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Proceedings of the Second DREAM-GO Workshop

Real-Time Demand Response and Intelligent Direct Load Control

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Proceedings of the Second DREAM-GO Workshop
University of Salamanca, Salamanca, Spain, March 22-23, 2017.

Contents

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Real-time demand response and intelligent direct load control

Second DREAM-GO Workshop

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Demand Response Programs Implementation in North American Markets – Technical Features Comparison

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Abstract

The daily increment of the electricity demand in worldwide, obliges the electricity providers to hardly manage the relation between the generation and consumption. Therefore, the electricity operators should keep a gap between the total amount of generation and consumption in order to have not met the lack of energy generation, which leads to provide more energy resources. There is another solution to keep the gap between the amount of generation and consumption, which is defining such a program in specific periods for the demand side in order to reduce their consumption in response to the incentive paid by the electricity providers. This is defined as demand response program. These kinds of programs have been implemented worldwide, especially North America. Therefore, this paper provides a summarized report of the implemented DR programs on North American in 2015. More than 45 demand response programs have been surveyed and investigated. The main contribution of this paper is to compare the implemented DR programs parameters between 2013 and 2015. The results indicates that most of DR programs have kept the same values in the parameters, and there are several DR programs that they are not exist in 2013 and have been implemented in 2015.

Keywords: demand response, electricity retailer, service type.

1. Introduction

Nowadays, the use of Demand Response (DR) programs is widely surveyed. The DR programs are referred to the altering the consumption profile of the demand side, in order to response to the price variation and other technical or economic issues [1]. There are two major classifications for the DR programs: incentive-based and price-based [2, 3]. The incentive-based is related to the fixed or time varying incentive plans that is paid by the Retail Electricity Provider (REP). Price-based is referred to reforming of the end-users consumption curves for responding to the price variations [4]. Although, the DR programs can also be organized by the other parameters namely Service Type. These service types are: energy, capacity, regulation, and reserve [5], which can be defined as [6]:

- Energy: this service is based on the amount of delivered power by the demand resource in MWhs;
- Capacity: in this service type, it is mandatory for the demand resource to control the energy demand of the end-users for one or several pre-defined periods, which should be measured in MW;
- Regulation: this is a type of service that the demand resource decreases or increases the amount of consumption, depending on the real-time signals received from the REP or other system operator. These operators have to uninterruptedly transmit the DR data in the defined periods. Furthermore, the

parameters of this service type, such as deadlines, time periods, etc. are not considered in the DR event definition.

- Reserve: This service type is related to the demand resources that should be standby for the system operator in order to compensate the demand reduction.

The interesting point is that regulation and reserve services are two ancillary services, which are defined as support services in the power system and are essential in maintaining power quality, reliability and security [7].

Currently the DR programs has been implemented worldwide and they are transmitted to the customers in day-ahead of the DR event or very close to the event starting time (close to real-time). In the case of announcing the DR program in the event starting time, a ramp time will be considered for the customers in order to adapt the data and decrease the consumption till the desired value. Furthermore, the participation of the customers in the DR programs is completely voluntary and they indicate their availability in the DR programs. However, if they participate in the DR programs, there are several mandatory roles, namely total DR contribution limits, minimum resource size and reduction amount, etc. that should be considered by the customers.

The work presented in this paper is a summarized report of the implemented DR programs on North American Independent System Operator/ Regional transmission organization (ISO/RTO), called “North American Wholesale Electricity Demand Response Program Comparison” published in 2016 [8]. There are up to 48 DR programs presented in this paper and classified by the service types represented in above. The main focus is given to comparison between the present work, and the one presented in [5] regarding the same DR implementation report in North American but in the year of 2013. This paper also provides the all of the modifications in the DR parameters that have been occurred between 2013 and 2015.

After this introductory section, the classification of the DR programs based on service type is proposed in section 2. Then, Section 3 represents the DR programs based on primary drivers. Section 4 describes Telemetry and After-The-Fact-Metering, and finally, the conclusion of the work is indicated in section 5.

2. DR programs based on Service Type

As it was described in the previous section, the DR programs can be classified in four main type: energy, capacity, regulation, and reserve. In this part, four tables are presented according to these four service types. These four tables are represented on Table 1 to Table 4. Each table may include several rows indicated by green. The values signified by this color in the tables, are the new DR programs that currently have been implemented by the North American wholesale electricity markets. In all of these tables, “OP” and “AR” are respectively the abbreviation of “Operational Procedure” and “Automated Response”. The definition of other parameters used in the tables are available in [5], and they are not mentioned in the present paper due to space constraints.

Table 1 is referred to energy service type DR programs. As you can see the programs are classified to economic and reliability. In addition to green rows, red rows indicate the DR programs that have been excluded and are not executed now. One of these ignored DR programs is a specific case, which its trigger logic was defied as $100/MWh, and the rest were price-triggered programs. The other DR programs (uncolored rows), are the programs that were implemented in 2013 and still they are executing.

As it can be seen in Table 1, there are several parameters with the value of “-”. They mean “undefined” or non-applicable”, and they are completely different with “0”. Additionally, the value “0” have different meanings in different parameters. For example, in aggregation allowed and response required, the value “1” means “Yes” and value “0” means “No”, however, in the ramp period, “0” means “0 minutes”.

All of the new DR programs in the energy service type, are in economic primary driver and their trigger logic is based on the price. Also, more than 75% of the DR programs are implementing in this service type are economic. As a general overview of the Table 1, it represents that in new DR programs minimum resource size and minimum reduction are not equal, and in most of the time aggregation is allowed and response is required as well. Additionally, there is no limit for the DR contribution.

Table 1. Energy Service Type in 2015.

Primary Driver	Trigger Logic	Min. Resource Size (kW)	Minimum Reduction (kW)	Aggregation Allowed	Response Required	DR Contribution Limit (%)	Min. Sustained Response Period (m)	Max. Sustained Response Period (m)	Advance Notification (m)	Ramp Period (m)	Sustained Response (m)	Recovery Period (m)
Economic	$100/MWh	100	100	1	0	-	-	-	-	0	-	-
	price	100	100	1	1	-	-	-	1200	0	-	-
	price	100	100	1	1	-	-	-	1200	0	-	-
	op	100	100	1	0	-	-	-	120	30	-	-
	price	100	10	1	1	-	-	-	1200/0	-	60	-
		100	1	1	1	-	60	660	1200	-	-	-
		100	100	1	0	-	-	-	120	-	-	-
		100	100	1	1	-	-	-	-	5	5	-
		100	100	1	1	-	60	-	5	5	5	5
		1000	0	0/1	0	-	-	-	1200	5	60	-
		1000	100	1	1	-	240	240	150	-	240	-
		1000	100	0	1	-	5	-	5	5	60	-
		1000	100	1	1	-	5	-	5	5	60	-
		1000	1000	1	1	-	60	-	1200	-	-	-
Reliab.	OP	0	0	1	1	-	-	240	-	60	-	-
		100	0	1	0	-	-	-	-	-	-	-
		100	100	1	0/1	-	-	-	120	120/30	240/-	-

The second table (Table 2) is related to the capacity service, which is only classified by reliability primary driver. In contrary with the energy type and similar to the DR programs implemented in 2013, the most of the DR programs have economic trigger logic and in some cases, it is based on the peak consumption hours. As specified with green color in the Table 2, there are three new DR programs that have been implemented in 2015. Two of them are exactly repeated from a program which was implemented in 2013. It means there are three distinct programs, with same features and same event timing.

Table 2. Capacity Service Type in 2015.

Primary Driver	Trigger Logic	Min. Resource Size	Minimum Reduction	Aggregation Allowed	Response Required	DR Contribution Limit	Min. Sustained Response Period	Max. Sustained Response Period	Advance Notification	Ramp Period	Sustained Response	Recovery Period
Reliability	load >= 90% peak	100	1	1	1	-	-	-	-	0	-	-
	Peak hours / Price	100	1	1	1	-	-	-	-	0	-	-
	OP	0	0	1	1	-	-	-	-	7	480	-
		100	100	1	1	-	-	720	-	30/10	-	600
		100	1	1	1	-	-	-	30	30	-	-
		100	0	1	1	-	240	-	-	-	240	-
		100	100	1	1	-	-	360	120	30	-	-
		100	100	1	1	-	-	600	120	30	-	-
		100	100	1	1	-	-	600	120	30	-	-
		100	100	1	1	-	-	600	120	30	-	-
		100	100	1	1	-	-	-	120	30	-	-
		500	500	1	1	-	-	180	-	10	-	-

Also, it is obvious that in the capacity service type, the aggregation is always allowed and the response requirement is always mandatory as well. There is no limitation for contributing in DR programs that refers to the demand resources obligation described in introduction part.

Next table (Table 3) concerns about one of the ancillary services named regulation service. In this service type there is no new program and the DR programs that were implemented in the 2013, still are executing. Similar to the year of 2013, the ramp period is always equal to zero and vindicate this sentence that regulation service does not follow the time periods of DR event definition [5].

The last table of this section (Table 4) represents the DR programs categorized by the reserve service type. In this table, there is one new and one modified DR programs comparing with 2013. These two DR programs are colored by green in the Table 4.

Table 3. Regulation Service Type 2015.

Primary Driver	Trigger Logic	Min. Resource Size	Minimum Reduction	Aggregation Allowed	Response Required	DR Contribution Limit	Min. Sustained Response Period	Max. Sustained Response Period	Advance Notification	Ramp Period	Sustained Response	Recovery Period
Econ.	OP	100	100	1	1	-	60	-	5	0	-	-
	Price	1000	0	0	1	-	-	-	1200	0	60	-
		1000	1000	1	1	-	60	-	5	0	-	-
Reli.	AR	100	100	0	1	-	-	-	-	0	-	-
	OP	100	100	1	1	0,25	-	-	-	0	-	-
	Price	1000	100	1	1	-	-	-	1200	0	-	-

Table 4. Reserve Service Type 2015.

Primary Driver	Trigger Logic	Min. Resource Size	Minimum Reduction	Aggregation Allowed	Response Required	DR Contribution Limit	Min. Sustained Response Period	Max. Sustained Response Period	Advance Notification	Ramp Period	Sustained Response	Recovery Period
Economic	OP	100	100	1	0	-	60	-	5	10	60	-
	Price	500	10	1	1	-	-	-	1200	10	-	-
		1000	0	1	1	0,4	-	-	1200	10	60	-
		1000	1	1	1	-	-	-	-	-	-	-
		1000	1000	1	1	-	60	-	75	10/30	-	-
Reliability	Freq.	1000	1000	1	1	-	-	-	-	0	60	-
	OP	100	100	1	1	-	-	-	-	30	-	-
						0,33	-	30	0	10	-	-
						0,25	-	-	120	30	-	-
		5000	5000	1	1	-	-	-	-	10	60	-
		10000	10000	0	1	-	-	-	-	10	60	-
	OP+AR	100	100	0	1	-/0,5	-	-	-	10	-	-/180

The modified program is the first green row, which is economic-driven and is triggered by price. The only parameter that has been changed, is the DR contribution limit, which was 30% in 2013, and is 40 % in 2015. The new added program is the second green row, which is a reliability-driven program and has OP in the trigger logic. The minimum resource size has been significantly increased and reached to 10000 kW. This is equal for the minimum reduction amount, which is 10000 kW as well. However, the maximum of these two parameters in the entire implemented DR programs in 2013, were 5 MW. Furthermore, the aggregation is not allowed in this program, however, the response is required. The ramp period and sustained response are equal to the programs defined in 2013, which are respectively 10 and 60 minutes.

3. DR Programs based on Primary Driver

As it was shown in previous section, all the service types, except capacity, were classified by two features "economic" and "reliability" named as primary driver. In this part several charts have been demonstrated, which organized the DR programs according to primary driver. The analysis of DR programs by primary driver is presented in Figure 1 and in Figure 2, respectively for the DR program features and for the DR event timing. Figure 1 (a) and Figure 2 (a) are depicted the reliability results, while Figure 1 (b) and Figure 2 (b) illustrate the economic-driven programs. As it can be seen in all figures, the data has been normalized, i.e. all of the values have been scaled in 0-1. It was assumed that the top scale actual values are: 10000 kW for minimum resource size and minimum reduction, 1200 minutes for the advance notification, 120 minutes for the ramp period, 480 minutes for the sustained response, and 600 minutes for the recovery.

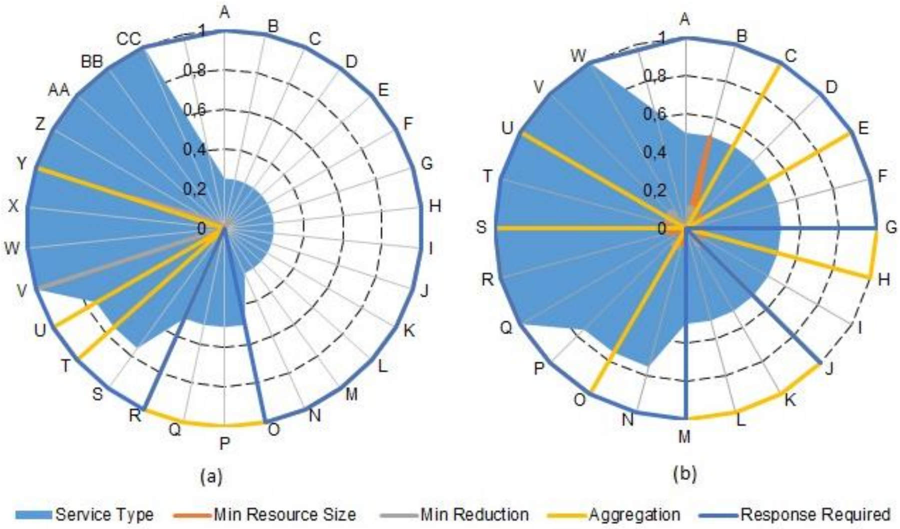

Fig. 1: DR programs classified by features; (a) Reliability, (b) Economic.

For better comparison between 2013 and 2015, the service types is the same in the both years: Capacity – 0,25; Energy – 0,5; regulation – 0,75; Reserve – 1. Additionally, it is clear that there is no modification in the service type sorting. In one of the DR programs, the minimum resource size and minimum reduction have been increased to 10000 kW. This leads that the smaller scales of the other DR programs parameters, will not be able to be demonstrated in the figures.

Concerning the aggregation permission, there are a few number of new DR programs that have more restrictions comparing with 2013. In addition, for the new DR Programs, the response is always required.

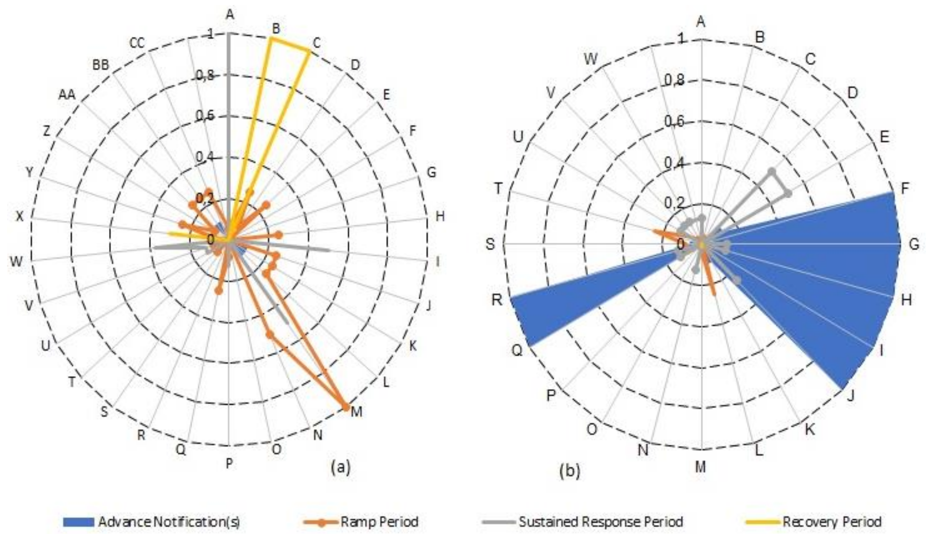

Fig. 2: DR event timing; (a) Reliability, (b) Economic.

As it mentioned in above, Figure 2 is correlated to DR event timing that divided by reliability and economic primary driver. According to the results obtained in 2013, in the economic-driven event timing programs there are more changes comparing with the reliability-driven programs. Furthermore, based on the obtained results in 2015, ramp period in reliability-driven is higher than economic-driven and this is in contrary of results acquired in 2013. Additionally, Figure 2 illustrates this fact that new DR programs implemented are more similar to previous programs in parameters such as minimum resource size, minimum reduction, aggregation and response required, comparing with the event timing. The Event timing in the new programs caused the variations between them.

4. Telemetry and After The Fact Metering

For each DR service, there is an efficiency analyze in order to dedicate the reduction of the specific demand resource. For this analyze, two fundamental methods is employed for the DR event, which are Telemetry and After The Fact Metering.

Telemetry is defined as a component to measure a quantity, and conveys the outputs to a remote place in order to manage, monitor, and store the data. After The Fact Metering is related to the measured data that are metered with a specific time interval. This method may not be utilized for the demand resources, which are below the Baseline Type II (Non-Interval Meter) [6]. Table 5 shows the comparison of four service types according to telemetry and after the fact metering [8].

Table 5. DR service types based on Telemetry and After The Fact Metering.

	Telemetry			After The Fact Metering		
Service Type	**Telemetry Requirement**	**Telemetry Reporting Interval**	**On Site Generation Telemetry Requirement**	**After-The-Fact-Metering Requirement**	**Meter Data Reporting Deadline**	**Meter Data Reporting Interval**
Energy	25%	2sec_5min	15%	100%	Max. 103 days	Max. 1 hour
Capacity	21.4 %	4sec_5min	21.4 %	100%	Max. 103 days	Max. 1 hour
Regulation	100%	2sec_6sec	50%	83%	Max. 55 days	Max. 1 hour
Reserve	73%	2sec_1min	40%	80%	Max. 55 days	Max. 1 hour

As it can be seen in Table 5, these two methods of DR programs measuring are essential for all service types that discussed before. However, telemetry is more utilized in the ancillary services (regulation and reserve). It is clear that telemetry reporting interval is up to 5 minutes. The parameter “On Site Generation Telemetry Requirement” is shown based on DR service types categories. Furthermore, After The Fact Metering is always required for energy and capacity services and in the most of the time is required for regulation and reserve services. Meter data reporting interval for energy and capacity services should not be more than 103 days after DR event, and for regulation and reserve service should not be more than 55 days after DR event as well. Additionally, the maximum time of data reporting interval for all of the service types are up to 1 hour.

5. Conclusions

The implementing and executing demand response programs is becoming a reality in the current power systems. The demand response program is cost effective for the both sides of the grid, the electricity customers by reducing their electricity bills and the grid operators by shifting the high consumption loads to the off-peak moments. Additionally, by implementing these types of programs, the grid congestions can be relived, which leads to decrease the requirements of peaking generation capacity. North American electricity markets are vanguard in the implementation of demand response programs.

In this paper, we presented a summarized report of the implemented demand response programs on North American electricity market in 2015. More than 45 programs have investigated and categorized based on different parameters of the demand response programs. Additionally, this paper provided a comparison between the implemented demand response programs on North American in 2013 and 2015. The modified and added programs have been illustrated and surveyed.

The results of this papers demonstrates that the utilization of demand response programs has been increased comparing with the past years, since they are several new programs that were not exist in 2013, and currently they are executing. Furthermore, there is several programs that their capacities has been enlarged, which proves the interest of electricity provides as well as the customers to employ demand response programs.

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References

[1] P. Faria, J. Spínola, and Z. Vale, “Aggregation and Remuneration of Electricity Consumers and Producers for the Definition of Demand-Response Programs,” in IEEE Transactions on Industrial Informatics, vol. 12, no. 3, pp. 952-961, June 2016.

[2] P. Faria, Z. Vale, P. Antunes, and A. Souza, “Using baseline methods to identify non-technical losses in the context of smart grids,” in 2013 IEEE PES Conference on Innovative Smart Grid Technologies (ISGT Latin America), Sao Paulo, Brazil, 2013.

[3] M. Rahmani-andebili, “Nonlinear demand response programs for residential customers with nonlinear behavioral models,” in Energy and Buildings, vol. 119, pp. 352-362, 2016.

[4] O. Abrishambaf, M. A. F. Ghazvini, L. Gomes, P. Faria, Z. Vale, and J. M. Corchado, “Application of a Home Energy Management System for Incentive-Based Demand Response Program Implementation,” in 2016 27th International Workshop on Database and Expert Systems Applications (DEXA), Porto, Portugal, 2016.

[5] P. Faria, and Zita Vale, “Overview and Comparison of Demand Response Programs in North American Electricity Markets.” in 6th International Conference on Security-enriched Urban Computing and Smart Grids (SUComS 2015), Porto, Portugal, 2015.

[6] NAESB, “Recommendation to NAESB Executive Committee: Review and Develop Business Practice Standards to Support DR and DSM-EE Programs”, Available: http://www.naesb.org. [Accessed:20-Feb-2017].

[7] M. Jason, P. Cappers, D. Callaway, and S. Kiliccote, “Demand response providing ancillary services: A comparison of opportunities and challenges in the us wholesale markets.” in Getting Beyond Fear, Uncertainty, and Doubt (Grid-Interop 2012), Irving, TX, USA, 2012.

[8] ISORTO – North America ISO and RTO association, “North American Wholesale Electricity Demand Response Program Comparison – 2015 Edition.” Available: http://www.isorto.org/ircreportsandfilings/2015-north-american-demand-response-characteristics-available [Accessed: 20-Feb-2017].

Real-time demand response and intelligent direct load control
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Optimal Rescheduling of Distributed Energy Resources Managed by an Aggregator

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Abstract

Distributed energy resources integration into energy markets and power systems operation has been one of the main concerns of operators and other entities, mainly because of the recent growth and the features that these resources can provide. The need for managing tools that provide solutions to these concerns is evident, and can be addressed through several ways. The present paper proposes a model for the integration of distributed energy resources into power systems operation using an aggregator. The management considers the aggregator's perspective, and therefore, the objective is to minimize the costs of system balance. For this, it is proposed a re-scheduling of resources, i.e. after a first scheduling with individual prices the resources are clustered, and for each group, a tariff is defined and applied to each of the resources that belong to it, being then scheduled again considering the new group tariffs.

Keywords: aggregator, demand response, energy markets, smart grid

1. Introduction

Distributed energy resources have been on the raise since the energy market liberalizations, since new and more sustainable technologies gain more relevance, both for the operators of power systems and consumers [1]–[4]. Several countries provide incentives to the consumers to adopt these kind of technologies through promoting schemes and monetary incentives [5]–[7]. In this context, two major concepts arise as the most preferable and easily implemented, distributed generation and demand response [8]–[10]. For the first, it defines that generation is scattered along distribution networks and located more near consumption centers [11], [12], while the latter, defines that consumers can provide flexibility to the power system by adjusting their consumption in certain periods, being given price or monetary incentives/signals in return [13], [14]. Moreover, aggregators gain a significant importance in the latter concept, since small-size resources (as consumers) that are involved, individually are far beyond the possibility of participating in energy markets due to the requirements that each market imposes [15]. In this way, aggregators facilitate the integration of distributed energy resources by providing a virtual resource built of many small-size resources.

Besides aggregators, virtual power plants and microgrids represent solutions to integrate distributed energy resources, however, the first is only relevant for the participation in energy markets while the latter is only to management of resources and not so focused in the energy markets [16]. In this way, aggregators present a hybrid solution that complement the management of resources with energy markets participation.

Additionally, [17] presents a model for the communication between the consumer's smart meter and the aggregator, providing useful information that the aggregator can use to perform an appropriate scheduling, that considers the consumer's preferences and characteristics. In [18], the authors propose a flexibility provider approach to the aggregator's operation, through the implementation of demand response programs, namely, load shifting, load curtailment, and load recovery. The model proposed also includes the participation of the aggregator in the balancing, day-ahead, and forward contract energy markets.

The current literature often approaches the aggregator's activities through a bottom and upper level models [18], [19], which in the first case consider that the aggregator's activities starts conditioned by the resources availability and characteristics [20], [21], and in the second case, focus is given to the negotiations that the aggregator performs during its participation in the energy markets [22], [23]. These two approaches consider different sides of the aggregator's activities, and that give this entity such a relevant position in the integration of smart grid concepts in current power systems.

The present paper addresses a model for the rescheduling of distributed energy resources, given group tariffs defined by their clustering. The clustering is only applied to the resources that participated in the scheduling, so that the prices from non-participant resources do not affect the group tariff. The group tariff is defined by the average of the resources prices, that belong to a given group. After the clustering is made, a new scheduling is made considering all of the resources as in the first, however, the prices of the resources that were included in the clustering are updated according to the group tariff of which they belong to. Both schedules consider demand response and distributed generators, being these separately clustered into several groups, i.e. there are groups for consumers and other groups for distributed generators. The proposed model intends to provide a management tool for the minimization of the aggregator's operation costs, and simultaneously provide decision support for the participation in the energy market.

2. Rescheduling of Resources

As mentioned before, the rescheduling of resources intends to provide the aggregator with an optimal solution for the minimization of operation costs. The proposed methodology is shown in Fig. 1, which explains the lower and upper level that compose the aggregator's activities. In the management level, the resources communicate to the aggregator their information, which may include capacity, user preferences, tariffs, amongst others, that is later on addressed by the aggregator to perform the scheduling. In the aggregation level, the aggregator uses the energy scheduled and prices of each individual resource as basis to perform the clustering, in order to obtain the resource distribution amongst the groups and the respective tariffs of each.

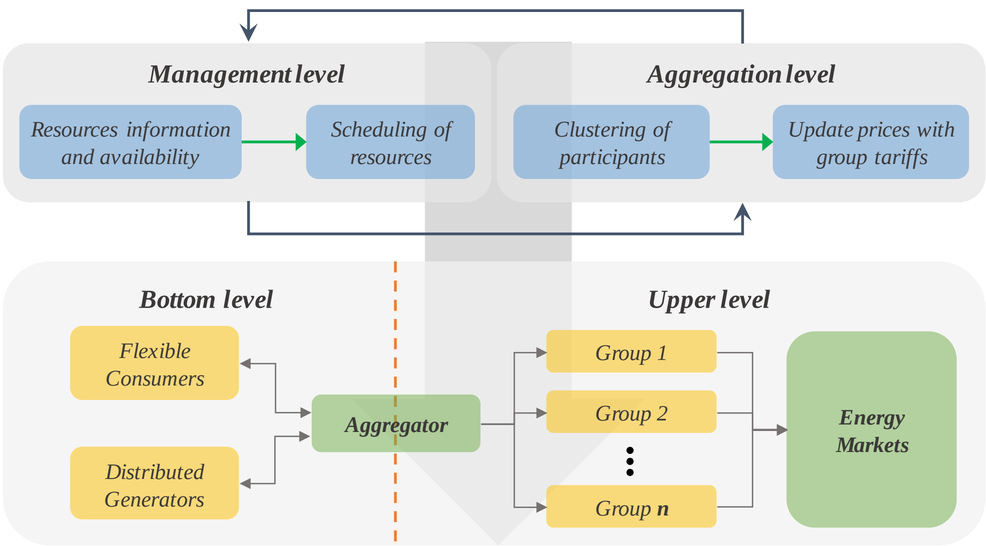

Fig. 1: Scheme of the proposed methodology.

Equation (1) represents the objective function implemented in the proposed methodology, which includes the consideration of external suppliers, distributed generators, and demand response programs (load reduction and curtailment). The aggregator when managing a small region composed of several resources, assumes a role of operator, and therefore must ensure the balance of this small region, i.e. the power system. In this context, equation (2) translated the load and generation balance that guarantees the security and reliability of the network.

$$\min \textit{Operation Costs}$$

$$\sum_{s=1}^{S} P_{(s)}^{Sup} \cdot C_{(s)}^{Sup} + \sum_{p=1}^{P} P_{(p)}^{DG} \cdot C_{(p)}^{DG} + \sum_{c=1}^{C} \left(\left[P_{(c)}^{Red} + P_{(c)}^{Cut} \right] \cdot C_{(c)}^{Red} + P_{(c)}^{ENS} \cdot C_{(c)}^{ENS} \right) \tag{1}$$

$$\sum_{s=1}^{S} P_{(s)}^{Sup} + \sum_{p=1}^{P} P_{(p)}^{DG} = \sum_{c=1}^{C} \left(P_{(c)}^{Load} - P_{(c)}^{Red} + P_{(c)}^{Cut} + P_{(c)}^{ENS} \right) \tag{2}$$

Regarding the generation limits, these are imposed for external suppliers and distributed generators, equation (3) and (4), respectively. In the case of external suppliers, these limits are relatable to the ones applied to a normal consumer, by defining a maximum level of energy that can be supplied giving a certain contract established. For distributed generators, these are limited according to their current or expected production levels, since most of these units do not rely on fossil fuels to operate, but rather on renewable resources.

$$P_{(s)}^{SupMin} \le P_{(s)}^{Sup} \le P_{(s)}^{SupMax}, \forall s \in \{1,...,S\} \tag{3}$$

$$P_{(p)}^{DGMin} \le P_{(p)}^{DG} \le P_{(p)}^{DGMax}, \forall p \in \{1,...,P\} \tag{4}$$

In what concerns consumers, these can provide flexibility through load modification programs, namely, reduction, curtailment, and energy non-supplied (ENS), although the last has a high cost for the aggregator. In the load reduction program and energy non-supplied situation, the aggregator can modify the consumer's load dynamically – equations (5) and (8), while on the curtailment program the load is shed in a given energy step – equations (6) and (7).

$$P_{(c)}^{RedMin} \le P_{(c)}^{Red} \le P_{(c)}^{RedMax}, \forall c \in \{1,...,C\} \tag{5}$$

$$P_{(c)}^{CutMin} \le P_{(c)}^{Cut} \le P_{(c)}^{CutMax}, \forall c \in \{1,...,C\} \tag{6}$$

$$P_{(c)}^{Cut} = P_{(c)}^{CutMax} \cdot \lambda_{(c)}^{Cut}, \forall c \in \{1,...,C\}, \lambda_{(c)}^{Cut} \in \{0,1\} \tag{7}$$

$$P_{(c)}^{ENSMin} \le P_{(c)}^{ENS} \le P_{(c)}^{Load}, \forall c \in \{1,...,C\} \tag{8}$$

Also, so that the demand response programs do not provide flexibility in an uncontrolled form that can affect the consumer's important activities, the proposed methodology includes equation (9), which provides a limitation of demand response amounts in the load reduction and curtailment programs, through a maximum of *a* percent of the original expected load – in this case defined as 0,6 (60%).

$$P_{(c)}^{Red} + P_{(c)}^{Cut} \le a \cdot P_{(c)}^{Load}, \forall c \in \{1,...,C\} \tag{9}$$

After the scheduling of resources, the clustering considers *k*-means algorithm with energy scheduled as base data for its process. The *k*-means clustering algorithm starts with a random assignment of elements to the desired groups, and then iteratively computes the distances between the several elements minimizing the following equation (10). Equation (11) represents the need for a given resource to be assigned to a group, i.e. all resources must be assigned to a group [24].

$$J(T,Q) = \sum_{i=1}^{K} \sum_{j=1}^{N} \gamma_{ij} \cdot \left\| x_j - m_i \right\|^2, \qquad \gamma_{ij} = \begin{cases} 1, \textit{if } x_j \in \textit{cluster } i \\ 0, \textit{otherwise} \end{cases} \tag{10}$$

$$\textit{with} \sum_{i=1}^{K} \gamma_{ij} = 1, \forall j \in \{1,...,N\} \tag{11}$$

The algorithm has as inputs a partition matrix with resources (objects) to be clustered in the rows, and several variables (observations) in the columns. This is represented in equation (10) through T, while Q represents an initial solution that can be given (cluster prototype or centroids matrix) [24]. The output of the algorithm returns a column vector with the group indexes for each of the resources, and with this is possible to obtain relevant parameters, such as, energy capacity/schedule, group tariff, and number of resources.

In the present section, it was approached the proposed methodology and all of its components and contextualization (as showed in Fig. 1). Moreover, the mathematical formulation used in the methodology and the resources that compose it, was also presented and explained.

3. Case Study

The case study that is evaluated with the proposed methodology, is composed of 117 generation units, of which one is an external supplier (others are distributed generators), and 90 consumers. There are several types of distributed generators, namely, photovoltaic, biomass, wind, small hydro, and co-generation, with different individual prices. Table 1 shows the resource's characteristics, namely, total energy available in the time considered (day), price applied to each type of resource, and the number of resources per type.

Table 1. Generation units characteristics.

	Total Energy (kWh)	Price (m.u./kWh)	nº of Resources
External supplier	240,00	Dynamic	1
Wind	52,40	0,0964	53
Biomass	10,80	0,1231	1
Photovoltaic	39,59	0,1560	60
Small Hydro	22,39	0,1014	1
Co-generation	50,40	0,0796	1
Total	**415,58**	-	**117**

In Fig. 2, it is presented the energy available from each type of resource, in each period, and also the dynamic energy price of the external supplier. Also, generation is clearly sufficient to meet demand, giving possibility for distributed generators to be sufficient for satisfying consumption. The contribution of demand response in this case will be only reflected in a cost perspective, i.e. demand response is used only to reduce the operation costs of the aggregator.

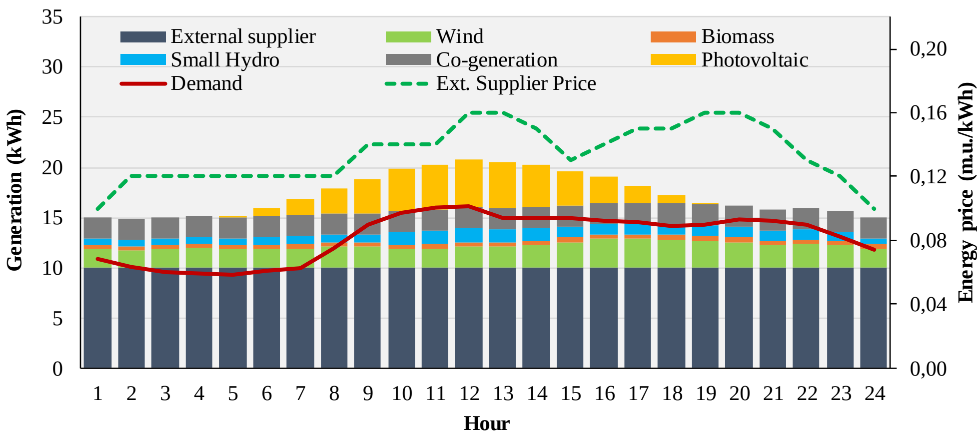

Fig. 2: Available generation through the periods and dynamic price (ext. supplier).

The dynamic price of external suppliers allows the aggregator to manage its operation costs, since there are periods where supply is cheaper and can balance this with the use of distributed generators and demand response accordingly.

4. Results

The results presented concern the implementation of the proposed methodology in the case study, with special focus on the rescheduling of resources after the clustering. The resources prices are changed after the clustering (for the second scheduling), according to the group tariff. The group tariff is obtained through the prices average of the elements in the group, and then is applied to the resources as their prices for the new scheduling. The analysis of the rescheduling is performed for a single period, that in this paper corresponds to period 12, matching the consumption peak.

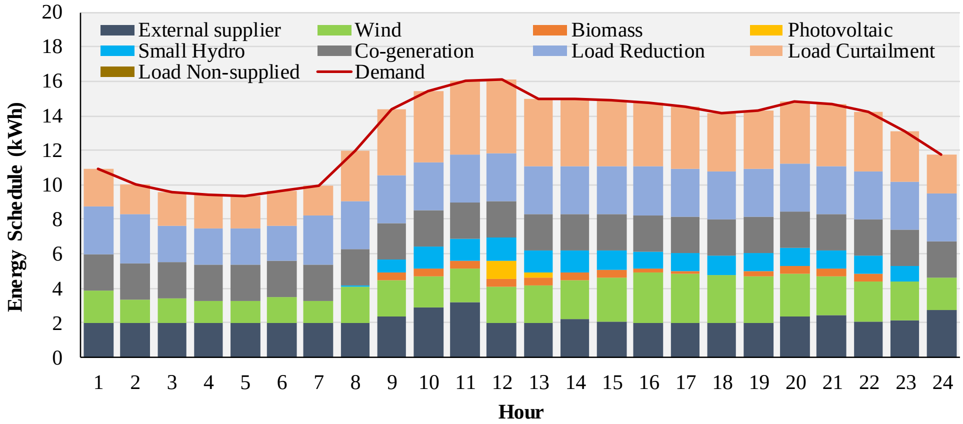

Fig. 3: Initial scheduling of resources.

Following the first scheduling of resources, Fig. 3, only the resources that participated in this scheduling are considered further in the clustering, such that the non-participants do not influence the group tariff obtained.

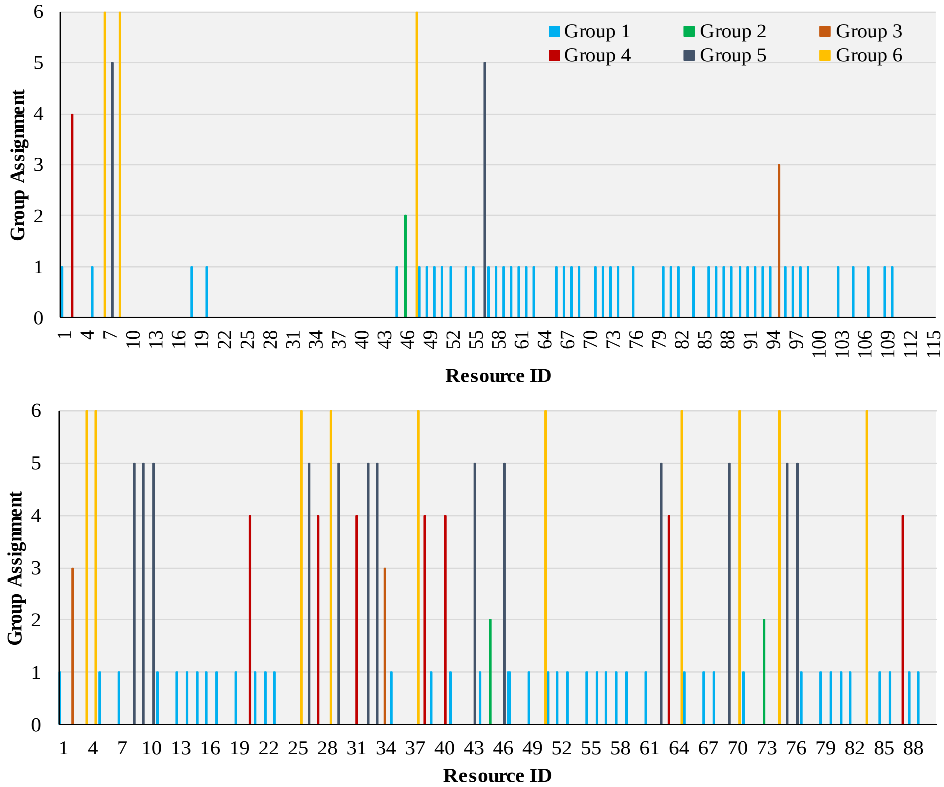

Fig. 4: Group assignment for each resource, in period 12 – Upper for DG, Lower for DR.

In Fig. 4, it is presented the group assignment obtained for each resource in period 12, considering that the non-participants are shown with a group assignment equal to zero. One can also see that the majority of the participant resources are clustered into group 1, due to their energy capacity and respective schedule. In Table 2, it is presented the obtained results for the clustering in a summarized form for each of the groups, namely, the energy schedule, group tariff obtained, and number of resources. In period 12, only 59 of the 116 distributed generators participated in the scheduling and therefore were clustered into six groups. The group tariffs will now be applied to the resources belonging to the respective group, in the new scheduling.

Table 2. Results for the clustering in period 12.

		Group energy (kWh)	Group tariff (m.u./kWh)	nº of Resources	Group energy (kWh)	Group tariff (m.u./kWh)	nº of Resources
Group Number	1	1,0247	0,0975	51	1,7415	0,1000	41
	2	1,3768	0,1014	1	0,7875		2
	3	2,1000	0,0796	1	0,6229		2
	4	0,4500	0,1231	1	1,4188		7
	5	1,8239	0,1262	2	1,6441		13
	6	0,2924	0,1162	3	0,8268		10
Total		**7,0678**	**-**	**59**	**7,0415**	**-**	**75**

With these results, the cost reduction regarding the first scheduling is around 4,22%, considering that in the second schedule the group prices obtained in the clustering are applied to the schedule participants – the new schedule is as presented by Fig. 5. The figure reveals an increase of use of photovoltaic units, when comparing with Fig. 3.

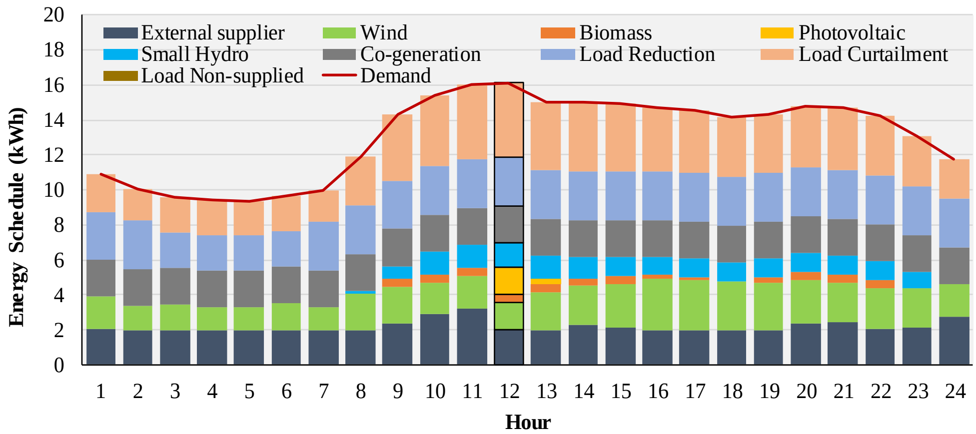

Fig. 5: Final scheduling of resources, for period 12.

5. Conclusions

The present paper addresses a rescheduling model for the aggregator's operation, considering distributed generators and demand response providers. Considering that the aggregator performs clustering processes to evaluate its market participation, this can also be used to identify resources that can become cheaper when approached with a group tariff, facilitating therefore their participation into a scheduling. The proposed methodology obtains a rescheduling of resources considering group tariffs, giving possibility to the aggregator to choose between market participation or resources scheduling in isolation mode, resembling a microgrid's operation.

The results obtained show that the aggregator, by using clustering and group tariffs to address several resources, can indeed reduce its operation costs, through an efficient use of resources potential under different operating conditions. As mentioned before, in case of more profit is obtained, the aggregator can choose to participate in energy markets, such that the groups and respective tariffs are already computed, facilitating in this way another one of the activities of the aggregator's interest.

Acknowledgements. The present work was done and funded in the scope of the following projects: H2020 DREAM-GO Project (Marie Sklodowska-Curie grant agreement No 641794); EUREKA - ITEA2 Project SEAS with project number 12004; NETEFFICITY Project (P2020 - 18015); and UID/EEA/00760/2013 funded by FEDER Funds through COMPETE program and by National Funds through FCT.

References

[1] P. Ringler, D. Keles, and W. Fichtner, "How to benefit from a common European electricity market design," *Energy Policy*, vol. 101, pp. 629–643, 2017.

[2] E. Erdogdu, "Implications of liberalization policies on government support to R&D: Lessons from electricity markets," *Renew. Sustain. Energy Rev.*, vol. 17, pp. 110–118, 2013.

[3] R. Müller, M. Steinert, and S. Teufel, "Successful diversification strategies of electricity companies: An explorative empirical study on the success of different diversification strategies of German electricity companies in the wake of the European market liberalization," *Energy Policy*, vol. 36, no. 1, pp. 398–412, 2008.

[4] V. Grimm, A. Martin, M. Schmidt, M. Weibelzahl, and G. Zöttl, "Transmission and generation investment in electricity markets: The effects of market splitting and network fee regimes," *Eur. J. Oper. Res.*, vol. 254, no. 2, pp. 493–509, 2016.

[5] SEDC, "A Demand Response Action Plan For Europe. Regulatory requirements and market models.," 2013, Available: .

[6] H. C. Gils, "Assessment of the theoretical demand response potential in Europe," *Energy*, vol. 67, pp. 1–18, 2014.

[7] Federal Energy Regulatory Commission, "Assessment of Demand Response & Advanced Metering," 2011, Available: .

[8] S. Parhizi, H. Lotfi, A. Khodaei, and S. Bahramirad, "State of the Art in Research on Microgrids: A Review," *IEEE Access*, vol. 3. pp. 890–925, 2015, Available: .

[9] P. Ringler, D. Keles, and W. Fichtner, "Agent-based modelling and simulation of smart electricity grids and markets - A literature review," *Renew. Sustain. Energy Rev.*, vol. 57, pp. 205–215, 2016.

[10] M. L. Tuballa and M. L. Abundo, "A review of the development of Smart Grid technologies," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 710–725, 2016.

[11] W. L. Theo, J. S. Lim, W. S. Ho, H. Hashim, and C. T. Lee, "Review of distributed generation (DG) system planning and optimisation techniques: Comparison of numerical and mathematical modelling methods," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 531–573, 2017.

[12] A. Rezaee Jordehi, "Allocation of distributed generation units in electric power systems: A review," *Renew. Sustain. Energy Rev.*, vol. 56, pp. 893–905, 2016.

[13] H. Morais, P. Faria, and Z. Vale, "Demand response design and use based on network locational marginal prices," *Int. J. Electr. Power Energy Syst.*, vol. 61, pp. 180–191, 2014.

[14] M. Behrangrad, "A review of demand side management business models in the electricity market," *Renew. Sustain. Energy Rev.*, vol. 47, pp. 270–283, 2015.

[15] P. Faria, J. Spínola, and Z. Vale, "Aggregation and Remuneration of Electricity Consumers and Producers for the Definition of Demand-Response Programs," *IEEE Transactions on Industrial Informatics*, vol. 12, no. 3. pp. 952–961, 2016, Available: .

[16] S. M. Nosratabadi, R.-A. Hooshmand, and E. Gholipour, "A comprehensive review on microgrid and virtual power plant concepts employed for distributed energy resources scheduling in power systems," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 341–363, 2017.

[17] P. H. J. Nardelli, M. de Castro Tomé, H. Alves, C. H. M. de Lima, and M. Latva-aho, "Maximizing the link throughput between smart meters and aggregators as secondary users under power and outage constraints," *Ad Hoc Networks*, vol. 41, pp. 57–68, 2016.

[18] N. Mahmoudi, E. Heydarian-Forushani, M. Shafie-khah, T. K. Saha, M. E. H. Golshan, and P. Siano, "A bottom-up approach for demand response aggregators' participation in electricity markets," *Electr. Power Syst. Res.*, vol. 143, pp. 121–129, 2017.

[19] M. Heleno, M. A. Matos, and J. A. P. Lopes, "A bottom-up approach to leverage the participation of residential aggregators in reserve services markets," *Electr. Power Syst. Res.*, vol. 136, pp. 425–433, 2016.

[20] S. Rahnama, S. E. Shafiei, J. Stoustrup, H. Rasmussen, and J. Bendtsen, "Evaluation of Aggregators for Integration of Large-scale Consumers in Smart Grid," *IFAC Proc. Vol.*, vol. 47, no. 3, pp. 1879–1885, 2014.

[21] N. Mahmoudi, T. K. Saha, and M. Eghbal, "Modelling demand response aggregator behavior in wind power offering strategies," *Appl. Energy*, vol. 133, pp. 347–355, 2014.

[22] R. J. Bessa and M. A. Matos, "Optimization models for an EV aggregator selling secondary reserve in the electricity market," *Electr. Power Syst. Res.*, vol. 106, pp. 36–50, 2014.

[23] M. Alipour, B. Mohammadi-Ivatloo, M. Moradi-Dalvand, and K. Zare, "Stochastic scheduling of aggregators of plug-in electric vehicles for participation in energy and ancillary service markets," *Energy*, vol. 118, pp. 1168–1179, 2017.

[24] R. Xu and D. Wunsch, "Survey of clustering algorithms," *IEEE Trans. Neural Networks*, vol. 16, no. 3, pp. 645–678, 2005.

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A Case Study for a Smart City Energy Management Resources

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Abstract

A physical smart city model environment is used to presents the demonstration of an energy resources management approach. The demand for smart cities has been created by several factors from the governments, society and industry. Thus, smart grids focus on the intelligent management of energy resources in order to maximize the usage of the energy from renewable sources in order to the final consumers feel the positive effects of less expensive (and pollutant) energy sources, namely in their energy bills. A large amount of work is being developed in the energy resources management domain, but an effective and realistic experimentation are still missing. This paper presents a realistic and physical experimentation of the energy resource management. This is done by using a physical smart city model, which includes several consumers, generation units, and electric vehicles.

Keywords: energy resource management, optimization, physical models, smart cities, smart grids

1. Introduction

Smart cities are one of the trending topics in the global research agenda. A smart city concept is the combination of ICT solutions, government policies and society involvement. As defined by the IEEE Smart Cities group a smart city has the following characteristics [1]: a smart economy, smart mobility, a smart environment, smart people, smart living and smart governance.

With the increasing population and urbanization, the availability of natural resources will be significant problem. Based on BSI Study [2], today cities are occupied by 51% of population, but consume 80% of the resources. The accelerating growth of cities and their disproportionate consumption of physical and social resources is addressed by the United Nations to be the greatest challenge.

The European Union (EU) is mostly concerned about the eventual fuel based primary source shortage, and hence the impact of electricity use in the environment is presently taken as very serious at scientific, economic and politic levels [3]. These concerns have led to intensive research and to new energy policies envisaging the increased use of renewable energy sources for electricity production and increased energy use efficiency. The EU has, in fact, assumed a pioneer and leading role in energy matters, namely in what concerns the increase of renewable energy sources. EU as a whole has committed to reach its 20% renewable energy target for 2020. [4]. Moreover, in 23 October 2014, EU leaders agreed on setting a revised target for increasing the share of renewable based energy to at least 27% of the EU's energy consumption by 2030 [5]. The EU presents even more ambitious targets for 2050, with the commitment to reduce emissions to 80-95% below 1990 levels [6].

Such ambitions targets demand that energy resources are managed in a completely different way from what was usual so far. In this scope, the Smart Grid (SG) paradigm arises, as the most commonly accepted solution for this problem [3]. The distributed management approach supported by SG boosts the emergence of several innovative energy resource management approaches. The penetration of a large number of electric vehicles is one of the most important topics in this domain, due to the large dimensionality that it brings to the optimization problem. This problem is usually solved using meta-heuristics, namely with simulated annealing in [7] and with a novel multi-dimensional signaling method, in [8], just to name a few. A solid survey on this theme, with an overview of different angles to address this problem can be consulted in [9]. The impact of different sources of uncertainty is also broadly explored, such as the work presented in [10]. Although a significant amount of work is being done in this domain, the large majority of the performed studies are conducted solely under simulated environmental settings. This is mostly because SG are still an emerging reality, and thus, practical implementations are still not sufficiently widely spread. Even when considering the real implementations that are available, the execution of innovative experimental studies is difficult, because of the implications on the several users that are present in the real environment.

In order to surpass these hurdles, this paper presents an experimental study of an innovative energy resources management approach, in a smart city environment, using a laboratorial physical model of the city. The considered model is located in a BISITE laboratory, and departs from a previous implementation, done in collaboration with IBM as a product for Vodafone. This model has been developed to show how their real services work. So different requirements about the communication protocol have been set (MQTT messages with a specific frequency and format) in order to be integrated with their IOC software [11]. These models have already allowed the demonstration of a large range of different studies, namely: waste trucks routing optimization, home care, public lighting services, and something that involves the participation of the citizens. The model has been updated to include energy generation systems like solar panels and wind energy generators, so as to allow being used for the demonstration of energy management resources on the scope of the DREAM-GO project [12], and more specifically, the work presented in this paper.

After this introductory section, section II presents the proposed energy resources management optimization model. Section III presents the case study using a real model of a Smart City and the results are presented in Section IV. Finally, in Section V, the most relevant conclusions are presented.

2. Proposed Method

The proposed method deals with the optimal scheduling of the available resources in a Smart City (SC) context. The optimization model considers the energy sold or purchased from the external suppliers or from the electricity market. The Smart City Operator (SCO) that acts in behalf of its consumers, will sell or buy electrical energy taking into account the available resources. 24 periods of the day-ahead scheduling are used in the proposed method. The diagram of the proposed method is depicted in Fig. 1.

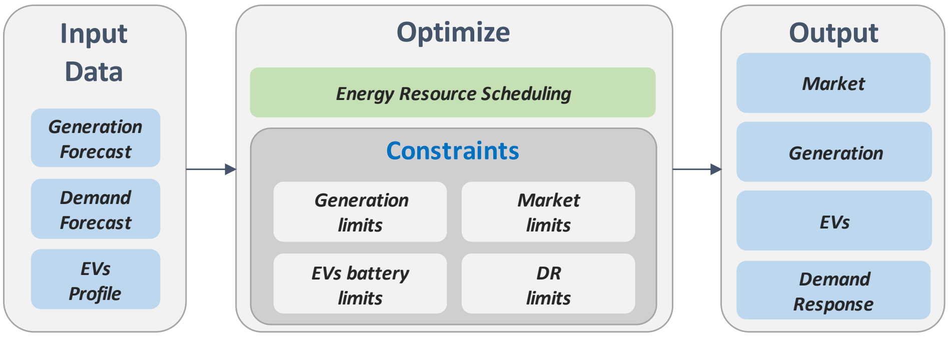

Fig. 1. Proposed method diagram

The objective function for this problem, defined as in (1), aims at minimizing the operation cost of the SC, thus optimizing the use of generation, the charge of electric vehicles, the application of demand response, and transactions with external entities, in order to assure the supply of energy to consumers. The constraints of the proposed method are presented as follows. Equations (3), (6) and (7) present the EV technical limits for each period t. The generation units' limits are described by equations (4) and (5).

$$Min\ OC = \sum_{t=1}^{T}\sum_{b=1}^{B}\left[\begin{array}{l} \sum_{sp=1}^{SP} P_{(sp,b,t)}^{Main}\cdot C_{(sp,b,t)}^{Main} - \sum_{m=1}^{M} P_{(m,b)}^{Market}\cdot C_{(m,b)}^{Market} + \sum_{v=1}^{V}\left(P_{(v,b,t)}^{EV\_Dsc}\cdot C_{(v,b,t)}^{EV\_Dsc}\right) \\ +\sum_{g=1}^{G}\left[\begin{array}{l}\left(P_{(g,b,t)}^{Gen}\right)^2\cdot C_{(g,b,t)}^{Gen\_A} + P_{(g,b,t)}^{Gen}\cdot C_{(g,b,t)}^{Gen\_B} \\ +C_{(g,b,t)}^{Gen\_C}\cdot X_{(g,b,t)}^{Gen} + P_{(g,b,t)}^{EAP}\cdot C_{(g,b,t)}^{EAP}\end{array}\right] + \sum_{c=1}^{C} P_{(c,b,t)}^{NSD}\cdot C_{(c,b,t)}^{NSD}\end{array}\right] \tag{1}$$

2.1. Equality constraints

- Power balance in each period t and in each bus b.

$$\begin{aligned} &\sum_{sp=1}^{SP} P_{(sp,b,t)}^{Main} + \sum_{g=1}^{G}\left(P_{(g,b,t)}^{Gen} - P_{(g,b,t)}^{EAP}\right) - \sum_{m=1}^{M} P_{(m,b)}^{Market} \\ &-\sum_{c=1}^{C} P_{(c,b,t)}^{Demand} + \sum_{v=1}^{V}\left(P_{(v,b,t)}^{EV\_Dsc} - P_{(v,b,t)}^{EV\_Ch}\right) = 0 \\ &\forall t\in\{1,...,T\}, \forall b\in\{1,...,B\}, \forall m\in\{1,...,M\}\end{aligned} \tag{2}$$

- EV battery balance determined by the energy remaining from the previous period, the trip demand and charge/discharge in the current period.

$$\begin{aligned} &E_{(v,b,t)}^{EV} = E_{(v,b,t-1)}^{EV} + P_{(v,b,t)}^{EV\_Ch}\times\Delta t\times\eta_{ch} - P_{(v,b,t)}^{EV\_Dsc}\times\Delta t\times\frac{1}{\eta_{Dch}} - E_{(v,t)}^{EV\_trip} \\ &\forall t\in\{1,...,T\}, \forall b\in\{1,...,B\}, \forall v\in\{1,...,V\}\end{aligned} \tag{3}$$

2.2. Inequality constraints

- Generation units limits in each period t.

$$\begin{aligned} &P_{(g,b,t)}^{MinGen} \le P_{(g,b,t)}^{Gen} \le P_{(g,b,t)}^{MaxGen} \\ &\forall t\in\{1,...,T\}, \forall b\in\{1,...,B\}, \forall g\in\{1,...,G\}\end{aligned} \tag{4}$$

- Main network supplier maximum limit in each period t.

$$\begin{aligned} &P_{(sp,b,t)}^{Main} \le P_{(sp,b,t)}^{MaxMain} \\ &\forall t\in\{1,...,T\}, \forall b\in\{1,...,B\}, \forall sp\in\{1,...,SP\}\end{aligned} \tag{5}$$

- Vehicle charge and discharge are not simultaneous.

$$\begin{aligned} &X_{(v,b,t)}^{EV} + Y_{(v,b,t)}^{EV} \le 1 \\ &\forall t\in\{1,...,T\}, \forall b\in\{1,...,B\}, \forall v\in\{1,...,V\},\ X_{(v,b,t)}^{EV}, Y_{(v,b,t)}^{EV}\in\{0,1\}\end{aligned} \tag{6}$$

- Charge and discharge limit for each storage unit considering the battery charge rate and battery balance.

$$\begin{aligned} &P_{(v,b,t)}^{EV\_Ch} \le P_{(v,b,t)}^{MaxEV\_Ch}\times Y_{(v,b,t)}^{EV} \\ &P_{(v,b,t)}^{EV\_Dsc} \le P_{(v,b,t)}^{MaxEV\_Dsc}\times X_{(v,b,t)}^{EV} \\ &P_{(v,b,t)}^{EV\_Dsc}\times\Delta t \le E_{(v,b,t-1)}^{EV} \\ &P_{(v,b,t)}^{EV\_Ch}\times\Delta t \le E_{(v,b)}^{EV} - E_{(v,b,t-1)}^{EV} \\ &\forall t\in\{1,...,T\}, \forall b\in\{1,...,B\}, \forall v\in\{1,...,V\}\end{aligned} \tag{7}$$

3. Case Study

The following case study demonstrates the use of the proposed methodology. The SC has 14 buses as can be seen in the one-line diagram presented in Fig. 2. Fig. 3 shows the real model of the Smart City. The SC distribution power network has 15kV with one feeder. As can be seen the network is completely meshed but radiality operated. The SC includes:

- 1 shopping mall – installed power: 1,500kW;
- 1 hospital – installed power: 800kW;
- 1 fire station – installed power: 600kW;
- 15 individual houses – installed power: 190kW;
- 7 office buildings: installed power: 555kW;
- 3 EVs – 2 cars (25kW each) and 1 waste truck (250kW);
- 1 wind farm (2 wind generators with 1,000kW each);
- 1 PV power station (2 PV units with 250kW each);
- 1 waste to energy power station (500kW);
- 1 power plant (external supplier – 5,000kW);
- 5 PV panels for individual houses (3.68kW each);
- 7 PV panels for office buildings (11.04kW each).

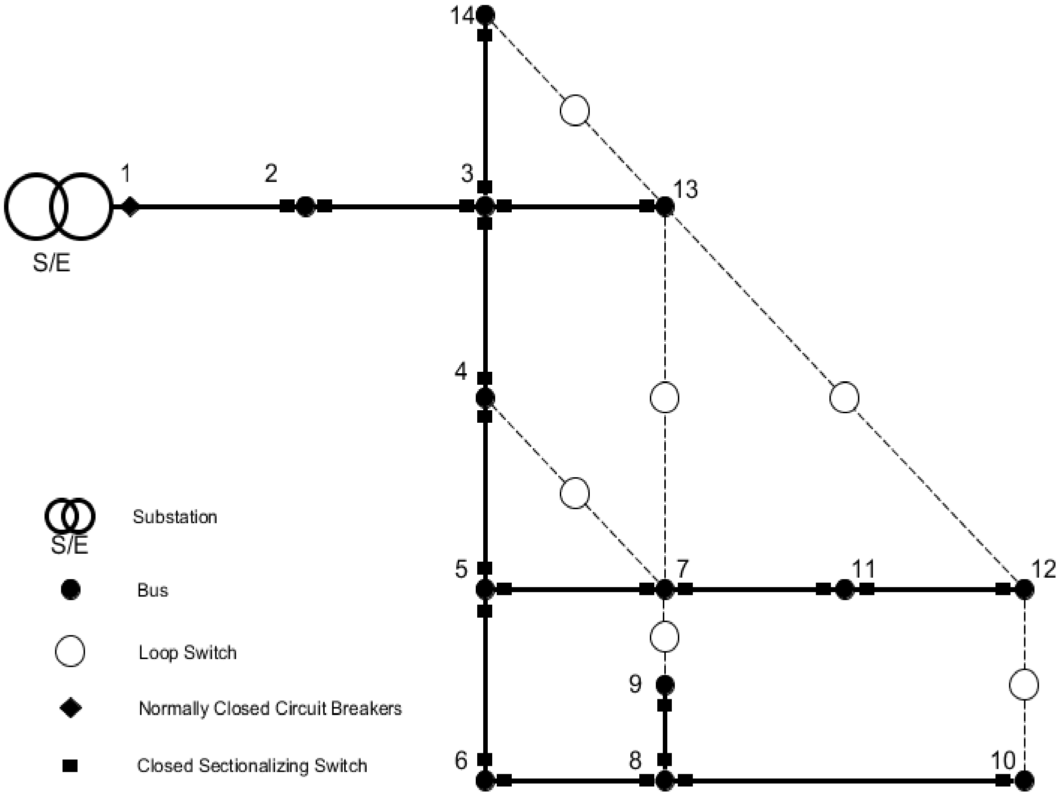

Fig. 2. Smart City one-line diagram

The present case study allows the use of incentive-based demand response programs in all loads with exception of the hospital and fire station. This program pays participating customers to reduce their load at maximum until 20% of the initial load. The incite value is 0.09 m.u./kW. For the period 1, the two EV cars are located in bus 4 and the waste truck in the bus 3. Table 1 shows the location of each building type in the Smart City.

The considered prices are 0.02 m.u./kW for PV, 0.09 m.u./kW for wind power, 0.04 m.u./kW for waste-to-energy power, 0.10 m.u./kW for the external supplier and 0.15 m.u./kW for V2G discharge. Charge of V2G is considered 0.13 m.u./kW. The initial state for vehicles was considered randomly in the beginning of the day.

Fig. 3. Smart City model

Table 1. Smart city building type location.

Bus	Building Type
1	External supplier
2	Wind farm
3	PV power station
4	Individual Houses
5	Waste to energy power station
6-12	Office buildings
13	Shopping mall
14	Hospital
14	Fire station

Fig. 4 presents the forecasted power demand for each type of building as well as the solar and wind generation profile in the SC, not considering the EVs load. It can be seen that the peak load is expected at afternoon periods due to the great contribution of shopping mall, hospital and office buildings. Fig. 5 shows the forecasted EVs' trip demand in kWh. The tool presented in [13] was used to generate the scenarios. Most trips occur at due to a great contribution of the waste truck.

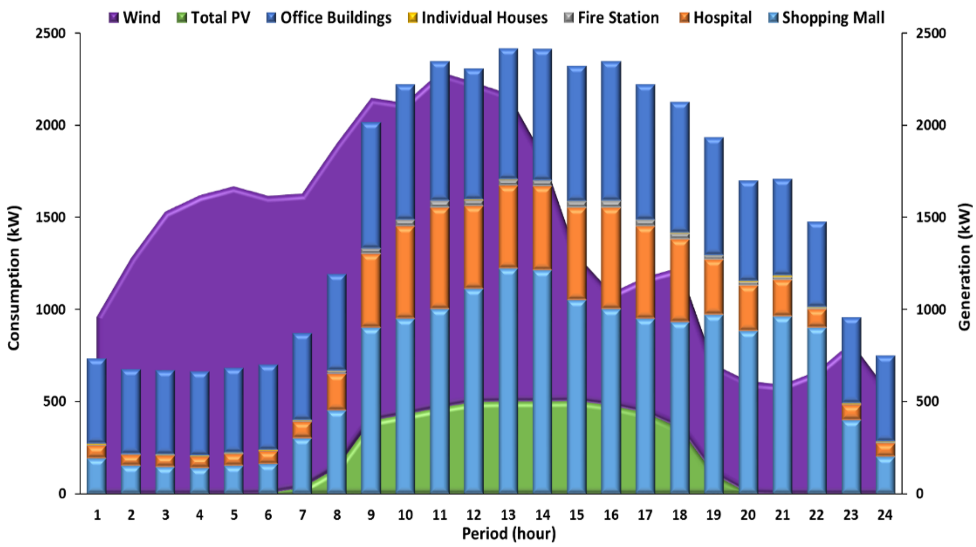

Fig. 4. Forecasted load consumption (by type), PV and wind power profile.

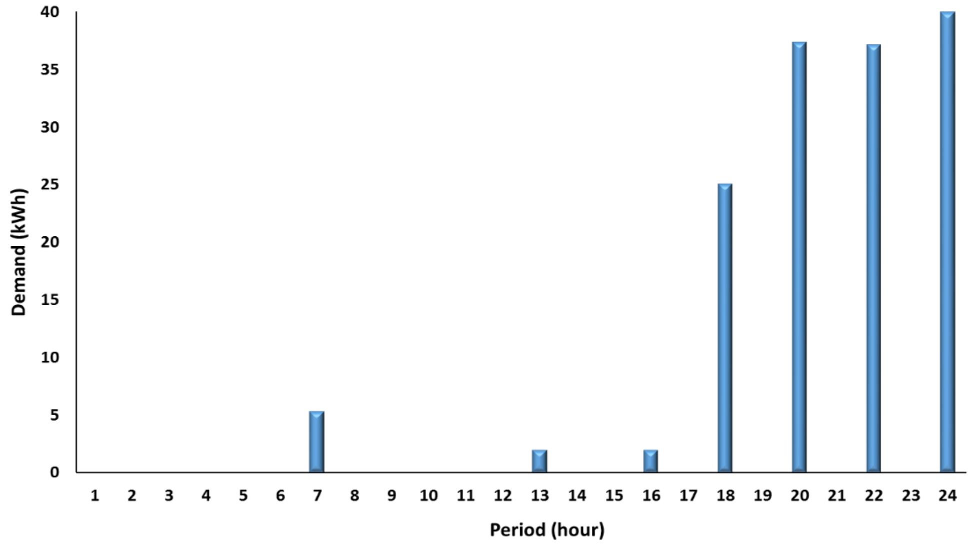

Fig. 5. Forecast for EVs trip demand

4. Results

The optimization method and simulations were performed in MATLAB 2014a 64-bit using the TOMLAB software [14]. A computer with one processor Intel Xeon E5-2620v2 2.10 GHz with twelve cores, 16 GB of random access memory, and Windows 10 Professional 64-bit operating system was used.

In order to compute the proposed method, the algorithm took around 0.65 seconds. The result of the objective function, i.e., the final cost is 30.12 m.u..

Fig. 6 presents the power supplied by the external supplier and the all distributed generators considered in the case study. It can also be seen the results for the energy sold to the market and the values for the total consumption. It is important to note that the total consumption considers also the EVs charge. These results are for the 24 periods under study. One can see that the external supplier is required at the beginning of the afternoon until the night. In these periods the DG power generation decreases and the demand remains higher. Also, it is possible to see that in early morning exists an excess of generation. Due to this, the model considered that there is an advantage to sell the remaining power to the market.

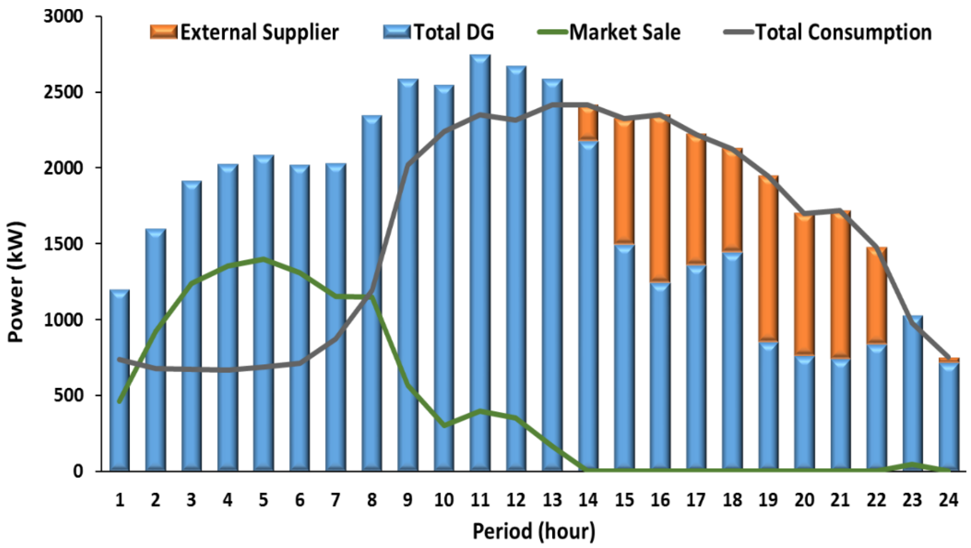

Fig. 6. Power supplied scheduling

As can be seen in Fig.7 the generation by wind power has the higher contribution to supply all the demand. The wind power and waste-to-energy power are supplying in all periods. The main reason is related to their cost when compared with external supplier. Additionally, for the wind power, it is considered having dispatchable power.

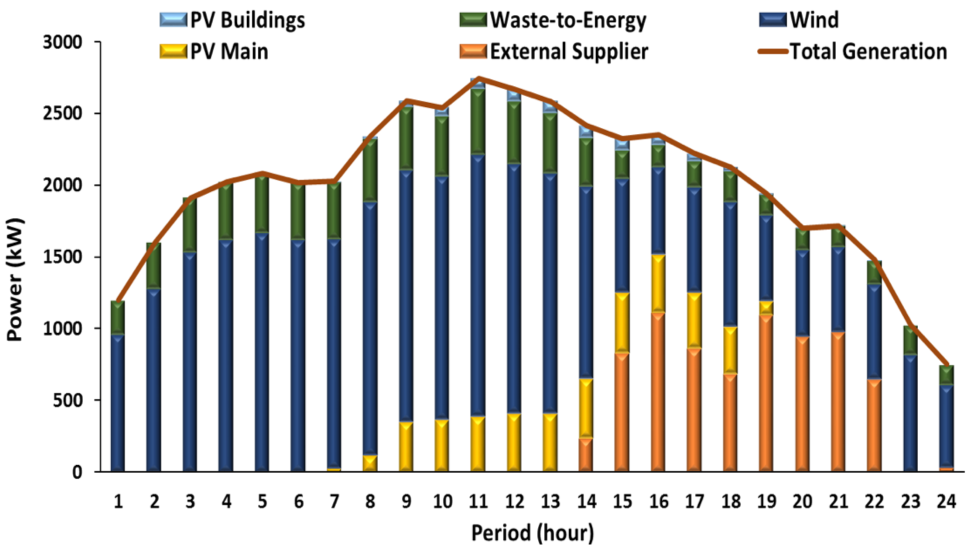

Fig. 7. Power supplied scheduling by generator type

Fig. 8 depicts the scheduling for demand response (in this case study is was considered only the reduction program) and for EVs. The demand response program is verified in periods 20, 21, 22. Table 2 shows the power reduced by the demand response program for the respective periods. Regarding to EVs scheduling it is only verified the charging and no discharging. It is possible to see in Fig. 8 that the EVs charging occurs in periods 5, 6, 10, 12, 19, 21 and 23.

Table 2. Load Reduction by Demand Response Program.

Period	Power (kW)
20	220.00
21	240.19
22	13.41

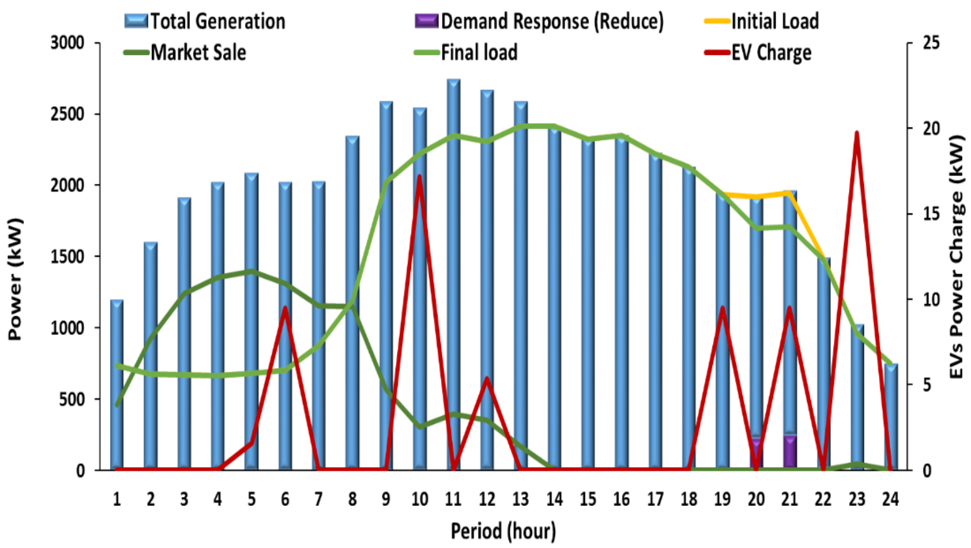

Fig. 8. Demand response and EV scheduling

5. Conclusions

This paper has presented a resource scheduling management approach applied to a physical smart city model environment. The Smart City Operator can use its resources at their optimal operating point while minimizing operation costs and obtaining more profit taking into account the several constraints associated with their resources and energy suppliers. This can be achieved with adequate resource scheduling algorithms a, such as the method proposed in this paper.

The proposed method proved to be adequate to support the Smart City Operator in the operation field which can lead to operation costs reduction. The experimentation in a realistic, physical modelling environment allows validating the applicability of this type of methods. In this way, one can actually observe what occurs in the diverse buildings, and study the influence of the management methods on the actual loads.

As future work, the inclusion of further assets in the physical modelled environment will be proposed, such as other generation units (namely cogeneration or even hydric power plant), in order to experiment the impacts of using the different types of generation in the scope of the smart city. Additionally, further management models will be experimented, namely concerning the reliability of the power network, and also the reconfiguration of the network in case of failure.

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References

[1] IEEE Smart Cities group website, available: http://smartcities.ieee.org/, accessed June 2016

[2] BSi report, "The Role of Standards in Smart Cities",issue 2, August 2014, available: http://www.bsigroup.com/LocalFiles/en-GB/smart-cities/resources/The-Role-of-Standards-in-Smart-Cities-Issue-2-August-2014.pdf, [accessed June 2016]

[3] Lund, H., "Renewable Energy Systems, Renewable Energy Systems – A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions", Academic Press, 2nd Edition, May 2014

[4] European Commission, "The 2020 climate and energy package", 2009, Available: http://ec.europa.eu/clima/policies/package/index_en.htm [accessed in June 2016]

[5] European Commission, "2030 framework for climate and energy policies", 2014, Available: http://ec.europa.eu/clima/policies/2030/index_en.htm [accessed in June 2016]

[6] European Commission, "A Roadmap for moving to a competitive low carbon economy in 2050", 2011, Available: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52011DC0112R(01) [accessed in June 2016]

[7] T. Sousa, Z. Vale, J. P. Carvalho, T. Pinto, and H. Morais, "A hybrid simulated annealing approach to handle energy resource management considering an intensive use of electric vehicles," Energy, vol. 67, pp. 81-96, 2014.

[8] Soares, J., Fotouhi Ghazvini, M.A., Silva, M., and Vale, Z. 2016. Multi-dimensional signaling method for population-based metaheuristics: Solving the large-scale scheduling problem in smart grids. Swarm and Evolutionary Computation.

[9] M. Iqbal, M. Azam, M. Naeem, A. Khwaja, and A. Anpalagan, "Optimization classification, algorithms and tools for renewable energy: A review," Renewable and Sustainable Energy Reviews, vol. 39, pp. 640-654, 2014.

[10] Conejo, A., Carrión, M., and Morales, J. 2010. Decision making under uncertainty in electricity markets. .

[11] Bisite,http://www-03.ibm.com/software/products/es/intelligent-operations-center [accessed in June 2016]

[12] Dream-go, http://www.dream-go.ipp.pt/ [accessed in June 2016]

[13] J. Soares, B. Canizes, C. Lobo, Z. Vale, and H. Morais, "Electric Vehicle Scenario Simulator Tool for Smart Grid Operators," Energies, vol. 5, pp. 1881-1899, Jun 2012.

[14] TOMLAB, http://tomopt.com/tomlab/ [accessed in June 2016]

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Real-time demand response and intelligent direct load control

Second DREAM-GO Workshop

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Building Management Model Considering Demand Response and Occupancy Data

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Abstract

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

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

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1. Introduction

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

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

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

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

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

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

2. Proposed Methodology

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

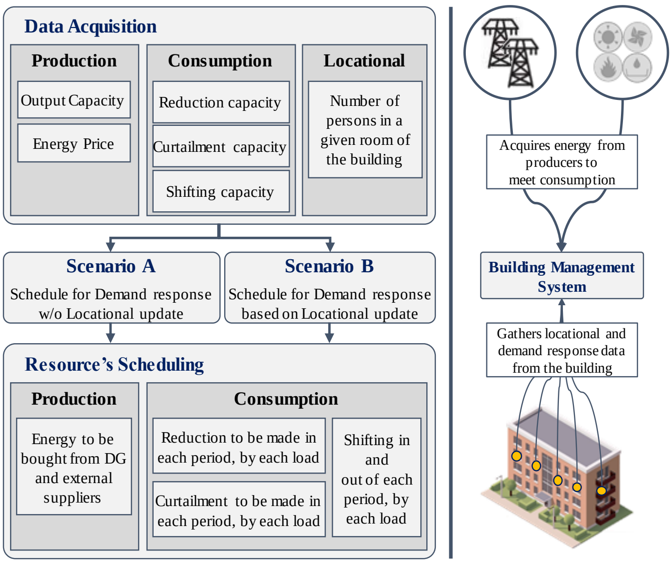

Fig. 1: Proposed methodology and implementation.

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

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

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

3. Mathematical Formulation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4. Case Study

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

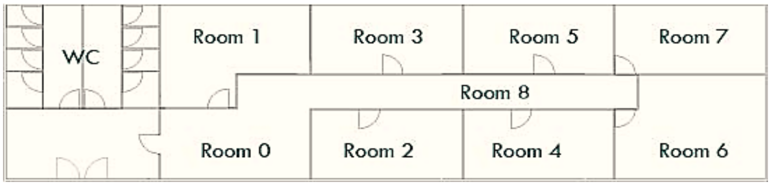

Fig. 2: Building plant and rooms designation.

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

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

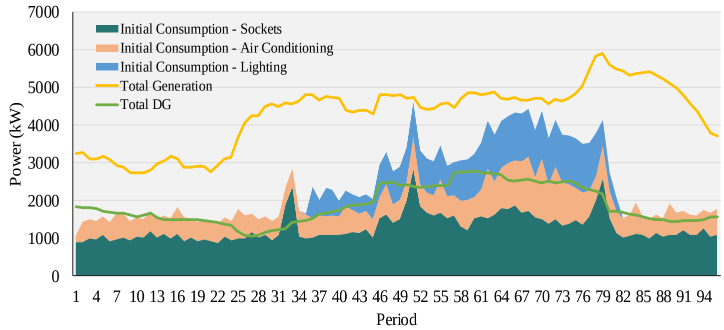

Fig. 3: Expected load consumption and available generation from producers and external suppliers.

Table 1. Resources' characteristics.

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

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

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

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

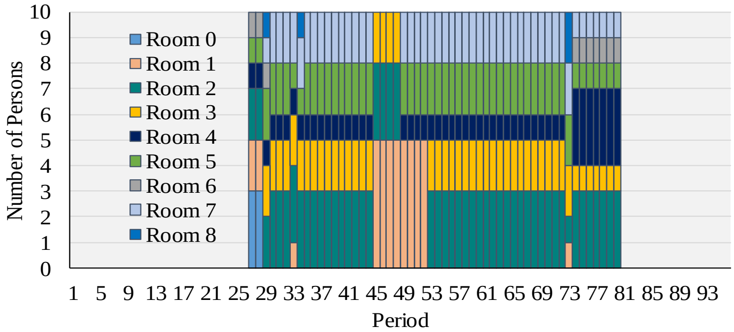

Fig. 4: Locational data data throughout the rooms, in the periods considered.

5. Results

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

A. Scheduling without Locational Data

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

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

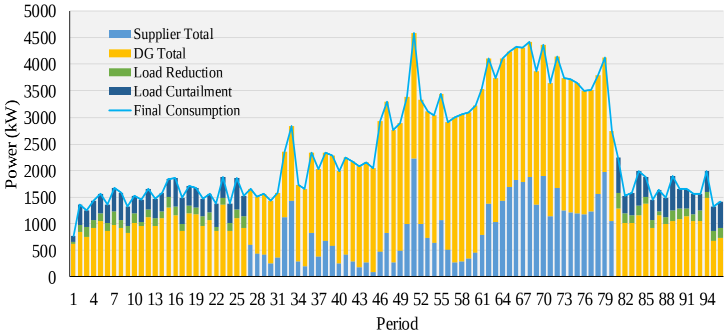

Fig. 5: Scheduling results for the consumer, in scenario A.

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

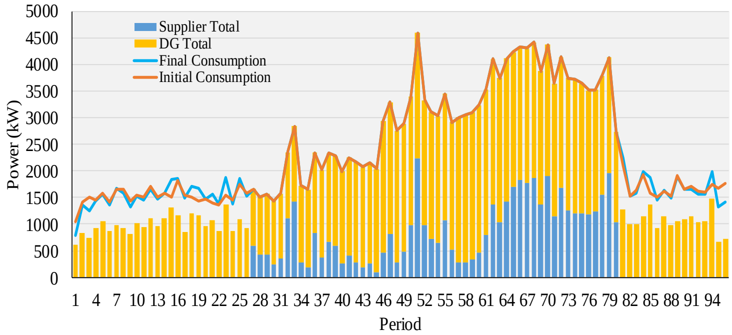

Fig. 6: Detail results for the consumer's final versus initial consumption, in scenario A.

B. Scheduling with Locational Data

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

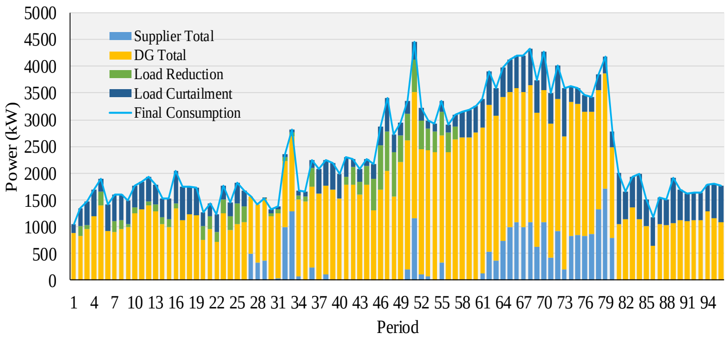

Fig. 7: Scheduling results for the consumer, in scenario B.

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

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

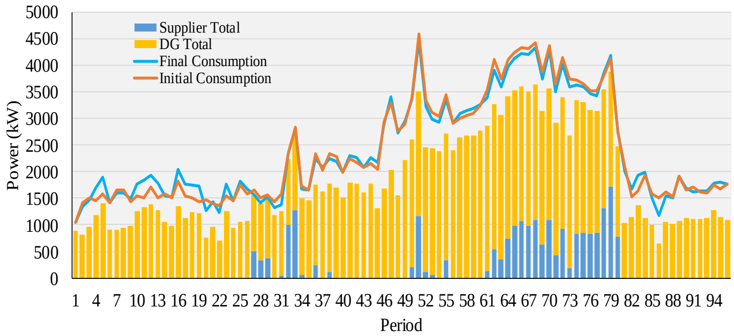

Fig. 8: Detail results for the consumer's final versus initial consumption, in scenario B.

C. Scenario Comparison & Analysis

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

Table 2. Scenarios' results summary.

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

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

6. Conclusions and Future Work

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

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

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

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References

[1] B. Sivaneasan, K. N. Kumar, K. T. Tan, and P. L. So, "Preemptive Demand Response Management for Buildings," *IEEE Transactions on Sustainable Energy*, vol. 6, no. 2. pp. 346–356, 2015.

[2] M. A. Piette, J. Granderson, M. Wetter, and S. Kiliccote, "Intelligent Building Energy Information and Control Systems for Low-Energy Operations and Optimal Demand Response," *IEEE Design & Test of Computers*, vol. 29, no. 4. pp. 8–16, 2012.

[3] T. Hubert and S. Grijalva, "Modeling for Residential Electricity Optimization in Dynamic Pricing Environments," *IEEE Transactions on Smart Grid*, vol. 3, no. 4. pp. 2224–2231, 2012.

[4] W. T. Li, C. Yuen, N. U. Hassan, W. Tushar, C. K. Wen, K. L. Wood, K. Hu, and X. Liu, "Demand Response Management for Residential Smart Grid: From Theory to Practice," *IEEE Access*, vol. 3. pp. 2431–2440, 2015.

[5] M. Muratori and G. Rizzoni, "Residential Demand Response: Dynamic Energy Management and Time-Varying Electricity Pricing," *IEEE Transactions on Power Systems*, vol. 31, no. 2. pp. 1108–1117, 2016.

[6] A. Safdarian, M. Fotuhi-Firuzabad, and M. Lehtonen, "Benefits of Demand Response on Operation of Distribution Networks: A Case Study," *IEEE Systems Journal*, vol. 10, no. 1. pp. 189–197, 2016.

[7] T. Borsche and G. Andersson, "A review of demand response business cases," *IEEE PES Innovative Smart Grid Technologies, Europe*. pp. 1–6, 2014.

[8] V. Pradhan, V. S. K. M. Balijepalli, and S. A. Khaparde, "An Effective Model for Demand Response Management Systems of Residential Electricity Consumers," *IEEE Systems Journal*, vol. 10, no. 2. pp. 434–445, 2016.

[9] Y. Wang, Q. Chen, C. Kang, M. Zhang, K. Wang, and Y. Zhao, "Load profiling and its application to demand response: A review," *Tsinghua Science and Technology*, vol. 20, no. 2. pp. 117–129, 2015.

[10] D. Zhang, S. Li, M. Sun, and Z. O’Neill, "An Optimal and Learning-Based Demand Response and Home Energy Management System," *IEEE Transactions on Smart Grid*, vol. 7, no. 4. pp. 1790–1801, 2016.

[11] P. Palensky and D. Dietrich, "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads," *IEEE Trans. Ind. Informatics*, vol. 7, no. 3, pp. 381–388, 2011.

[12] P. Faria, Z. Vale, and J. Baptista, "Constrained consumption shifting management in the distributed energy resources scheduling considering demand response," *Energy Convers. Manag.*, vol. 93, pp. 309–320, Mar. 2015.

[13] S. Mohagheghi and N. Raji, "Dynamic Demand Response : A Solution for Improved Energy Efficiency for Industrial Customers," *IEEE Industry Applications Magazine*, vol. 21, no. 2. pp. 54–62, 2015.

[14] D. He, W. Lin, N. Liu, R. G. Harley, and T. G. Habetler, "Incorporating Non-Intrusive Load Monitoring Into Building Level Demand Response," *IEEE Transactions on Smart Grid*, vol. 4, no. 4. pp. 1870–1877, 2013.

[15] A. Ouammi, "Optimal Power Scheduling for a Cooperative Network of Smart Residential Buildings," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 3. pp. 1317–1326, 2016.

[16] J. L. Mathieu, P. N. Price, S. Kiliccote, and M. A. Piette, "Quantifying Changes in Building Electricity Use, With Application to Demand Response," *IEEE Transactions on Smart Grid*, vol. 2, no. 3. pp. 507–518, 2011.

[17] Y. t. Lee, W. h. Hsiao, C. m. Huang, and S. c. T. Chou, "An integrated cloud-based smart home management system with community hierarchy," *IEEE Transactions on Consumer Electronics*, vol. 62, no. 1. pp. 1–9, 2016.

[18] J. Pan, R. Jain, S. Paul, T. Vu, A. Saifullah, and M. Sha, "An Internet of Things Framework for Smart Energy in Buildings: Designs, Prototype, and Experiments," *IEEE Internet of Things Journal*, vol. 2, no. 6. pp. 527–537, 2015.

[19] V. Moreno, M. A. Zamora, and A. F. Skarmeta, "A Low-Cost Indoor Localization System for Energy Sustainability in Smart Buildings," *IEEE Sensors Journal*, vol. 16, no. 9. pp. 3246–3262, 2016.

[20] T. Weng and Y. Agarwal, "From Buildings to Smart Buildings - Sensing and Actuation to Improve Energy Efficiency," *IEEE Design & Test of Computers*, vol. 29, no. 4. pp. 36–44, 2012.

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Application of Artificial Immune System to Domestic Energy Management Problem

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Abstract

Devices connected in smart homes needs to be optimally scheduled, in order to save energy and money. There are different optimization models applied, based on fuzzy logic, linear programming or bioinspired algorithms. Here, we aim to apply an artificial immune system to solve an electric manage- ment problem in domestic environments. We carry out a deep analysis about the parameters of the artificial immune system to demonstrate it is able to find a successful optimum respecting the problem constraints.

Keywords: energy management problem, artificial immune system, optimization

1. Introduction

Domestic buildings with linked devices via communications channels are commonly termed smart homes [1]. These constitute the building blocks or prosumers (i.e. both consumers and producers) in smart grids (SGs), and have an important role in the optimization of electrical energy scheduling [1][2]. Hence, Domestic Energy Management System (DEMS) is necessary for achieving an economic improvement through automation technologies.

Various researches have been conducted for optimal scheduling of home energy, and different algorithms and methods have been presented. In [3], the Domestic Energy Management (DEM) problem has been solved by modelling the controllable loads and the loads that depend on weather conditions. In the proposed method of [4], demand response (DR) program has been applied automatically on the controllers to use and control the appliances under uncertainty of outdoor temperature and electricity price. In [5], three methods of DEM have been shown to reduce the domestic energy costs in the time-varying electricity price market. These methods are based on the partially observable Markov decision process. An energy service modeling method is addressed in [6]. Finally, the Particle Swarm Optimization (PSO) method has been used to solve the optimization problem in [6].

However, some works take a different path and explore the optimization mechanisms inspired by the biological immune system. The artificial immune system (AIS) proposed by [7] aims to give solution to a specific problem using a mutation operator that depends on the quality of the individuals (i.e. solutions) created. This is an improvement over the classical genetic algorithm, where the mutation parameters are fixed.

Artificial Immune Systems are applied in different contexts. For instance, a version of AIS has been developed to solve combinatorial problems [8][9]. In [10] the authors present an AIS to detect intrusions in wireless sensor networks. A recent version of opt-aiNet is used to generate chord progressions [11]. There are some preliminary achievements in energy management, such as the energy dispatch problem-solving [12], or electrical reconfigurations [13]. In [14] an AIS is used to control thermal units at residential buildings and in [15] the authors optimize a wind-thermal generating system also with an AIS.

In this paper, we present an AIS based method to optimize a domestic energy management problem. We demonstrate that AIS can be successfully applied for electric management problems in microgrids or domestic environments. Among the different AIS variants, we selected Opt-aiNet [16], which has been used for function optimization successfully [16] in different contexts. The working flow of an AIS and its corresponding mutation operators design allows to find multiple optima if they exist. Thus, in this work we show how an AIS can be used to solve efficiently a power system optimization problem. To this end, we have adapted the opt-aiNet algorithm to include complex constraints in the optimization problem and to work with a large number of variables efficiently.

This paper is structured as follows. Section 2 presents an overview of the AIS structure and design. Section 3 describes the technical details of the electrical problem addressed herein. The selected AIS is applied to the electrical problem in Section 4. Finally, the conclusions from our research are presented in Section 5.

2. Artificial Immune Systems

Bioinspired algorithms are capable of solving different research problems. They imitate biological behavior to find solutions, otherwise too expensive to be obtained through classical computing in terms of time and resources. Among them, artificial neural networks, genetic algorithms and swarm intelligence are widely known [17].

In [18] the authors present the *CLONALG* algorithm, a clonal selection procedure to perform pattern recognition. This algorithm allows to mutate some individuals according to their affinity to an antigen. To do so, it generates copies of the individuals according to their affinity with the antigen. The copies are mutated with a rate inversely proportional to their affinity with the antigen. This new individuals are added to the general population and re-evaluated to be reproduced and mutated again. Thus, based upon an evolutionary-like behavior, *CLONALG* learns how to recognize patterns [18].

From the available optimization algorithms, we developed a new formulation based on the [16] work, called opt-aiNet. The information provided is represented through the antigens to be recognized by the antibodies. We define fitness as the affinity between the antigen and the antibody. Hence, high fitness values reflect high affinity. Also, fitness can be compared with a distance metric between antigen and antibody. Small distances represent high affinity, while long distances mean low affinity.

The most important features of opt-aiNet are:

- Its ability to find several optima of the objective function in parallel while preserving diversity of the solutions. This means that opt-aiNet can find a set of good candidates for the solution of the optimization problem that are different from one another.
- Its memory to preserve those individuals that are good enough to be reproduced and mutated in consecutive iterations

Opt-aiNet has been prepared to optimize functions with no constraints and with a low number of variables. In our case, the AIS was tested with 336 variables and we improved it to admit linear constraints too.

3. Electric System

The objective function is to maximize the profit of energy services provided in a domestic energy management system. The overall system includes:

- *PV System*

- *Electrical Loads: Electrical loads can be controllable and/or shiftable, or not. The power and energy consumed must be limited by the electrical loads.*
- *Battery System:* Battery system can be utilized based on the charge and discharge strategies in the domestic energy management system. Based on this strategy, the main purpose of the system is to provide the domestic electrical demand locally. In this case, the surplus of the PV power generation is stored in the battery. Then, the domestic energy management system will sell the power to the grid if the battery is charged completely. On the other hand, the battery system is going to the discharging mode if the electrical demand is more the power generation of the PV.

4. Results

To assess the performance of the proposed DEMS, the physical system from [6] is applied. However, some modifications of the system parameters are made. The maximum energy 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 (23˚C). The thermal resistance of the building shell is equal to 18˚C/kW, and C equals 0.525 kWh/˚C. The energy capacity of the Storage Water Heater (SWH) is 10.46 kWh (180 L) which has 2 kW heating element. With these fixed parameters set, we made a comparison of different case studies, as we explained in the previous section, considering the battery device or not.

AIS needs some parameters to be set in order to optimize a problem correctly. These variables are related to the clonation and mutation process: the suppression algorithm and the convergence criterion. For each iteration, a number of clones N_c are generated per each cell. This number N_c is set manually by the user, and can influence the final results. Generally, if we set N_c with a very low value, we can delay the convergence criterion, as we are not able to 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.

The mutation process depends on mutation constant β which measures the influence that the fitness value can have to mutate the different clones. If β is set to a very high value, the individuals can be randomly mutated, as the fitness values are not influenced the mutation process. Otherwise, if β is very low the individuals are very strongly mutated, which can be biased our final results.

The suppression constant t_s is related to the minimum value for similarity between two individuals. If it is set to a very low value, the list of similar individuals can be very 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 give a false convergence upon a false optimum value.

Finally, the convergence criterion depends on the number of maximum iterations *gen* and the population N . If we set a few iterations or 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.

Given both scenarios, we measure how the most important parameters of the AIS can influence the optimization process considering the time elapsed to find the optima and the maximum fitness value found, and adjust them to obtain the best results.

Figure 2 collects the time and optima results for each parameter not considering the battery (Case Study I). Additionally, Figure 3 plots the time and optima results for parameters in the second case study, considering the battery flowchart. In both cases, we need to find a balance between time and fitness, in order to obtain and optimum system.

In both cases, N oscillates between 10 and 350, and N_c between 4 and 20. The maximum number of generation is set between 10 and 500. The suppression and mutation parameters depends on the fitness values, so they would be adjusted to the range of fitness values retrieved. Therefore, in Case Study I t_s changes from 5 to 20 and β takes values from 0 to 100, while in Case Study II, ts goes from 1 to 15 and β oscillates between 0.5 and 5.

In both cases, the first row corresponds to maximum fitness values found, while the second row represents the time elapsed to solve the problem with the AIS. The first column compares the time and fitness when the initial population N is changing. The second column plots the values for the number of clones generated Nc. The third column represents the maximum number of iterations upon convergence gen while the fourth column compares values of time and fitness when the suppression parameter is oscillating ts. Finally, the last column considers changes in β to measure time and fitness.

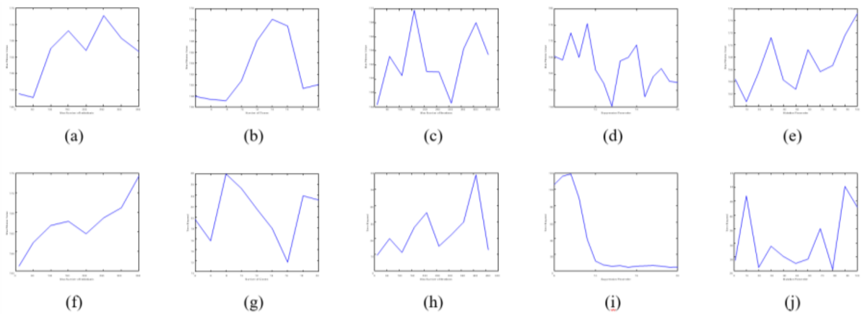

Fig. 1: Plots of the results for maximum fitness values (first row) and time elapsed (second rows) when setting N, N_C, gen, t_S and β. In this case the battery is not considered.

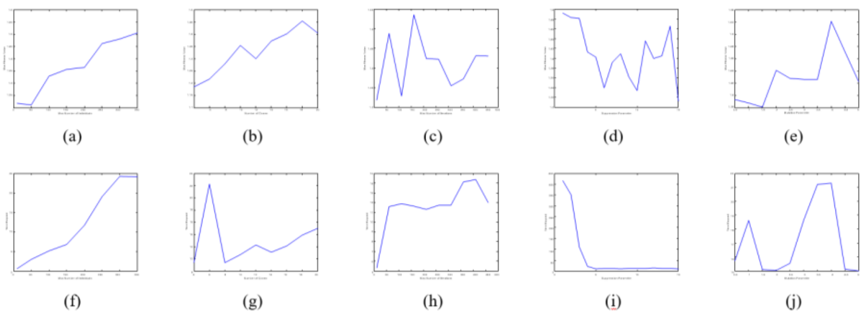

Fig. 2: Plots of the results for maximum fitness values (first row) and time elapsed (second rows) when setting N, Nc, gen, ts and β. In this case the battery is considered.

On the one hand, Figure 1 shows the results according to the Case Study I. Firstly, as the number of individuals in the initial population N is increasing, the time elapsed also increases exponentially. However, the maximum fitness values is oscillating between the values 150 and 250. The maximum fitness value is empirically achieved when N = 250. The number of clones Nc gives only good results according to the fitness values when the clones created are between 8 and 18. The maximum is achieved at 12. The number of iterations allowed upon convergence can affect the time elapsed and the fitness values obtained. However, in this case we have oscillations. Than can happen when the initial individuals, which are randomly generated, are very good candidates as the optimum solution. In that case, a few iterations are enough to select the best optimum and finish the algorithm. Despite this, we can see a general increase in time when the number of iterations gen takes higher values. ts has a plot inverse, meaning that the time elapsed is inversely proportional to the fitness values found. As we can see, when ts is higher than 10, the time elapsed is very short, but the algorithm cannot find a good optimum for the optimization problem. Finally, β oscillates in different points, although the best results are given when it takes higher values according to fitness maxima. On the othe hand in Figure 2, as the number of individuals in the initial population N is increasing, the time elapsed also increases, as well as the maximum fitness. Nevertheless, the maximum fitness is slightly increasing between 250 and 350. When the number of clones Nc is low, the time elapsed is in- creased. That means the algorithm is able to find good optima very slowly because we do not provide enough diversity. The best value of Nc occurs at 18 according to the fitness values found. The number of iterations allowed upon convergence can affect the time elapsed and the fitness values obtained. In general, the time is increasing when the iterations allowed take high values. In the fitness values, there are some oscillations, maybe because of the explanation given in the Case Study II. We can conclude that to some extent more iterations does not mean better results in fitness function. Here ts has also a plot inverse, meaning that the time elapsed is inversely proportional to the fitness values found. As we can see, when ts is higher than 4, the time elapsed is very short, but the algorithm cannot find a good optimum for the optimization problem. Finally, an increase in β parameter up to 4.5 provokes improvement in the fitness values obtained, although that means a longer time working according to the graphic of the Figure 2j.

Table 1. Optima values set for N, N_C, gen, t_S and β in both case studies.

N	N_c	gen	t_s	β
250	12	250	10	100

We finally set the AIS parameters according to Table 1, which gave the optimum performance in terms of fitness and time following the discussion above.

5. Conclusions

Residential buildings in smart grids have an important role in the optimization of energy scheduling. In order to optimize such problems, here we applied an Artificial Immune System based on Opt-aiNet, an optimization version of an AIS used in different contexts [16]. In this work, we show how an AIS can be used to solve efficiently a power system optimization problem. To this end, we have adapted the opt-aiNet algorithm to include complex constraints in the optimization problem and to work with a large number of variables efficiently.

From an electrical point of view, we analyze two different case study, depending whether the battery variables are considered or not to optimize the energy problem. In both cases, the parameters applied to the AIS to manage the mutation, clonation or convergence criteria are fully analyzed to optimize the performance of the algorithm. Once the best parameters are set, the final results show that the battery application increases the efficiency and reliability of the model.

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References

[1] M. A. A. Pedrasa, T. D. Spooner, and I. F. MacGill, “The value of accurate forecasts and a probabilistic method for robust scheduling of residential distributed energy resources,” in Probabilistic Methods Applied to Power Systems (PMAPS), 2010 IEEE 11th International Conference on. IEEE, 2010, pp. 587–592.

[2] Molderink, V. Bakker, M. G. Bosman, J. L. Hurink, and G. J. Smit, “Domestic energy management methodology for optimizing efficiency in smart grids,” in PowerTech, 2009 IEEE Bucharest. IEEE, 2009, pp.1–7.

[3] M. Nistor and C. Antunes, “Integrated management of energy resources in residential buildings-a markovian approach,” IEEE Transactions on Smart Grid, 2016.

[4] S. Althaher, P. Mancarella, and J. Mutale, “Automated demand response from home energy management system under dynamic pricing and power and comfort constraints,” IEEE Transactions on Smart Grid, vol. 6, no. 4, pp. 1874–1883, 2015.

[5] T. Hansen, E. Chong, S. Suryanarayanan, A. Maciejewski, and H. Siegel, “A partially observable markov decision process approach to residential home energy management,” IEEE Transactions on Smart Grid, 2016.

[6] M. A. Pedrasa, E. Spooner, and I. MacGill, “Improved energy services provision through the intelligent control of distributed energy resources,” in PowerTech, 2009 IEEE Bucharest. IEEE, 2009, pp. 1–8.

[7] L. N. De Castro and J. Timmis, Artificial immune systems: a new computational intelligence approach. Springer Science & Business Media, 2002.

[8] M.-H. Chen, P.-C. Chang, and C.-H. Lin, “A self-evolving artificial immune system ii with t-cell and b-cell for permutation flow-shop problem,” Journal of Intelligent Manufacturing, vol. 25, no. 6, pp. 1257– 1270, 2014.

[9] L.-F. Hsu, C.-C. Hsu, and T.-D. Lin, “An intelligent artificial system: artificial immune based hybrid genetic algorithm for the vehicle routing problem,” Applied Mathematics & Information Sciences, vol. 8, no. 3, p. 1191, 2014.

[10] S. Shamshirband, N. B. Anuar, M. L. M. Kiah, V. A. Rohani, D. Petkovic´, S. Misra, and A. N. Khan, “Co-fais: cooperative fuzzy artificial immune system for detecting intrusion in wireless sensor networks,” Journal of Network and Computer Applications, vol. 42, pp. 102–117, 2014.

[11] M. Navarro, M. Caetano, G. Bernardes, L. N. de Castro, and J. M. Corchado, “Automatic generation of chord progressions with an artificial immune system,” in International Conference on Evolutionary and Biologically Inspired Music and Art. Springer, 2015, pp. 175–186.

[12] L. dos Santos Coelho and V. C. Mariani, “Chaotic artificial immune approach applied to economic dispatch of electric energy using thermal units,” Chaos, Solitons & Fractals, vol. 40, no. 5, pp. 2376–2383, 2009.

[13] F. Alonso, D. Oliveira, and A. Z. de Souza, “Artificial immune systems optimization approach for multiobjective distribution system reconfigu- ration,” IEEE Transactions on Power Systems, vol. 30, no. 2, pp. 840– 847, 2015.
[14] J. Zhu, F. Lauri, A. Koukam, V. Hilaire, and M. G. Simoes, “Improving thermal comfort in residential buildings using artificial immune system,” in Ubiquitous Intelligence and Computing, 2013 IEEE 10th International Conference on and 10th International Conference on Autonomic and Trusted Computing (UIC/ATC). IEEE, 2013, pp. 194–200.
[15] K. Lakshmi and S. Vasantharathna, “Gencos wind–thermal scheduling problem using artificial immune system algorithm,” International Jour- nal of Electrical Power & Energy Systems, vol. 54, pp. 112–122, 2014.

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Real-time demand response and intelligent direct load control
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Appliance Shifting for Sequential Processes in Home Management System

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Abstract

Home management systems are evolving to enable a more adaptive model to the many consumer's behaviors, such as, periods of more consumption, habits of appliance use, amongst others. In another perspective, there are processes that require a start-after and sequential operation of multiple appliances, which currently is not a feature that exists in many of the home management systems. The present paper proposes a model to formulate sequential appliances load shifting, such that, the respective processes that the consumer has are maintained implemented correctly. The case study considers multiple appliances that exist in a home, with a sampling of 15 minutes, which is important in order to better observe the appliances consumption cycles.

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

1. Introduction

Home energy management systems are on the raise since the green and sustainable mentality has become a trend in the present consumers and power systems [1]. The need for these systems is related with the implementation of demand flexibility providers and on-site generators in a new stage of power systems operation, focused in the smart grids implementation. Home energy management systems gain a new relevance in the context of power systems, since the majority of consumers is residential, and thus a high potential of efficiency can still be uncovered by these systems [2]–[5]. The architecture of a home energy management system depends upon the available resources and the functionalities that can be adopted. In [6], it is presented a table that clarifies the possible functionalities of home energy management systems - Table **1**.

Demand Response (DR) is characterized by the modification of the consumer's typical consumption profile, in response to price signals or monetary incentives [7], [8]. This concept is a major pillar of smart grids implementation, since it allows for flexibility provision which grants more robustness to power systems. DR can be integrated in energy management systems, per example, control over given appliances or loads that can be optimized either by unnecessary consumption reduction or wise choice of consumption times [9]–[11]. In the consumer's perspective, energy management systems can bring several adaptive features that increase the consumer's comfort, and also reduce the energy expenditure of the consumer's operation with an efficient strategy [12], [13]. From an upper level, such as system operators, the energy systems of the consumers allow for an easier control related with the implementation of DR [14].

Table 1. Possible functionalities assumed by the home energy management system.

Modules	Service Description
Monitoring	Real-time information about the present operating conditions of the system, allow for a more reasoning by the consumer and energy saving potential
Logging	Historical data storage allows for a deeper analysis of the consumption profile and the main sectors that can be improved through demand response
Control	Direct and remote control of loads
Management	Management of several resources, as demand response strategies, on-site generators, plug-in electrical vehicles, and energy storage
Alarm	Fault detection and notice is also an important part of a management system

In the demand response environment, load shifting is a program that provides a useful management of both consumption and generation [15]. In what concerns consumption, load shifting allows for the transfer of load from less to more attractive periods (e.g. lower energy tariffs when dynamic pricing is considered) [16], [17]. Regarding generation, and from an operator's point of view, load shifting is important to transfer load from periods where the generation availability is lacking to others when it is abundant (e.g. photovoltaic energy is only available during the day). Also, the load shifting approach insures that the removed load is reallocated to another time, and therefore the consumer's consumption is respected. The implementation of DR programs is often associated with management systems which suggest optimized operation scheduling using these DR strategies.

The inclusion of home management systems is related with multi-agent systems, such that each agent is characterized by being an autonomous and distributed entity, that can be intelligent (in this case yes, since the consumer is an active part of the energy management system) or not, and which are capable of interacting with other agents building up a bigger system and bidirectional communication [18]. In this way, the smart grid implementation implies multi-agent systems that offer several features of sustainability and robustness, moreover, promotes an agent network interaction amongst its several components considering a mutual goal, the power system adequate and secure operation [19], [20].

2. Home Energy Management System

The objective function considered for the energy management system is showed by equation (1), that considers the minimization of the energy bought, $P_{(s,t)}^{Sup}$, from the main network. The energy tariff from the main network is dynamic changing hourly over time, $C_{(s,t)}^{Sup}$, and in this way there is the need to adjust the energy amounts in each period, since it is considered over a sampling time of 15 minutes, thus, $\Delta t = 4$ since one hour is composed of 4 periods of 15 minutes. In equation (2), it is presented the power balance of the home that considers the energy bought from the main network, the load shifting, $P_{(a,t,d)}^{Shift}$, and load reduction, $P_{(a,t,t)}^{Shift}$, in each period. The load curtailment program considers only the appliances that are not participating in the load shifting, and the loads that are in the load shifting program are not participating in the load curtailment program.

The dependency vector (*D*), with length equal to the total number of appliances, that the consumer uses to declare the mandatory sequential operation of an appliance or appliances. This is made by assigning a non-zero integer number to the appliances which are sequential, where different sequences must have distinct integer numbers. In this way, the consumption verified by sequential appliances is summed and considered as a single load to the scheduling optimization, therefore, the modelling is made easier by considering a single given process that implies several appliances. Also, when considering sequential operation of a given appliance, an integer number is also assigned in the dependency vector, and being a single load, is equally modelled as the sequential appliance.

$$\min OC = \sum_{s=1}^{S} P_{(s,t)}^{Sup} \cdot C_{(s,t)}^{Sup} \cdot \frac{1}{\Delta t} \quad (1)$$

$$\sum_{s=1}^{S} P_{(s,t)}^{Sup} = \sum_{a \in D=0}^{A} P_{(a,t)}^{Load} + \sum_{a \in D>0}^{A} P_{(a,t)}^{Load} - \sum_{d=1}^{T} \left[P_{(a,t,d)}^{Shift} - P_{(a,d,t)}^{Shift} \right] \quad (2)$$
$$\forall t \in \{1,...,T\}, D = \left[a_1, a_2, (...), a_n \right]$$

The energy contract that the consumer has with the main network limits the energy use in certain amount (e.g. this is often performed by a circuit breaker at the connection before the installation). This is formulated according to equation (3) that imposes limits to the energy bought from the main network.

The load shifting demand response program considers that a given load can be transferred from or to another period, being this decided according to the energy consumption cost in each of the periods considered. In this way, $P_{(a,t,d)}^{Shift}$ is a 3D matrix where in the first dimension, *a*, represents a given appliance, and in the second and third dimension, *t* and *d* represent a given period. In this paper it is considered that $P_{(a,t,d)}^{Shift}$ represents the energy transferred from period *t* to any other period *d*, thus, the sum along the third dimension reflects all the energy that has been transferred from period *t*, while the sum along the second dimension reflects all the energy transferred into period *t*. The load shifting limits are represented by equation (4) and these in this case are defined by the consumer which is the owner of the installation and the appliances that compose it. In order to perform sequential appliance or operation shifting, equations (5), it is used decision binary variables that provide the necessary conditions to implement these processes.

$$P_{(s,t)}^{SupMin} \le P_{(s,t)}^{Sup} \le P_{(s,t)}^{SupMax}, \forall s \in \{1,...,S\}, \forall t \in \{1,...,T\} \quad (3)$$

$$P_{(a,t,d)}^{ShiftMin} \le P_{(a,t,d)}^{Shift} \le P_{(a,t,d)}^{ShiftMax}, \forall a \in \{1,...,A\}, \forall t,d \in \{1,...,T\} \quad (4)$$

$$P_{(a,t,d)}^{Shift} = \begin{cases} P_{(a,t)}^{Load} \cdot \lambda_{(a,t,d)}^{Shift}, t \ne d \\ P_{(a,t)}^{Load} \cdot \lambda_{(a,t-1,d-1)}^{Shift}, t \ne d \wedge t,d > 1 \end{cases} \quad (5)$$
$$\forall a \in \{1,...,A\} \wedge a \in D > 0, \forall t,d \in \{1,...,T\}$$

In this section, it was approached the mathematical formulation of the optimization problem regarding the implementation of consumer's flexibility. The consumer can obtain its consumption scheduling such that its operation costs are minimized, considering the energy tariff at different periods of the energy supplied from the main network, and considering load shifting that respects the consumer's preferences of operation.

3. Case Study of Sequential Scheduling

In the present section, the case study approaches a sequential scheduling of appliances namely, a washing and drying machines sequential operation, and an individual operation of a cooker. In Fig. 1, it is presented the scheme of the proposed methodology and also the context of the applied case study.

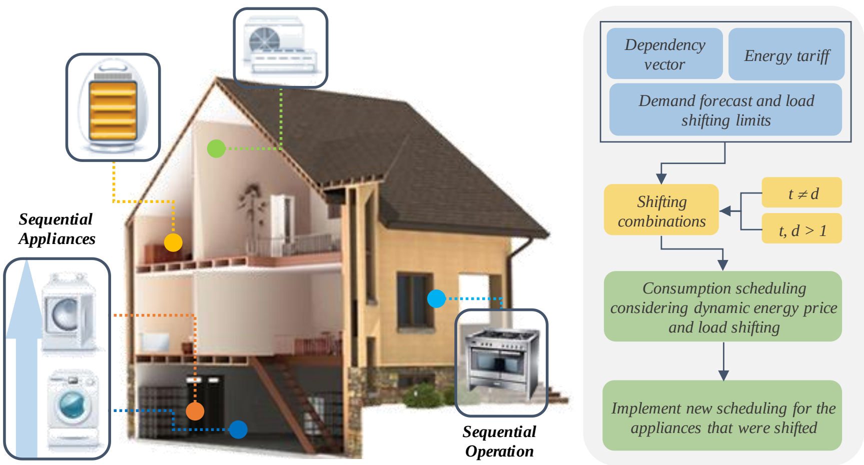

Fig. 1: Overall scheme of the proposed methodology.

The case study involves twelve appliances: television, fan, fridge, computer, electric heating, oven, drying machine, washing machine, microwave, toaster, sockets, and cooker (this is the order considered in the *D* vector of dependency), however, only three of these are considered for load shifting (washing, drying machine, and cooker). The drying machine follows up the activity of the washing machine (sequential appliance), and the cooker must be respected due to the comfort and process restraints that it involves (sequential operation). The following Fig. 2 shows the consumption forecast for each of the appliances considered.

By Fig. 2 it is possible to see that the peak consumption occurs at 00:15, with an amount of 2.1 kWh/Δt, and the major contributor for this amount is the consumption from sockets. The data presented from Fig. 2 is adapted from [21]. The data concerns a single household located in the Netherlands, that is monitored regarding four sets: electricity monitoring, ambient, occupancy, and household information. The level of data available allows for a wider consideration of consumer comfort preferences that may influence and provide more interest in the demand response programs implementation.

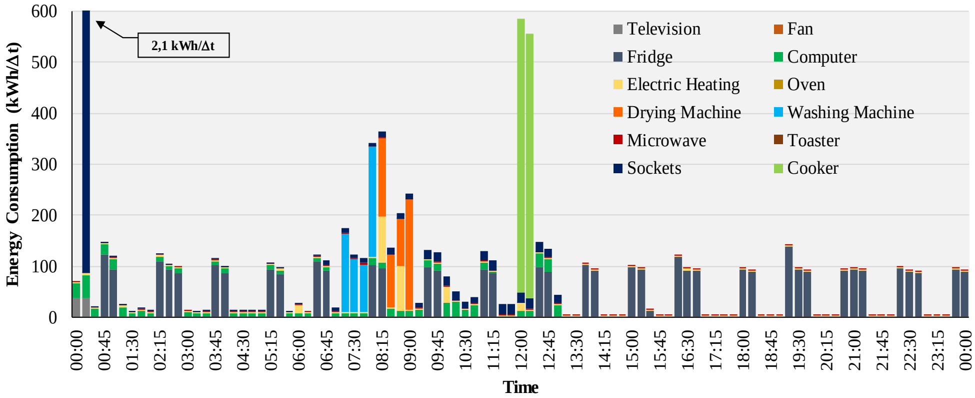

Fig. 2: Consumption forecast discriminated by appliance.

The energy price considered is dynamic over time, thus inducing the consumer to be more aware of its consumption in given periods. In this way, the following Fig. 3 shows the energy tariff considered from the main network. The green area in the graph shows the time table that is more advantageous for the consumer to apply load, since is where the lowest energy tariff is located. In equation (6), it is showed the considered vector of dependency.

$$D = [0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 2] \quad (6)$$

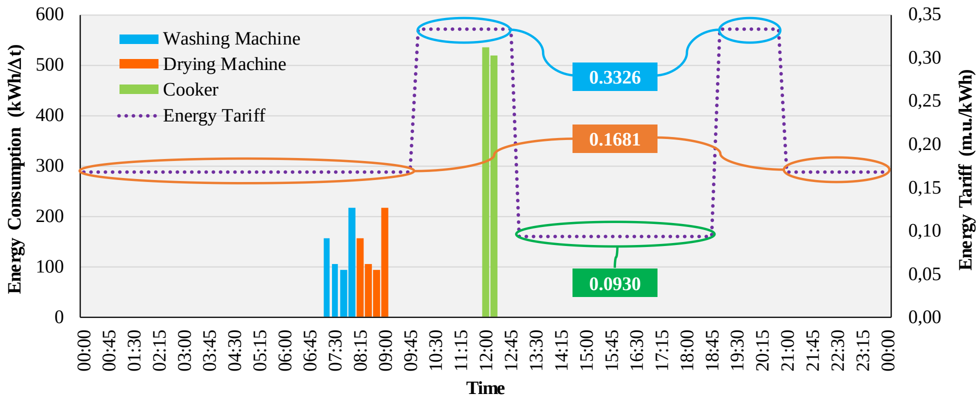

Fig. 3: Energy tariff along the given periods and consumption forecast of the shifting loads.

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.

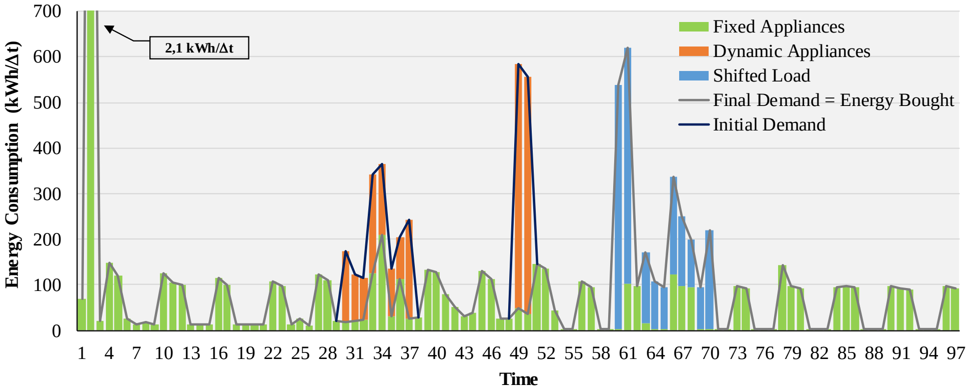

Fig. 4: Energy schedule obtained from the optimization with changes in consumption.

In Fig. 5 is shown in more detail the load shifting amounts and periods where were applied the dynamic appliances. As one can see, the operation of the drying machine follows the operation of the washing machine, sequentially, and these are shifted as so, demonstrated by the below figure. In the case of the cooker, this is not related to any other appliance, however, its operation must be respected since is normally associated to a process that requires a certain level of consumption that cannot be interrupted. In this way, the proposed methodology insures that these appliances operation and processes are respected during their scheduling minimizing the impact on the consumer's comfort and preferences.

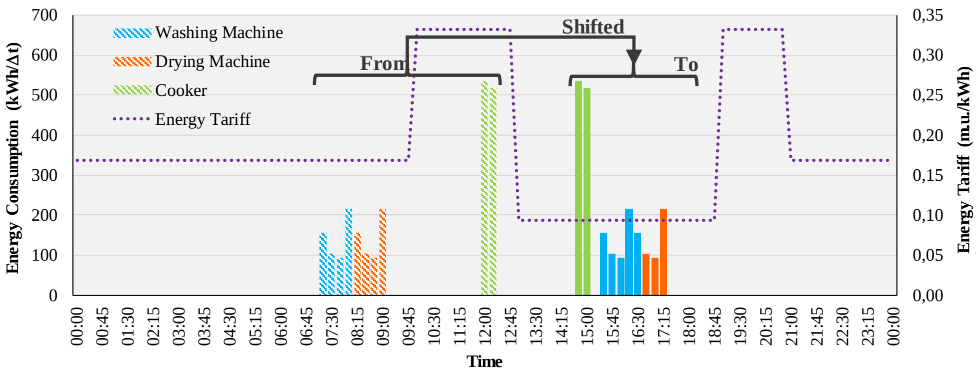

Fig. 5: Initial consumption forecast and load shifting obtained from the optimization.

The example given by this case study is related to residential consumer's operation, however, this methodology is equally useful or more in a commercial and industrial context. Specially in industrial context, the sequential operation of individual appliances or processes becomes more relevant, since normally these are needed to obtain a final product or results.

5. Conclusions

The increasing number of appliances in every type of consumers, brings several modifications in the consumption profile, and changes the operation costs of the consumers. Moreover, the need for efficiency in power systems is nowadays more important than ever, with a raising sustainability and green energy trend. In this way, the present methodology proposes a scheduling optimization of the consumer's consumption, discriminating individual appliances contribution to the total load. The scheduling considers sequential load shifting of certain appliances together with dynamic tariffs offered by the supplier (main network), in order to minimize the operation costs of the consumer. In this way, the algorithm searches for the least costly periods to shift consumption into, being it from periods where a higher cost is at play. Future work related to the present paper, involves the consideration of more resources for the scheduling, namely, the modelling of on-site generation and with growing importance of the industrial context, since this environment presents itself as the one with more to gain from sequential load shifting. Also, the inclusion of more demand response programs is interesting to analyse, in order to observe the influence that these may have on the load shifting, considering other relevant data associated with the consumer operation (e.g. occupancy).

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References

[1] S. S. van Dam, C. A. Bakker, and J. C. Buiter, “Do home energy management systems make sense? Assessing their overall lifecycle impact,” *Energy Policy*, vol. 63, pp. 398–407, 2013.

[2] R. Missaoui, H. Joumaa, S. Ploix, and S. Bacha, “Managing energy Smart Homes according to energy prices: Analysis of a Building Energy Management System,” *Energy Build.*, vol. 71, pp. 155–167, 2014.

[3] G. Brusco, A. Burgio, D. Menniti, A. Pinnarelli, and N. Sorrentino, “Energy Management System for an Energy District With Demand Response Availability,” *IEEE Transactions on Smart Grid*, vol. 5, no. 5. pp. 2385–2393, 2014.

[4] J. Byun, I. Hong, and S. Park, “Intelligent cloud home energy management system using household appliance priority based scheduling based on prediction of renewable energy capability,” *IEEE Transactions on Consumer Electronics*, vol. 58, no. 4. pp. 1194–1201, 2012.

[5] J. Honold, C. Kandler, P. Wimmer, B. Schropp, R. Reichle, M. Gröne, M. Bünemann, J. Klein, and M. Kufner, “Distributed integrated energy management systems in residential buildings,” *Appl. Therm. Eng.*, vol. 114, pp. 1468–1475, 2017.

[6] B. Zhou, W. Li, K. W. Chan, Y. Cao, Y. Kuang, X. Liu, and X. Wang, “Smart home energy management systems: Concept, configurations, and scheduling strategies,” *Renew. Sustain. Energy Rev.*, vol. 61, pp. 30–40, 2016.

[7] P. Faria, J. Spínola, and Z. Vale, “Aggregation and Remuneration of Electricity Consumers and Producers for the Definition of Demand-Response Programs,” *IEEE Trans. Ind. Informatics*, vol. 12, no. 3, 2016.

[8] P. Faria and Z. Vale, “Remuneration Structure Definition for Distributed Generation Units and Demand Response Participants Aggregation,” *2014 IEEE PES Gen. Meet. | Conf. Expo.*, pp. 1–5, 2014.

[9] H. A. Özkan, “Appliance based control for Home Power Management Systems,” *Energy*, vol. 114, pp. 693–707, 2016.

[10] C. O. Adika and L. Wang, “Autonomous Appliance Scheduling for Household Energy Management,” *IEEE Transactions on Smart Grid*, vol. 5, no. 2. pp. 673–682, 2014.

[11] Y. Tsunoda, C. Tsuchiya, Y. Segawa, H. Sawaya, M. Hasegawa, S. Ishigaki, and K. Ishibashi, “A Small-Size Energy-Harvesting Electric Power Sensor for Implementing Existing Electrical Appliances Into HEMS,” *IEEE Sensors Journal*, vol. 16, no. 2. pp. 457–463, 2016.

[12] C. Vivekananthan, Y. Mishra, and F. Li, “Real-Time Price Based Home Energy Management Scheduler,” *IEEE Transactions on Power Systems*, vol. 30, no. 4. pp. 2149–2159, 2015.

[13] J. H. Yoon, R. Baldick, and A. Novoselac, “Dynamic Demand Response Controller Based on Real-Time Retail Price for Residential Buildings,” *IEEE Transactions on Smart Grid*, vol. 5, no. 1. pp. 121–129, 2014.

[14] M. Liu, F. L. Quilumba, and W. J. Lee, “A Collaborative Design of Aggregated Residential Appliances and Renewable Energy for Demand Response Participation,” *IEEE Transactions on Industry Applications*, vol. 51, no. 5. pp. 3561–3569, 2015.

[15] Y. Liu, B. Qiu, X. Fan, H. Zhu, and B. Han, “Review of Smart Home Energy Management Systems,” *Energy Procedia*, vol. 104, pp. 504–508, 2016.

[16] M. C. Vlot, J. D. Knigge, and J. G. Slootweg, “Economical Regulation Power Through Load Shifting With Smart Energy Appliances,” *IEEE Transactions on Smart Grid*, vol. 4, no. 3. pp. 1705–1712, 2013.

[17] P. Faria, Z. Vale, and J. Baptista, “Constrained consumption shifting management in the distributed energy resources scheduling considering demand response,” *Energy Convers. Manag.*, vol. 93, pp. 309–320, 2015.

[18] E. Karfopoulos, L. Tena, A. Torres, P. Salas, J. G. Jorda, A. Dimeas, and N. Hatziargyriou, “A multi-agent system providing demand response services from residential consumers,” *Electr. Power Syst. Res.*, vol. 120, pp. 163–176, 2015.

[19] N. Good, K. A. Ellis, and P. Mancarella, “Review and classification of barriers and enablers of demand response in the smart grid,” *Renew. Sustain. Energy Rev.*, vol. 72, pp. 57–72, 2017.

[20] B. M. Radhakrishnan and D. Srinivasan, "A multi-agent based distributed energy management scheme for smart grid applications," *Energy*, vol. 103, pp. 192–204, 2016.

[21] A. Uttama, N. S. N. A. Reyes, and L. R. V. Prasad, "LocED: Location-aware Energy Disaggregation Framework."

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Real-time demand response and intelligent direct load control
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A Short Review of the Main Approaches of Electrical Energy Consumption Disaggregation

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Abstract

Energy consumption monitoring systems are evolving towards a perspective of Reducing energy consumption within buildings. This energy saving approach is based on the capabilities of these systems to recognize electrical appliances and other electrical devices plugged into the home through their electrical consumption and the automatic obtaining of energy costs in each system. Use to obtain a lower cost. These systems are formed mainly by subsystems; A subsystem for the acquisition, monitoring and tracking of consumption data and a second search engine subsystem to obtain the price of power automatically independent of the tariff and the company. However, it is a main objective to detect that the appliance is consuming so that the system by acquiring this data can perform patterns of user behaviour and recommend to users when using household appliance in order to obtain an economic savings. Therefore, in this work a review of the main methods of disaggregation of electricity consumption through its individual loads has been carried out.

Keywords: disaggregation, energy efficiency, intelligent management

1. Introduction

Prior to the liberalization of the electricity market, consumers were not free and were closely linked to the tariff of the generating and distributing energy company that corresponded to it by geographical area, so that factors such as consumption habits were not valued. Due to the liberalization of the electricity market, there has been a boom in the supply of energy trading and distribution companies with different tariffs by energy trading companies. This range of possibility to contract rates requires knowing the consumption habits of users in a way that suits their habits. This knowledge of the habits also serves to know and recommend that different slots in which to use appliances such as washing machine, oven and reduce consumption.

It is therefore necessary to carry out a review of the techniques of disaggregation of energy consumption that allows to recognize consumption in isolation in the home or in work offices. The problem of the disaggregation of electrical consumption is not a new problem, within the techniques applied machine learning algorithms - early algorithms [1, 2] search for "edges" in the power signal to indicate if a device Name is on or off; The subsequent work focused on the computation of power harmonics at steady state or current draw [3, 4]. With the use and development of new techniques, non-intrusive load monitoring (NILM) is one of the techniques that has evolved most in the field of the disaggregation of electrical consumption signals [5]. NILM is a non-intrusive method because the loads are measured through total consumption as opposed to the ILM technique that is based on obtaining the loads measured through low intensity meters distributed in the home itself [6].

Systems based on this approach are based on the analysis of the load curve (total energy consumption in the home). However, it is necessary to know the current state of the rest of the most used techniques so that we can understand what possibilities offer to be improved and complemented with other techniques or algorithms. This knowledge will allow us to apply this solution to offer a greater knowledge of energy consumption not only to know what rate is more suitable but also to know if there is presence or absence of people in the house, warn users if they have left any appliance on and there are no people at home.

2. Methods

The non-intrusive load monitoring (NILM) is one of the most used techniques in the solution of problems of signalling of household appliances, used both in the disaggregation of water and gas consumption [7] and in the study of consumption electric. In the disaggregation of electrical consumption signals, these systems are based on the analysis of the load curve (aggregate household electrical consumption) [8], as shown in Fig 1.

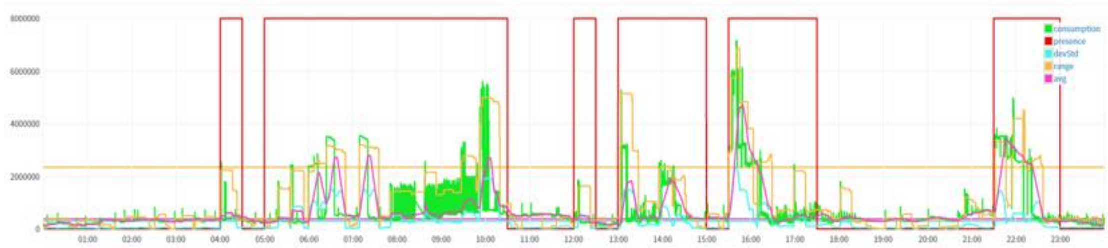

Fig. 1: Example of signal disaggregation of household appliances.

Hidden Markov Models (HMM) to be considered the simplest dynamic Bayesian network has been used as the natural approach for signal disaggregation. In addition, this method for intrusive loading methods has a number of important advantages such as not having to use metering devices per plug and the method can be implemented within Smart meters or management systems. Although HMM has been the first option, this technique has also evolved, evolving towards the well-known Factorial Hidden Markov Models (FHMM). Both techniques are briefly detailed below.

2.1. Hidden Markov Model (HMM)

The use of Hidden Markov Model with the objective of disaggregating the signals of electric energy consumption is due to the possibility of modelling each device as an HMM, each variable representing the state of the device at a specific instant of time, as shown in Fig 2. The objective is to determine the unknown parameters (electrical charges of each device) being the output of the aggregate consumption. One of the disadvantages of using this method is that although there are several algorithms for HMM decoding, such as the Viterbi algorithm [9] and Forward Backward Algorithm [10], and their variants, the main obstacle to load disaggregation is the complexity involved in the Process

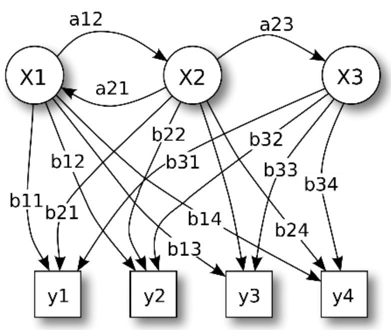

Fig. 2: Probabilistic parameters schema of a hidden Markov model.

The only problem with this approach is that in the case of HMM we have a process with multiple states generating the observed output signal. In our case of use on electrical signals with multiple devices each with multiple states that generate the observed output. A good solution to this problem is an extension to a standard HMM approach known as Factorial Hidden Markov Model.

2.2. Factorial Hidden Markov Model (FHMM)

Factorial Hidden Markov Model is an extension of the basic Hidden Markov Model where several independently evolve in parallel and whose output is a joint function of all hidden states that have evolved independently in parallel [11]. It is because of its ability to capture aggregate signals which makes FHMM an ideal method to be applied in the disaggregation of electrical consumption, as well as in audio separation [12,13] or voice recognition [14]. In a Markov factorial model we have M independent Markov chains of latent variables, each of which can be in S states. The distribution of the observed variable in a given time step is conditioned to the states of all corresponding latent variables in that same step of time, as shown in Fig 3.

FHMM can be considered a mixture of independent hidden Markov models that are coupled by observations [15]. factorial HMM representation provides an advantage over traditional HMMs in predictive modelling of the complex temporal patterns in disaggregation.

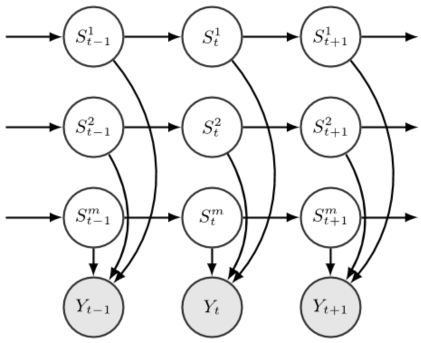

Fig. 3: Schematic of appliances HMM in a specialized structure to form FHMM.

3. Conclusions

This paper presents an overview of the different methods of disaggregating household appliances and electrical devices. This review shows that all the methods used in the control and identification of energy consumptions have advantages and disadvantages. There is no method that can guarantee the control and monitoring of domestic appliances. Although it is possible to emphasize that NILM is the most convenient method in this kind of problems once known and adjusted the parameters of the size of moving window and the different thresholds, as well as the detection of continuously variable appliance like light dimmers and devices that works constantly such as clocks. A further disadvantage of this approach is the limitation of not being able to detect identical electrical appliances. However, the NILM method in terms of implementation is an easy and simple method to implement and maintain, there are numerous open source libraries that implement their algorithm and is employed through visualization tools.

The use of these methods therefore requires a process of adaptation to the problem, being necessary to have a prior knowledge of the time of presence of the user at home to adjust the size of moving window and also know the average value of the statistics to set the values of the thresholds.

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References

[1] Hart, G. W. (1992). Nonintrusive appliance load monitoring. Proceedings of the IEEE, 80(12), 1870-1891.

[2] Sultanem, F. (1991). Using appliance signatures for monitoring residential loads at meter panel level. IEEE Transactions on Power Delivery, 6(4), 1380-1385.

[3] Berges, M., Goldman, E., Matthews, H. S., & Soibelman, L. (2009). Learning systems for electric consumption of buildings. In Computing in Civil Engineering (2009) (pp. 1-10).

[4] Lee, W. K., Fung, G. S. K., Lam, H. Y., Chan, F. H. Y., & Lucente, M. (2004, July). Exploration on load signatures. In International conference on electrical Engineering (ICEE) (Vol. 2, pp. 690-694).

[5] Figueiredo, M., De Almeida, A., & Ribeiro, B. (2012). Home electrical signal disaggregation for non-intrusive load monitoring (NILM) systems. Neurocomputing, 96, 66-73.

[6] Ridi, A., Gisler, C., & Hennebert, J. (2014, August). A survey on intrusive load monitoring for appliance recognition. In Pattern Recognition (ICPR), 2014 22nd International Conference on (pp. 3702-3707). IEEE.

[7] Froehlich, J., Larson, E., Gupta, S., Cohn, G., Reynolds, M., & Patel, S. (2011). Disaggregated end-use energy sensing for the smart grid. IEEE Pervasive Computing, 10(1), 28-39.

[8] Aladesanmi, E. J., & Folly, K. A. (2015). Overview of non-intrusive load monitoring and identification techniques. IFAC-PapersOnLine, 48(30), 415-420.

[9] Viterbi, A. (1967). Error bounds for convolutional codes and an asymptotically optimum decoding algorithm. IEEE transactions on Information Theory, 13(2), 260-269.

[10] Rabiner, L. R. (1989). A tutorial on hidden Markov models and selected applications in speech recognition. Proceedings of the IEEE, 77(2), 257-286.

[11] Kolter, J. Z., & Jaakkola, T. S. (2012, April). Approximate Inference in Additive Factorial HMMs with Application to Energy Disaggregation. In AISTATS (Vol. 22, pp. 1472-1482).

[12] Ozerov, A., Févotte, C., & Charbit, M. (2009, October). Factorial scaled hidden Markov model for polyphonic audio representation and source separation. In Applications of Signal Processing to Audio and Acoustics, 2009. WASPAA'09. IEEE Workshop on (pp. 121-124). IEEE.

[13] Logan, B., & Moreno, P. (1998, May). Factorial HMMs for acoustic modeling. In Acoustics, Speech and Signal Processing, 1998. Proceedings of the 1998 IEEE International Conference on (Vol. 2, pp. 813-816). IEEE.

[14] Virtanen, T. (2006, September). Speech recognition using factorial hidden Markov models for separation in the feature space. In Interspeech.

[15] Ghahramani, Z., Jordan, M. I., & Smyth, P. (1997). Factorial hidden Markov models. Machine learning, 29(2-3), 245-273.

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A Fusion Framework of Gene Filter Method Solutions in Microarrays

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Abstract

A major research area in the analysis of gene expression microarrays is selection of gene subsets able to differentiate between sample classes of a studied disease. Feature/Gene selection is an NP-hard problem and despite the fact that there are many proposals facing this subject, these have not been able to reach a common consensus on their results, due to the instability problem of their solutions. In consequence, there is no winning filter method able to hold all requirements demanded by the biological domain of this complex problem. Hence, this research proposes a gene selection method that fusions, in a convenient way, gene subsets given as results of other filter methods, in order to face the instability problem.

Keywords: DNA-microarray, gene expression data, feature/gene selection.

1. Introduction

The study of gene expression data from DNA microarrays is of great interest for Bioinformatics (and functional genomics), because it allows us to simultaneously analyze expression levels from hundreds of thousands of genes in a living organism sample. This feature makes gene expression analysis a fundamental tool of research for human health. It provides identification of new genes that are key factors in the genesis and development of diseases [1]. However, the exploration of these large data sets is an important yet difficult problem.

Meanwhile, feature/gene selection has received a lot of attention in Bioinformatics, and many approaches for reducing dimensionality and selecting biomarkers have been proposed [2–5]. However, the wide range of existing techniques has resulted in different results, making it difficult to apply the gained knowledge to clinical practice. Gene selection methods have been divided into four categories: filters, wrappers, embedded and ensemble [6,2,3,7]. Filter methods determine the relevance of features by ranking them on the basis of statistical criteria whereas wrappers use a classifier to determine feature sets with high discrimination power. Similar to wrappers, embedded methods are based on learning methods but allow to interact with them, which decreases the runtime taken by wrappers. Meanwhile, ensembles are the most recent among feature selection methods and merge different strategies to face instability problems presented by other methods due to data perturbations.

This paper proposes a hybrid technique operating as an approach fusing gene selection solutions. The goal is to select biomarkers for diagnosis (classification tasks) by combining results from different gene selection methods to face information loss and provide a unified and coherent biomarker subset.

2. A Fusion Approach for Gene Selection

This section explains the main features of our gene selection approach, which consists of four linked stages, each developing a different gene filtering process until reaching an informative gene subset. In general sense, the first stage (Stage-I) prepares the data for the following stages, while Stage-II is responsible for removing noise presented in the data (genes considered noise). Meanwhile, Stage-III represents an ensemble of different gene selection methods applied to the input dataset. The result of this stage, a gene set, is passed to Stage-IV, which carries out a wrapper-based gene filtering to achieve an informative gene subset as an end result. In the following subsections, we are going to describe in detail each stage shown in this figure, which builds the proposed method.

2.1 Data Preprocessing: Stage-I

In this stage, a raw dataset is given as input by the user for its processing. This implies that several processes such as, data transformation, missing value estimation and data cleaning will be run if needed. Thus, this stage is in charge of preparing data for the next stages, which are that actually perform the filtering process. At the end of this stage, a new dataset is returned to Stage-II.

2.2 Noise Removing Methods: Stage-II

As its name suggests, this stage is responsible for removing noise in the data. This process involves two gene filter methods to reach such a propose. By applying the Mann-Whitney test to the input dataset as the first filter method, we will have a gene significance test, relating genes to the studied disease. This test is nonparametric and states a null hypothesis by relating samples to the same population whereas the alternative hypothesis relates samples to different populations [8]. Thus, once applied this test, genes with p-value under 0.01 are filtered out towards the next filter method, S2N. Note that such genes are who reject the null hypothesis and in consequence, they have the greatest statistical significance.

S2N (Signal-to-Noise, [9,10]) performs a second noise filtering from the input data and computes the statistic that determines the correlation of each gene with respect to both tissue sample classes given in the dataset. Thus, the most positive values are more correlated with the positive class whereas the most negative values are more correlated with the negative class. Hence, a determined number of genes is selected for each class based on a threshold and finally passed to the next stage. Once both methods have been applied, the resulting dataset is assumed as noise-free and the gene selection processes can be run.

2.3 Gene Selection Ensemble: Stage-III

This stage acts as an ensemble of gene selection methods by combining solutions of different methods in a single gene set. The idea consists of individually applying each gene selection method and merge their results by running the union operation (in mathematical terms) between them. Therefore, the gene set resulting from this operation (which we call Union-set) will have all genes found by each of different applied methods. Hence, it would be desirable to find a gene combination from such a Union-set, being representative for the remaining genes and optimizing the classification process of the study disease. Another important factor in this stage is that new gene selection methods can included to the list of existing ones to improve the results. Once Union-set has been achieved, it is necessary to run some strategy able to find a small gene subset from Union-set whose genes maximize the accuracy of the classifier used to identify tissue samples from the input dataset. This is the goal of the following stage.

2.4 Two Wrapper Strategies: Stage-IV

This stage is in charge of finding a small gene subset from Union-set, whose genes maximize the accuracy of a determined classifier. To deal with this problem, we have developed two greedy strategies acting as wrapper methods, which involve, on the one hand, a gene removing strategy and on the other hand, a gene addition strategy. Both strategies share the same classifier to maximize its accuracy and the strategy whose gene subset reaches the best accuracy across the presented classifier is the winner. The gene subset of the winner strategy will be the subset of informative genes end. The operation mode developed by both strategies (which we call WM1 and WM2) is presented as follows:

– Gene removing strategy WM1: This strategy takes as input the Union-set set and a classifier. In each step, it deletes a gene from Union-set to evaluate the accuracy of the remaining genes. If the accuracy of the classifier is greater than or equal to the accuracy of the previous Union-set, then such a deleted gene is not significant for classification and it is permanently removed from Union-set. The new Union-set replaces the previous one. The process is repeated for the resulting Union-set by selecting (deleting) a new gene until all genes have been selected. Note that if a deleted gene decreases the accuracy of the classifier, then it is returned back to the set (because it is important for the classifier) to select another gene. As a final result, a small gene subset where no gene can be removed is returned.

– Gene addition strategy WM2: Union-set set and a classifier are also the input to this method. The strategy applied in this method performs in reverse sense to WM1. It starts from choosing a single gene from Union-set in such a way that maximizes the accuracy of the input classifier. Such a gene is added to an empty set (which we call NG) and removed from Union-set. The process above is repeated by adding another gene from the remaining genes in Unionset to NG in such a way that, the accuracy of the new NG is greater than the accuracy the previous NG on the classifier. The strategy above continues until no more genes can be added to NG, i.e., any other gene added to NG decreases the accuracy of the input classifier. Finally, NG is returned as an informative gene subset.

3. Conclusions

The goal of this paper has been to provide a solution fusion method for gene selection from DNA-microarray data. Our proposal has been divided into four stages which have been explained throughout of this paper. Taking into account the problems presented by the current proposals of gene selection, we have that our approach of solution fusion could give solution to some of such problems.

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References

[1] Bourne, P., Wissig, H.: Structural Bioinformatics. Wiley-Liss, Inc., Hoboken, New Jersey (2003)

[2] Natarajan, A., Ravi, T.: A survey on gene feature selection using microarray data for cancer classification. International Journal of Computer Science & Communication (IJCSC) 5(1) (2014) 126–129

[3] Shraddha, S., Anuradha, N.and Swapnil, S.: Feature selection techniques and microarray data: A survey. International Journal of Emerging Technology and Advanced Engineering 4(1) (2014) 179–183

[4] Tyagi, V., Mishra, A.: A survey on different feature selection methods for microarray data analysis. International Journal of Computer Applications 67(16) (2013) 36–40

[5] Wang, Y., Tetko, I., Hall, M., Frank, E., A., F., Mayer, K., Mewes, H.: Gene selection from microarray data for cancer classification - a machine learning approach. Computational Biology and Chemistry, Elsevier 29 (2005) 37–46

[6] Kumari, B., Swarnkar, T.: Filter versus wrapper feature subset selection in large dimensionality microarray: A review. International Journal of Computer Science and Information Technologies (IJCSIT) 2(3) (2011) 1048–1053

[7] Castellanos-Garzón, J.A., Ramos, J.: A gene selection approach based on clustering for classification tasks in colon cancer. Advances in Distributed Computing and Artificial Intelligence Journal (ADCAIJ), DOI: http://dx.doi.org/10.14201/ADCAIJ201543110 4(3) (2015) 1–10

[8] Weiss, P.: Applications of generating functions in nonparametric tests. The Mathematica Journal 9(4) (2005) 803–823

[9] Lazar, C., Taminau, J., Meganck, S.and Steenhoff, D., Coletta, A., Molter, C. and de Schaetzen, V., Duque, R.and Bersini, H., Now´e, A.: A survey on filter techniques for feature selection in gene expression microarray analysis. IEEE/ACM Transactions On Computational Biology and Bioinformatics 9(4) (2012) 1106– 1118

[10] Berrar, D.P., Dubitzky, W., Granzow, M.: A Practical Approach to Microarray Data Analysis. Kluwer Academic Publishers, New York, Boston, Dordrecht, London, Moscow (2003)

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Web Page Classification with Pre-Trained Deep Convolutional Neural Networks

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Abstract

In this paper, we propose mining the growing amount of information present on the internet in the form of visual content. We address the problem of web page categorization based on the multimedia elements present on it. To achieve this, our framework leverages a pre-trained deep convolutional neural network model, which is used as a feature extractor for later classification. This paper presents experimental results concerning the effectiveness of different classifiers trained with features extracted at various depths of the convolutional neural network.

Keywords: web mining, neural networks, deep learning

1. Introduction

During the last decades, the number of web pages available on the internet has grown exponentially. The proliferation of blog-hosting and free content management sys-tems (CMS) such as WordPress, Blogger or Tumblr have contributed to this growth by making it possible for users with no experience in managing digital systems to share a variety of contents. The nature of these hosting services promotes the publishing of multimedia contents, especially images and videos. However, this democratization of the internet has originated new and challenging problems. Specifically, it has become increasingly difficult for users to find the content that they demand while avoiding related but undesired results. In addition, the availability of abundant multimedia content supposes challenge to recommender and search systems. Conventional recommender and search systems do not usually take into account the discriminative information provided by multimedia content, limiting themselves to the analysis of textual information. This is because mining multimedia data is a highly complex problem that frequently demands intensive computations and large training datasets.

On the other hand, the field of artificial vision, and specifically the sub-field of visual object recognition, has experienced a major breakthrough after the general adoption of the deep learning paradigm in recent years [10]. Deep learning models are composed of a previously intractable number of processing layers, which allows the models to learn more complex representations of the data by taking into consideration multiple levels of abstraction. This eventually led to a dramatic improvement in the state-of-the-art of visual object recognition, object detection and other related domains [4]. The keys to success for deep learning are the complexity of the models and the availability of large datasets with training data. The major drawback of deep learning techniques is their computational cost both in training and test phases.

In this paper, we propose applying a state-of-the-art model in visual object recognition to the field of multimedia web mining. Specifically, we propose using a deep convolutional neural network (DCNN) to the task of web page categorization based on the available multimedia content. To overcome the problems of computational cost and the need for large training datasets, we propose using a technique called transfer learning, which makes it possible to use the knowledge gained while solving one problem to another different but somehow related problem.

2. Proposed Framework

In this section the proposed method is described in detail. First, the global structure and elements of the processing pipeline are presented, followed by a detailed description of each element in the chain. Our system is designed to perform the following task: given an URL, the system must (1) access that URL, extract all the images available in the web page, and filter those that do not contain discriminative information; (2) extract a feature descriptor from each image such that the classification problem becomes easier over that feature space; and (3) analyze each feature descriptor and combine the results to emit a prediction concerning the category of the web page. This process is schematically shown in Figure 1.

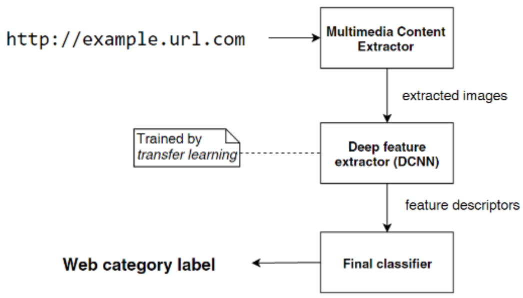

Fig. 1: Steps of the proposed framework

2.1 Visual Content Extraction

The first module of the proposed method is in charge of extracting all the images that are present in a given web page and filter the ones that do not contain useful information (i.e. advertisements, banners, etc.). To do this, the system begins by downloading the HTML document to which the provided URL points. Then, we use the Beautiful Soup library [7] to analyze the structure and the hierarchy in the document. After this, the web page is represented as a tree whose leaves are the elements of the document (e.g. titles, links, images, etc.). This representation of the document is explored exhaustively in order to find image elements; the URLs that point to those images are stored and later used to download the pictures.Several criteria can be applied to filter the extracted images; for example, it is possible to discard the images that contain a specific group of keywords in the alt attribute (e.g. we might discard images that contain the word “advertisement” in its alt attribute). Another possible approach consists of rejecting the images whose dimensions are outside a specific range. This is because images with rare proportions do not usually contain discriminative information. For example, very small images might correspond to navigation icons, and images of elongated shape tend to be advertisement banners.

2.2 Deep Feature Extractor

Once a number of images have been extracted from a web page, it would be possible to directly apply any classification method. However, the complexity of the image recognition problem that we are trying to solve demands a large number of training instances and a very complex model that can manage the difficulty of the classification problem. This is mainly due to the high intra-class variability of the samples from such artificial vision problems. Collecting such an extensive dataset can be a tedious and very time-consuming task. In addition, the training time of such a classifier would be very long even if we used complex computation parallelization techniques and expensive devices.

To overcome these limitations, we propose applying a technique known as transfer learning (see [8] for a recent survey on the topic). The key idea of this method is to apply the knowledge gained while solving one problem to a different but related problem. In practice, this technique has been mainly applied in the context of artificial neural networks. Here, some of the layers of the network are initialized with the weights learned by another network that was trained to solve a different problem; the remaining weights are initialized at random (as usual). A short training phase is then executed to tune the weights of the network that were randomly initialized. While the transferred layers may also be fine-tuned by executing various iterations of the chosen training algorithm, in principle this step is not mandatory. Avoiding this adjustment process will allow us to use any kind of classifier on top of the transferred neutral layers, even if it is not compatible with the backpropagation method.

In the case study for this paper, we propose using a pre-trained model of DCNN. Specifically, the selected model is the VGG-16 DCNN [11] developed by the Visual Geometry Group at the University of Oxford. The VGG-16 network achieved second place in the classification task of the Large Scale Visual Recognition Challenge 2014. It was trained on the ImageNet dataset, which consists of 14 million images belonging to 1000 categories; the model achieves 92.7% top-5 test accuracy on this benchmark. Although several models have outperformed VGG16, this model remains competitive with the state-of-the-art. In addition, it was designed with computational costs in mind. The number of parameters of the network was significantly reduced by using small 3×3 kernels in the convolution layers of the network. We chose the VGG16 model because it maintains a balance between computational costs and accuracy. Figure 2 shows the overall architecture of the network; we will refer to this figure to name each of the layers of the model in the experimental results section.

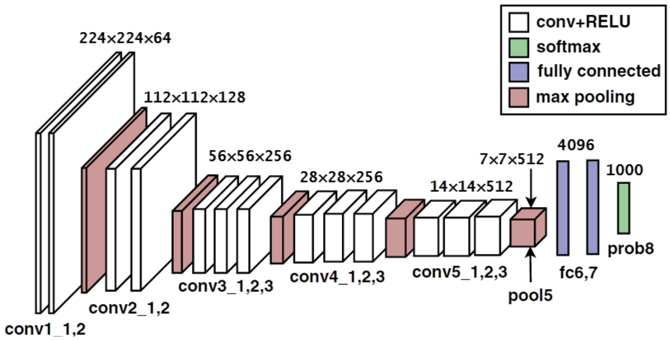

Fig. 2: VGG16 CNN architecture

In the proposed framework, the network is cut at a specific layer and the activations of the neurons in that layer are used as a representation of the input image. A simpler classifier is then applied over that feature space.

It has been proved that the outermost layers provide a more abstract and compact representation of the input images [12]. However, the final layers are more task-dependent and might not be useful if the target problem we want to address is very different from the problem the network was originally trained to solve. The layer that produces the most suitable representation for a given task must be determined empirically. To this end, the accuracy rates obtained with features from different layers and various classification methods are reported in section 3.

2.3 Final Classifiers

After the high level features have been extracted from the images using the deep neural network, a simpler classifier is in charge of emitting the final class prediction. Given that the features are sufficiently abstract, the use of a linear classifier is adequate. However, we also evaluated a simple nonparametric classifier that is not strictly a liner classifier, namely the k-Nearest Neighbor (kNN) algorithm.

In addition, the following linear classifiers were applied:

1. Support Vector Machine (C-SVM) with a linear kernel, as implemented in LIBSVM [1]. The decision function of this classifier is the following:

$$h(x) = sgn(w^T \varphi(x) + b) = sgn(w^T x + b)$$

where w is calculated by solving the optimization problem presented in [2]. The multi-class support is obtained following a one-vs-one scheme.

2. Perceptron with linear activation function as implemented by scikit-learn [9]

$$h(x) = w^T x + b$$

where w was optimized according to the mean squared error (mse) loss function. The stopping criteria was five iterations in all the experiments.

3. Logistic Regression (LR) as implemented in LIBLINEAR [3]. The decision function of this method is the following:

1

$$h(x) = \frac{1}{1 + e^{-\mu}} \; where \; \mu = w^T x + b$$

Here, the multi-class support was obtained using a one-vs-rest scheme. Note that despite the nonlinearity of the decision function, the decision boundary $\{x: h(x) = 0.5\}$ is a hyperplane and therefore this classifier is considered to be linear.

The majority of the web pages that we analyzed contained several images with relevant information. All the images must be taken into account to emit a prediction about the category of the web page. The simplest approach is taken where the final prediction is the most common label among the images of the web; when a tie occurs it is solved at random.

3. Experimental Results

In this section, we evaluate the proposed method on a real word dataset for web page categorization. We provide insight into the suitability of transferred DCNN features by means of data visualization techniques and evaluate our system against individual image classification and web page categorization.

To the best of our knowledge, there is no standard dataset for web page classification that focuses on visual content. For this reason we decided to collect a new database of web pages and the visual content present on them at the time. Our dataset consists of the images extracted from 75 web sites, uniformly distributed among five categories, namely “food and cooking”, “interior design”, “pets and wildlife”, “motor and races” and “fashion”. A total of 1,232 images were extracted from those web pages. The train/test split was arranged with 15 web pages for training and 60 web pages for testing purposes. As proved by our experimental results, the use of the transfer learning technique provides high accuracy rates in spite of the lack of a large training dataset.

We report experimental results concerning the classification accuracy of both individual images and complete web pages. As described before, several classification methods were trained on the images extracted from 15 web pages, using the features at various depth levels of the network. The classification accuracy was then evaluated on the images extracted from the 60 remaining web sites. The accuracies for single image categorization are reported in Table 1. As explained before, the predictions for individual images are combined to categorize the complete web page. The accuracy rates for web page classification are shown in Table 2.

Table 1. Accuracy rates (%) on individual images

Features	**SVM**	**LR**	**Perceptron**	**kNN**
fc7	0.905	0.821	0.886	0.589
fc6	0.884	0.884	0.876	0.340
pool5	0.869	0.843	0.864	0.263
pool4	0.753	0.727	0.729	0.367
pool3	0.650	0.605	0.649	0.261
pool2	0.554	0.557	0.544	0.203

Table 2. Accuracy rates (%) on web categorization

Features	**SVM**	**LR**	**Perceptron**	**kNN**
fc7	0.966	0.9	0.93	0.56
fc6	0.916	0.95	0.933	0.31
pool5	0.9	0.85	0.916	0.25
pool4	0.816	0.816	0.766	0.4
pool3	0.766	0.583	0.766	0.25
pool2	0.733	0.55	0.7	0.2

4. Conclusions

In this paper, a novel framework for web page categorization was proposed. The system is able to classify web pages based on their visual content rather than their textual information. This makes the proposed technique very appropriate to modern web site analysis where visual elements have a dominant role. The major contribution of this paper is the application of transfer learning techniques to the problem of web page categorization. Experimental results show that this approach enables the construction of very accurate classifiers even when the artificial vision task to solve is significantly complex. In addition, our experiments show that competitive accuracy rates can be obtained with training phases of minutes, while training a complete deep neural network model to solve such a complex vision task typically requires hours or days, even if expensive specialized hardware is available. The second major advantage of the transfer learning approach is that it allows decent accuracy rates even if the training set is of reduced length.

The proposed approach could be further improved. First, a more sophisticated method to filter advertisements and other non-relevant content from web pages could be implemented. In addition, if more training data were available, it would be possible to adjust the weights of the deep neural network by executing various iterations of backpropagation. This would likely improve the accuracy rate of the proposed framework. Finally, a more advanced way of combining individual image predictions to categorize web pages could be developed, including techniques such as ensemble classification and mixture of experts [6].

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References

[1] Blondel, V. D., Guillaume, J. L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. Journal of statistical mechanics: theory and experiment, 2008(10), P10008.

[2] Bostock, M., Ogievetsky, V., & Heer, J. (2011). D³ data-driven documents. Visualization and Computer Graphics, IEEE Transactions on, 17(12), 2301-2309.

[3] Klusch, M. (Ed.). (2012). Intelligent information agents: agent-based information discovery and management on the Internet. Springer Science & Business Media.

[4] Liu, B. (2012). Sentiment analysis and opinion mining. Synthesis lectures on human language technologies, 5(1), 1-167.

[5] McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. Annual review of sociology, 415-444.

[6] Mislove, A., Marcon, M., Gummadi, K. P., Druschel, P., & Bhattacharjee, B. (2007, October). Measurement and analysis of online social networks. In Proceedings of the 7th ACM SIGCOMM conference on Internet measurement (pp. 29-42). ACM.

[7] Newman, M. E. (2006). Modularity and community structure in networks. Proceedings of the national academy of sciences, 103(23), 8577-8582.

[8] Nguyen, D., Demeester, T., Trieschnigg, D., & Hiemstra, D. (2012, October). Federated search in the wild: the combined power of over a hundred search engines. In Proceedings of the 21st ACM international conference on Information and knowledge management (pp. 1874-1878). ACM.

[9] Pfalzner, S., & Gibbon, P. (2005). Many-body tree methods in physics. Cambridge University Press.

[10] Schrenk, M. (2012). Webbots, spiders, and screen scrapers: A guide to developing Internet agents with PHP/CURL. No Starch Press.

[11] Stefanidis, A., Crooks, A., & Radzikowski, J. (2013). Harvesting ambient geospatial information from social media feeds. GeoJournal, 78(2), 319-338.

[12] Tapscott, D. (2008). Grown Up Digital: How the Net Generation is Changing Your World HC. McGraw-Hill.

[13] Westerman, D., Spence, P. R., & Van Der Heide, B. (2014). Social media as information source: Recency of updates and credibility of information. Journal of Computer-Mediated Communication, 19(2), 171-183.

[14] Sanchez Martin, A. J., de la Prieta Pintado, F., & De Gasperis, G. (2014, July). Fixing and evaluating texts: Mixed text reconstruction method for data fusion environments. In Information Fusion (FUSION), 2014 17th International Conference on (pp. 1-6). IEEE.

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Real-time demand response and intelligent direct load control

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Evaluation of Classifiers Applied to the Appliances Identification

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Abstract

In recent years, traditional power meters have evolved to smart power meters, which allow not only the measuring, but the recording of the electrical consumption. This kind of devices are a key part in the development of the Smart Grid, since they allow the study of the consumer's electrical consumption patterns. In this work, we are focused in the evaluation of different classification techniques, applied to distinguish an appliance according to its individual consumption.

Keywords: classifiers, appliances recognition

1. Introduction

In recent years, there has been a significant increase in the price of electricity, both for households and industry around the world. In some countries of the European Union, such as France or Germany, the price of electricity has increased by more than 40% in 2015 (in comparison to previous years). In the case of Spain, according to official data from Eurostat (the statistical office of the European Union) [1] between the second half of 2008 and the second half of 2014, the cost of electricity increased by 0.081 euros / kilowatt hour, which is the almost the double of the average increase recorded in the EU (0.042 euros / kwh). Controlling the electrical usage in both households and industry is a necessity if we want to manage energy costs efficiently. Monitoring the amount of electricity that is consumed by the elements connected to the grid, lets us establish which of them is the most energy demanding. Knowing this is essential for the reduction and optimization of energy consumption.

Current electrical installations do not provide a simple way to collect the consumption data from the different devices that are connected to the grid. Therefore, the most widespread monitoring techniques are based on the analysis of the whole household consumption, that is, the sum of all the individual consumptions that are produced by the connected devices. In order to obtain an estimated value for the different elements, data disaggregation techniques are used. For this reason, creating a system that allows for the automatic detection and classification of household appliances is important for analyzing energy consumption.

Most electrical consumption disaggregation methods are designed to detect switch on/off events of a single appliance. But the reality is that multiple devices can be activated or deactivated simultaneously.

Therefore, disaggregation of consumption can be complicated by the simultaneous switch on/off of multiple devices. This technique is known as Non-Intrusive Appliance Load Monitoring (NIALM). One of the first approaches regarding NIALM systems was introduced in the late 1980s by George Hart at MIT[2]. Since then, the NIALM systems have evolved, improving the capacity of disaggregation and reducing their dependency to activation and deactivation events of the devices [3][4].

In recent years, the cost of technology production has fallen significantly. This has led to new phenomena such as Internet of Things (IOT) [5]. The devices and objects around us are more connected and accessible through the grid each day. There are already devices that are able to monitor the individual consumption of different appliances in real time, sending this data wirelessly. These devices are called Smart Power Plugs. Thanks to these new devices, it is easier to monitor the electrical consumption of certain devices without turning to NIALM systems. The individual consumption profile of the connected appliances can serve to improve the accuracy of NIALM systems.

In this work we show an evaluation and comparison of different classifiers in order to obtain the highest precision when identifying which electrical appliance is connected to a Smart Power Plug. Classifiers based on different algorithms such as fuzzy logic, probabilistic models or neural networks have been used. To perform the tests, real consumption data has been used by installing smart plugs, which are connected to a central node through ZigBee-This central node retrieves the consumption data of all the devices. In this study, we gathered consumption data for seven months, from three different appliances in the same household.

The rest of the paper is organized as follows: Section 2 reviews the state of the art on appliance classification; Section 3 describes the dataset used in this work; Section 4 shows the used algorithms and a comparison of their performance and section 5 shows up the conclusions and future lines of work.

2. Background

Several studies have dealt with the classification of household appliances through their load curve. For example, authors in [6] present a system that provides real-time appliance recognition, based on a single energy monitor –using Zigbee technology- which is connected to the main electrical unit. The system generates consumption profiles for each device, recognizes the different profiles in real time using neuronal networks and is fed with additional information which is provided by the users. In [7] authors propose a new method for the classification and identification of residential appliances. This appliances classification method uses the main power consumption and the performance style as the characteristics of each device. Subsequently, an appliance identification platform is designed and implemented with these characteristics.

Authors in [8] have developed a system which is able to automatically recognize home appliances according to their electrical consumption profile, that is measured in low frequency with low end sensors. This system is based on the traditional machine learning approach. The system uses the consumption profiles from a set of appliances as training data. Authors achieved a classification success rate of 85%.

In the case of [9], authors propose a time-based classifier which first identifies the appliances, and then predicts the future use of those appliances which use a big amount of energy within the household. To that extent, authors propose a new set of meta-characteristics to be included. Their results have been validated with a dataset containing data from 100 houses that have been monitored during one whole year.

In [10], it is stated that the best approach in order to model the appliances classification problem is the use of bottom-up methodologies. These methodologies build the load curve from an elementary entity such as a domestic appliance, the end-use or even the household and aggregate it at the desired modelling level. Through the study of three appliances, authors discuss their main particularities, which are the most influential properties in the individual energy demand. Once these particularities are defined, authors apply the proposed methodology in order to identify similar curves in the consumption.

Authors of [11] use Hidden Markov models to identify different devices at the same time. The independent changes in the active power of each device are described by each Markov chain. With the active power measurements of a single Smart meter, it is required to calculate the hidden variables that define the possible states of the different appliances. In conclusion, the authors conclude that the probabilistic model allows for the identification of appliances that work simultaneously.

The mentioned works have been conceptualized as NILM systems; therefore, they are based on data obtained from the general consumption of the household, registered by a smart meter. This paper proposes the identification of appliances attending to their power demand profile. In this case, instead of using a single smart meter for the whole grid, single smart plugs are used individually for each appliance. The use of this kind of devices allows to create the consumption fingerprint of the appliances, so it can later be used to automatically recognize them with no user interaction. Similar topics are dealt with in previous works such as [12] or [13].

3. Used Dataset

3.1. Data Acquisition

The dataset which has been used when carrying out this research was provided by the Portuguese company Virtual Power Solutions (VPS). This company offers various products that are designed to monitor the electrical consumption of both households and industrial clients.

In the scope of this study, the used devices belong to three different groups: Cloogy® Plug Power, which were connected through wireless Zigbee technology to a Cloogy®Smart Hub, which, in turn, was connected to a central server. This central server was responsible for storing the received data. The data was collected from 05/05/2016 to 30/11/2016 in a single household, obtaining data from three different Cloogy® Plug Power, that were connected to three appliances: a fridge, a washing machine and an electric heater.

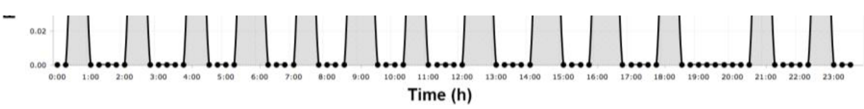
3.2. Dataset

The Smart Plug sends the accumulated consumption data to the central hub every 15 minutes, providing a total of 96 records per day and appliance. Each row of the generated dataset file corresponds to the electrical consumption of one of the appliances during one day. Each row has 97 columns; the first 96 gather the electrical consumption of the appliance for each measure, while the last one establishes to which appliance does the file correspond. Since we record three different appliance consumptions, the periodicity with which consumptions are recorded in the dataset is different. In the case of the fridge, there is a quasiperiodic consumption and magnitude throughout the day. For this appliance, user interaction does not significantly modify the consumption curve; while in the case of the other appliances -electric heater and washing machine-, user interaction does directly modify the consumption curve. The electric heater is only activated when the user activates it, and consumption frequency cannot be known, the same goes for the washing-machine. The user decides when to switch it on and, does it without a predictable frequency. In addition, the washing machine can be used in different modes (more or less powerful washing modes, using hot or cold water, etc.), it also goes through different cycles while being used.

During data collection, in the case of the fridge, consumption measurements were made every day. In contrast to the rest of appliances, since their activation directly depends on the user, there were no consumption measurements for those days when the user did not use these appliances. In order to evaluate the effect of including empty values -for those days where no activity was recorded, two different datasets were generated. The first dataset contained raw data, including those days with no consumption measurements from any of the appliances, and the second dataset which eliminated empty values, including only the days where activity was registered.

3.3. Appliances Comparison

As mentioned in the previous section, the three analyzed appliances present different usage patterns. Therefore, it was decided to perform the comparison between them since they operate differently and users use them in different ways.



onsumption type of this can be seen in

Fig. 1, the fridge has an average of 12 daily activations independently of the external factors. Weather (a higher temperature implies a higher consumption in order to keep food cold) or human intervention (opening the door or placing new food) can vary the consumption, but under normal conditions, the consumption cycle barely varies.

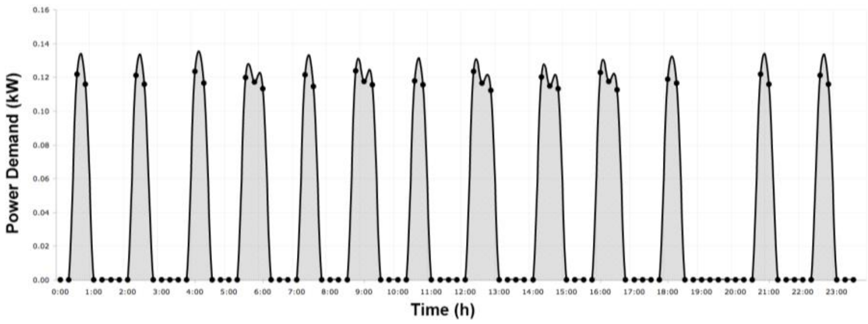


Fig. 1: Daily consumption of a fridge.

In contrast, the consumption of a washing machine is not continuous and exclusively depends on the user actions that generate consumption. In some households, the switching on of an appliance happens more or less at the same times, however, this will always depend on the family's habits. In any case, it is not a predictable or periodic consumption. In addition, current washing machines can be programmed with different functions, such as an intensive wash or a high temperature wash (which means an increase in energy consumption).

Time (h)

Fig. 2 shows a consumption chart of the energy consumption of a washing machine during 24 hours. As it can be observed, the appliance has been connected at three different times, and for each of this periods, the load curves are somewhat different.

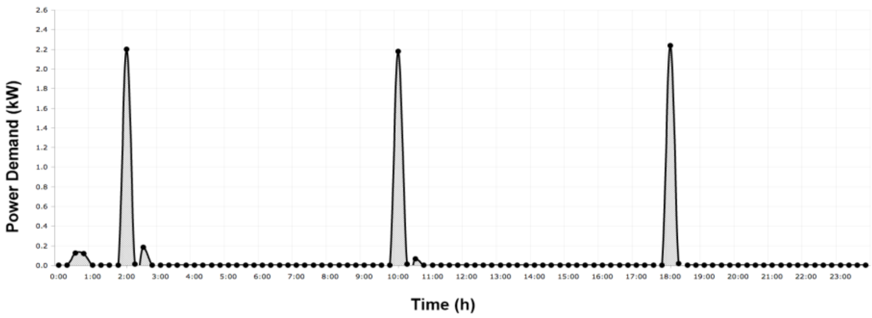
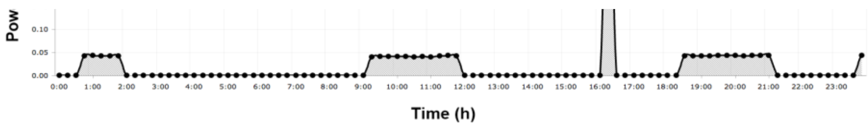


Fig. 2: Daily consumption of a washing machine.



s user-dependent. It is a utside temperature, the used. In figure

Fig. 3 we can see the consumption produced by this appliance during a 24-hour period. In this figure, we can observe how the electric heater has been connected five times. Four of these connections present a similar consumption pattern, while one of them shows a substantially higher demand of energy.

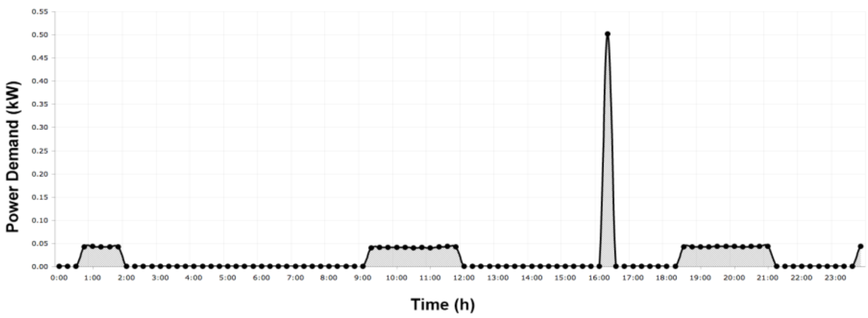


Fig. 3: Daily consumption of an electric heater.

4. Experiments, Comparisons and Results

In this section we analyze the results of the used algorithms. We have followed several steps: firstly, we have applied the classification methods with each pair of appliances (fridge and washing machine, fridge and electric heater and washing ma-chine and electric heater), and we have then applied those methods classifying the three appliances at the same time. The used algorithms were: bayesian network, na-ivebayes, random forest, random tree, REPtree, decision stump, hoeffding tree, J48, logistic model tree and gradient boost.

In order to validate the performance of the classifiers, we analyze different Cohen's kappa coefficient, which is a statistic that measures inter-rater agreement for qualita-tive (categorical) items. It is usually thought to be a more robust measure than simple percent agreement calculation, since κ considers the possibility of the agreement oc-curring by chance. Table 1 shows evaluation the of Kappa coefficient:

Table 1. Evaluation of Lappa coefficient.

Evaluation of Kappa coefficient	
K value	**Level of agreement**
<0.20	None
0.21-0.39	Minimal
0.40-0.59	Weak
0.60-0.79	Moderate
0.80-0.90	Strong
Above 0.90	Almost perfect

During the validation of results, on the one hand a 10 fold-cross validation iteration was performed and, on the other hand, a division of data with 66% of data for training and 33% of data for testing. In summary, we present the kappa statistic for each algorithm and dataset. This is a representative statistic, since it represents the level of agreement of the classifier.

Table 2. Algorithms performance with 10 fold cross-validation.

	All Data	All Data (no empty data)	Washing machine and electric heater	Fridge and electric heater	Fridge and Washing machine
Bayes Net	0.4924	0.7703	0	1	1
Naive Bayes	0.5744	0.5479	0.2949	0.9404	0.6623
RandomForest	0.6903	0.7867	0.4828	1	1
RandomTree	0.5384	0.6807	0.3802	0.9097	0.8063
REPtree	0.4292	0.6807	0	0.8339	0.7253
DecisionStump	0.2909	0.3973	0	0.5594	0.559
HoeffdingTree	0.4313	0	0	0.9399	0.5134
J48	0.5078	0.6077	0	0.9549	0.8802
Lmt	0.4241	0.5799	0	0.9399	0.7253
GradientBoost	0.46744	0.78263	0.11372	0.96988	0.88862

Table 3. Algorithms performance with percentage split (66%).

	All Data	All Data (no empty data)	Washing machine and electric heater	Fridge and electric heater	Fridge and Washing machine
Bayes Net	0.2971	0.7573	0	1	1
Naive Bayes	0.6058	0.5747	0.3296	0.9539	0.6057
RandomForest	0.6208	0.7812	0.4696	1	1
RandomTree	0.4495	0.6023	0.3581	1	0.6964
REPtree	0.4417	0.6393	0	0.9091	0.7829
DecisionStump	0.3187	0.2996	0	0.5594	0.5036
HoeffdingTree	0.4127	0.2996	0	0.9109	0.4068
J48	0.4417	0.6004	0	0.8643	0.6395
Lmt	0.3459	0.5609	0	0.9552	0.7829
GradientBoost	0.4045	0.7637	0.323170	1	0.93499

5. Conclusions and Future Lines of Work

In the view of the results, we can conclude that all the classifiers have been more accurate when classifying the fridge than any other appliance, as expected a priori, since the load curve of the fridge is more representative than the other appliances in the dataset, since it is continuously working and it has a more or less periodical consumption, while the other appliances are turned on by the householder, and the consumption fingerprint is not as representative as the fridge one. When classifying the fridge individually against the electric heater and the washing machine, we can say that all the algorithms have shown a better performance in the case of the electric heater, since the kappa statistic values denote a strong level of agreement. In the case of the washing machine, the classifiers performance has been slightly worse, but still reaching a moderate level of agreement.

Whereas, the worst results have been obtained when classifying the washing machine against the electric heater, as the kappa statistic points out the minimal or poor level of agreement of the majority of algorithms.

When we have faced the classification of all the appliances together, the results were not as good as we could expect, and the different performances oscillate in the different algorithms, obtaining a range of the kappa statistic results that vary from minimal to moderate levels of agreement.

Based on these results, we realized that it would be impossible to classify the appliances which may have periods of no electrical consumption along the day, because it is not possible to classify them, this no-value data is just noise for the classifiers, making their performance significantly lower. We proceeded to omit the data of the washing machine and the electric heater, for those days where there was no electrical consumption. After removing this data, we applied the classifiers once again (to all the three appliances together), and the results improved significantly.

In order to improve the obtained results, we plan to follow this research line, making additional investigation: although some of the algorithms have shown a good performance when classifying the appliances, the input data is still very time-dependent, that is to say that the specific moment of the day when an appliance is used, establishes to a large extent the proper classification of the appliance. So, in order to improve the performance of the algorithms, the extraction of new variables from the dataset is necessary, including: (i) from consumption data: maximum value, total consumption, mean, variance, standard deviation, interquartile range, number of activation periods (number of times when an appliance has been working along the day), average duration of the activation periods, total duration of the activation periods, (ii) others: maximum and minimum temperatures, day of the month, day of the week, month.

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References

[1] "Home - Eurostat." [Online]. Available: http://ec.europa.eu/eurostat. [Accessed: 12-Jan-2017].

[2] G. W. Hart, "Nonintrusive appliance load monitoring," Proc. IEEE, vol. 80, no. 12, pp. 1870–1891, 1992.

[3] H. Najmeddine, K. El Khamlichi Drissi, C. Pasquier, C. Faure, K. Kerroum, A. Diop, T. Jouannet, and M. Michou, "State of art on load monitoring methods," in 2008 IEEE 2nd International Power and Energy Conference, 2008, pp. 1256–1258.

[4] S. Kong, Y. Kim, R. Ko, and S.-K. Joo, "Home appliance load disaggregation using cepstrum-smoothing-based method," IEEE Trans. Consum. Electron., vol. 61, no. 1, pp. 24–30, Feb. 2015.

[5] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," Comput. Networks, vol. 54, no. 15, pp. 2787–2805, 2010.

[6] A. G. Ruzzelli, C. Nicolas, A. Schoofs, and G. M. P. O'Hare, "Real-Time Recognition and Profiling of Appliances through a Single Electricity Sensor," in 2010 7th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2010, pp. 1–9.

[7] Z. Wang and G. Zheng, "Residential Appliances Identification and Monitoring by a Nonintrusive Method," IEEE

Trans. Smart Grid, vol. 3, no. 1, pp. 80–92, Mar. 2012.

[8] D. Zufferey, C. Gisler, Omar Abou Khaled, and J. Hennebert, “Machine learning approaches for electric appliance classification,” in 2012 11th International Conference on Information Science, Signal Processing and their Applications (ISSPA), 2012, pp. 740–745.

[9] K. Basu, V. Debusschere, and S. Bacha, “Residential appliance identification and future usage prediction from smart meter,” in IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society, 2013, pp. 4994–4999.

[10] A. Grandjean, G. Binet, J. Bieret, and J. Adnot, “A functional analysis of electrical load curve modelling for some households specific electricity end-uses,” in 6th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL’11), 2011, p. 24.

[11] R. Lukaszewski, K. Liszewski, and W. Winiecki, “Methods of electrical appliances identification in systems monitoring electrical energy consumption,” in 2013 IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS), 2013, pp. 10–14.

[12] A. Ridi, C. Gisler, and J. Hennebert, “Automatic identification of electrical appliances using smart plugs,” in 2013 8th International Workshop on Systems, Signal Processing and their Applications (WoSSPA), 2013, pp. 301–305.

[13] S. Barker, M. Musthag, D. Irwin, and P. Shenoy, “Non-intrusive load identification for smart outlets,” in 2014 IEEE International Conference on Smart Grid Communications (SmartGridComm), 2014, pp. 548–553.

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Real-time demand response and intelligent direct load control

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Urban Exploration through Chemical Signalling Algorithms

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Abstract

We show how exploration times can be significantly reduced by a simple anti-pheromone ant foraging based algorithm. This is implemented in a distributed multi agent architecture. The swarm behavior is analyzed for different scenarios with varying number of units and map complexity. An increase in the number of vehicles results in smaller exploration times. Also, we measure how the complexity of the map topology affects the navigability. We validate our approach through numerical tests with both synthetic random generated maps and real bicycle routes in four cities.

Keywords: smart cities, route optimization, swarm intelligence.

1. Introduction

A major challenge in Smart Cities (SC) [1] is the dynamic optimization of routes under different criteria. The objective is to manage a flood of electrical vehicles (EV) efficiently and in a sustainable way. The problem can be solved with different strategies, one of the most common found in literature is the use of a bio-inspired algorithms [2].

In this work we provide an implementation of a well-known bio-inspired meta-heuristic to analyze the collaborative routing of EV in cities. Moreover, we investigate the behavior of a swarm of robots in real environments.

The main difficulty in coordinating a robot swarm lies in the communication among units. In this regard, previous works can be split into implicit/indirect and explicit/direct communication. Implicit communication –also known as stigmergy- is based on the context and some of its most typical uses can be found in [3]–[6]. In this regard, the Pioneer work of Pierre-Paul Grasse in termite colonies revealed the communication mechanisms of these insects by means of chemical signaling and in particular by pheromones [7]. These observations resulted in an ant-based exploration algorithm [8]. Here, each ant leaves a pheromone trail in its foraging activity. This trail persists for some time and it is followed by other ants in the search of food re-sources.

Also, the pheromone approach has been widely adapted to several artificial intelligence problems in its converse flavor (i.e. anti-pheromones) [9]–[11]. In particular, some researchers have used anti-pheromone (APH) proxies to optimize robot exploration [12]. The main advantage is that each unit accesses a different region fostering the diversity of the solutions by means of indirect and decentralized communication.

On the other hand, the efficient exploration and target localization in urban environments is gaining more and more attention [13], [14]. However, bio-inspired algorithms tailored to optimize robot exploration and dynamic route generation in SC are somewhat separate research fields. Therefore, in this work we propose an APH-based robot swarm exploration strategy to optimize routes in SC. In particular, we use the SC paradigm to analyze intelligent routing of cooperating electric vehicles. We describe how a simple APH-based algorithm can be effective in locating targets in different cities. To this end, we use both numerical simulation and real physical exploration with three prototypes.

This paper is organized as follows. In Section 2 we present the APH-based algorithm and Multi-Agent architecture for SC exploration. We apply the strategy in Section 3 for a case study of 4 different cities with different spatial complexity. The main outcomes from this study are summarized in Section 4 and we conclude in Section 5.

2. An Anti-Pheromone Swarm Algorithm for Exploration

In the following we describe both the proposed architecture and the Anti-pheromone based algorithm.

2.1. Proposed Architecture

For the distributed execution of the Anti-pheromone swarm algorithm we have used the multi-agent architecture PANGEA [15], previously developed in the BISITE re-search group. This Multi-Agent System (MAS) allows the implementation of embed-ded agents in computationally limited devices, allowing a simple communication among the different elements. The information transfer is based on the use of the ISO / IEC 20922: 2016 protocol, which allows flexible communication with optimum battery consumption

Virtual agents in a MAS cooperate with each other, aiming to solve a problem or reach a goal. In PANGEA, agents with the same goal are grouped into virtual organi-zations (VO). Fig. 1 shows an interaction diagram of the different virtual organiza-tions implemented in our study. Below we describe the virtual organizations in this work.

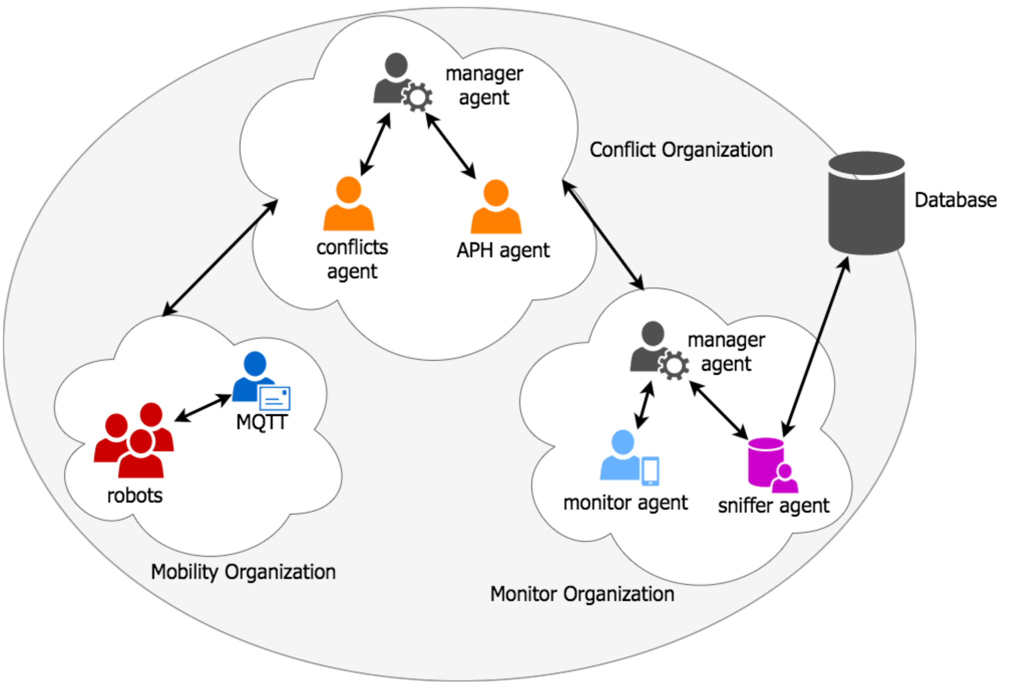

Fig. 1: MAS architecture. Three virtual organizations (Mobility, Conflict and Monitor) of agents cooperate in the navigation process.

The robots of the Mobility VO communicate through the MQTT agent. The Conflict VO manager receives the robot information and sends it to the conflicts and APH agents. He also sends back mobility instructions to the robots. All these messages are also monitored in the VO Monitor and finally stored.

- Mobility: Includes mobile agents for environment exploration.
  - Robots: mobile entities that move around the environment and eventually find targets.
  - MQTT: is the technology used for receiving and resending robot messages by means of the MQTT (MQ Telemetry Transport) protocol [16].
- Conflict: includes the following agents:
  - APH agent: it holds the virtual map and is responsible for counting the an-ti-pheromones at every location and time.
  - Conflicts agent: Aimed at solving potential emerging conflicts among agents when two robots coincide at the same location.
- Monitor: to monitor the process and store the information in a database. These agents do not interfere in the main process. This group is composed of:
  - Monitor agent: controls the life cycle of other agents and enables the inter-face to display the general state of the communications, organizations and agents. This agent is responsible for starting the agents of the platform in case of failure.
  - Sniffer agent: manages the message history and filters information by con-trolling communication initiated by queries.

In PANGEA the Manager agent verifies the creation and elimination of agents and the assignment of roles. Also, he is the communication hub among organizations.

2.2. Anti-Pheromone Algorithm

The navigation algorithm we present in this work (pseudocode in Fig. 2) is an adaptation of the classical two-dimensional APH gradient [4] to a 1D gridded world. This world consists of a set of parallel and perpendicular lines arranged in a way that mimics urban topologies.

```
while current location ≠ target do
    if current location = intersection then
        [paths] ← get all paths with the lowest and same level of
         anti-pheromones;
        if  size (paths) > 1 then
            angle ← angle of random path in [paths];
        else
            angle ← angle of the path in [paths];
        end
        turn ( angle );
        go on;
    else if current location = dead end then
        turn ( 180° );
    else
        drop anti-pheromone;
        go on;
    end
end
```

Fig. 2: Anti-pheromone navigation algorithm.

Each time a robot reaches an intersection which is neither a target nor a dead end, a negative APH gradient based route is followed. In the following section we apply this strategy to different scenarios.

3. Simulation

Our simulation consists of an NxN gridded world where robots move along paths generated according to a modification of the random walk algorithm as we explain below. In this setting we define the following parameters:

1. N_{robots}: number of robots
2. $R_{maze} = N_{path}/N \cdot N$ proportion of path units (N_{path}) with respect to the total number of cells.
3. $Pers_{rate}$: pheromone evaporation time (i.e. number of time units a pheromone takes to evaporate). At every time step the robots leave a pheromone unit.

There are two phases in our tests. Firstly, we generate synthetic topologies with parametrized complexity. Here the path generation algorithm is a simple adaptation of a 2D random walk with jumps of varying lengths. We however constrained the algorithm to avoid adjacent lines and prevent robot collisions. With this strategy we generated a population of $22x10^6$ samples by sweeping parameters as follows: $N = 40$, $N_{robots} \in [1, 10]$ with $steps = 1$, $R_{maze} \in [0.1, 0.6]$ with $steps = 0.05$ and $Pers_{rate} \in [1, 100]$ with $steps = 1$. For each parameter combination we repeated the tests 50 times. At every run, a synthetic topology is generated and both the target and robots' initial positions are selected randomly among the path locations.

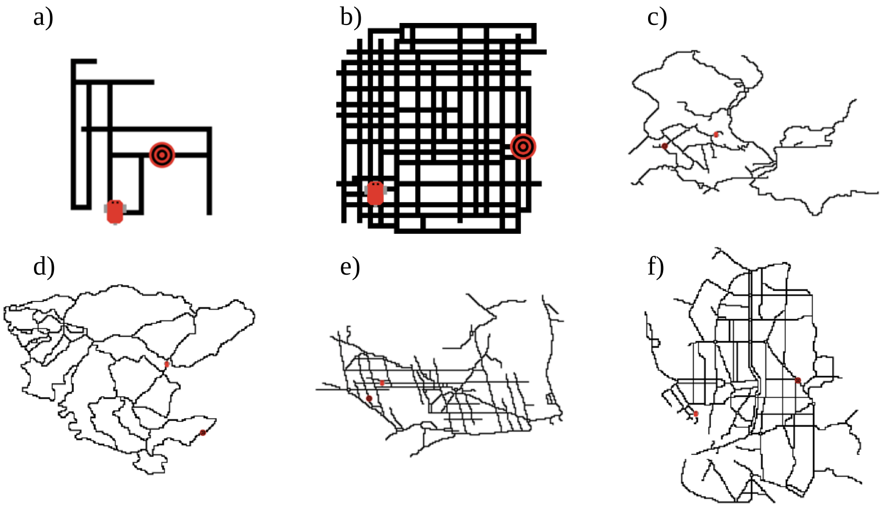

Fig. 3. (a) Synthetic topology with $R_{maze} = 0.1$. (b) Synthetic topology with $R_{maze} = 0.5$. (c) Map of Gijon with NM = 2.01. (d) Map of Castellón with NM = 2.02. (e) Map of Barcelona with NM = 0.6. (f) Map of Madrid with NM = 0.5.

In the next phase we have used real EV maps from four Spanish cities. In particular, the bike routes from Madrid, Barcelona, Gijon and a mountain bike trail in Castellón have been adapted to our simulations.

For each of these maps, we ran a parameter sweep with $N = 200$, $N_{robots} \in [1, 5, 10]$, and $Pers_{rate} \in [10, 250]$ with $steps = 10$.

As before, every combination of parameters has been repeated 50 times and the target and robot initial positions are chosen randomly at every iteration.

In both analyses (synthetic maps and real routes) we have obtained the following metrics:

1. $firstTime$ defined as the first time of arrival to the target by any of the robots,
2. $totalTime$: elapsed time until all the robots reach the target.
3. $robotPath$: the number of discrete locations (i.e. patches) covered by the robot along its path.

As stressed, every topology is parametrized by its spatial complexity. This is simply defined as the mean of the neighbourhood (Von Neumman) size of every path cell. The resulting complexities for Gijón, Castellón, Madrid and Barcelona are respectively: 2.01, 2.02, 2.05 and 2.06 (Fig. 3).

4. Results

In this work we analyse the mean first time of robot arrival to the target averaged over the 50 runs for every parameter combination. We use this observable as a proxy for robot collaboration. In Fig. 4 we show this metric for a value of 60 Persrate and increasing number of robots and for different levels of map complexity in a log scale. Here the times are normalized with the maximum time and the map complexity is computed as described above. Also in the plot we show data points corresponding to simulations with 5 and 10 units for the bike routes for Madrid, Barcelona, Gijón and Castellón (Fig. 3).

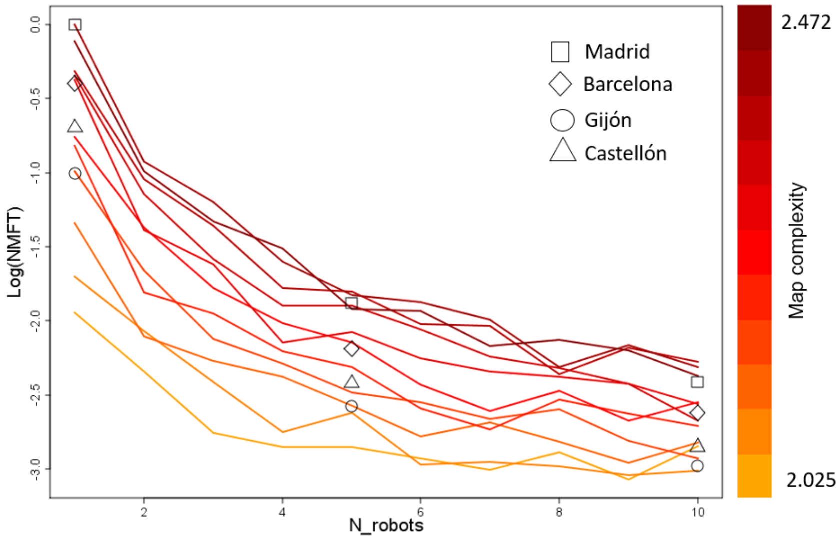

Fig. 4. Normalized first arrival times to the target for different number of robots and levels of map complexity. Data points represent the simulation on real bike routes in four Spanish cities.

It is observed that arrival times decrease with the number of robots. This result shows that swarm collaboration is actually happening. Also, as expected, the complexity of the map topology augments the exploration time for a fixed number of robots. For 10 robots the NMFT for Gijón, Castellón, Barcelona and Madrid are: 0.051, 0.057, 0.073 and 0.089 respectively. The complexities of Gijón (2.01) and Castellón (2.02) are similar, which is also the case for Barcelona (2.06) and Madrid (2.05). This is consistent with the disposition of the data points in Fig. 4. Interestingly, Madrid is slightly less optimizable than Barcelona, although its complexity is smaller.

In our setting, we predict that APH based navigation in Gijón-like cities is likely to be around 57% times shorter than Madrid-like cities only due to the differences in spatial complexity (see Fig. 3) regardless of city size.

5. Conclusions and Future Works

In this work the classical anti-pheromone ant foraging algorithm has been adapted to the problem of optimal routing in Smart Cities. We have validated our approach by numerical simulations. The simulations were performed with random-walk generated maps and with real bicycle routes of four Spanish cities with parametrized spatial complexity. The swarm collaboration is results in a significant reduction of the arrival times. Also, it is found that these times increase with map complexity.

From the statistical analysis of the experiments the collaboration among vehicles has been quantified in terms of the elapsed times to reach a target. We have shown how an increase in the number of units and in map complexity results in higher exploration times. The swarm collaboration mechanisms of our design has shown to be effective in simulations and can be implemented in real Smart City scenarios.

Regardless of the topology of the city, the proposed decentralized collaborative navigation strategy can be valuable to the design of new routing patterns without compromising efficiency. At its current stage the navigability improvement is only shown when compared with the non-swarm limit. Due to limitations of space and time the comparison with other mobility solutions is left for future work.

In future works, we will also consider combinations of different bio-inspired algorithms to improve city navigability under different factors. In particular, a suitable combination of different virtual signalling communication mechanisms (e.g. pheromone and anti-pheromone) can lead to significant improvements.

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References

[1] A. Degbelo, C. Granell, S. Trilles, D. Bhattacharya, S. Casteleyn, and C. Kray, “Opening up Smart Cities: Citizen-Centric Challenges and Opportunities from GIScience,” *ISPRS Int. J. Geo-Inf.*, vol. 5, no. 2, p. 16, Feb. 2016.

[2] F. Zambonelli, “Engineering self-organizing urban superorganisms,” *Eng. Appl. Artif. Intell.*, vol. 41, pp. 325–332, May 2015.

[3] D. Payton, R. Estkowski, and M. Howard, “Compound behaviors in pheromone robotics,” *Robot. Auton. Syst.*, vol. 44, no. 3–4, pp. 229–240, Sep. 2003.

[4] V. Trianni, T. H. Labella, and M. Dorigo, “Evolution of Direct Communication for a Swarm-bot Performing Hole Avoidance,” in *Ant Colony Optimization and Swarm Intelligence*, 2004, pp. 130–141.

[5] R. Kramer, “Animal & Machine Intelligence Essay Stigmergic Communication: Achieving so much without saying a word,” 2005.

[6] I. Mir and B. P. Amavasai, “A Fully Decentralized Approach for Incremental Perception,” in *Proceedings of the 1st International Conference on Robot Communication and Coordination*, Piscataway, NJ, USA, 2007, p. 10:1–10:7.

[7] P.-P. Grassé, “La reconstruction du nid et les coordinations interindividuelles chezBellicositermes natalensis etCubitermes sp. la théorie de la stigmergie: Essai d’interprétation du comportement des termites constructeurs,” *Insectes Sociaux*, vol. 6, no. 1, pp. 41–80, Mar. 1959.

[8] M. Dorigo, M. Birattari, and T. Stutzle, “Ant colony optimization,” *IEEE Comput. Intell. Mag.*, vol. 1, no. 4, pp. 28–39, Nov. 2006.

[9] R. Calvo, J. R. d Oliveira, M. Figueiredo, and R. A. F. Romero, “Bio-inspired coordination of multiple robots systems and stigmergy mechanims to cooperative exploration and surveillance tasks,” in *2011 IEEE 5th International Conference on Cybernetics and Intelligent Systems (CIS)*, 2011, pp. 223–228.

[10] F. Fossum, J. M. Montanier, and P. C. Haddow, “Repellent pheromones for effective swarm robot search in unknown environments,” in *2014 IEEE Symposium on Swarm Intelligence*, 2014, pp. 1–8.

[11] J. R. Oliveira, R. Calvo, and R. A. F. Romero, “Integration of virtual pheromones for mapping/exploration of environments by using multiple robots,” in *5th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics*, 2014, pp. 835–840.

[12] A. Ravankar, A. A. Ravankar, Y. Kobayashi, and T. Emaru, “On a bio-inspired hybrid pheromone signalling for efficient map exploration of multiple mobile service robots,” *Artif. Life Robot.*, vol. 21, no. 2, pp. 221–231, Jun. 2016.

[13] M. Lujak, S. Giordani, and S. Ossowski, “Route guidance: Bridging system and user optimization in traffic assignment,” *Neurocomputing*, vol. 151, Part 1, pp. 449–460, Mar. 2015.

[14] H. Billhardt, M. Lujak, V. Sánchez-Brunete, A. Fernández, and S. Ossowski, “Dynamic coordination of ambulances for emergency medical assistance services,” *Knowl.-Based Syst.*, vol. 70, pp. 268–280, Nov. 2014.

[15] G. Villarrubia, J. F. De Paz, J. Bajo, and J. M. Corchado, “Ambient Agents: Embedded Agents for Remote Control and Monitoring Using the PANGEA Platform,” *Sensors*, vol. 14, no. 8, pp. 13955–13979, Jul. 2014.

[16] “ISO/IEC 20922:2016 - Information technology -- Message Queuing Telemetry Transport (MQTT) v3.1.1.” [Online]. Available: https://www.iso.org/standard/69466.html. [Accessed: 20-Mar-2017].

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Real-time demand response and intelligent direct load control
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Framework to Enable Heterogeneous Systems Interoperability

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Abstract

The electricity markets have been suffering profound changes over the years. Nowadays, the European Union comes to reformulate its politics related with renewable energy sources, in order to encourage microgeneration, having demand response as one of the biggest challenges. Various simulators have been developed that intend to give decision support to the various entities. However, they present the limitation of being designed to answer specific problems. This paper proposes the framework Tools Control Center (TOOCC) as the mechanism to integrate various independent and heterogeneous simulators, so they operate as a unique simulation tool and become capable of answering to more complex problems.

Keywords: agent-based systems, demand response, ontologies, systems interoperability

1. Introduction

The use of energy from renewable sources is one of the major concerns of today's society. In recent years, the European Union has been changing legislation and implementing policies aimed at promoting its investment and encouraging its use in order to reduce the emission of greenhouse gases [1]. This leads to the emergence of a new paradigm in the energy sector, where there is a strong growth of microgeneration, which injects greater complexity into the Energy Markets (EM). Now, the entities that usually were consumers can also be producers, selling surplus energy to the network. As a result, new challenges arise, particularly in the production, distribution, storage and consumption of energy. By studying data collected from the network, it is possible to formulate strategies that make the system more sustainable, reliable and efficient, preventing waste and minimizing resources [2]. The use of simulators that use this information as a basis is an essential tool for decision support. However, the high complexity characteristic of the sector becomes a challenge [3] because there are several dimensions that influence the behavior of EM, and most of these tools are focused on a specific area of the problem. It is in this context that the Tools Control Center (TOOCC) emerges, a tool that allows interoperability between heterogeneous systems, in order to act as a single system. Thus, the various systems, focused on different problems, can work together to study energy systems, allowing the simulation of scenarios with a high degree of complexity.

2. The Framework

TOOCC is a multi-agent tool designed to allow the strategic communication of heterogeneous energy systems. The combination of their individual capacities creates a super system, providing results for more complete and complex scenarios, allowing to carry out more realistic studies on the sector. However, it is also possible to execute these systems/algorithms individually. Thus, TOOCC acts as a central entity, responsible for the setup, execution and analysis of different scenarios, which can use one or more systems, depending on the user objective. The agents were developed in JADE, which implements FIPA specifications.

To perform the simulation, TOOCC creates an agent for each scenario to execute, which is responsible for establishing communication with the required systems. The communication is made through ontologies, allowing the use of the same vocabulary in their interaction. In this way, it is guaranteed that the systems are able to understand each other and act in the way that is expected.

Currently, TOOCC is integrated with several energy systems, namely the Intelligence and Decision Support multi-agent system (IDeS), which executes the different DR, optimization, scheduling, forecasting, and decision support algorithms; Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) [4], that runs electricity market simulations; Adaptive Decision Support for Electricity Market Negotiation (AiD-EM) [5], which provides intelligent support for player's decisions in electricity market negotiations; Network Manager (NM) [6], that enables the energy management for a grid (Smart/Micro); Facility Manager (FM) [7], that manages facilities' energy resources; and Programmable Logic Controller Multi-Agent System (PLCMAS). However, the use of ontologies allows other external systems to easily communicate and interact with those presented here. Fig. 1 intends to present an overview of TOOCC execution process.

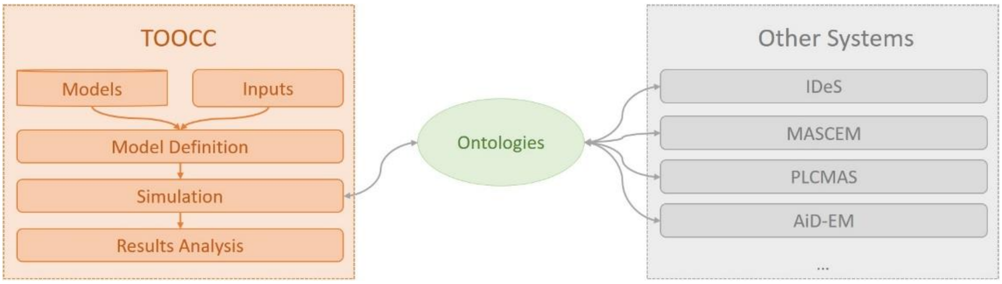

Fig. 1: TOOCC overview.

In addition, TOOCC has a mechanism for scheduling agents, guaranteeing that they will be (re)allocated to a machine that has the processing capacity, as well as the software needed to perform its task.

3. Demonstration

Due to the dynamism of the configuration of a scenario, TOOCC has a graphical interface that allows the user to configure it, in a process consisting of three phases: modeling, simulation and analysis. The user has a left menu which allows to user go back and make changes.

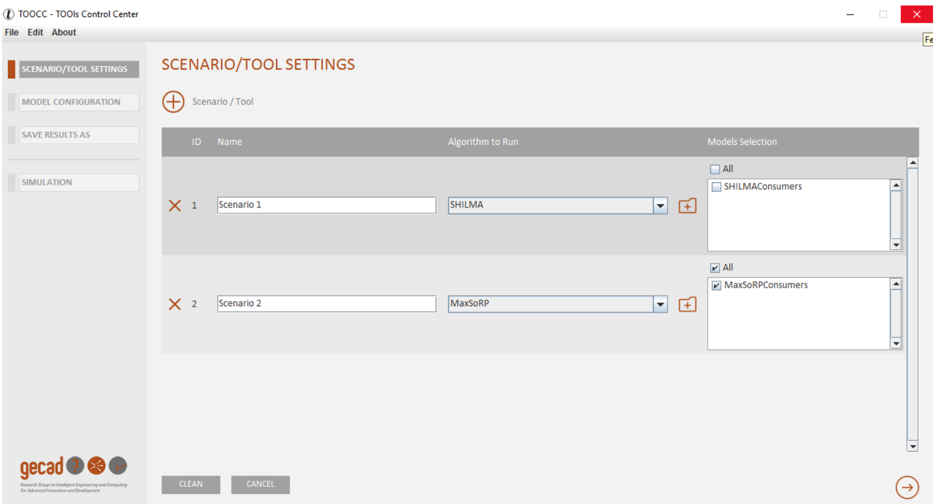

Fig. 2: TOOCC scenarios creation.

In the modeling phase, the created scenario (Fig. 2) is fed by stored models and input data. These models include the definition of distributed network components (storage units, loads and electric vehicles), demand response programs, energy tariffs, consumer definition, among others. In turn, the input data includes the parameterization required for the correct functioning of the systems/algorithms. Fig. 3 refers to an example of DR. This shows the TOOCC panel that allows the registration of consumer flexibility to shift its consumption for other hours. This information is important for the aggregator/manager entity, to know how the energy supply can be managed, in order to prevent the waste of energy, taking into account the consumer's preferences.

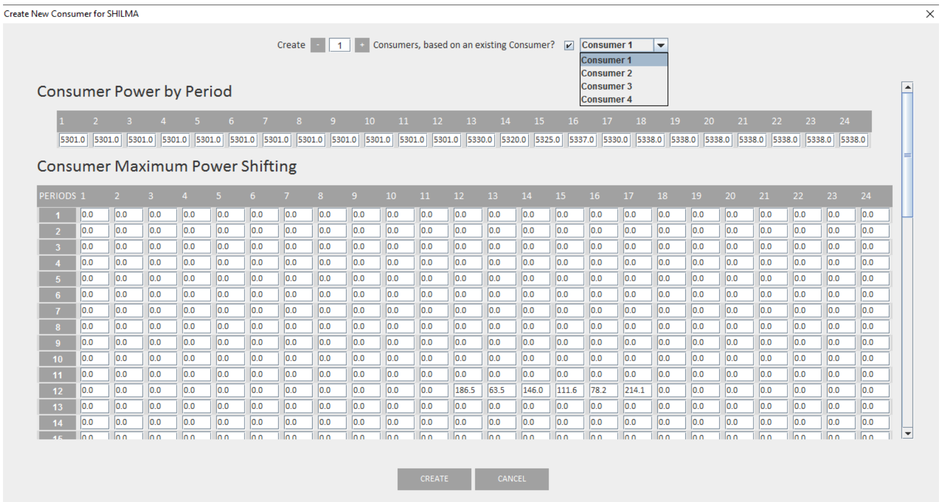

Fig. 3: Schematic of VPP in power market.

In the simulation phase, the agent responsible for the execution of the scenario will communicate with the necessary systems. For this, it uses ontologies designed for this purpose, which are available in [8]. During execution, agents may need to request a machine change in order to continue the simulation.

Finally, the last phase allows the user to analyze the results obtained from the execution, through graphs and drawn tables. These charts and tables can be saved for future use.

4. Conclusion

The growth in the use of renewable energy sources is increasing the complexity of EM. In this way, it is essential that its players can use mechanisms to support decision making, in order to deal with the unpredictability of the sector. There are several simulators that allow the study of EM, however, in that they act to respond to a specific problem.

In order to study the impact of all variables in EM, the TOOCC tool is proposed for the interoperability of heterogeneous energy systems, in order to allow the formulation of more complete and complex scenarios through the use of ontologies. In addition, this tool has a set of characteristics that gives it a great dynamism, because it allows the definition of the scenarios, and the configuration of models, which introduces the specification of simulation scenarios with very distinct natures and characteristics.

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References

[1] European Commission, "2030 framework for climate and energy policies," 2014. [Online]. Available: http://ec.europa.eu/clima/policies/2030/index%7B_%7Den.htm. [Accessed: 01-Mar-2016].

[2] S. Yang and Y. Wang, "Applying Support Vector Machine Method to Forecast Electricity Consumption," in *2006 International Conference on Computational Intelligence and Security*, 2006, vol. 1, pp. 929–932.

[3] L. A. Barroso and A. J. Conejo, “Decision making under uncertainty in electricity markets,” in *2006 IEEE Power Engineering Society General Meeting*, 2006, Available: .

[4] G. Santos, T. Pinto, I. Praça, and Z. Vale, “MASCEM: Optimizing the performance of a multi-agent system,” *Energy*, vol. 111, no. C, pp. 513–524, 2016.

[5] T. Pinto, H. Morais, T. M. Sousa, T. Sousa, Z. Vale, I. Praca, R. Faia, and E. J. S. Pires, “Adaptive Portfolio Optimization for Multiple Electricity Markets Participation,” *IEEE Trans. Neural Networks Learn. Syst.*, vol. 27, no. 8, pp. 1720–1733, Aug. 2016.

[6] M. Silva, H. Morais, T. Sousa, P. Faria, and Z. Vale, “Time-horizont distributed energy resources scheduling considering the integration of real-time pricing demand response,” in *2015 IEEE Eindhoven PowerTech*, 2015, pp. 1–6.

[7] F. Fernandes, H. Morais, Z. Vale, and C. Ramos, “Dynamic load management in a smart home to participate in demand response events,” *Energy Build.*, vol. 82, pp. 592–606, 2014.

[8] GECAD, “GECAD’s Inteligent Energy Systems Ontologies,” 2017. [Online]. Available: http://www.gecad.isep.ipp.pt/ontologies/ies/. [Accessed: 26-Jan-2017].

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Real-time demand response and intelligent direct load control
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Microgrid Demonstration Platform: Modbus TCP/IP Connection for Real-Time Monitoring of a Wind Turbine

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Abstract

Several countries promote wind energy despite their high installation cost, since over time these investments can become profitable. It is important that energy entrepreneurs have up-to-date information of operation parameters, to identify places where excessive energy consumption occurs. For energy management, it is necessary to have an overview of the whole system, such that reporting and further result analysis can be made. With monitoring and control systems, it is possible to enable an improved management of resources, especially in terms of balance between generation and consumption. In this work, it is proposed a graphical interface to monitor and control a wind turbine, in a simulation environment running four operation scenarios.

Keywords: wind turbine emulator, energy monitoring, generation control, modbus protocol

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1. Introduction

According to the Coal Industry Advisory Board CIAB, coal fuel represents around 42% of global electricity generation [33]. Many studies report a depleting trend of fossil fuels together with a raise in the concern for the environment. In this context, a lot of countries have started to intensively promote the use of renewable energy sources. The use of renewable energy sources, such as wind and solar can be an advantageous for consumers, since a reduction in energy consumption is made, as well as they become producers in times where generation is higher than consumption. This leads to a new concept in power systems operation, namely, the prosumers.

Since 1997 until 2014 in general, wind power capacity has been growing year by year, with a high contribution of large wind farms built by the national government of many countries. In 2014, the growth in produced energy by wind was almost the same as half of rising global produced electricity, therefore, carbon dioxide emissions remained stable [2]. Reaching the wind power capacity threshold of 50 GW, represented an historical value of capacity for wind energy, clearly underlining a trending path for the use of the distributed energy resources. The following year, 2015, the amount of produced energy went up by 22% reaching around 63 GW. Regarding yearly global energy produced from wind power, around 370 GW in 2014 and 433 GW in 2015, resulted in an 17% increase. This places wind turbine utilization as the most efficient method to produce energy than any other technologies [3]. In 2015, according to the IEA, China led the way with a record of 30.8 GW installed capacity, and until 2016, it had more than 145 GW (more than all of the European union). Considering the high level of implementation regarding wind energy generation, there is the need for systems and tools that can ease the integration of these resources into power systems, and provide complementary services to it, in a way that operation and energy quality are improved. The applications and advantages that wind energy provides, justify the investment made by several countries, for instance, China with a 100 billion USD in 2014.

The installation of distributed energy resources can guarantee several advantages for the operation of power systems, however, this implies the development of a feedback infrastructure capable of providing the power supply enterprises with the status of several energy quality parameters, such as, voltage level, frequency stability, power factor, amongst others. The current developed technology and accessible prices, allow for these systems to be used in households, and not just in large consumers [34]. Various studies show that how information is presented to the consumer, greatly affects the adoption of energy intelligent measures. For instance, a reduction in home energy use of 4-15% is possible, using home energy displays to simplify the human-machine interaction. This interaction between several agents and devices in a multi-layered grid, is associated to the concept of smart grids.

A smart grid is an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources. The implementation of the smart grid implies the development of communication infrastructures that complement the monitoring and control systems. Moreover, nowadays the monitoring and control systems are gaining relevance due to the possibilities that these allow for consumption and generation management. In a smaller scale, these infrastructures can also be installed in consumption or generation facilities, in the scope of energy management systems and building automation. In this way, the installation can become costly when considering all the costs that these involve, such as, meters of cable. To overcome this issue, standard communications have been developed based on Internet Protocols, in which devices can communicate between other devices and/or human to transmit information following a given predefined structure.

The present work, proposes a monitoring and control system based on Modbus TCP/IP protocol, for a wind turbine emulator. The system is composed of a web-based display that was developed in a PLC, namely, Saia PCD3.M5560 with a smart Remote Input/Output module (RIO), PCD3.T665. The manufacturer provided the necessary software for the creation of the webpage, Saia® PG5 Controls Suite. The PG5 contains a whole set of tools, which allows the creation of a SCADA system, without the need to use any other software.

2. Monitoring and Control System

The proposed monitoring and control system is built of three main components: remote unit, PLC, and wind turbine emulator. The work developed is related to the creation of a webpage interface in the PLC, for the monitoring and control of the wind turbine emulator. The communication between the remote unit and the PLC is performed using Modbus TCP/IP communication protocol.

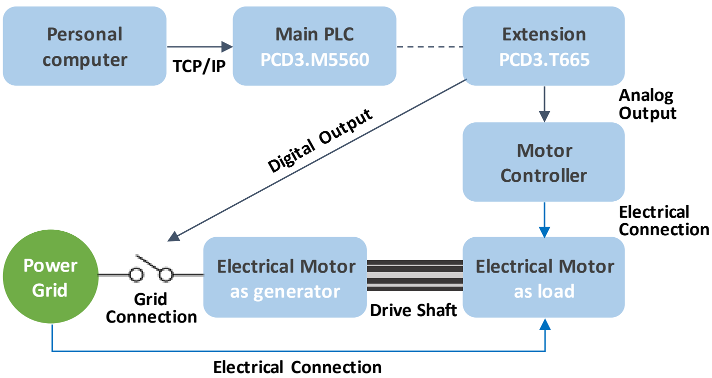

Fig. 1: Proposed system for monitoring and control.

As shown in Fig. 1, the remote-control unit (computer) communicates via TCP/IP protocol, controlling the main PLC and the operation of the motor. The rotor of the motor is connected to the rotor of the generator by common drive shaft. In this way, the wind turbine emulator works considering two electrical motors, that from the grid's perspective, one is acting as load and the other as generator. Mechanical energy of the motor is transformed by the generator into electrical energy and then synchronized with the main grid to perform coupling of the generator. Apart from controlling the device, the operator is also able to receive data from it. The software, provided by the manufacturer, and TCP/IP standard protocol represent a free starting-point for the development of management, monitoring, and control systems.

To connect PC with main PLC there is the need to configure it using the Saia PG5 Control Suite. In order to do that, it is needed to place the IP address of RIO module in destined place. The main PLC is connected to RIO extra module, which includes additional modules of I/O. In response to messages from the operator, RIO station sets suitable voltage output signals, which are sent to motor controller. The change of voltage value [30] induced in the magnetic circuit of the engine a rotating flux relative to the stator, which rotates the rotor through Foucault currents and Laplace forces. The electrical motor acting as a load is coupled with the electrical motor acting as generator by common drive shaft. The spinning rotor of the electrical motor acting as a load represents the source of mechanical energy used by the electrical motor acting as generator to produce energy, enabling a possible synchronization with the main grid.

3. Applied devices and network

Besides providing control over several devices or applications, a SCADA system is also responsible for the registration of data. In this case, the most relevant data to be monitored corresponds to the electrical energy produced and frequency level. Thus, this system allows for the current status of operation in real-time, graphical analysis of produced energy, as well as, store this data in an excel file. The rest of the data monitored is: voltage between one line and neutral wire, sum of current of three phases, and output voltage of the PLC RIO station. In Saia PG5 Control Suite, namely, in FUPLA editor, it is possible to create logical part of the control process. The FUPLA editor is an application for graphical programming with predefined functions, reducing time in the writing of specific code. Also, WebEditor tool made available by Saia, enables the easy construction of graphic interfaces to help the interaction between the user and the PLC actions. The master PLC is PCD3.M5560, and it was extended by an additional module PCD3.T665 which allows for a centralized control but distributed utilization. All signals controlling the work of the engine are sent from RIO station. The equipment used is described as follows:

- **Saia® PG5 Controls Suite** is a software created by the Swiss company, Saia Burgess Controls AG, to control the PLCs from the same company. The software contains a set of tools, which is required to carry out and operate automation solutions (software and hardware) complemented with the company’s instrumentation and control devices. In the software, it is included programming and engineering tools, ready-made libraries, and logic regulation/automation modules. Saia PG5 contains: Project Manager, Network Configurator, Device Configurator, Symbol Editor, Programming Methods, Libs, and WebEditor;
- **Saia® PCD3.M5560** is the master PLC used in the project together with the extension PCD3.T665 Smart RIO module. It can be used either as simple RIO or as intelligent and distributed smart automation stations, capable of executing PG5 user programs;
- **Janitza® UMG 96 RM** is the power analyser that measures the electrical values of the wind turbine emulator’s operation. It can measure voltage in TN, TT and IT system schemes. Moreover, other parameters can be obtained, such as, current, power factor, frequency, energy, power, amongst others;
- **Modbus Protocol** simple and robust, it has since become a standard communication protocol, and it is now a commonly available means of connecting industrial electronic devices. Modbus protocol enables communication between many devices (248), connected to the same network. It is very often used to connect prime PC (Master) with remote units (Slave) in SCADA system;
- **FUPLA** is a software created by the Saia Burgess Controls AG to ease the programming of PLC actions, considering the several inputs and outputs available.

4. Wind Emulation Platform

The proposed platform considers a monitoring and control system that enables its user, the possibility to manage the generation injection to the main grid. The operation frequency of the Portuguese power grid, as in other European countries, is established at 50 Hz. For a generator to inject power to the grid, it must be synchronized with the same frequency. It is considered that the wind turbine only starts to generate after the synchronization with main grid. Thus, the operation of the wind turbine starts at 9.355 V, at 50 Hz (~1500 rpm). From this point on, the increase in frequency leads to a change in the wind turbine, i.e. the wind turbine starts to generate and inject power in the main grid. The maximum value for frequency, being the wind turbine injecting power in the main grid, is around 53.1 Hz (maximum point of simulator work). In Table 1 showed below, illustrates the results measured in the generator mode.

The customer can control the rotational speed of the rotor through the analogue voltage output of the PLC, while the digital voltage output controls the grid connection. The voltage output is in percentage, where a voltage of 9.355 and 10 V, equals 0 and 100%, respectively.

Table 1. Measured results with increasing frequency

Frequency (Hz)	**Active Power** (W)	**Voltage** (V)	**Current** (A)	**Rotating Speed** (rpm)	**Torque** (Nm)
50	300	400	2.5	1497	0,56
50.5	0	400	2.7	1505	0.00
51	-100	400	2.7	1509	-2.32
51.5	-220	400	2.8	1515	-3.51
52	-400	400	2.9	1522	-4.50
52.5	-550	400	3.0	1528	-5.45
53	-650	400	3.1	1534	-6.28

The developed graphical interface is presented in Fig.2, and underlines some simplifications for its user. An operator does not have to know what is the lowest value they need to set to initialize the process of energy generation. Also, they do not need to calculate the voltage to achieve a determined level of wind turbine (e.g. 50%). Besides that, for the operator it is also possible to control the work of the device by using the buttons. Pressing the buttons causes an increase or decrease of the percent value about 20 %. No matter how many times the buttons are pressed, there is no chance to overstep them both, bottom value 9.355 V and the top 10 V.

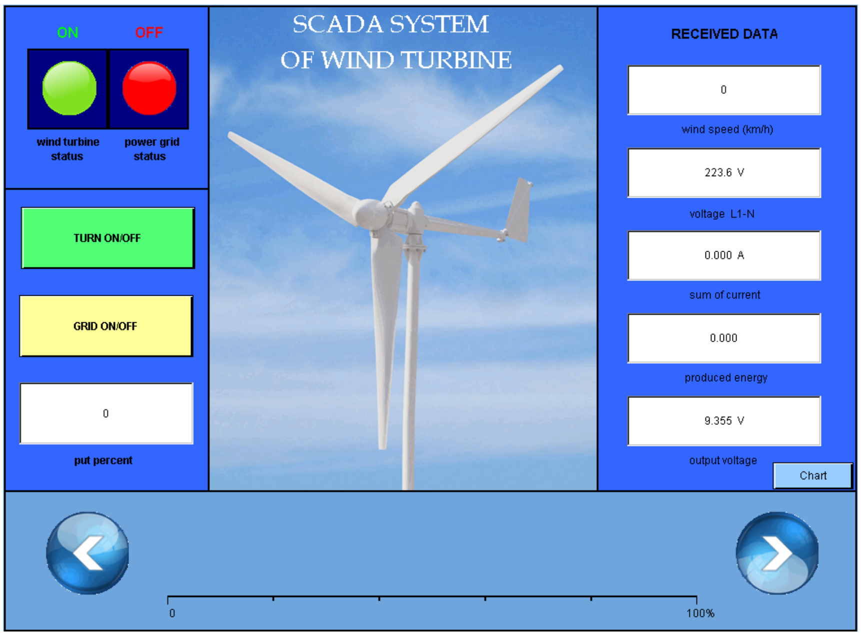

Fig. 2: SCADA system of wind turbine

In real wind turbines, the force that causes the production of energy, is the kinetic energy of the wind. Therefore, apart from the value of the work expressed in percentage, also it is expressed in wind speed. For each voltage value, a corresponding speed (km/h) is known. For values of voltage smaller than 9.355 V, established that there is no influence of wind. Table 2 shows the results. When the operator updates the value in percentage, it receives data, namely, digital output voltage, produced energy, the sum of the current of three lines, and voltage between line L1 and neutral wire. To ease the problem encountered during development of the FUPLA program, the flowchart presented in Fig. 3 was employed. This part exemplifies applied security system, where there is no possibility to connect the generator to the power grid in a time shorter than 6 seconds, as well as, to not turn off the whole simulator without precedent disconnecting the power grid from the device.

Table 2. Values of analogue outputs with corresponding values of wind speed.

Voltage (V)	Wind Speed (km/h)	Operation Percentage (%)
9.355	0	0
9.420	10	25
9.460	20	50
9.500	22	55
9.560	25	62.5
9.660	30	75
9.780	35	87.5
10.000	40	100

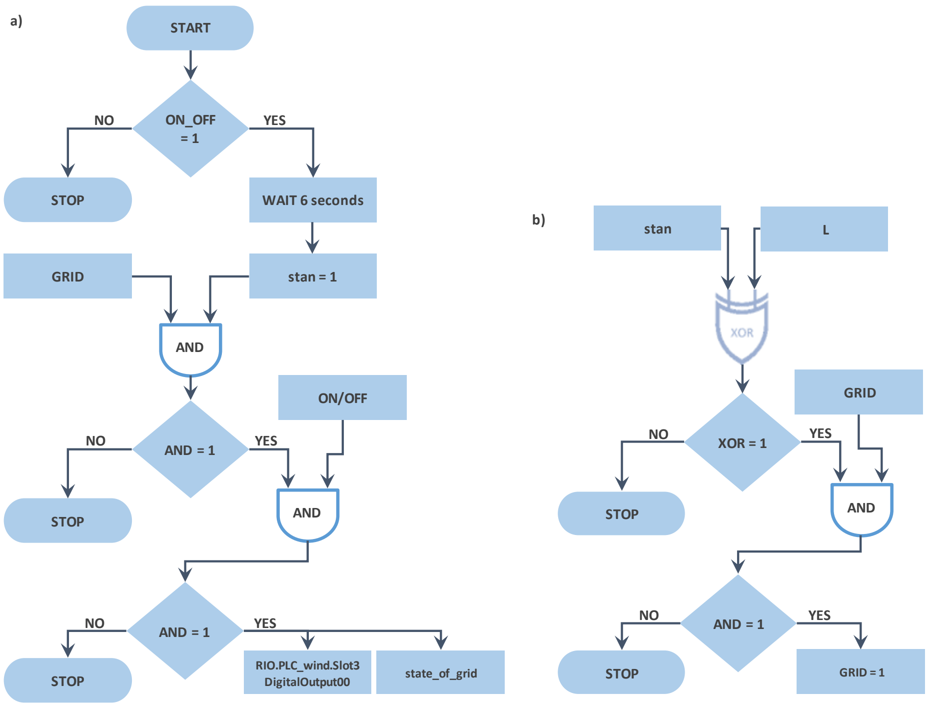

Fig. 3: Flowchart of the security rules for wind turbine operation.

The whole SCADA is segmented into four main sections:

- In the first section, there are lights indicating the present status: wind turbine status and power grid status. Once the wind turbine or grid is on, the lights change their colour from red to green (and vice-versa);-
- The second section, is responsible for changing the settings. When the input "TURN ON/OFF" button is pressed, and there is no value implemented in percentage, the frequency equals 50 Hz. To achieve this value the motor requires a time of 6 seconds, since during this period it is impossible to connect the dynamo to the grid. Only after 6 seconds, one may connect it by pressing the "GRID ON/OFF" button. The whole wind turbine simulator can be turned off only when the grid is turned off beforehand, otherwise, the device may be damaged. To avoid this situation, it is applied a security rule that does not allow the system to turn off the wind turbine emulator without disconnecting the power grid first;
- In the third section, named "RECEIVED DATA", it is displayed the data obtained from the analyser (Janitza UMG 96 RM). The received data is composed of the following: output voltage, the

produced the energy, the sum of the currents of three lines, and the voltage between line L1 and neutral [37];

- The fourth section of the window is responsible for displaying the values of the bar graph and respective altering buttons. The bar graph is divided into 5 pieces, each 20%.

4.1. Problems Encountered

In the beginning of the project it was assumed that there could be a possibility to change the speed of the rotor by changing both in percentage value of digital output and by wind speed. After many tries to solve this task, it was noticed that it is impossible to accomplish. When the percentage value would be set then it should be displayed with an estimated value of the wind speed. Through this way of thinking, there would be always a mistake when estimating the value.

Implementing into the put percent edit box value f.e. 7%, which is 9.4 V in the output, suits approximately the speed of the wind equals 10 km/h. However, for 10 km/h, that represents 9.42 V, gives a value in percent that equals 10%. And again, the value expressed in percents, points the value in volts, which in a row points the value in km/h. Then the whole situation repeats again- the loop was noticed . Fig. 4 shows that.

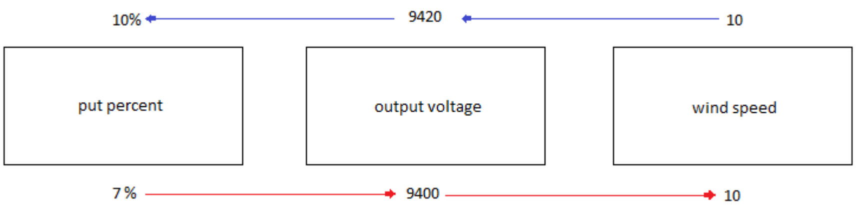

Fig. 4: The mistake perpetrated with initial assumptions.

5. Case Study and Results

On the webpage was possibility to change the wind speed and monitor produced energy in the process. The wind speed was changed in values [km/h]: 0, 10, 20, 22, 25, 30, 35, 40, 35, 30, 25, 22, 20, 10, 0.

In Fig. 5, it is showed a profile of produced energy considering wind speed. In the first second of the process, the generator is not connected to the grid, and no energy is being produced. After the first second, it is shown sudden growth of the value of produced energy to more than 600 W. With growth of the wind speed, there is growth of produced energy. The biggest value of produced energy is for wind speed equal to 40 km/h and corresponds to around 1100 W. After reaching this point, the value of wind speed falls down and the same happens with produced energy. After 8 seconds, the generator is disconnected from the power grid, and consequently turned off (no produced energy).

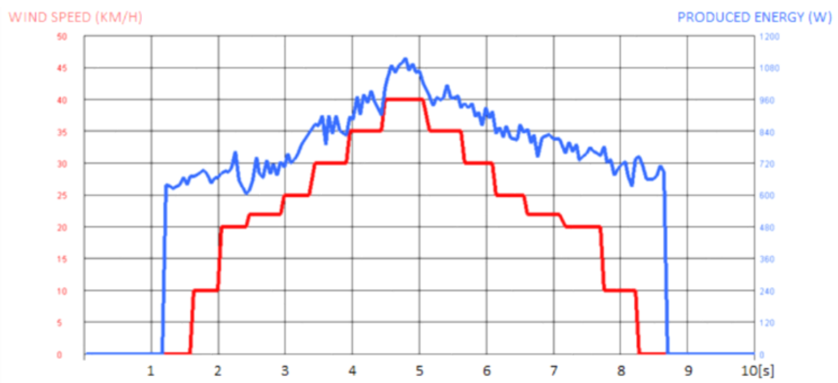

Fig. 5: Energy production profile versus wind speed.

Fig. 6 illustrates the profile of production energy related to a wind speed of 20 km/h. At the beginning of the simulation, the power generator is connected to the power grid, with a produced energy around 750 W. At 400ms, the value of wind speed increases to 20 km/h, raising also the produced energy to nearly 900 W. At these times, it was noticed loss of current.

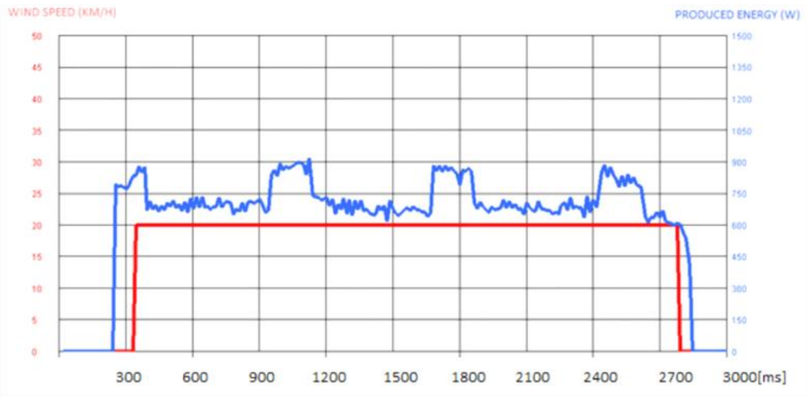

Fig. 6: Energy production profile versus wind speed equal to 20 km/h.

Fig. 7 is analogous to the previous chart and some common observations can be made, however, the value of wind speed this time equals 40 km/h. The difference is in the values of wind speed (max. 40 km/h) and energy produced (max. 1200 W).

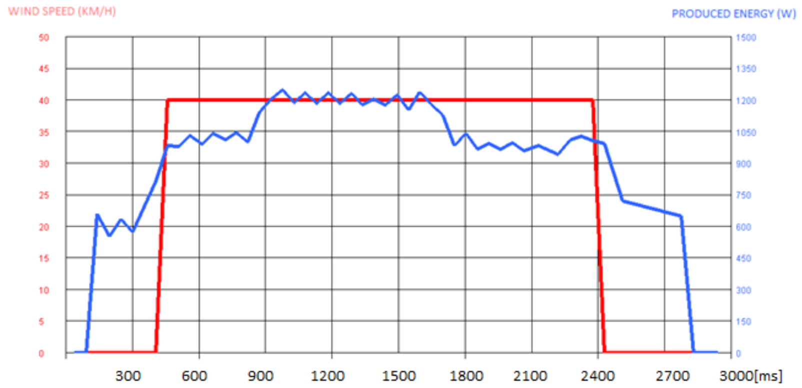

Fig. 7: Energy production profile versus wind speed equal to 40 km/h.

Fig. 8 shows the control process of the wind speed, between the frequency values of 50 Hz and 53.10 Hz. For the second value, energy produced reaches its highest, around 1300 W.

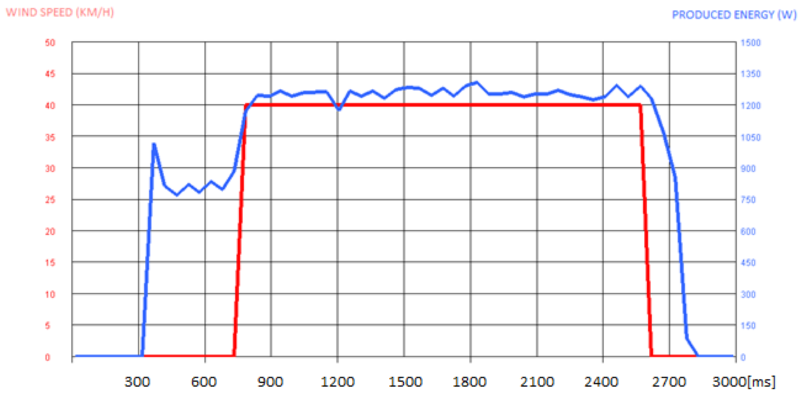

Fig. 8: Energy production profile versus frequency equal to 53.10 Hz.

Based on charts above, it is possible to conclude that with the increase of wind speed, the quantity of energy produced grows. When the simulation time is longer, the results are more accurate, and the highest value of produced energy is attained when frequency equals 53.10 Hz, namely, 1300 W. In the beginning, it was defined that for a frequency value of 50 Hz, the wind speed is zero. When the wind speed equals zero, the produced energy should be equal to zero, however, on charts, it can be seen some values. It explains that it was some inaccuracy in estimating value for wind speed when it equals zero.

6. Conclusions

The SCADA system represents an interesting environment where all editors and configurators can be integrated into one program, and where graphical programming is accessible. Most of the problems occurred not during programming or using WebEditor to create a visualization, but during the configuration of both. An initial assumption of control for the wind turbine was by changing the value in percentage or wind speed. However, it turned out impossible to do both correctly, therefore it was decided that controlling the power using percentage values would simplify the control of the wind turbine. Within the webpage view, there is a light visualization of the wind turbine status and of the connection to the power grid. After pressing the ON/OFF button on the webpage to turn it on, the light changes into a green colour, which means that the electrical engine is ON but effectively the engine can be OFF. The same situation happens with the connection to the power grid. To avoid the situation above, one should send signals to PLC informing about the real status of the wind turbine. The disadvantage of the Saia PG5 Controls Suit software, was that it worked obscurely from time to time. To eliminate compilation errors, it was needed to delete some blocks used in FUPLA editor and put it back again.

This paper can serve for some companies to solve similar problems or to the same systems. GECAD organization can also use it to measure the production of electrical energy by simulating and using it to desirable purposes.

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References

[1] http://www.cressall.com/load-banks/ac30-portable-load-bank/

[2] GWEC, GLOBAL WIND REPORT ANNUAL MARKET UPDATE 2015,Lauha Fried, Liming Qiao, Steve Sawyer and Shruti Shukla, page 6.

[3] GWEC, GLOBAL WIND REPORT ANNUAL MARKET UPDATE 2015, Lauha Fried, Liming Qiao, Steve Sawyer and Shruti Shukla,page 4.

[4] https://www.iea.org/ciab/papers/power_generation_from_coal.pdf, page 15.

[5] STUDENT LEAFLER EOLYP, page 6.

[6] Power Analyser UMG 96 RM Basic device: Operating instructions and technical data,http://www.janitza.com/download-manuals-current-devices.html?file=files/download/manuals/UMG96RM/Basic/Janitza-Manual-UMG96RM-20-250V-en.pdf, page 90.

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Real-time demand response and intelligent direct load control

Second DREAM-GO Workshop

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From Empirical to Intelligent Load Management in a Banking Energy Performance Contract

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Abstract

As stated in the H2020 Work Programme of the societal challenge, moderating energy demand will be crucial in the current energy transition. Demand Response (DR) strategies represent an appealing value proposition to end-users, as it enables them to monetise the flexibility embedded in their peak demand through the minimisation of unnecessary or excessive electricity usage. This market opportunity sets the base for the Virtual Power Solutions (VPS)' Kisense platform, which is an Active Energy Management System that delivers state-of-the-art DR technology for distributed blocks of buildings, providing new energy flexibility services as part of energy contracts and enabling micro-grid environments in liberalised energy market contexts. With that said, VPS engaged in an Energy Performance Contracting (EPC) with a major Spanish bank with activities across Portugal from 2013 to 2020. VPS equipped more than 100 bank branches with the Kisense platform, which enables the implementation of DR strategies, namely load shedding, load shifting and optimization of the energy contract towards RTP of electricity, which in approximately 15% annual energy saving (KWh) in 2016, when compared to the baseline year (2013). As for what VPS envisions for the future, the evolution of energy markets is accelerating in the direction of a greater reliance on Distributed Energy Resources, and the most promising strategy to address this trend is Virtual Power Plants (VPPs). In short, VPP creates better conditions for the introduction of new renewable energy sources and that is why VPS developed Kiplo, the first in the VPP platform market, designed to scale-up the Kisense platform. In conclusion, Kiplo will be in line with the growing European interest in open energy markets and Kiplo is expected to be a key tool in the future in this market segment.

Keywords: automated demand response, energy performance contracts, load management, virtual power plants

1. Introduction

As stated in the H2020 Work Programme of the societal challenge entitled 'Secure, Clean and Efficient Energy', moderating energy demand will be crucial in the current energy transition. A high level of energy efficiency is beneficial for security of supply, sustainability, affordability for households, SMEs and industry and competitiveness of the EU economy.

By seeking a solution to this challenge, Small and Medium Enterprises (SMEs) are identifying comprehensive market opportunities to deliver energy efficiency measures whilst ensuring high levels of indoor environment quality (thermal comfort, air quality, etc.) through Demand Response (DR) programmes.

In general terms, DR mainly refers to programmes that communicate to consumers the changes in energy market prices or in their overall energy consumption patterns, whilst encouraging them to alter their energy consumption behaviour and habits to reduce peak loads and save energy [1] [2].

In this sense, DR combines significant scientific fields such as energy efficiency, energy storage, distributed electricity production from renewable sources integration as well as Energy Management with valuable active end-user engagement to achieve the desired shifting of peak loads [1] [3].

DR offers several benefits to the energy systems, including increased efficiency of asset utilization, supporting greater penetration of renewables on the grid without decreasing stability, easing capacity issues on distribution networks to facilitate further uptake of distributed generation on congested local networks, reducing the required generator margin and costs of calling on traditional reserve, and including the associated environmental benefits through reduced emissions [2]. This represents an appealing value proposition to end-users, as it enables them to monetise the flexibility embedded in their peak demand through the minimisation of unnecessary or excessive electricity usage.

Banks represent a well-fitted addressable market for these solutions as it often has large-scale, diverse facilities with significant utility costs, complex operational requirements and increasing regulation requiring proof of effective energy and carbon management.

Currently, most of the DR tools available in the market provide only rather static and coarse means to control, monitor and estimate energy consumption at the consumption sites, which leads to energy wasting in buildings - e.g. non-optimal heating/cooling. Despite the many advantages of DR applications, there are still very few examples of the successful deployment of DR technologies in distributed blocks of buildings in the real world [6], achieving a reduction in peak grid demand and real savings for consumers.

This market opportunity sets the base for the Virtual Power Solutions' Kisense platform, which is an Active Energy Management System that delivers state-of-the-art DR technology for distributed blocks of buildings, providing new energy flexibility services as part of energy contracts and enabling micro-grid environments in liberalised energy market contexts.

2. Context

Virtual Power Solutions (VPS) is a technology company that addresses important market needs arisen from the current energy transition, thus targeting: i) energy consumers that want to minimise, optimise and monetise their energy demand, to be adapted to the future introduction of innovative dynamic tariffs in European markets, and to increase their energy independence and sustainability through low carbon buildings; and ii) energy suppliers, DSOs and aggregators who need to balance their grid, assure a secure operation and minimise the deviations to the forecasted demand by introducing automated DR capabilities in their customer base.

Accomplishing these huge market needs, VPS provides Energy Savings as a Service (ESaaS) to all sectors – i.e. industrial and commercial, SME and domestic - across Europe, contributing to a low carbon economy and the balancing of the electric grid. VPS has been strongly involved in European research collaborative projects to address such challenges in Europe, and has developed strong knowledge and experience in Internet of Things (IoT), developing highly scalable business supported on hardware and software solutions, M2M communication platforms based on cloud and mobile applications for Smart Homes and Smart Cities, acquiring and processing a grand portion of granular data to provide valuable information from its data centre to all-over the world.

With that said, VPS engaged in an Energy Performance Contracting (EPC), entitled Strategic Program on Energy Efficiency, with a major Spanish bank with activities across Portugal from 2013 to 2020. An EPC is an agreement between contracting parties where the contractor is engaged in the design, delivery, validation of comprehensive energy efficiency programs in customers´ buildings, often accompanied by a guarantee that it will be self-financed through savings produced through the life of the project [7] [8]. In light of this, VPS carries all the risks inherent to this EPC project and thus must act proactively and propose practical measures in order to deliver the promised energy savings to the bank.

For the purposes of the EPC, more than 100 bank branches spread across mainland Portugal were encompassed in the Strategic Program on Energy Efficiency proposed by VPS. It was agreed a priori that the active consumption of energy in 2013 would be used as baseline in the process of measuring energy savings. Then, an annual comparison analysis between active energy consumption before and after the implementation of the comprehensive energy efficiency measures is carried out to uncover energy saving results, with the appropriated adjustments that take into consideration potential changes in the baseline conditions.

3. Application scenario

On average, the bank branch dimension is 182 m2. Work time ranges from 8:30am to 05:30pm. Nonetheless, the bank branches encompassed in the scope of this project differs in several variables that have strong correlation with the baseline conditions, such as type of electricity contracts - e.g. fixed rates, Time-Of-Use (TOU) rates, etc. -, facility size, location and bioclimatic zone, number of facility´s users, type and number of electric equipment installed, etc. Therefore, all these factors were considered for the saving analysis.

VPS equipped each bank branch with the abovementioned Kisense platform, which enables the implementation of DR strategies, namely the remote on-off control of the outdoor advertising lighting sign, indoor lighting, HVAC system and ventilation. Data collected includes total active electricity consumption, partial HVAC electricity consumption, and in some cases, the temperature near the air duct and at user level.

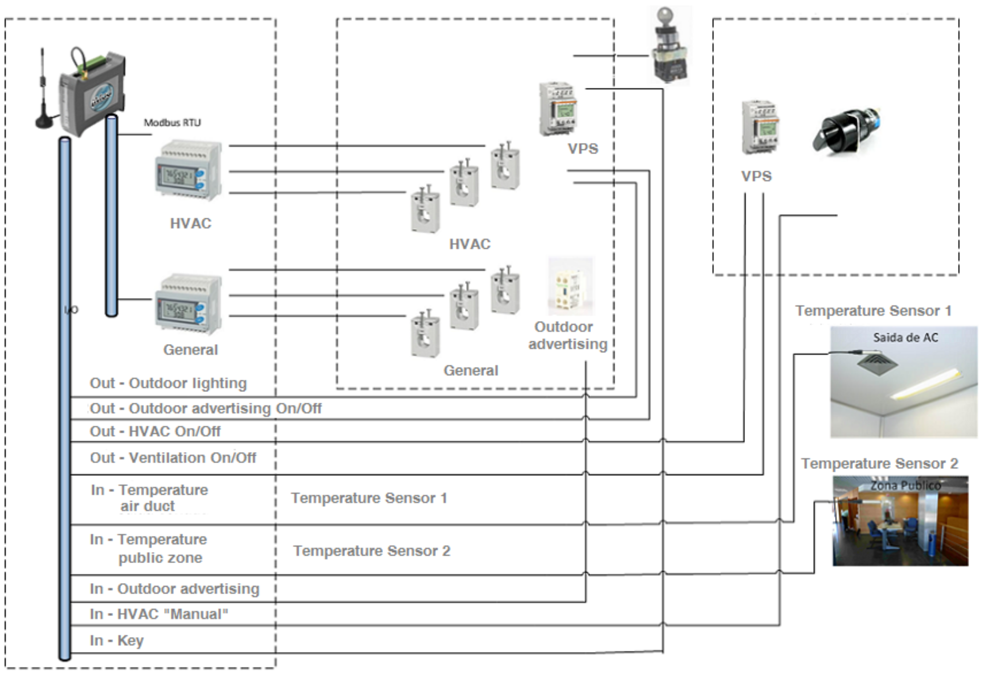

Fig. 1: Typical branch setup.

Kisense is composed by the following elements:

- Sensors & Actuators: smart meters, sensors and actuators;
- Communication Module (CM): responsible for retrieving data from the field with several communication protocols. After acquisition, raw data from sensors are stored in a database. This module implements a number of standards and protocols that goes beyond VPS´s protocols, thus assuring the openness of the solution;
- API - Web Service: this module allows the remote access and data delivery from sensors. It is based on RESTful Web Services, also known as REST APIs. This API is a default door to web applications

data, providing a powerful yet simple tool to integrate different systems. This approach allows quick prototyping and interoperability capabilities between web applications and other systems in the physical world and its integration potential is enabled by the existing web infrastructure;

- Data Processing Module (DPM): this module receives data from CM or Web Service as well as processed and aggregated data, performing operations such as unit conversion, format adaptation, tariff calculation, and distributing hourly and daily values. This data treatment layer offers a unified interface for other applications (UI, advanced analysis, forecasts) through another API – Web Service. Additionally, CM and DPM, working as back office applications, may be installed on the same physical machine (server) of each site;
- User Interfaces: a set of visual modules that provide access to end-users to several features, such as historic data visualization, consumptions normalization and benchmarking, alarm definition and visualization as well as remote real-time monitoring and control, as illustrated in Figure 2.

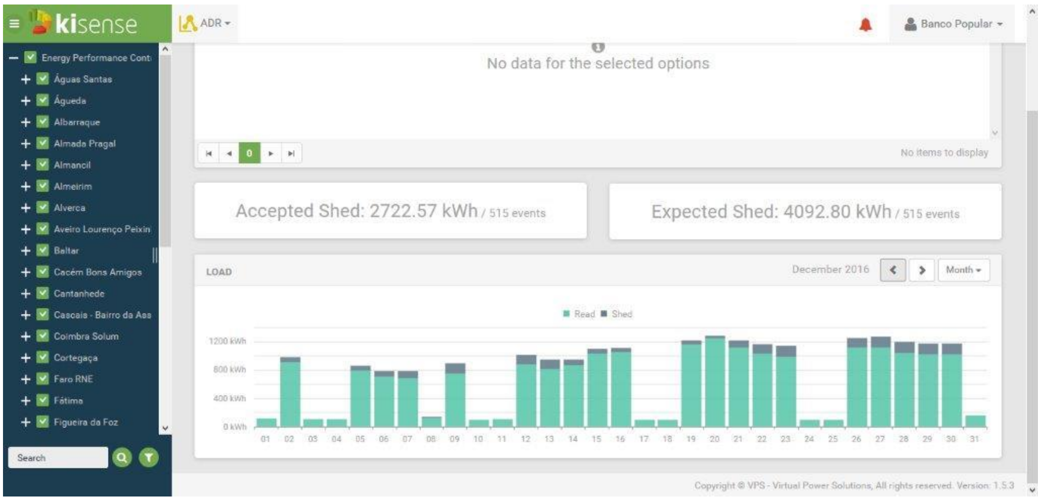

Fig. 2: Kisense´s DR user interface.

The implementation of the Kisense platform brings the following benefits to the bank:

- Minimisation of consumption, by permanently eliminating wasted consumption through the incorporation of energy efficient assets and the elimination of 'wasted' energy – i.e. standby consumption;
- Optimisation of consumption, through real-time management of non-essential consumption away from peak times and optimization of embedded generation and storage.
- Monetisation of consumption: revenue earning by allowing end-users consumption profiles to be used to help balance the grid. This dynamic platform manages the optimisation of consumption with revenue available from grid based DR programmes.
- Energy sharing initiatives between bank branches have also been simulated. Although impending deregulation is still to be overcome in this matter, the technology already allows to monitoring surplus of energy generation and the use of shared energy with predefined end-users.

4. Simulations

In terms of the proposed energy efficiency measures that were implemented in the initial stages of the project, it includes load shedding and load shifting of HVAC loads. A survey concluded that the HVAC system alone corresponds to approximately 39% of the annual active electricity consumption in the bank branches. In light of this, during winter, the HVAC systems were remotely turned off in predetermined times.

The same rationale applies to load shifting. During periods of mild climatic conditions, for bank branches with 3- or 4-period TOU rates in certain bioclimatic zones, automated DR strategies were implemented to shift HVAC load to off-peak periods – i.e. when electricity tariff is the cheapest.

Additionally to these two energy efficiency measures, Real- Time Pricing (RTP) of electricity appears to be very promising in such application scenarios, according to a number of meta-analysis collating findings [3] [4] [5] from many DR trials that indicate that economic and other incentives are effective in changing consumer behaviour, offering new opportunities and challenges in the energy performance of buildings [9]. Therefore, the electricity tariff optimization – i.e. energy contract renegotiation, shift in electricity provider, reduction of contracted power, etc. – towards RTP is a potential future energy efficiency measure to be implemented when proper conditions and regulations in the Portuguese liberalised energy market are set in place. In such cases, the reduction of the electricity bill is not necessarily associated with a reduction in energy consumption, but to the adjustment in tariff options to fit customers´ energy consumption profiles better and to reflect more appropriately the fluctuation of the electricity price in the wholesale market. The combination of a real-time monitoring and management system with access to the electricity consumption history, as well as with the possibility to remotely operate sub circuits such as the HVAC system, makes RTP of electricity an even more appealing energy efficiency measure. That is because such DR systems are able to schedule action orders that allow the HVAC system to be remotely switched on and off in periods when the electricity presents the most advantageous prices, based on cost fluctuation signals in the wholesale market. As illustration, Figure 3 presents a comparison analysis that uncovered how much electricity would had been saved during the first semester of 2016 if the bank branches encompassed in the data sample had adhered to RTP of electricity.

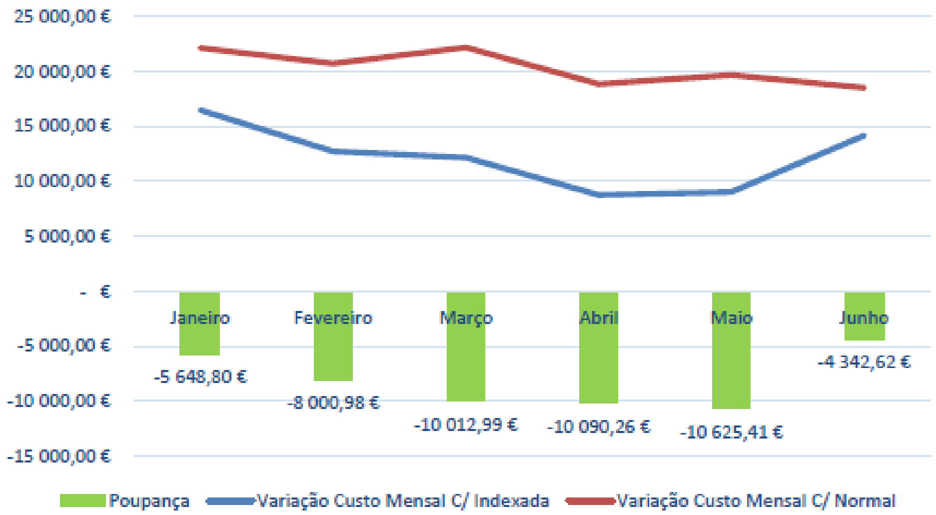

Fig. 3: Monthly electricity cost fluctuation of a TOU rate versus RTP of electricity for the data sample (2016).

The analysis of the graph allows to infer that, with the current tariff structures in place, the bank branches spent approximate 122,054€ with active electricity consumption in the first half of 2016 (distribution costs were neglected in this analysis). The introduction of RTP would have represented electricity savings in the order of 48,721€, with corresponds to approximately 40% of the semiannual electricity costs. Globally, with the implementation of all the energy efficiency measures abovementioned, a 15.4% annual energy saving (KWh) was achieved for the data sample in 2016, as seen in Table 1:

Table 1: Energy savings between 2013 and 2016 with the implementation of energy efficiency measures.

	Peak	**Mid-Peak**	**Hollow**	**Off-Peak**	**Without cycle**	**Very Hollow**	**TOTAL**
2013 (kWh)	753 349	2 090 313	1 021 721	183 127	380 791	24 363	4 453 663
2016 (kWh)	665 686	1 903 261	682 149	160 588	337 581	16 430	3 765 696
Savings (kWh)	87 662	187 052	339 572	22 538	43 210	7 933	687 967

5. Future applications

As for what is envisioned for the future, the evolution of energy markets is accelerating in the direction of a greater reliance on Distributed Energy Resources, and the most promising strategy to address this trend is Virtual Power Plants (VPPs). A VPP is a cluster of energy producers and energy consumers, creating a new large virtual entity [10]. VPPs act as a single operating entity towards the power market, which may contain storage devices and is internally controllable due to a balanced portfolio of generators and consumers [10]. Within VPP, balance can be reached in different ways; for instance, aggregators – i.e. those who operate VPPs - can decide to switch off a number of electricity consuming installations or to switch on big power consuming units – e.g. electrical cars that have to be charged or charge batteries - in moments when production in the system is at its peak. By doing so, it increases the flexibility of the electric grid, thus decreasing the risk of destabilisation of the grid associated with the incorporation of decentralised renewable energy generators. Therefore, the core of VPP consist of a coordinating mechanisms resulting in a predictable and stable outcome. Aggregators can negotiate much more favourable contracts with electricity companies in this way. In short, VPP creates better conditions for the introduction of new renewable energy sources and that is why Virtual Power Solutions (VPS) developed Kiplo.

Kiplo was designed to scale-up the Kisense platform, by including a series of novel tools within it, such as: i) a multi-level DR forecasting engine to satisfy conflicting real-time demand and supply of electricity, enabling automatic and dynamic pricing and incentive-based DR for distributed blocks of buildings; ii) consumption matchmaking engine to provide optimal mapping among DR programs/strategies and available elasticity/flexibility of consumption to facilitate the integration of local energy generation into the power grid, iii) a sharing tool to support small and medium energy communities to manage and share the lack and/or surplus of renewable local generation – i.e. the creation of Nearly-Zero Energy Communities; and iv) context-aware HMIs to provide easy-to-use and intuitive user interfaces supported by visualisation techniques, alarms and recommendation.

In this sense, Kiplo represents the opportunity to shift from local management – i.e. end-user level - to aggregated – i.e. community-level - flexible management. By aggregating end-user's individual flexibilities, the product allows flexible consumption, solar-PV generation and electricity storage to be managed at the local community level by the aggregator. The platform will collect community user's electricity consumption, generation, and storage in real-time and, considering each consumer individual contract. In this way, the energy trading shifts away from a centralised structure – e.g. exchanges, trading platforms, energy companies - towards a decentralised system – e.g. end customers, energy consumers. Therefore, third-parties are no longer required, cutting costs and speeding up processes. As a result, the entire energy system becomes more flexible, as many previously manual work tasks are carried out automatically through smart contracts.

In conclusion, Kiplo will be in line with the growing European interest in open energy markets. In 2016, the European Parliament and the Council presented a proposal on common rules for the internal market in electricity. With that, Kiplo is expected be a key tool in the future.

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References

[1] Capgemini, “Demand Response: a decisive breakthrough for Europe”, 2008, Available: https://www.capgemini.com/resource-file-access/resource/pdf/Demand_Response__a_decisive_breakthrough_for_Europe.pdf.

[2] Office of Electricity Delivery & Energy Reliability, “The Smart Grid: an introduction”, Available: https://energy.gov/oe/services/technology-development/smart-grid.

[3] A. Faruqui, and S. Sergici, “Household response to dynamic pricing of electricity— a survey of the experimental evidence”, *Harvard University*, The Brattle Group, Tech. Rep., 2009, pp. 1–53, 2009, Available: http://www.science.smith.edu/ ~jcardell/Readings/uGrid/House%20DemandResp%20Experience.pdf.

[4] K. Ehrhardt-Martinez, K. A. Donnelly, and J.A. Laitner, “Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities”, *American Council for an Energy-Efficient Economy*, Washington DC, Tech. Rep., p. 128, 2010, Available: https://www.burlingtonelectric.com/ELBO/assets/smartgrid/ACEEE%20report%20on%20smart%20gr id.pdf.

[5] A. Faruqui, and J. Palmer, “The Discovery of Price Responsiveness–A Survey of Experiments Involving Dynamic Pricing of Electricity, Social Science Research Network”, pp. 1–13, 2012, Available: http://ssrn.com/abstract=2020587.

[6] Hu, Zheng, et al., “Review of dynamic pricing programs in the US and Europe: Status quo and policy recommendations”, *Renewable and Sustainable Energy Reviews*, 42: 743-751, 2015.

[7] Victorian Government Purchasing Board, "Energy Performance Contracting", 2016, Available: http://www.procurement.vic.gov.au/State-Purchase-Contracts/Energy-Performance-Contracting.

[8] Lee, P.T.I. Lam, W.L. Lee, "Risks in Energy Performance Contracting (EPC) projects", *Energy and Buildings*, vol. 92, pp. 116-127, 2015.

[9] L. Klein, J. Landeck, L. Matos, I. Torres, A. Bernardes, "Cost-Benefit Comparison of a Time-of-Use Tariff and Real-Time Pricing of Electricity Associated with Automated HVAC Load Management Strategies in Bank Across Mainland Portugal", paper to be presented at the 2017 International Conference on Renewable Energies and Power Quality (ICREPQ 2017), Malaga, Spain, April 4-6, 2017.

[10] The North Sea Region Programme, "The Interreg IVB Noth Sea Region Programme: Smart Grids and Virtual Power Plants'", 2011, Available: http://archive.northsearegion.eu/ivb/projects/details/&tid=131.