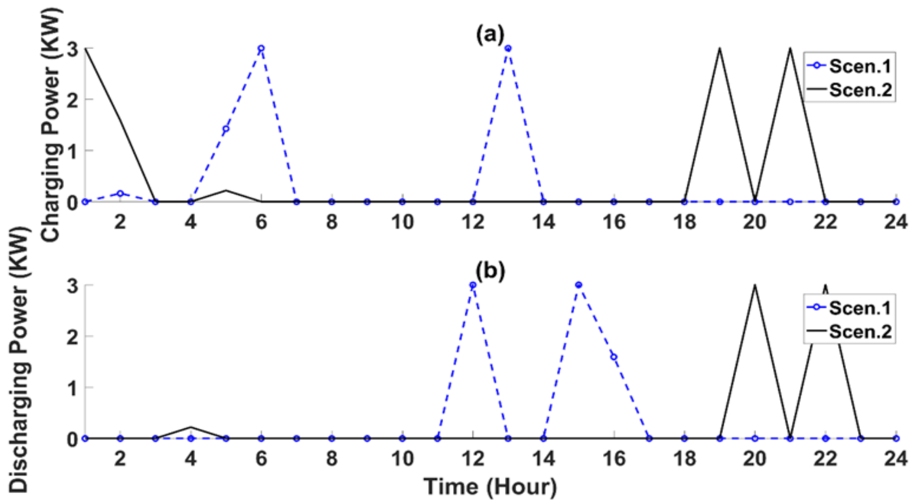

Fig. 2: Impact of (a) Charging power of EV., (b) Discharging power of EV.

5. Conclusions

In this paper, the multi agent-based smart home electricity system has been presented. The performance of the proposed residential energy management model has been evaluated can exchange electrical energy with the local market based on the impacts of PV system and EV. The proposed hardware implementation presented that multi agent model reduces the response time to any changes in the agents and hence improve the adaptability of the system. Additionally, flexibility and reconfigurability are two main important characteristics that an MAS-based smart home offers.

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