DREAM-GO

D4.1

Deliverable D4.1

Direct Load Control in the Scope of Short and Real-Time Demand Response

MARIE CURIE ACTIONS

Deliverable

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1. Introduction

Demand Response (DR) implementation considers several timescales, from years or months of planning to short and real-time actuations. In the first case, the DR actuation is planned or pre-arranged in monthly or yearly timescales, being later on dispatched when agreed upon at the time of the contract establishment. In the latter approach, a short to real-time timescale, it is considered that the DR program organizing entity requires load variations in a very short time period. Given these conditions, the exchange of communications and requests between the DR program organizing entity and the consumer, is not reliable. In this way, direct load control programs have been developed by DR organizing entities, that provides direct link between the organizer and the load controller of the consumer, allowing it to control the load as desired in a very short time period without the need of exchanging requests and responses with the consumer.

DR program became a reality of nowadays power system (Cappers, 2013). DR program is defined as the modification in the consumption patterns of the end-users in order to respond to the incentive paid from the network operator due to some technical or economic reasons (Fotouhi, 2017). There are two main classifications for the DR: incentive-based, and price-based. The incentive based DR are related to the programs that the customers are paid with the fixed or time varying incentive, which is provided by the grid operator (Dave, 2013). The price based DR programs are referred to the changes in the consumption of the customers based on the electricity price variations. By this way, the end-users can reduce their monthly electricity bills if they reduce their consumption while the electricity price is high, and shift it to moments that the electricity price is lower (Guo, 2017). In this context, if the Renewable Energy Resources (RERs) are integrated with the DR programs; both consumers and grid operators will fully benefit from the advantages of smart grids and microgrids (Fang, 2012).

However, to bring consumers to DR programs, the capacity of the resources should be matched. According to (Bakr, 2015), (Ceseña, 2015), the minimum reduction capacity for consumers to participate in a DR program is typically 100 kW. Small typical consumers, namely residential or commercial are not able to participate in DR programs individually. Curtailment Service Provider (CSP) can overcome the mentioned barriers (Ramos, 2011). A CSP is referred to a grid player that aggregates the small and medium consumers, who do not have enough capacity of consumption reduction for participating in the DR programs. In other words, a CSP aggregates the small and medium consumers and participate them in the DR program as one (Gomes, 2014). Virtual Power Players (VPP) are also aggregators with the ability to combine end-consumers in other to participate in DR programs with high curtailment demands (Faria, 2016).

In this way, the present report will analyse possible available solutions for load control and communication protocols, that can be used to integrate existing loads in Direct Load Control (DLC) contracts. After this analysis the report will show the DREAM-GO vision regarding the DLC in the scope of short and real-time DR. The direct contribution of DREAM-GO project will also be demonstrated, in this report, by analysing part of its use cases results. Figure 1 presents the work structure considered, namely, the focus areas and developed sections.

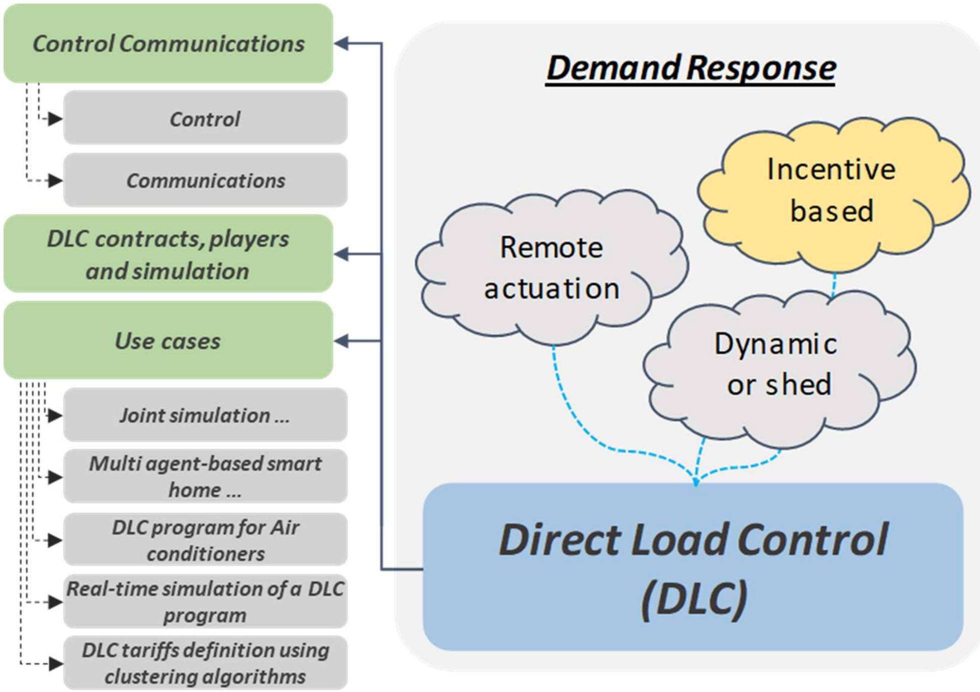


Figure 1. Points of interest and context of direct load control implementation.

This report refers to deliverable 4.1 of the DREAM-GO[1] project. DREAM-GO is a H2020 project with ID 641794 under the program MSCA-RISE-2014 - Marie Skłodowska-Curie Research and Innovation Staff Exchange. The project has as full name: “Enabling Demand Response for Short and Real-time Efficient and Market Based Smart Grid Operation - An Intelligent and Real-time Simulation Approach”. This is a four-year project with partners from four countries: Portugal, Spain, Germany and United States of America.

[1] http://dream-go.ipp.pt/

2. Control and communications

An important concept to the implementation of DLC is duty-cycle. This concept defines the ratio between the time where a certain load is active and the time where it is not. This is especially important in permanently connected loads, such as refrigerators. By identifying the duty-cycle of a given load, savings can be achieved by shedding stand-by consumption in the off duty-cycle of loads. This concept is of the utmost importance for the application of direct load control programs, being an important feature for DLC participants evaluation. Moreover, the acting on the load can assume three types: manual, remote, automatic. The first assumes that the consumer manually modifies its load given a request from the DR organizing entity. In the second approach, the organizing entity has direct control over the load and thus can modify it according to its needs without much notification time (or none at all) for the consumer. The third approach considers that neither the consumer nor the organizing entity, need to control the load, is an automatic system.

For the remote actuation on a load there is the need for a control mechanism to establish communications. Actually, most of the devices still don't have control and communication interfaces. For the widespread application of DR, mechanisms to perform DLC on these devices need to be developed. But is possible to apply retrofitting in buildings of our days. In the next section some approaches to perform load control and feasible communications protocols for DLC events will be presented.

2.1. Control

A control module is responsible for switching on/off appliances or adjusting (increase/decrease) the operating set point. While on/off control is adequate for some loads, like electric water heaters, for other type of loads, like clothes dryers and electric vehicles, the adjustable mode is the most suitable.

2.1.1. Using Relays

The use of relays in direct load control programs is the most common and simple solution to enable their implementation. The use of relays implicates an integrated system that decides upon the states of the relay. The most often used relay type, is the latching relay, which defines a “normally” status that is useful given the load’s working conditions. In a more detailed view, the load can be connected to one of two types of connectors present in the relay, namely, normally open and normally closed. In the first approach, the load is normally not supplied since the relay is open in these connectors, while in the latter approach, the opposite is considered by the load being supplied in normal operation. Then, the relay status can be easily changed by providing a certain impulse (often low voltage signals of 5, 12, or 24 V), as shown in Figure 2.

Relays can also be used together with trigger systems that decide intervention based on operation rules, e.g. for ancillary services frequency control the relay can be installed together with a frequency measurement device that, given a certain threshold, is triggered and an impulse is sent to the relay enabling load modification. In this case, it is considered that the decision upon the status of the relay, is not programmable nor remote, but automatic.

The COM connectors are related to the internal switch, to which the load or power supply are connected to. In fact, when in operation, only two of the four “normally” connectors will close the circuit with the COM connectors. This status, as mentioned before, is dependent on the impulse signal, namely, if it is present or not.

A controller to decide on whether to apply the voltage rating or not, as the impulse signal for the relay, is usually complemented with a device with processing capacity, for example, a programmable logic controller (PLC) (Battegay, 2015). Using a PLC, rules can be programmed and/or requests can be sent, to define the action on the relay.

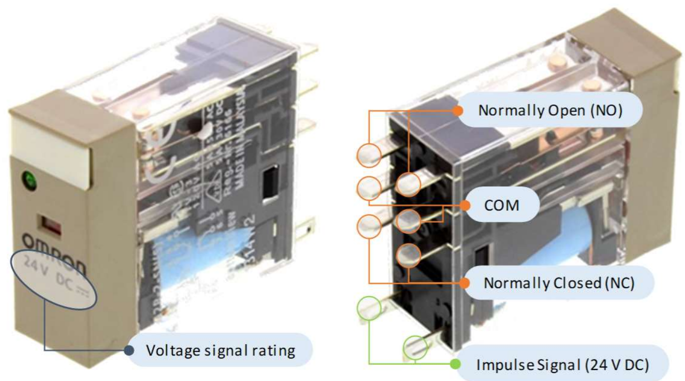


Figure 2. Example of relay G2R-2-S connections from OMRON manufacturer.

2.1.2. Using Adaptive Switches

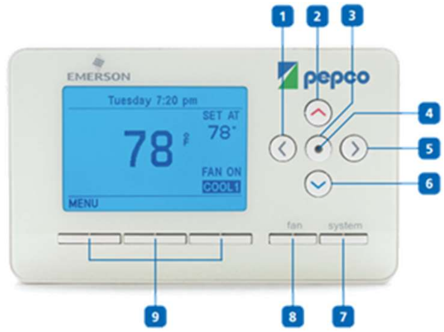
Adaptive switches can modify the consumption of a given load, using duty-cycle considerations, namely, a certain percentage of the time can be defined during which the status of the load is switched from on to off, and vice-versa. For example, 50% in each hour means that the load is on half of the period considered. For instance, in (Alexander, 2008), it is demonstrated a direct load control program that is implemented through the use of adaptive switches. These are also capable of learning the load's daily behaviour, and thus estimate the most appropriate periods to intervene in the load. This capability allows for more specific savings, since it supports the consumer in identifying the appropriate duty-cycle of a given load.

It is important to notice that this strategy involving the shedding of in-between duty-cycles periods, has potential to reduce consumption costs for a given load, however, there are loads that can suffer from this intervention. In other words, the constant switching the load on and off in the considered time horizon, may cause a reduction in the device lifetime due to the transition regimes verified when the load is activated (Facchinetti, 2011).

2.1.3. Using Thermostats

The use of thermostats is clearly focused on the temperature for the consumer. This involves the control of thermal loads (e.g. air conditioners and water heaters) and maybe even others, in order to ensure that the consumer's comfort is respected while reducing the consumption associated with the several loads.

For instance, PEPCO (Potomac Electric Power Company) (PEPCO, n.d.a), an electric service provider of Maryland, enables a demand response program based on the use of a thermostat called Energy Wise Rewards™. There are two thermostat solutions, available: with and without wi-fi web-programmable thermostat. By using internet connection, either with wi-fi or wired connections, both thermostats provide remote control opportunities for the consumer, controlling the heating and cooling system. These solutions are often plug & play, which provide an easier installation and replacement of previous thermal control. Moreover, smart applications are available that enable schedule programming, and alerts about peak savings days. The PEPCO solution for direct load control of heating and cooling system is shown in Figure 3.



1	Left Arrow	Navigates menu items
2	Up Arrow	Raises temperature setpoint/changes selected menu item
3	Action Button	Selects action of selected menu item
4	LED	Indicates occurrence of curtailment event
5	Right Arrow	Navigates menu items
6	Down Arrow	Lowers temperature setpoint/changes selected menu item
7	SYSTEM Button	Changes system selection (OFF, COOL, HEAT, AUX [displayed on heat pump units only])
8	FAN Button	Changes fan setting (Auto/On)
9	Soft Keys	Performs action listed on display above the button

Figure 3. Example of thermostat from PEPCO for the energy wise reward program (PEPCO, n.d.b).

In the literature, it is also possible to find models for the implementation of direct load control programs, based on the use of thermostats. For instance, in (Ruiz, 2009), the authors present a scheduling methodology of demand response flexibility using direct load control, considering load modifications through the use of thermostats. Also, by the definition of on and off cycles (associated with the duty cycle concept), the scheduling becomes more representative of real-life applications. The authors developed a simple optimization model that represents the direct load control program implementation.

2.2. Communications

Today, there are several protocols available on the market. In this current stage, there is not yet a clear winner for load communications. Communications protocols can be divided in two main groups: the group of wired communications that needs a physical channel between emitter and receiver; and the group of wireless communications that use radio signals to communicate.

Digital Addressable Lighting Interface

Digital Addressable Lighting Interface (DALI) is a protocol that enables a network between lights in a specific building. This protocol is specified by the standards IEC 62386 (DALI, 2017). At the present moment, it just supports the control of lights, enabling the dimmer of the light and the turn on and off. DALI protocol uses two wires for communications. It has an asynchronous, half-duplex and serial communication.

The use of DALI protocol for DLC can be done using a gateway in the building to receive the DLC event and then apply it to the building lights. But because it will only work with lights, this protocol is very limited regarding the types of loads available for DLC.

Power-Line Communications

Power-Line Communications enables data communications using power lines. There are several applications using power-line communications, from medium voltage lines (10-20 kV) to the application in residential houses (230 V). There is no need of new wired installations with this technology since it uses the power lines for communication. Its capability to operate outside buildings enables its use for DLC events. If the load, to be used in a DLC contract, has the ability to communicate using power-line communications that means that we just need to plug the load to an electrical socket. The main problem of power-line communications are the failures that can occur if the electrical wave has some problems.

Zigbee

Zigbee is a wireless protocol based on IEEE 802.15.4 (Zigbee, 2017). It has the possibility to have mesh topologies using low-power devices with sleep capabilities. This protocol can achieve more than 1 km in open field, however, it has a big drop inside buildings. This problem can be overcome using its ability to work in a mesh topology. This is a very powerful protocol used worldwide and available in market solutions, such as, Philips HUE (lights) and Cloogy (smart plug). EDP Distribuição, the main Distribution System Operator in Portugal, also supports Zigbee in their solution for smart homes named EDP RE:DY. Because there are some market solutions for load control and monitoring, Zigbee is a feasible communications solution to be used in DLC events.

Z-Wave

Z-Wave is a wireless protocol created for home automation. Like Zigbee, Z-Wave also allows mesh topologies. At this moment there are 2100 interoperable products using Z-Wave (Z-Wave, 2017). From sensors to actuators, to the combination of both, like smart plugs (with control and monitoring capabilities), the use of Z-Wave can be applied in everything. One of the key players in Z-Wave product is FIBARO. Because it is a widely spread protocol, it can be used for DLC events.

DASH7

DASH7 is a new wireless protocol that tries to overcome existing problems and limitations in the other wireless protocols. The protocol comes from the standard ISO/IEC 18000-7 and promises very low-power devices capable to transmitting data within a 2 km range and overpass concrete and water (DASH7, 2017). This is an open-source communications protocol that has been developed in the last years. Although it is a recent protocol, its capabilities are amazing and for this reason its use in DLC events can be a reality.

TCP/IP

The combination of the Transmission Control Protocol (TCP) and the Internet Protocol (IP) almost rules our world. The use of internet in everywhere increased the use of TCP/IP. It can be used in wired mode or wireless mode and is commonly available in buildings. For this same reason, the application of TCP/IP in smart plugs, lights and other loads is common. Although it has clear disadvantages, such as the price, consumption and range, its use enables the direct connection to a web server and smartphones without the need of a gateway. Also, its price has been decreasing while new hardware for IoT appears in the market, such as the appearance of ESP-8266 (Wi-Fi device with a cost around 3 EUR). Because of its wide dissemination and because of the available market solutions, TCP/IP can be applied in DLC events to control loads.

Modbus

Modbus is a communications protocol with several variants, although the two main variants are (Modbus, 2017): Modbus/RTU, and Modbus/TCP. Modbus/RTU is a wired serial communications protocol that uses a RS-485 network. It is a common protocol in energy devices, such as, energy analysers, power inverters and motor controllers. Because of its implementation in energy devices, Modbus/RTU can be used in DLC events for monitoring or controlling loads. Modbus/TCP uses TCP/IP protocols instead of using the RS-485 network. This increases the range of communications and enables the communications between a computer or server directly to the Modbus/TCP device.

Mobile telecommunications

For long communications without internet connection, the most common is mobile telecommunication, such as, GSM, 3G or 4G. Usually this is the perfect solution for long range communications, but it usually comes with a high cost. For remote loads, mobile telecommunication can be used to perform DLC.

DREAM-GO project tested the following communications protocols: DALI, Power-Line Communications, Zigbee, DASH7, TCP/IP, Modbus/RTU, and Modbus/TCP. The use of DASH7 was limited because of hardware and protocol stack limitations. From the descripted communications, the project only left out Z-wave and mobile telecommunications. The use of mobile communications was out of the scope because as it only makes sense to use for remote loads (that was not the case). Z-Waze was not tested but the project recognizes its capabilities and market advantages, regarding commercial products, and therefore, it can be a good option for energy management systems. However, DREAM-GO chose the use of Zigbee and TCP/IP for wireless and wired communication.

3. DLC contracts, players and simulation

In order to integrate the algorithms, systems and devices in the scope of DREAM-GO, the TOOls Control Center (TOOCC) has been developed (Teixeira, 2017). TOOCC is a centralized facilitator for setting up and launching a complete multi-agent based simulation, as well as to provide the independent usage of algorithms and tools for scenarios analysis. Besides the way TOOCC define the models and setting up all the necessary parameters and definitions, TOOCC also allows the system execution in any domain machine, avoiding the need to install all the needed software on each specific computer being used to perform a case study. Rather, the centralized support tool for the considered models communicates with the server that contains all the required software and algorithms, and guarantees that everything is available for agents, as needed. This approach also enables the execution of algorithms and the use of models from external entities (e.g. different types of agents from different partners) without the need for installing the required software and setting up all definitions locally.

TOOCC receives and stores information regarding the models to be used, the required inputs to setup the execution of different algorithms, or even of entire simulations, including diverse agents using distinct algorithms/tools, and also information about the demand response and DLC contracts, etc. TOOCC is itself controlled by an independent software agent that interacts with the remainder multi-agent framework, as shown in Figure 4.

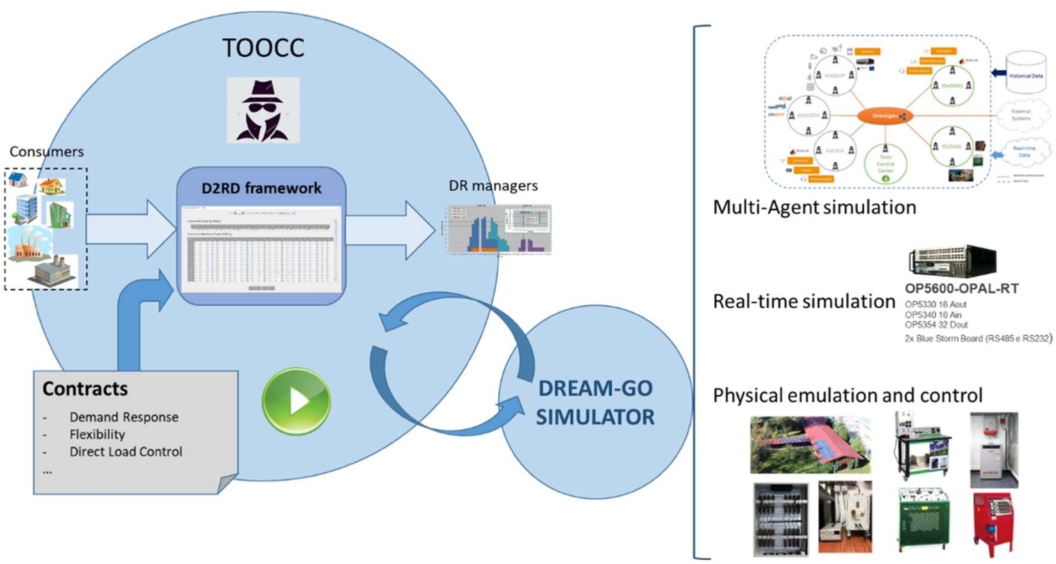
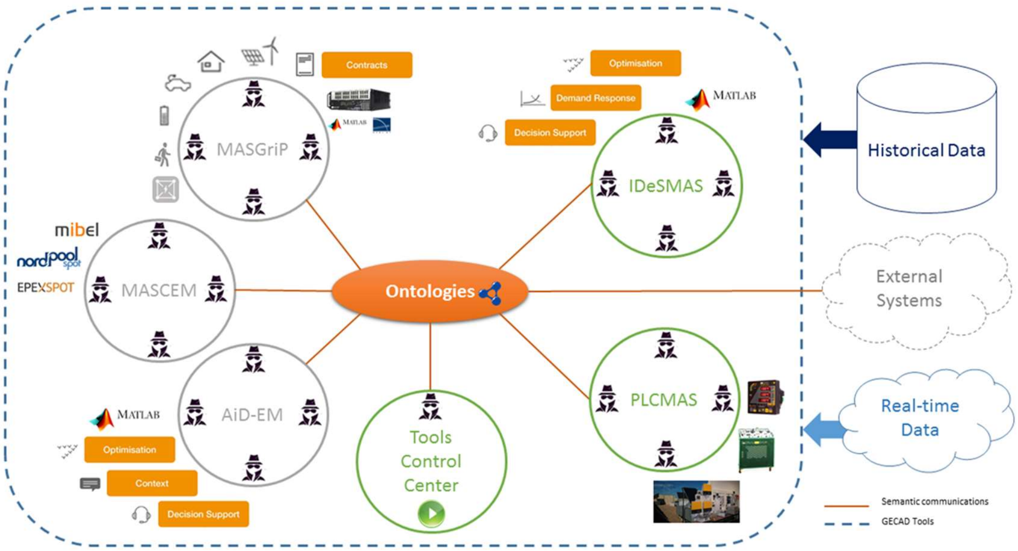


Figure 4. Tools Control Center overview.

By integrating all models, systems and algorithms in a centralized framework, TOOCC also enables the simulation by different means, namely through multi-agent simulation, the connection to real-time simulation using OPAL-RT, and also the physical emulation and control of real devices and buildings. Thereby, TOOCC facilitates the entire simulation and emulation process of DREAM-GO.

Ontologies are used to support the communications between the different algorithms, systems and devices in the scope of DREAM-GO. Ontologies provide the means to successfully exchange meaningful information that can be easily interpreted by software agents. On the other hand, using a reasoner, ontologies also enable to infer knowledge from the gathered information.

The developed ontologies are useful not only for communication purposes, but also for knowledge representation and sharing among the software agents. The use of semantics for heterogeneous systems' interoperability enables full knowledge exchange, taking advantage of the functionalities made available by each system. Figure 5 shows an overview of communications between several systems and algorithms developed by DREAM-GO.



AiD-EM - Adaptive Decision Support for Electricity Markets negotiations
MASCEM - Multi-Agent Simulator of Competitive Electricity Markets
MASGriP - Multi-Agent Smart Grid Platform
IDeSMAS - Intelligence and Decision Support Multi-Agent System
PLCMAS - Programmable Logic Control Multi-Agent System

Figure 5. Interaction between systems, algorithms and agents.

To enable interoperability with electricity market agent-based systems the Electricity Markets Ontology (EMO) has been developed (Santos, 2016a). EMO includes abstract concepts and axioms representing the main existing electricity market. It tries to be as inclusive as possible in order to be reused and/or extended in the development of EM specific ontologies.

To enable semantic communications using EMO concepts, two additional modules have been developed separately: the Call for Proposal (CFP); and the Electricity Markets Results (EMR) ontologies. These modules define Requests, Responses and Informs, enabling a semantic interaction between the participating software agents.

EMO, CFP and EMR are publicly available (www.mascem.gecad.isep.ipp.pt/ontologies/) so they can be (re)used by third-party developers in the context of the wholesale electricity markets. More details about EMO, CFP and EMR can be found in (Santos, 2016a).

Additionally, several other ontologies have been developed. Some of these are specific to enable the communications with a particular system or algorithm (representing its inputs and outputs), and others to represent the knowledge related to smart grid domain, namely: The ActorOntology, ActorVocabulary, AreaOntology, BuildingCategoriesVocabulary, EnergyFormVocabulary, ElectricityPlayerOntology, ElectricPowerSystemVocabulary, SEAS-FlexibilityVocabulary, LightSystemOntology ThermodynamicSystemOntology

The developed ontologies not only enable the interoperability between different systems and algorithms but also represent the concepts needed to understand and use real data, from different sources.These data can be acquired in real time through analysers/sensors, or even databases available online.

For that, the developed ontologies allow the representation of knowledge in a common vocabulary, regardless of the source; thus facilitating interoperability between the various heterogeneous systems and data, information and knowledge sources, with the ultimate goal of achieving an enhanced simulation platform for fully transactive energy systems.

4. Use cases

In this section some use cases from DREAM-GO project, regarding the execution of DLC events, will be presented. The use cases demonstrate the capabilities and advantages of using DLC and how consumers can respond to these events.

4.1. Joint simulation of smart grid and consumer energy management: enabling real time DLC

The systems interoperability enabled by DREAM-GO's TOOCC allows the simulation of comprehensive scenarios, considering e.g. the electricity market, the smart grid and the residential energy management with different types of DR, including DLC. Figure 6 shows the overview of a simulation scenario that makes use of semantics to enable the connection from the aggregator to the device inside the facility, through DLC.

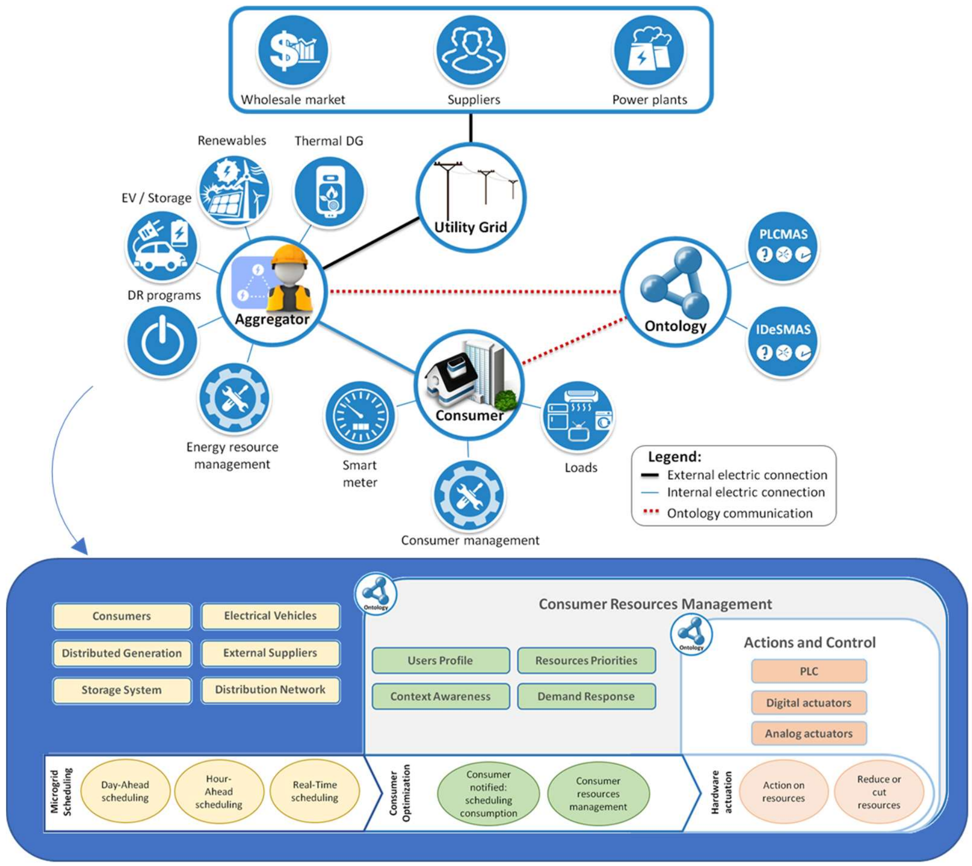


Figure 6. Simulation scenario defined using TOOCC.

The main Ontologies used in this simulation are: the (i) PLC Ontology; (ii) Facility Ontology; (iii) SHIM Ontology; and the (iv) Production, (v) Consumption and (vi) Flexibility ontologies, which are described as follows. The remaining ontologies only define knowledge modules that are reused by the other.

- *PLC Ontology* – enables the interoperability of any Facility Manager Agent with PLCMAS, a multi-agent system developed with the purpose of controlling physical devices connected to any PLC. This ontology defines a PLC including its resources characteristics about a light, a window, a HVAC, etc.;

- *Facility Ontology* – defines an abstract facility, i.e. a building, a house or an office; its divisions (Room, Kitchen, Living Room, etc.) and devices per division. This ontology represents the main concepts of the Facility Manager Agent knowledge base;
- *SHIM Ontology* – allows any Facility Manager Agent to request for a SHIM Optimization Agent to the OptiMAS, a multi-agent system developed with the intention of making available different types of optimization algorithms in the field of Power Energy Systems. This agent runs the SHIM optimization after receiving the DR event from the aggregator, e.g. Virtual Power Player (VPP);
- *Production, Consumption and Flexibility ontologies* – represents the communications between the VPP and its aggregated players, namely consumers, producers and prosumers. Each aggregated player informs, periodically, the VPP about its consumption and/or production; using respectively the Consumption and Production ontologies. After the VPP runs the distributed energy resources optimization, it informs all aggregated players about their scheduling accordingly to their DR contracts.

4.1.1. Case Study

The simulation considers a 25-bus microgrid, shown in Figure 7 that includes a simulated house based on data gathered in real time from one anonymized client of Discovergy, in Germany, the real ISEP/GECAD campus building, and a typical residential consumer located in GECAD laboratory. The results aim to show the increase of energy efficiency in a house management system, through communication with the several agents. The simulation is obtained through the following process:

- Energy Resources Management (ERM) platform in microgrid (Silva, 2015a);
- Communication with house management system for consumption scheduling;
- Execution of the house management algorithm of SCADA House Intelligent Management system (SHIM) – (Fernandes, 2014);
- Action on the loads through DLC using the PLC.

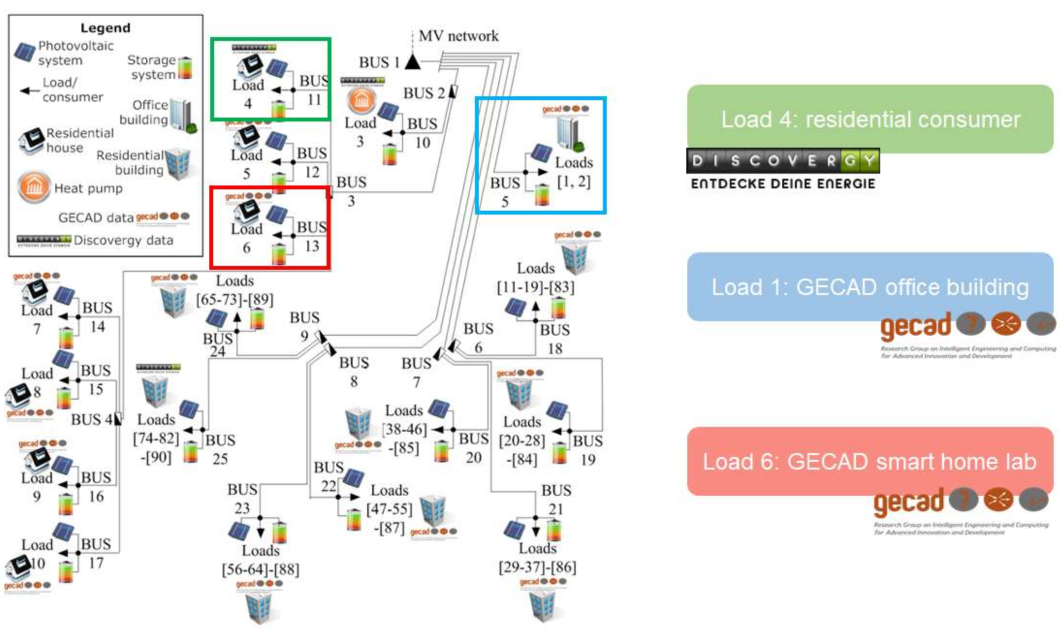


Figure 7. Simulated microgrid network

The private distribution network used in the simulation is a real distribution network of a residential area located in Portugal (Canizes, 2015). The VPP operator manages 25 distributed generation units (Photovoltaic system), 5 external suppliers (main grid supply in bus 1), and 82 consumers with DR programs (load reduce program). A total of 24 lines with 1.65 km length represent the radial microgrid. The technical limits of the lines can be seen in (Canizes, 2015). Load 6 is the GECAD real laboratory. The presented case study considers a simulation day in winter in Portugal, namely 22nd January 2013. In this context, the PV generation reaches low values, insufficient to supply the expected loads consumption. Table I shows the residential microgrid characterization. There are 8 residential houses and buildings. The buildings connect 72 apartments, each one representing one consumer (Loads 11-72). There are also 2 commercial buildings (Loads 1-2). Residential houses are located in bus 10 to 17. Each residential house and building, and commercial building has one PV system and one storage system. There is also a real installation in the roof of GECAD. Figure 8 presents the forecasted power demand and solar generation in the microgrid scenario. It can be seen that the peak load is expected at night periods (over than 52 kW).

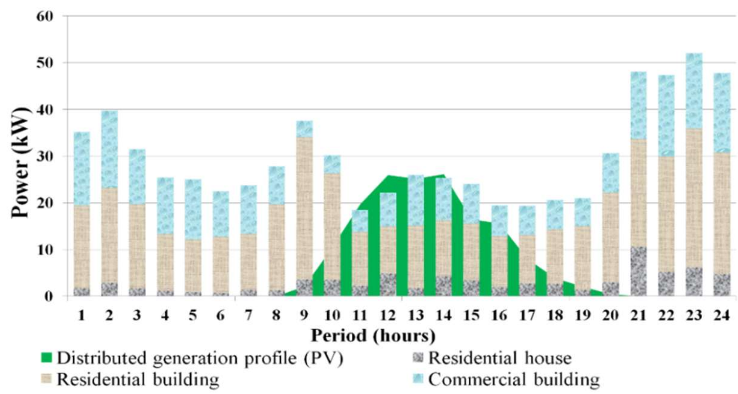


Figure 8. Power demand and solar generation profiles

4.1.2. Results

The results of the simulation present the scheduling of the ERM platform and the SHIM optimization. Figure 9 presents the real-time scheduling results of the ERM concerning the energy use by the several resources managed by VPP operator in order to fulfill the consumption needs. To fulfill the goals of the VPP and satisfy the consumers, the operator needed to acquire: 67.95% of energy from external suppliers, even using all the energy produced by the photovoltaic systems; 1.16% of energy storage systems through the discharge and; 6.79% using DR programs during peak consumption periods. It was possible to sell 2.96% of energy to external suppliers.

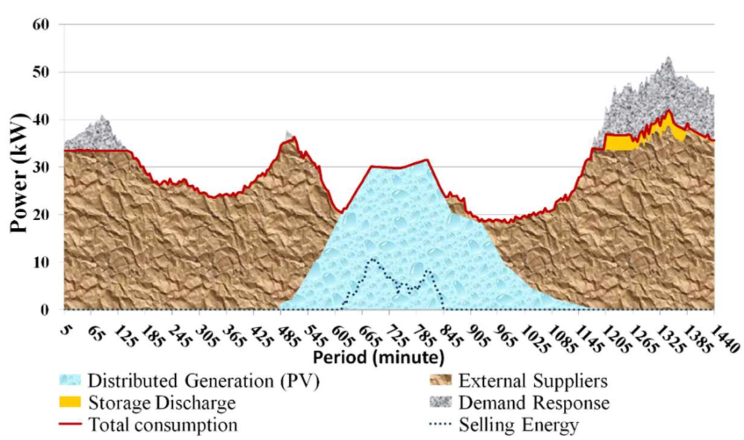


Figure 9. Real-time ERM results.

Load 6 (simulated house in GECAD lab) has the characteristics shown in Figure 10, in which the simulated house is composed by a living room, kitchen, bathroom, hall and bedroom.

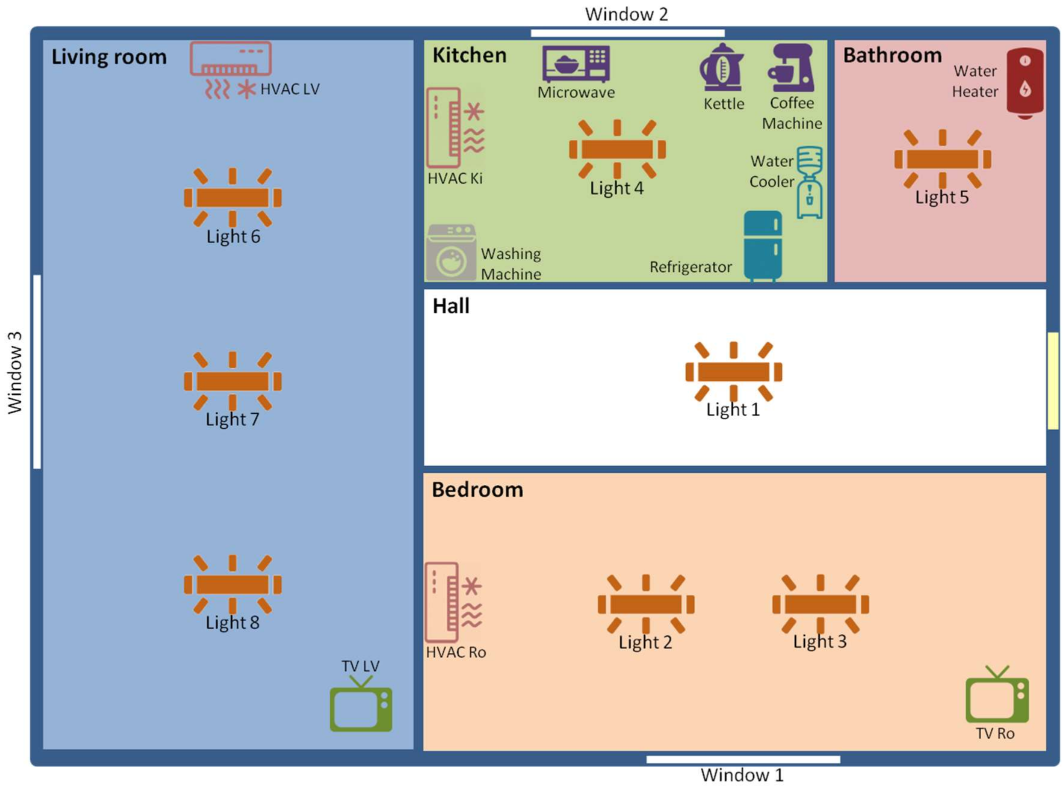


Figure 10. Configuration of the simulated house (Load 6).

The devices included in the simulated house, all are simulated except the lights, which are real lights controlled physically in the GECAD lab. Figure 11 shows the correspondence between the lights of the simulated house and the real lights controlled in GECAD lab.

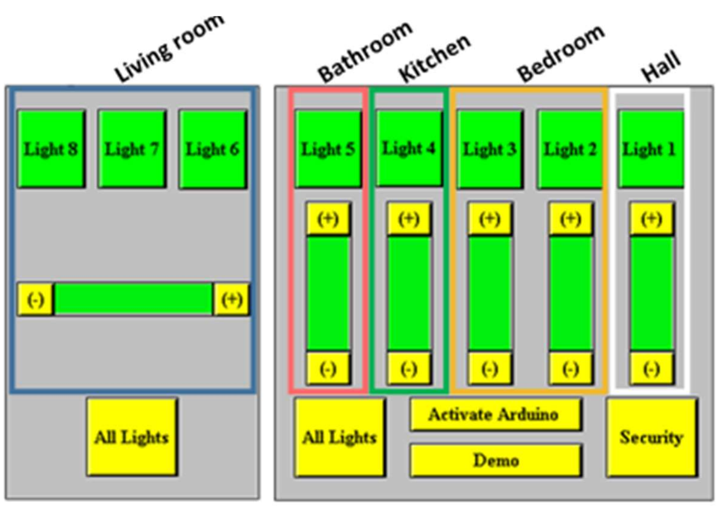


Figure 11. Correspondence between the lights of the simulated house (Load 6) and the lights controlled in the GECAD lab, through the PLC interface.

The consumption of Load 6 resulting from the scheduling of the VPP operator, can be seen in Figure 12. The changes in the load forecasts for Load 6 resulted in the reduction of the energy supply during times of peak consumption. The real-time results show a reduction of 19.63% in the expected load.

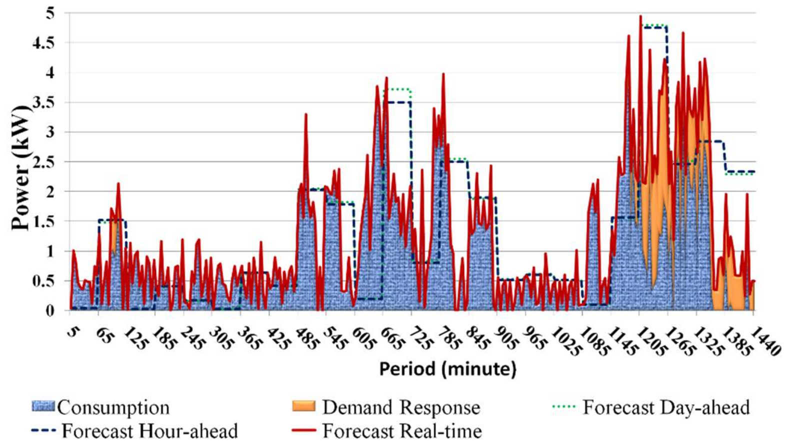


Figure 12. Consumption results for Load 6 (from ERM platform).

The SHIM system obtains the optimization results for each load according to the ERM limit indicated by the VPP operator. The ERM limit represents the difference between consumption and DR, as seen in Figure 12. The SHIM results for each device of Load 6 are presented in Figure 13. A comparison to the ERM limit is also provided. Being a winter scenario, the HVAC and Water Heater assume higher priority for the optimization. Also, it is important to mention, for the interpretation of results, the capacity of lights to control the consumption through electronic ballasts. Results show that the optimization in the house was able to adapt the consumption in moments when DR events occur, for example, between the period 1205 and 1440 (peak consumption period – see Figure 12).

If the simulation contained a summer scenario, different conditions had been taking into account changing the priorities values to each load. For example, Water Heater can be represented by a lower priority for the SHIM system and the same happens with the lights due to the higher number of hours with luminosity. And in the case of ERM results, in a summer scenario there are more sun hours, which results in the higher power generated by photovoltaic system.

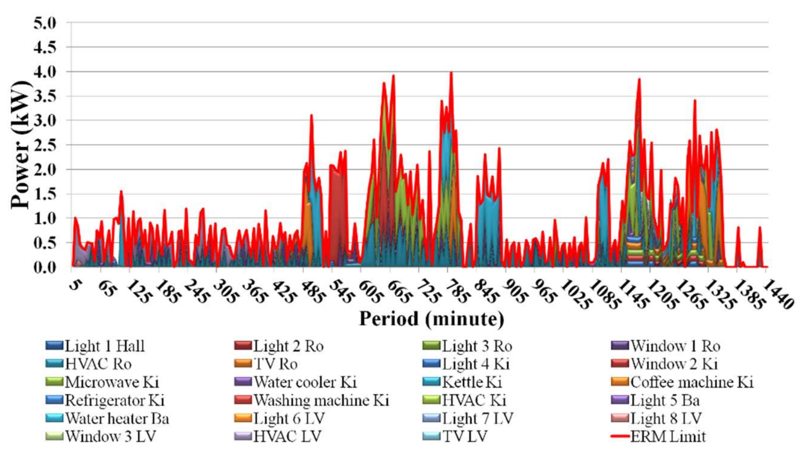


Figure 13. Optimization results obtained by the SHIM for Load 6.

4.2. Multi agent-based smart home energy system for short and real-time energy management

4.2.1. Implementation of the multi agent-based smart home energy system

According to our proposed model for the DREAM-GO project, we define that the Smart Home Energy System (SHES) consists of different organization-based agents where each of them has different tasks in the system. In this section, all agents of the SHES will be introduced and their task will be described. Moreover, the physical system of the organization-based Multi Agent-based SHES (MASHES) is seen in Figure 14. MASHES includes two layers. First layer is the electricity system, which is displayed by black lines. The second layer is the communication system that is shown by blue lines. SHES is one type of energy systems, so it is clear that agents of SHES and energy systems can be the same as described in the following.

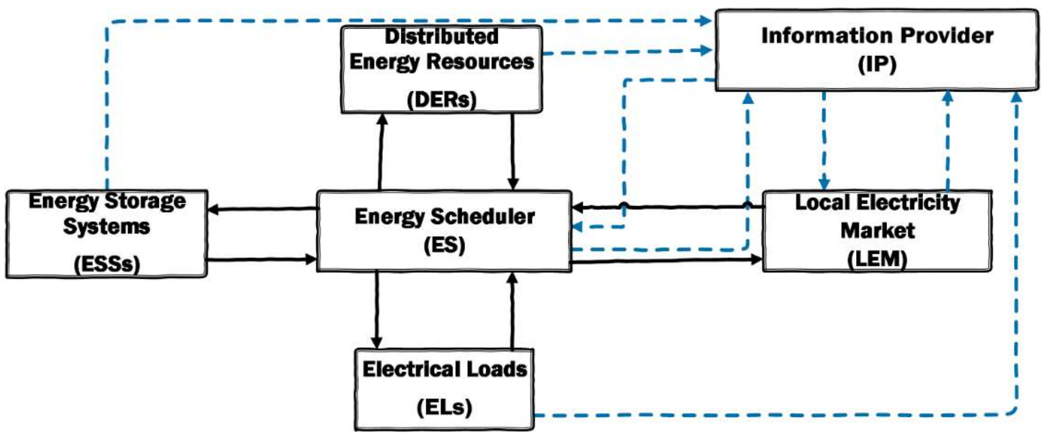


Figure 14. MASHES physical system (Shokri Gazafroudi, 2017b).

Electrical Loads (ELs)

Electrical Loads (ELs) are a group of agents that consume electrical energy in the SHES. Generally, ELs are classified into different types of loads such as shiftable, controllable, Must-Run Services (MRS), etc. Therefore, ELs can be considered as an organization basis for different agent types in the MASHES.

Distributed Energy Resources (DERs)

DERs are a set of agents that are responsible for the generation of electrical energy in a smart home. DERs are intermittent energy resources, so they introduced uncertainty in the system. However, increasing the prediction accuracy of these stochastic variables can decrease the corresponding uncertainty in the system.

Energy Storage Systems (ESSs)

ESSs are the agents in the MASHES that can store electrical energy such as EVs and batteries. Batteries can help to smooth the electrical demand profile. On the other hand, even though the main purpose of EVs is to provide clean transportation, they can assist the MASHES as ESSs too.

Information Provider (IP)

IP is an agent in the SHES that is in charge of sensing and recording all information of agents and environmental conditions, and convey them. This information consists of the real-time data that is recorded by the electronic electricity meter LZQJ-XC (LZQJ-XC, 2017), and its corresponding historical data. In addition, the information can be the personal data of the residents, the time-series of the weather parameters, the time-based data, the real-time data of the system that are sensed by the sensors. The interactions of the IP with other agents of the SHES are shown in Figure 14.

Local Electricity Market (LEM)

LEM is defined as an external agent that consists of a retailer (the energy supplier) and a DR aggregator. Smart homes should be able to connect to the LEM to trade electricity. Hence, electricity price and power are two variables that are exchanged between smart homes and the LEM.

Energy Scheduler (ES)

ES is a virtual organization of agents who plays as a system operator in the MASHES. The proposed energy scheduling method is based on day-ahead energy management approach. The ES consists of two agents in the MASHES, one is the Prediction Engine (PE) and the other is the Energy Management System (EMS). The tasks of both are described below:

- *Prediction Engine (PE)* – PE provides accurate prediction of all stochastic variables of the system (e.g. wind speed, solar radiation, weather temperature, electricity price and electrical unshiftable loads) for EMS. Hence, the outputs of this agent will be the inputs of the EMS. As the DERs utilized in the SHES are non-dispatchable resources, the forecasting of its power output will be very important for the EMS. Hence, accurate forecasting of PE can assist the EMS to make optimum decisions.
- *Energy Management System (EMS)* – The task of the EMS is to make optimum decisions in the MASHES. An optimum decision depends on the objective(s) of the smart home owner. Maximizing the profit of the SHES is the proposed objective function (OF) of this report. Therefore, after the OF is defined in the system, this agent should make an optimum decision. In this case, EMS faces a discrete optimization problem under uncertainty of the PE's outputs. This uncertainty causes some problems for the EMS, such as increasing the operating costs of the MASHES and computational overload. There are different methods to model the uncertainty in the optimization problems such as stochastic programming (Conejo, 2010), interval optimization (Pandzic, 2015), robust optimization (Soroudi, 2013), etc.

The MAS for home energy management system allows for modelling different devices in a house through autonomous agents as discussed before. In addition to the representation of the different devices through software agents, the modeling of possible existing generation sources that can be connected to the house is also considered. Through this multi-agent modeling, it is possible to simulate different scenarios taking into account the optimization of the costs related to energy consumption. To this end, this MAS includes negotiation methods that allow various devices to reach consensus when it is necessary to reduce the overall energy consumption of a house in order to respond to the changes in energy prices, e.g. times of the day when the tariff is the highest, and to variations in generation due to their variable nature because of climatic conditions.

This MAS is implemented in JADE (JADE, 2017), which is compliant with FIPA (FIPA, 2016) guidelines. The architecture of the agent society can be seen in Figure 15.

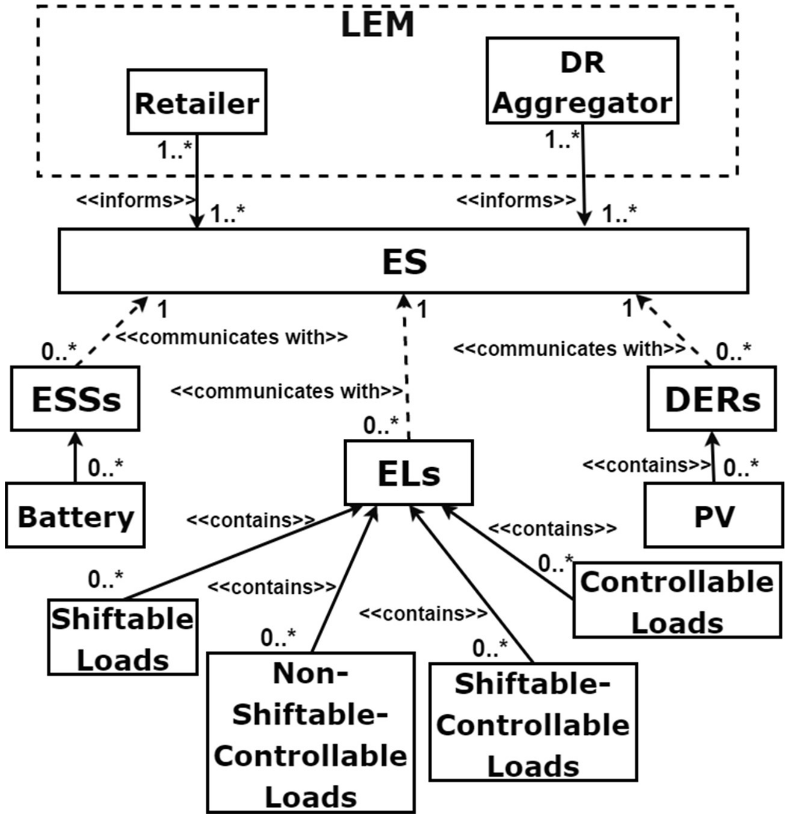


Figure 15. MAS architecture (Shokri Gazafroudi, 2017b).

LEM

Two external agents are considered, the retailer (the energy supplier) and the DR aggregator.

IP

In our structure, the Main Agent is created initially when the simulation is performed. It is responsible for creating the remainder agents. Another agent in the IP (consists of the electricity meter LZQJ-XC) is called Management Information Base (MIB) that is responsible for interconnecting agents.

ES

The ES-agent is included in this group of agents because it is responsible for connecting all the agents in a house. In addition, it analyses and predicts data. Also, the energy management is done by the ES.

DERs

This agent is responsible for renewable energy resources, e.g. as wind micro-turbines and PV panels.

ESSs

ESSs is a set of agents, that represent the energy storage units, e.g. battery, EVs.

ELs

ELs is an organization-based agent of different agents that only consume the electrical energy but whose type is different:

- *Shiftable Loads* are responsible for all units that may have changeable consumption.
- *Shiftable-Controllable Loads* are another type of agents that are responsible for all units which can be controlled and changed in their turn.

- *Controllable Loads* are the type of agents that are responsible for all units in which only consumption amount can vary each time, but not to change their consumption in another time.
- *Non-Shiftable-Controllable Loads* are responsible for all units that have not been included in any of the previously defined agents, i.e. all units that can neither control nor vary their power consumption in time.

In the agents representing the smart home, only the Manager agent is unique for each smart home and is responsible for the energy management of the respective house.

This proposed organization-based MAS structure is also capable of interacting with the Multi-Agent Smart Grid Simulation Platform (MASGriP) (Oliveira, 2012), which is a simulation platform that simulates, manages and controls the most relevant players acting in a smart grid and microgrid environment. Moreover, the Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) is yet another MAS that enables the simulation of electricity markets (Santos, 2016b). Interaction with this system allows for the simulation of the participation of different players, even small players like houses, in distinct types of electricity market negotiations. The interaction between these different MAS is achieved through the use of specifically conceived ontologies, which are used to set a communication language between agents of the different systems, thus allowing them to understand each other and communicate effectively (Santos, 2015).

4.2.2. Short and real-time energy management assessment of a multi agent-based smart home energy system

In this section, we present an energy management solution using Multi Agent-based Smart Home Energy System (MASHES) to implement direct load control. The MASHES consists of different agents each of whom has different tasks in the system. Also, our proposed DEMS is defined to manage electrical energy inside the house. Besides, the home system is able to trade energy with the Local Electricity System (LEM) to maximize its expected profit according to the energy flexibility that is provided by the Electric Vehicle (EV). In addition, an interval method is used to model uncertainty of the decision-making variables. In these interval methods, uncertainty is modelled based on the bands that depend on the central and error forecasting of the stochastic variables that are provided by the predictor system in this report.

Predictor System

To generate the fuzzy rules, the learning process in HyFIS method is divided in two phases, which are (Kim, 1999):

- Structure learning, i.e., finding the rules by using the knowledge acquisition module;
- Parameter learning phase in order to tune the fuzzy membership functions (Gomide, 2007) to achieve a desired level of performance.

This approach can be easily updated when there is new available data (Wang, 1991) which is one of the advantages of using this method. As the Figure 16 shows, while there is a new available pair data, the fuzzy rule base will be updated by a new rule, created for this data.

In the first phase, a multi-layered perceptron (MLP) network based on a gradient descent learning algorithm is used by the neuro-fuzzy model to adapt the parameters of the fuzzy model (Rudd, 2014). Learning from data and approximate reasoning is simplified by this architecture, as well as knowledge acquisition. It allows using the combination of both numerical data and fuzzy rules thus producing the synergistic benefits associated with the two sources.

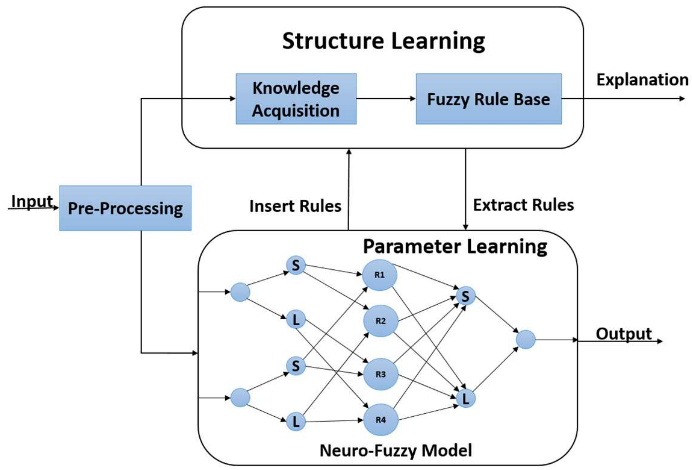


Figure 16. General schematic diagram of the HyFIS (Jozi, 2016 and Shokri Gazafroudi, 2017d).

A multi-layer Artificial Neural Network(ANN), based on a combination with fuzzy systems is the proposed neuro-fuzzy model in the HyFIS. As the Figure 17 shows, this system is divided in five layers. In this structure, the input and output nodes are the input state and output control/decision signals respectively. In the hidden layers, the nodes detain the responsibility of representing the membership functions and rules.

The first layer includes the nodes which are the inputs that transmit input signals to the next layer. The nodes in the second and fourth layers, are the term nodes. The term nodes act as membership functions to express the input-output fuzzy linguistic variables. The fuzzy sets defined for the input-output variables are divided in three groups: Large (L), Medium (M), and Small (S) in these layers. Although, in some implementations or specific cases, these can be divided in more specific groups as, e.g. Large Positive (LP), Small Positive (SP), Zero (ZE), Small Negative (SN), and Large Negative (LN).

The third layer includes the rule nodes, where every node represents one fuzzy rule. The connection weights between the third and fourth layer represent certainty factors of the associated rules, i.e. each rule is activated to a certain degree controlled by the weight values. Finally, the nodes in the last layer represent the output of the system.

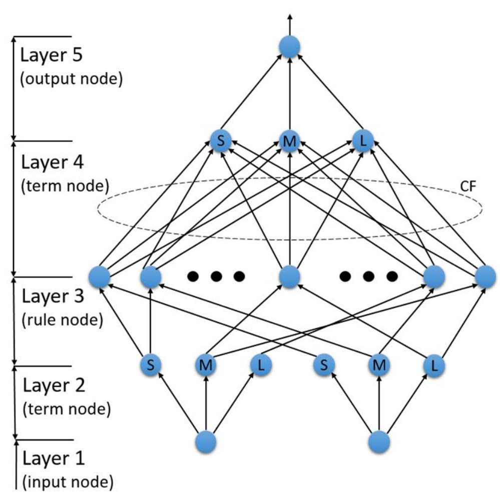


Figure 17. The structure of the Neuro-Fuzzy model from the HyFIS architecture (Jozi, 2016 and Shokri Gazafroudi, 2017d).

Domestic Energy Management and Control System

The task of Domestic Energy Management System (DEMS) is to make optimum decisions in the MASHES. In this case, faces a discrete optimization problem. We considered there are two LEMs: Day-ahead Local Electricity Market (DALEM) and Real-Time Local Electricity Market (RTLEM). Hence, each smart home can participate in the DALEM and RTLEM. In this section, the Domestic Energy Management (DEM) problem is modeled as a two-stage problem. The first stage is called Day-Ahead (DA) stage, and the second stage is called the Real-Time (RT) stage.

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

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

Day-Ahead Stage obtains optimum decisions for the system in day d-1. Hence, the EP for the DA stage is represented as Eq. (1).

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

EP^{da} consists of two parts. While the first part represents the revenue of selling the electrical energy produced by the PV system to the DALEM, the second part states the costs of buying the electrical energy from the DALEM. The constraints of the DA stage are:

$$P^{da}_{net\,t} + P^{da}_{pv,in_t} = \sum_{j:\{ELs\}} L^{da}_{j\ \ t} \tag{3}$$

$$-f_{max} \le P^{da}_{net\,t} - P^{da}_{pv,out\,t} \le f_{max} \tag{4}$$

Eq. (3) establishes the power balance equation due to the power output of the PV system that is injected into the home, P^{da}_{pv,in_t}, grid power input, $P^{da}_{net\,t}$, and electrical loads, $L^{da}_{j\ \ t}$. In this report, power loss is not considered for simplicity. Eq. (4) represents the power flow limitation through the distribution line which ends at the building. f_{max} expresses the maximum power capacity of the distribution line that links the end-user and the power grid. Moreover, some limitations correspond to all appliances. It is noteworthy that the power produced/consumed by all devices has been considered to be equal to its central predicted amount at this stage because the uncertainty is not considered in the DA stage.

$$P^{da}_{pv\ \ t} = P^{da}_{pv,in_t} + P^{da}_{pv,out\,t} \tag{5}$$

$$P^{da}_{pv\ \ t} = P^{pred}_{pv\ \ \ \ t} \tag{6}$$

$$L^{da}_{j\ \ t} = L^{pred}_{j\ \ \ \ t} \tag{7}$$

$$\sum_{j:\{ELs\}} L^{da}_{j\ \ t} = L^{da}_{sh\,t} + L^{da}_{swh\,t} + L^{da}_{pp\,t} + L^{da}_{mrs\,t} \tag{8}$$

The total power generation of the PV system is stated in Eq. (5). Eq. (6) states the power output limitations of PV. Besides, Eq. (6) represents the electrical power consumed by ELs' agents.

In the ***Real-Time Stage***, the expected profit of the smart home due to participating in the RTLEM is defined. The objective function of the RT stage, $\mathrm{EP}^{\mathrm{rt}}$, is represented as:

$$EP^{rt} = \sum_{t=1}^{N^t} (\lambda_t (P_{pv,out_t}^{rt} - P_{pv,out_t}^{da}) + \lambda_t P_{dis,out_t}^{rt} - \lambda_t P_{ch_t}^{rt} - \sum_{j:\{ELs\}} VOLL_j L_j^{shed}{}_t - V_{pv}^s S_{pv_t}) \tag{9}$$

EP^{rt} consists of five parts. The first part represents the revenue for selling energy produced by the PV system to the RTLEM. The total cost of electrical energy that is bought from the RTLEM is represented in the second part. The third part expresses the profit due to selling the stored electrical energy of the EV to the RTLEM. Also, the charging cost of the EV is represented in the forth term. The Value of Loss Load (VOLL), $VOLL_j$, is stated in the fifth part. Finally, the spillage cost of the PV system is represented in the last part. As seen in Eq. (9), it is proposed that if the PV power generation in the RT stage, P_{pv,out_t}^{rt}, is more than the PV power generation in the DA stage, the smart home can only sell its extra power at the net price, λ_t, that is less than the price that is established for the purchase of the power generated by the PV on the DALEM, λ_t'. In the RT stage, Eq. (10) is the power balance equation, and Eq. (11) shows the power flow limitation in a distribution line. Also, there are specific definitions for all appliances in the DEMS whose uncertainties are considered.

$$P_{net}^{rt}{}_t + P_{pv,in}^{rt}{}_t + P_{dis,in_t}^{rt} = \sum_{j:\{ELs\}} (L_j^{rt}{}_t - L_j^{shed}{}_t) + P_{ch_t}^{rt} \tag{10}$$

$$-f_{max} \leq P_{net}^{rt}{}_t - P_{pv,out}^{rt}{}_t - P_{dis,out_t}^{rt} \leq f_{max} \tag{11}$$

PV System, the power output of the PV panels in the RT stage, $P_{pv}^{rt}{}_t$, is obtained based on Eq. (12), whereas Eq. (12), $P_{pv,p}^{rt}{}_t$ is the potential power generation of the PV system in the real-time, and S_{pv_t} is the spillage power of the PV. Eq. (13) determines $P_{pv,p}^{rt}{}_t$ according to the interval predicted bands.

$$P_{pv}^{rt}{}_t = P_{pv,p}^{rt}{}_t - S_{pv_t} \tag{12}$$

$$P_{pv}^{pred}{}_t - \sigma_{pv_t}^{down}(1 - \alpha_{pv}) \leq P_{pv,p}^{rt}{}_t \leq P_{pv}^{pred}{}_t + \sigma_{pv_t}^{up}\alpha_{pv} \tag{13}$$

$$P_{pv}^{rt}{}_t = P_{pv,in}^{rt}{}_t + P_{pv,out}^{rt}{}_t \tag{14}$$

$$0 \leq S_{pv_t} \leq P_{pv,p}^{rt}{}_t \tag{15}$$

In Eq. (13), $P_{pv,p}^{rt}{}_t$ is the forecasted PV power generation, $\sigma_{pv_t}^{down}/\sigma_{pv_t}^{up}$ is the upper/lower variance of the prediction. Besides, α_{pv}*-Optimistic Coefficient (OC)*- is defined as a parameter that its amount is between 0 and 1. The amount of α_{pv} is set by the decision-maker of the MASHES. Eq. (14) represents that the total power output of the PV system equals its power output consumed in the home, $P_{pv,in}^{rt}{}_t$, and the amount of power generation that is sold to the RTLEM, $P_{pv,out}^{rt}{}_t$. The spillage amount of the PV system is the amount of power that is spilled in period t. This amount is positive or equal to zero, and is limited to the actual power generation of the PV panels as presented in Eq. (15).

EV, the EV can be utilized based on the charge and discharge strategies in the DEM problem.

$$\begin{aligned} C_t &= C_{t-1} + P_{ch_t}^{rt}\eta_{B2V} - \frac{P_{dis_t}^{rt}}{\eta_{V2B}} \quad , \quad \forall\, t \geq 2 \\ C_t &= C_i \quad , \quad \forall\, t = 1 \end{aligned} \tag{16}$$

$$P_{ev}^{min}{}_t \leq C_t \leq P_{ev}^{max}{}_t \quad (17)$$

$$-\omega^{min} \leq C_t - C_{t-1} \leq \omega^{max} \quad , \quad \forall\, t \geq 2$$
$$-\omega^{min} \leq C_t - C_i \leq \omega^{max} \quad , \quad \forall\, t = 1 \quad (18)$$

$$0 \leq P_{dis_t}^{rt} \leq \omega^{max} u_t \quad (19)$$

$$0 \leq P_{ch_t}^{rt} \leq \omega^{min}(1 - u_t) \quad (20)$$

$$P_{dis_t}^{rt} = P_{dis,in_t}^{rt} + P_{dis,out_t}^{rt} \quad (21)$$

Eq. (16) represents the state of charge balance equation of the EV in the real-time, where C_i is the initial state of charge in the EV. Eq. (17) represents the state of charge balance equation in an EV. Eq. (18) represents the maximum and minimum limitations of the EV's state of charge. Maximum and minimum limitations of the discharge current is represented in Eq. (19). Moreover, Eq. (20) expresses the constraint of the EV in the charge state. The discharge power of the EV, $P_{dis_t}^{rt}$, is expressed in Eq. (21).

Electrical Loads, ELs consist of loads that can be controllable and/or shiftable. Equations (22) and (23) define total electrical load and total load shedding, respectively.

$$\sum_{j:\{ELs\}} L_j^{rt}{}_t = L_{sh_t}^{rt} + L_{swh_t}^{rt} + L_{pp_t}^{rt} + L_{mrs_t}^{rt} \quad (22)$$

$$\sum_{j:\{ELs\}} L_j^{shed}{}_t = L_{sh}^{shed}{}_t + L_{swh}^{shed}{}_t + L_{pp}^{shed}{}_t + L_{mrs}^{shed}{}_t \quad (23)$$

Space Heater, the space heater provides the indoor temperature at the desired temperature. Eq. (24) defines the relation between the indoor temperature and the electrical load of the space heater. In Eq. (24), θ_0 is the initial indoor temperature which is assumed to be equal the desired temperature. Eq. (25) represents that indoor temperature is limited to 1 °C more and less than the desired temperature. Also, the maximum and minimum bands of the space heater load is stated in Eq. (26). Besides, the load shedding limitation of the space heater is represented in Eq. (27).

$$\theta_{in_{t+1}} = \theta_{in_t}.e^{-1/RC} + L_{sh_t}^{rt}.R.\left(1 - e^{-1/RC}\right) + \theta_{out}^{pred}{}_t.\left(1 - e^{-1/RC}\right), \forall\, t \geq 2 \quad (24)$$
$$\theta_{in_t} = \theta_0 = \theta_{des}\,, \quad \forall\, t = 1$$

$$-1 \leq \theta_{in_t} - \theta_{des} \leq 1 \quad (25)$$

$$L_{sh}^{min}{}_t \leq L_{sh_t}^{rt} \leq L_{sh}^{max}{}_t \quad (26)$$

$$0 \leq L_{sh}^{shed}{}_t \leq L_{sh_t}^{rt} \quad (27)$$

Storage water heater is in charge of storing the heat in the water tank. The maximum and minimum constraints of the storage water heater's power and energy consumption are stated in Eq. (28) and (29), respectively. The load shedding constraint related to the storage water heater is represented in Eq. (30).

$$L_{swh_t}^{min} \leq L_{swh_t}^{rt} \leq L_{swh_t}^{max} \quad (28)$$

$$\sum_{t=1}^{N_T} L_{swh_t}^{rt} = U_{swh\ t}^{max} \tag{29}$$

$$0 \leq L_{swh\ t}^{shed} \leq L_{swh_t}^{rt} \tag{30}$$

Pool Pump, the pool pump is modelled according to Eq. (31), Eq. (32) and Eq. (33). According to Eq. (31) the maximum and minimum bands of the pool pump load in each hour are defined. Each pool pump should not run more than T_{ON} hours in a day, according to Eq. (32).

$$L_{pp\ t}^{min}.z_t \leq L_{pp_t}^{rt} \leq L_{pp\ t}^{max}.z_t \tag{31}$$

$$\sum_{t=1}^{N_T} z_t \leq T_{ON} \tag{32}$$

$$0 \leq L_{pp\ t}^{shed} \leq L_{pp_t}^{rt} \tag{33}$$

Must-Run Services are modelled according to Eq. (34) and Eq. (35). The Must-Run Services include the loads that should be provided quickly - e.g. lighting, entertainment, etc. The load shedding constraint is stated by Eq. (35).

$$L_{mrs_t}^{rt} = L_{mrs\ t}^{pred} \tag{34}$$

$$0 \leq L_{mrs\ t}^{shed} \leq L_{mrs_t}^{rt} \tag{35}$$

Proposed Hardware Implementation

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

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

In this system, a space heater is considered as a controllable load. The maximum capacity specified for this load is 5.525 kW. Storage water heater and pool pump are the other electrical loads considered as shiftable loads. The storage water heater is in charge of storing the heat in the water tank, and the pool pump is a part of swimming pool installations. The energy capacity of the storage water heater is 10.46 kWh (180 L), which has 2 kW heating element. The rated power of the pool pump is 1.1 kW, and it is considered that it can operate for a maximum of 6 hours during the day. Additionally, several types of loads, such as lighting, or entertainment, are considered as must-run loads.

The maximum energy produced by the PV system is 2.5 kWh. Furthermore, an EV is propounded for the system playing the role of an ESS. This ESS unit can store energy between 1.77 and 5.9 kWh, and its maximum charging/discharging rates are 3 kW. Besides, charging and discharging efficiencies are 90%. Figure 18 represents the overall system architecture. In this system, the PV and ESS can supply local demand, and while there is more generation than local demand, the system is able to inject the exceed power to the utility grid.

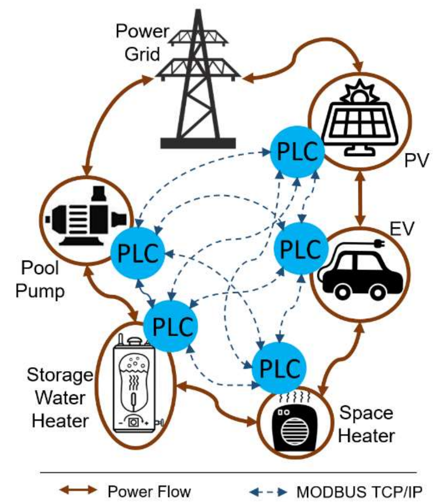


Figure 18. Proposed MAS architecture for the system control (Shokri Gazafroudi, 2017d).

As Figure 18 shows, there are five main agents namely, PV, EV, Water Heater, Space Heater, and Pool Pump agent. As also illustrated in Figure 18, each agent is equipped with a Programmable Logic Controller (PLC) in order to perform decision-making locally and communicate with other agents to fulfil the overall system's goal.

Moreover, Figure 19 presents the deployment diagram which addresses the static realization of the system. In this figure, each agent is represented by its corresponding representation in UML deployment diagram called node. A node consists of several components which are the instances of the components shown in Figure 18. The nodes communicate via Ethernet interface, with MODBUS TCP/IP protocol. The agents constantly exchange messages in order to share their latest status in the network. This will reduce the response time to any changes in the agents and hence improve the adaptability. On the other hand, flexibility and reconfigurability are two main important characteristics that an agent-based system offers. For instance, any faulty machine or agent can be easily repaired and replaced without any disruption in the overall system's task.

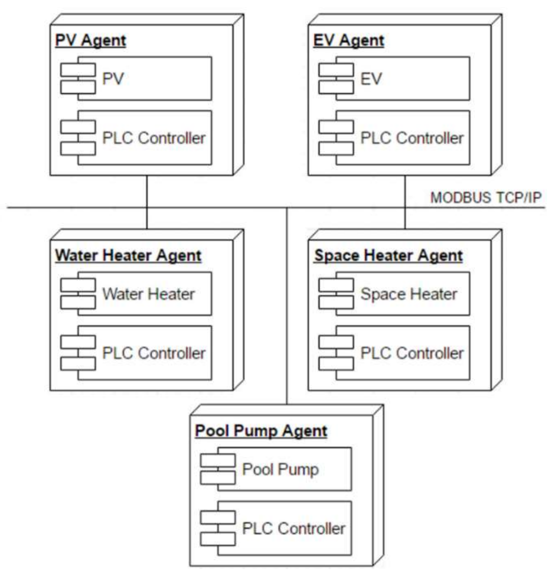


Figure 19. Agent-based deployment diagram (Shokri Gazafroudi, 2017d).

Simulation results from WP4 based on short and real-time demand response program

A physical system from (Pedrasa, 2009) is used to evaluate the performance of the proposed DEMS. However, some modifications of the system parameters are made. For instance, the predicted data of PV power generation and the must-run services are used from (Shokri Gazafroudi, 2017a), (Shokri Gazafroudi, 2017b) and (Shokri Gazafroudi, 2017c). The performance of the proposed DEM model is assessed in two cases. The program implemented is solved in GAMS 23.7 (GAMS, 1999). In this section, the performance of proposed DEMS is studied in two cases: Case 1: Effect of PV system, and Case 2: Effect of EV.

The ***impact of the PV system*** on the expected profit is evaluated in three scenarios in this section. In Scenario 1, PV system is not considered in the MASHES. In Scenario 2, the proposed DEMS is assessed when α equals 0 and 1. In Scenario 3, uncertainty of PV generation is not considered. Table 1 states the amount of expected profit and energy produced by the PV system in the RT stage. As seen in Table 1, the expected profit is the highest in Scenario 2 when α equals 1, because it is the optimistic scenario of PV power generation. Besides, the results of the system in Scenario 2 when α equals 0 is equal to the results of the Scenario 3 where uncertainty of PV power generation is not considered because the power generation of the PV system tends to converge to the central forecasting when α equals zero. Moreover, Table 2 describes the amounts of the day-ahead, real-time, and total expected profits of the system in Scenario 1. As seen in Table 2 the total and day-ahead expected profits are negative because PV generation is equal to zero and DEMS must provide its electrical demand from the electricity market. However, $\mathrm{EP}^{\mathrm{rt}}$ is positive because of flexibility influence of the EV in the RTLEM.

Table 1. Impact of PV system on the expected profit and total energy produced by the PV system (Shokri Gazafroudi, 2017d).

	PV System			
	Scen. 1	***Scen. 2 (α=0)***	***Scen. 2 (α=1)***	***Scen. 3***
EP	-6.142	9.962	10.132	9.962
E_{pv}^{rt}	0	7.32	8.41	7.32

Table 2. Day-ahead, real-time, and total expected profits without considering PV system (Shokri Gazafroudi, 2017d).

	Without PV System		
	EP	EP^{da}	EP^{rt}
Scenario 1	-6.142	11.268	5.126

The ***impact of the EV*** is assessed in two scenarios in this section. In Scenario 1, EV is available in all hours in the MASHES, and plays as the battery in the system. In Scenario 2, EV is out of home in period 6-17. Also, it is assumed that the EV should be full of charge at 6, and it has the minimum capacity at 17. Moreover, α is set to be 0 in this section. As seen in Table 3, the expected profit of the system in Scenario 1 is more than Scenario 2 because the EV is completely available at home in Scenario 1. Besides, there is no constraint to force the state of charge of the EV in some specific times in Scenario 1. On the other hand, the electrical energy from the LEM is less in Scenario 1. However, in Scenario 1 the amount of energy sold to the LEM is higher.

Table 3. Impact of EV on the total expected profit, the bought/sold energy from/to the local electricity market (Shokri Gazafroudi, 2017d).

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

Table 4. Impact of battery system and demand response program on the amount of sold/ bought electrical energy to/from electricity market (Shokri Gazafroudi, 2017d).

	$\alpha = 1$			
	With battery	**Without battery**	**With DRP**	**Without DRP**
E_{sold}	12.68	7.88	12.68	12.68
E_{bought}	32.23	37.497	32.23	41.918

Table 5. Impact of PV power generation uncertainty, battery, and demand response program on day-ahead, balancing, and total objective functions (Shokri Gazafroudi, 2017d).

	$\alpha = 0.4$			$\alpha = 1$		
Scenarios	EP^{da}	EP^{rt}	EP	EP^{da}	EP^{rt}	EP
With uncertainty	4.836	6.613	11.449	49.232	2.475	51.707
Without uncertainty	49.232	2.386	51.618	49.232	2.386	51.618
With battery	4.836	6.613	11.449	49.232	2.475	51.707
Without battery	4.232	5.553	10.389	49.232	1.416	50.647
With DRP	4.836	6.613	11.449	49.232	2.475	51.707
Without DRP	6.063	0.723	6.786	50.459	-2.087	48.372

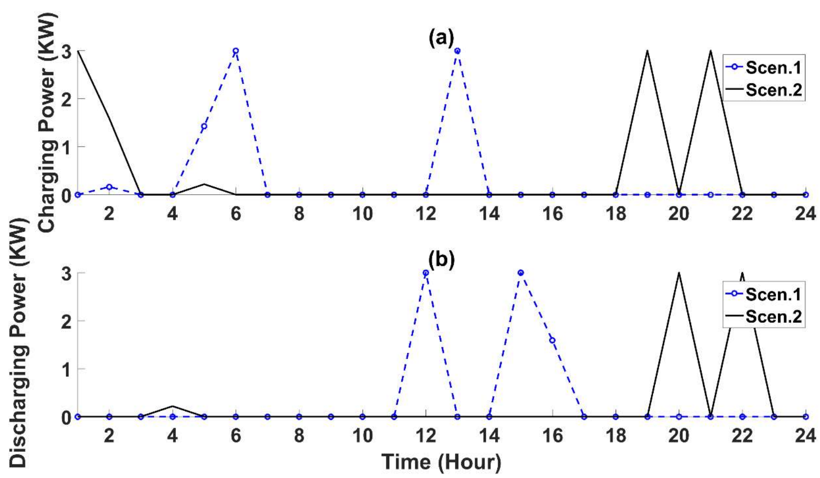


Figure 20. Impact of (a) Charging power of EV., (b) Discharging power of EV (Shokri Gazafroudi, 2017d).

The *impact of a battery system* on the EPs is shown in Table 4. From this table it is clear that the battery system can increase the amounts of all objective functions in both cases. In other words, the positive influence of the battery system on the DEMS's EP does not depend on the α. Also, Table 5 expresses that considering the battery in the DEMS causes to increase the amount of smart home's electrical energy that is sold to the local electricity market, and it decreases the amount of smart home's electrical energy that is bought from the local electricity market.

Moreover, the effect of the *Demand Response Program (DRP)* on the EPs and the smart home's electrical energy that is sold/bought to/from locale electricity market is assessed. Here, TOU program is used. As seen in Table 5, DRP causes the positive effect on the amount of total objective function on the DEMS. In other words, while EP^{da} is increased when DRP is not considered in the system, EP^{rt} is decreased dramatically because electrical loads are not flexible when DRP is not considered in the DEMS. Furthermore, considering DRP decreases the amount of electrical energy that a smart home buys from the LEM, because the main purpose of applying DRP is to eliminate the need of electrical energy by shifting the electrical load in the energy management time-period, and to reduce the electrical loads in some situations.

4.3. DLC program for air conditioners

Nowadays, the world is facing increasing electricity energy consumption in many sectors like industrial, transportation, residential, and commercial. However, unlike the industrial sector that had a lot of variation and inconstant situation in energy consumption between 1949 to 2011, the other sectors presented considerable more sharply energy consumption in 1949 to 2011.

In this situation, Demand Response (DR) program plays an important role in the topics of energy consumption. Programs with variable prices in the time, require a response from the customers that change their energy consumption according with the price variation over time. The different types of the DR program are listed as follow (Faria, 2011):

- *Direct Load Control (DLC)* is a program that considers a remote shut down or cycle of a customer's electrical equipment by the program operator. These programs are primarily offered to residential or small commercial customers;
- *Interruptible/Curtailable Service* (ICS) is based on curtailment options integrated into retail tariffs that provide a rate discount or bill credit by agreeing to reduce load during system contingencies and includes penalties for contractual response failures. These programs are traditionally offered to larger industrial customers;
- In *Demand Bidding/Buyback* (DBB) programs, customers offer curtailment capacity bids and large customers are normally preferred;
- *Emergency Demand Response* (EDR) can be seen as a mix of DLC and ICS and is targeted for periods when reserve becomes insufficient;
- In *Capacity Market* (CM) programs, customers offer load curtailment as system capacity to replace conventional generation or delivery resources;
- *Ancillary Services Market* (ASM) programs are similar to DBB programs, whereas in this case the offer is just made for the ancillary services market. As in traditional ancillary services, the remuneration can be paid for reserve and energy provision of energy separately.

The amount of DR programs applied to air conditioners is not very common in Europe. However, in the USA, as in other regions of the world, some DR programs for air conditioners have been studied. The regulation of the DR in air conditioners is made by the actuation in the air conditioners. Thus, this type of DR program is called DLC, because there is direct control over the load.

4.3.1. Optimization Model

The proposed model regarding the optimization of consumption of air conditioners and in reducing the total cost of the energy consumption in the building is based on the priority of them. In this way, the maximum consumption reduction for each air conditioner has been considered. The overall architecture of the presented optimization problem is illustrated in Figure 21.

As you can see in Figure 21, the optimization model starts with definition of input data including generation of the PV, total consumption of the building, and the detail of the total consumption of the air conditioning system. After checking these values, if the desired power consumption is met, the optimization process is not required and should check the values again as long as the system is in the high consumption level. Then, the program starts to optimize the consumption of the air conditioners to fulfill the system goal. For this purpose, priorities are defined in the program. This means each air conditioner of the building has a priority based on its location and user preferences. After that, the required power reduction of whole air conditioning system and the maximum consumption reduction of each air conditioner is defined, as well as several constraints for the proposed optimization problem. This methodology is run for a single period, however, the optimization process depends on the input values of the system.

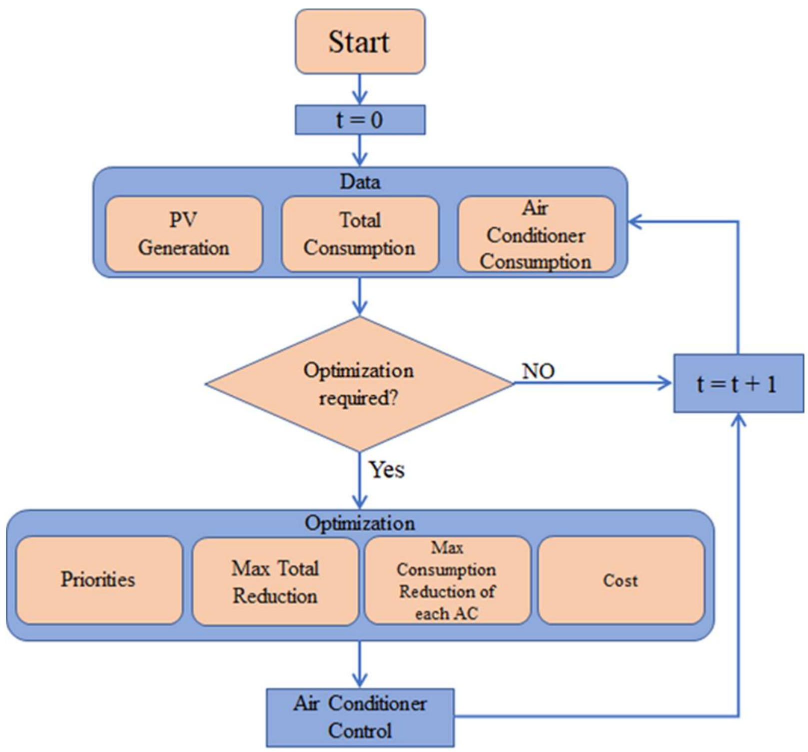


Figure 21. The flowchart of the proposed optimization model.

Equation (36) demonstrates the objective function of the optimization problem:

$$Minimize\ EB = \sum_{t=1}^{T}\sum_{d=1}^{D}((P_{red_{(d,t)}} * W_{(t,d)}) + P_{total} - PV) * Cost_{(t)} \qquad (36)$$

$$\forall\, t\ \in \{1, \dots, T\}$$

$$\forall\, d\ \in \{1, \dots, D\}$$

Where P_{red} is power consumption reduction of each air conditioner, and W is abbreviation of weight of the priority of each air conditioner that depends on the user and situation of the room. D and T represent the total number of devices that mean the air conditioners and number of time periods respectively. Moreover, P_{total} represents the total power consumption of the building, PV indicates the generation of Photovoltaic system in the building, and Cost is the electricity energy cost in each period. Moreover, the model constraints include: the required consumption reduction of the system; the consumption reduction for each device, which limited to maximum consumption reduction for each device.

4.3.2. Case Study

This subsection represents the case study used for verifying the proposed optimization model. As it was mentioned, the main purpose of this section is to optimize the consumption of the air conditioning system in an office building (The office building is a part of GECAD research center located in ISEP/IPP, Porto, Portugal). This building consists of 9 offices and a corridor as Figure 22 shows. Daily, the building has more than 16 researchers working inside. The control of the air conditioners was made by developing an infrared emitter to transmit the air conditioner signals to turn on/off or to regulate the desired temperature and operation mode. The infrared emitter is connected to a PLC that receives orders using a Modbus/TCP connection and then send the desired signals to each air conditioner.

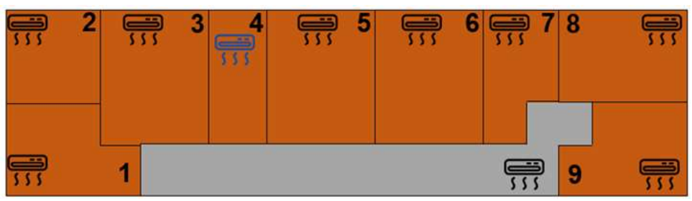


Figure 22. Plan of GECAD office building.

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

The time period used in this case study is one minute, within a total period of 24 hours. Two situations should consider for defining the required reduction value: periods that the generation of the PV is more than the power consumption of the building (that requires a reduction with a negative value), and periods of the day where the power consumption of the building is higher than PV generation (where the optimization must reduce the consumption). Figure 23 illustrates the results of the optimization.

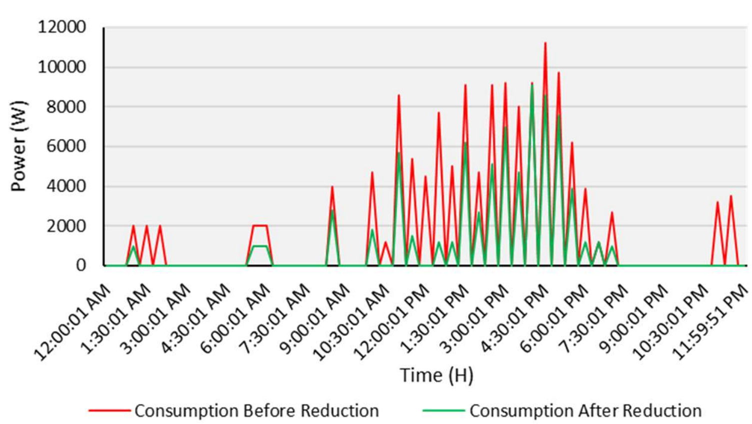


Figure 23. Comparison of the power consumption before and after the optimization.

As it is clear in Figure 23, most of the optimization periods are in the working hours of the office building where the total power consumption is more than the PV generation.

The results obtained show that optimization of the air conditioning consumption in the buildings can effectively reduce the final energy consumption and keeps the rights and comfort of the user. In this way, the use of renewable energy for internal use can be increased in the commercial, domestic, and office buildings eliminating environmental problems.

4.4. Real-time simulation of a DLC program

This section represents a real-time simulation of a CSP that consists of 220 consumers, and 68 distributed generation. The focus is given to small and medium prosumers (a consumer that can also produce energy), which cannot participate in the DR program individually since they do not have enough reduction capacity for the DR, and they established a contract with the CSP. The CSP model is executed in real-time digital simulator, and both prosumers are emulated by the real and laboratorial hardware resources.

4.4.1. Curtailment Service Provider

In this subsection, the theory of CSP and its operation in a real-time DR program will be proposed. The CSP demand response procurement model presented in this section is adapted and improved from (Gomes, 2014). Generally, if a particular customer has an adequate amount of energy to attain the minimum required reduction of a DR event, then it can establish a direct contract with the DR program managing entity (which usually is an ISO). On the other hand, players that are not able to provide the sufficient reduction by themselves can make a contract with the CSP to be aggregated and participate in DR events. In this model, it is considered that the players are equipped with the RERs and Energy Storage System (ESS), and they are capable to store their own generation in the ESS as well as inject energy to the main grid. When a contract is made between a prosumer and the CSP, the prosumer should specify three specific values. These values are ordered in below based on the incentives paid by the CSP to the prosumers:

- *Regular reduction* – is the amount of energy that the prosumer can reduce it in real-time; (cheapest reduction from CSP stand point);
- *Renewable use* – is the real-time amount of RER generation, that the prosumer should inject it to the grid, and it is not allowed to store it in ESS;
- *Direct Load Control (DLC)* – is related to the loads that CSP is able to directly tcontrol (most expensive reduction from CSP stand point).

During a DR event, the CSP has a specific time to achieve the amount of consumption reduction mentioned in the contracts. This specific time is called ramp period. If the proposed event is a real-time DR program, the prosumers should transmit their regular reduction values and the amount of renewable use to the CSP at the beginning of the event. Figure 24 illustrates the procedure done by CSP during the ramp period of a real-time DR program.

As Figure 24 shows, the procedure done by CSP during the ramp period of a real-time DR program consists of six steps. In the first step, the CSP informs the prosumers from the DR event. After that, in the second step, the prosumers transmit both values of regular and renewable energy. In the third step, the CSP evaluates the amount of the regular reduction. If the regular reduction cannot provide the minimum reduction for the event, the CSP evaluates the amount of renewable use. In the fourth level, the CSP transmits the final decisions of the evaluation to the prosumers. If both regular and renewable use are not adequate for DR reduction, in fifth level, the CSP estimates the DLC reduction, and evaluates the three mentioned resources (regular + Renewable + DLC). Finally, in the last step, the CSP decides concerning the players that can participate in the DR event or not, and the players that cannot provide the sufficient reduction, will be excluded from the DR event.

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

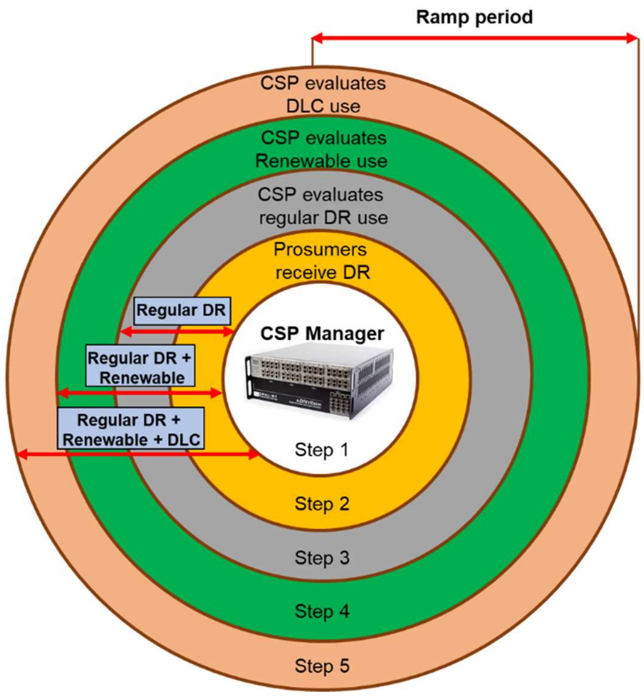


Figure 24. CSP procedure during the ramp period of a real-time DR event.

4.4.2. Real-Time Simulation Architecture

In this part, the real-time simulation model and the network (with their hardware structures) proposed for the CSP will be demonstrated and explained in detail.

The main core of the CSP model is OP5600 (www.opal-rt.com), which is a real-time digital simulator. In the presented model, the OP5600 is the main controller of the CSP, and is based on MATLABTM/Simulink. Moreover, the Hardware-In-the-Loop (HIL) capability of the OP5600, enables the model to integrate and control the real hardware resources from the Simulink environment.

The power distribution network presented for the CSP is a 33 buses distribution grid with 220 consumers and 68 distributed generation units (including RERs) (Abrishambaf, 2017). This distribution network was implemented in the MATLABTM/Simulink, in order to be compatible with the OP5600. Figure 25 illustrates the developed distribution network.

As it was mentioned, the main focus is to survey the behavior of the small and medium prosumers while they have been aggregated by the CSP in order to participate in the DR event. For this purpose, bus #10 and #24 of the distribution network are dedicated respectively to a medium and a small prosumer. As Figure 25 shows, the medium prosumer consists of a 30 kW resistive load emulating the consumption of the player, and a 7.5 kW PV unit as a renewable energy producer. Additionally, the small prosumer includes a 4 kVA load and a 1.2 kW wind turbine emulator.

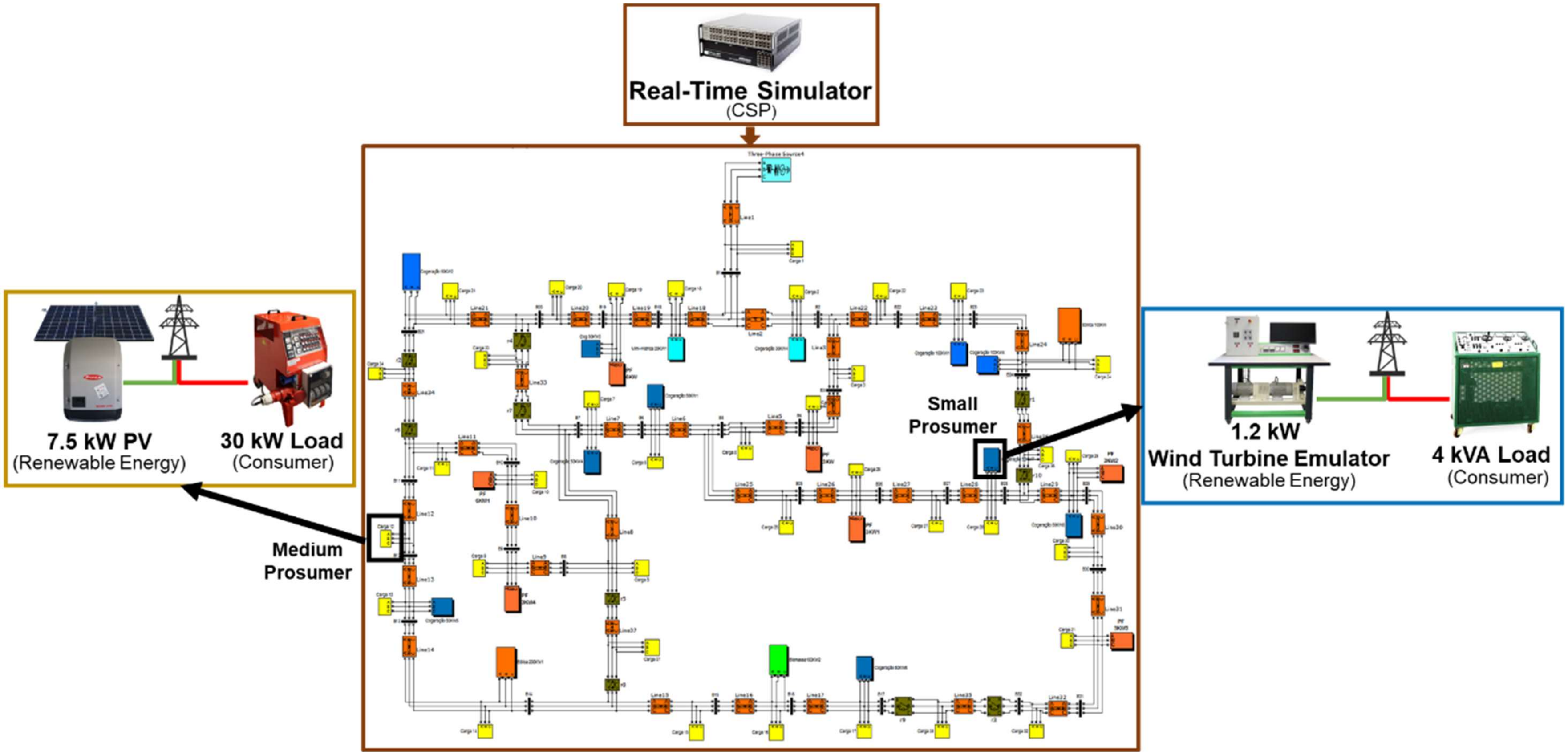


Figure 25. Real-Time simulation of CSP using real hardware resources.

The hardware equipment used for small and medium prosumers simulator are physical equipment connected, in real-time, with the real-time simulator (OP5600) by the HIL methodology. Figure 26 and Figure 27 illustrate the details on how these medium and small prosumers have been integrated in the OP5600. From the CSP stand point, these prosumers are capable to deliver the produced energy to the grid, and also, they can store it in the ESS.

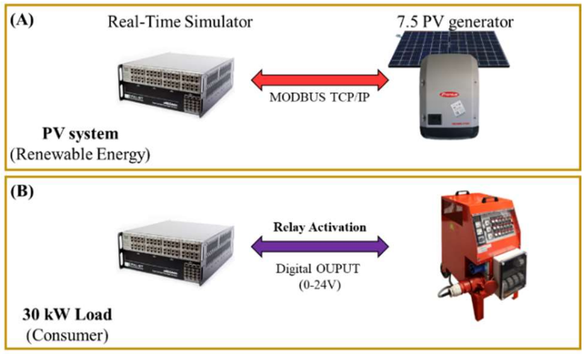


Figure 26. HIL Methodology for medium prosumer.

As it is clear in Figure 26-(A), for acquiring and monitoring the real-time generation data from the PV system to OP5600 and Simulink model, Modbus/TCP protocol has been used. Also, for the 30 kW load, (Figure 26-(B)), the OP5600 applies several Digital outputs in order to activate the related relays installed on the load (Abrishambaf, 2015).

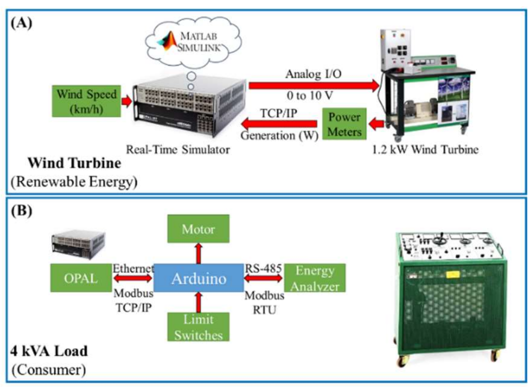


Figure 27. HIL Methodology for small prosumer (Abrishambaf, 2016).

As Figure 27-(A) shows, for controlling the wind turbine emulator of the small prosumer, the analog input terminal of the speed controller unit has been integrated to the analog output board of the OP5600. Then, the wind speed data have been converted from km/h to a value in the range of 0 to 10 V, provided to the analog output board of the OP5600. The computations of this conversion have been done in the Simulink environment. In the last stage, the related power meter of the wind turbine emulator has been connected to the OP5600 via Ethernet interface, with Modbus/TCP protocol. Moreover, for the consumption of the small prosumer, the 4 KVA load is used. The 4 kVA load consists of three independent parts: resistive, inductive, and capacitive. The resistive part is automatically varied through a control process that is illustrated in Figure 27 (B), using a 12 V DC motor to control the motion of the resistive gauge. Therefore, by controlling the direction of the rotation in this small motor (clockwise or counterclockwise) the resistive gauge can be moved upward or downward in order to increase or decrease the load consumption. Moreover, a power meter was used for measuring the real-time consumption of the 4 kVA load. An Arduino® (www.arduino.cc) equipped with an Ethernet shield and a Relay module has been employed for controlling the 4 kVA load (Abrishambaf, 2016).

4.4.3. Case Studies

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

The consumption and generation profiles regarding these two players during 17 periods of one minute each are demonstrated in Figure 28. The consumption profile of the factory (Figure 28 – (a)) has been adapted from (IEEE, 2017), and its generation profile is the real production curve of the PV system installed in GECAD research center, ISEP/IPP, Porto, Portugal. Moreover, the consumption pattern of the office building (Figure 28– (b)) is the real consumption profile of the GECAD research center, and the wind speed data for the wind generation profile were chosen from ISEP website (ISEP, 2017). Also, the established contract between the two presented prosumers and the CSP is shown in Table 6.

For the case studies, we considered that the CSP receives a real-time DR program from the DR managing entity, such as ISO, for 15 minutes with the minimum reduction capacity of 100 kW. Therefore, the CSP considers 120 kW as the minimum reduction in order to overcome the possible failures.

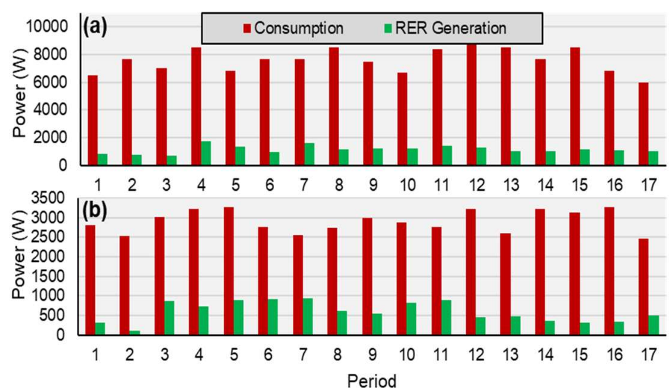


Figure 28.Consumption and generation profiles of: (a) factory - (b) office.

Table 6. CSP information during the DR events in thecase studies (All values are in kW).

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

Case Study 1

In this case study, it is assumed that the factory player has 3 kW capacity in the regular reduction (Reg. in Table 6), and it can provide around 1 kW renewable use (RER in Table 6) to the CSP, and finally, 1 kW capacity in the DLC reduction (DLC in Table 6). Moreover, the office player has 1.5 kW capacity in the regular reduction, around 0.5 kW renewable use, and 0.2 kW capacity in the DLC reduction. Additionally, the other players available in the CSP provide 124.5 kW in regular, 20.4 kW in renewable use, and 9 kW in the DLC. These values are transmitted from the players to the CSP during the ramp period (as Figure 24 showed), consequently, the

CSP can achieve the minimum required reduction by the regular reductions provided by the players, which is the cheapest one.

The behaviors of the factory and office building during the DR event are illustrated in the Figure 29. The results shown in Figure 29 are for 1020 seconds (17 periods, one minute per period), provided by the real-time simulator (OP5600) in MATLABTM/Simulink. As Figure 29 shows, the DR event starts from 60 to 960 seconds, which is period 2 to 16. In Figure 29– (A), the consumption profiles of the factory are emulated by the 30 kW load, where the red line is the consumption before the reduction, and the purple line indicates the consumption after the reduction. The difference between these two lines demonstrates the regular reduction (3 kW). Also, in Figure 29 – (B), the consumption profiles of the office building are emulated by the 4 kVA load, and the difference of the red line (consumption without DR event), and the purple line (consumption during DR event) indicates the amount of the regular reduction by the office building (1.5 kW).

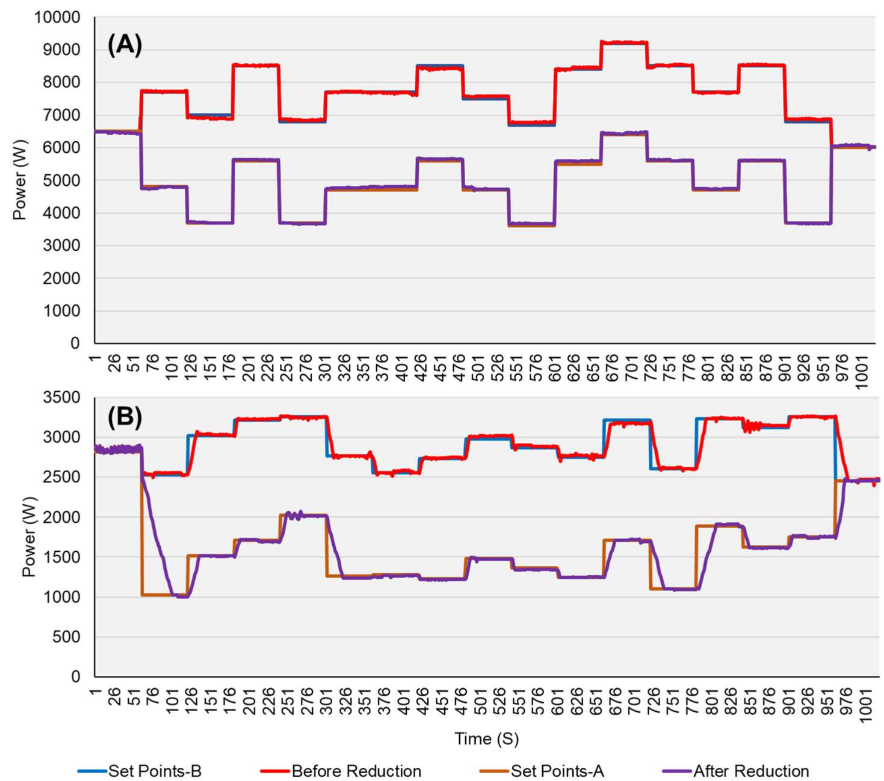


Figure 29. The reactions of the two CSP prosumers in the case study 1: (A) factory - (B) office building.

The blue and brown lines in Figure 29 are related to the real-time simulation and HIL methodology. In other words, these lines are the values that OP5600 transmits from the Simulink to 30 kW and 4 kVA load with one minute time interval, and the red and purple lines are the real-time consumption values transmitted by the devices to the Simulink environment with one second time interval.

Case Study 2

In the second case study, it is considered that all the conditions explained in the case study 1 will be equal, except the amount of reductions that the other players of the CSP will provide. As Table 6 shows, for the case study 2 it is assumed that the other players provide 88.3 kW in the regular reduction, 40.9 kW in the renewable use, and 13 kW in the DLC. In this moment, the CSP computes the provided reductions in the ramp period, and since the sum of regular reductions are not sufficient for participating in the DR event, it decides to use the second reduction resource, which is renewable use. Therefore, by using both reduction resources (Reg. + RER in Table 1), the CSP achieves the minimum reduction with 135.2 kW, and there is no need to use the DLC resource. In the next step, the CSP transmits its decision to the players, which is reducing their consumption until the regular reduction, and do not storing their produced renewable energy in the ESS, however, inject it to the main grid. While the players inject their own produced energy to the main grid, the CSP will see a reduction. The reactions of the factory and the office building during the DR event in this case study are shown on Figure 30.

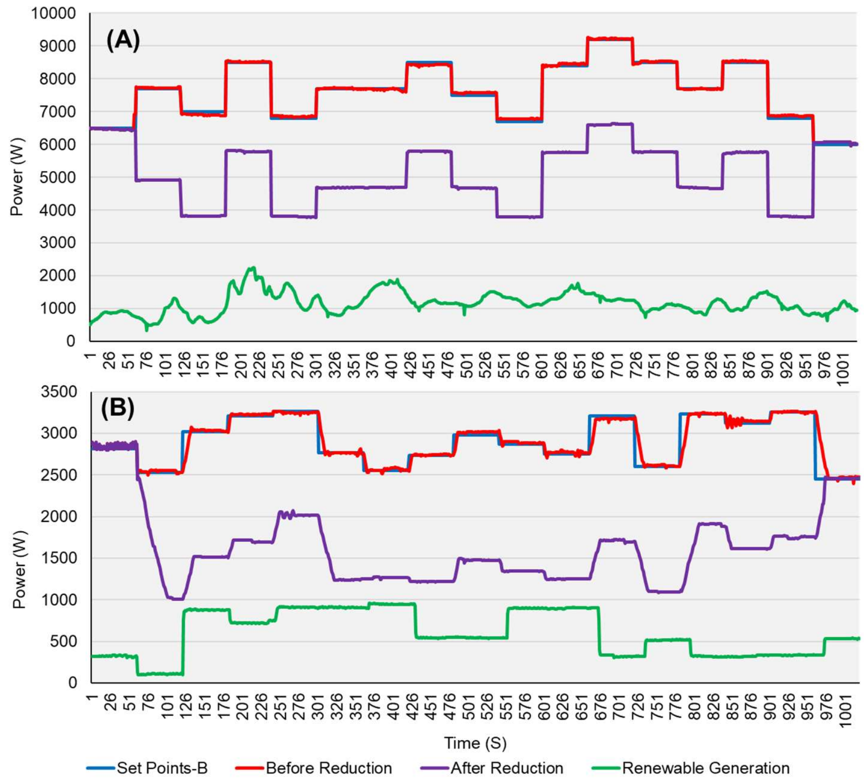


Figure 30. The behavior of the two CSP prosumers in the case study 2: (A) factory - (B) office building.

Similar to the case study 1, in Figure 30 the DR event starts from the period 2 to 16, which is 60 to 960 seconds. The amount of reduction in both prosumers is the same as the case study 1, which is around 3 kW and 1.5 kW in the factory and office respectively. However, in this case study, all CSP players including these two prosumers are bounded to inject their own produced energy to the grid.

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

Case Study 3

In the case study 3, we considered that the CSP encountered with significant reduction in the RER generation by the players. Therefore, as Table 6 showed, the regular reduction and renewable use will not be adequate for the CSP to achieve 120 kW reduction. Consequently, the CSP should use the DLC contracts, which enable the CSP to directly turn off the loads that are involved in the contract. Figure 31 illustrates the final results of the case study 3. As it is clear in

Figure 31, the CSP utilizes its DLC reduction, which is the last and most expensive resource, in order to reach the minimum reduction capacity for participating in the DR event.

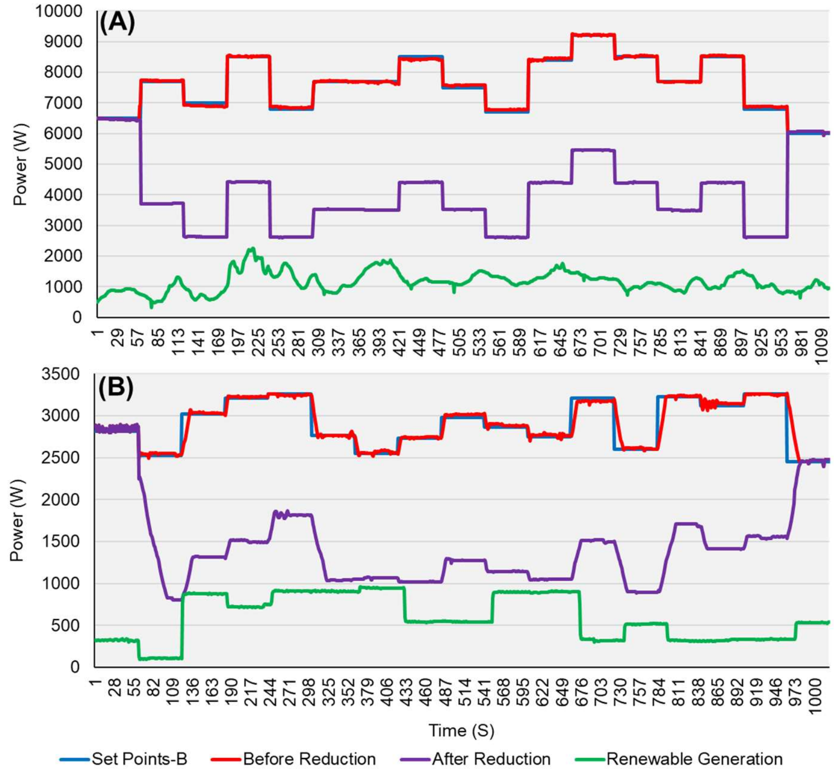


Figure 31. The reactions of the two CSP prosumers in the case study 3: (a) factory - (b) office building.

During these three case studies, the energy that the CSP sold to the two prosumers is illustrated in Figure 32, and also the voltage variations during the real-time simulation of the three case studies are shown on Figure 33.

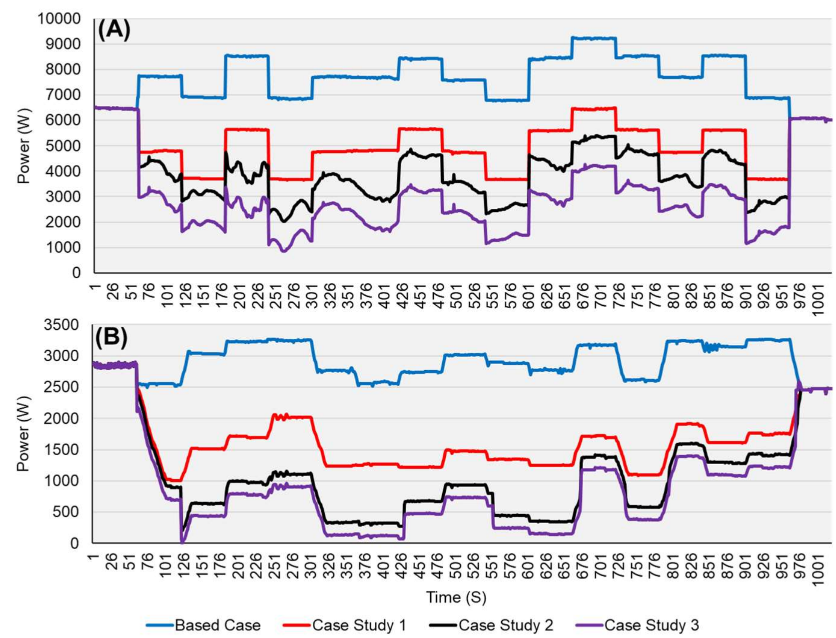


Figure 32. The energy consumption of the two prosumers during the three case studies from the CSP stand point: (A) factory – (B) office building.

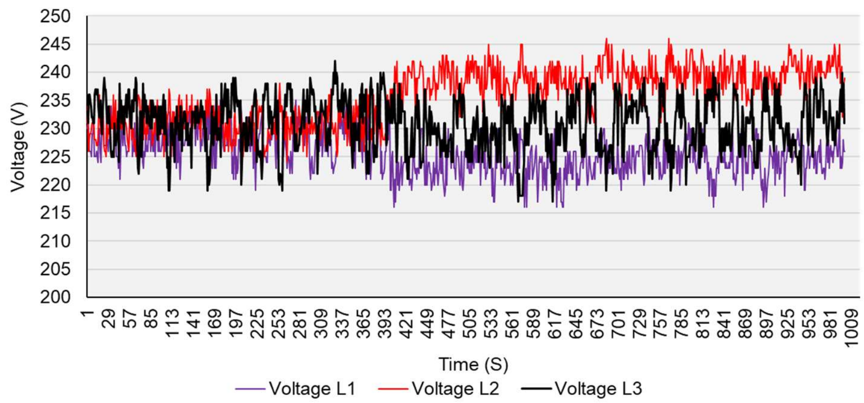


Figure 33. Voltage variations during the real-time simulation of three case studies.

As you can see in Figure 32, the blue line indicates the consumption of the prosumers while there was no DR event. When the DR event starts, in the case study 1, the transmitted energy from CSP to the prosumers is reduced based on the regular reduction. Also, in the case studies 2 and 3, by the involvement of the produced renewable energy by the prosumers, the CSP sold less energy to them. Therefore, it sees a reduction in the consumption and consequently, the CSP was able to participate in the DR event. The most important novelty showed by the case studies, is when the load schedule is changed, the actual and real consumption devices take a while to reach the desired consumption level. This is the fact that was not considered in the electrical network simulation models, and has been addressed by the real-time simulation test bed using HIL methodology.

A realistic model of a Curtailment Service Provider consisted of 220 consumers, and 68 distributed generations was simulated in real-time, which supports decision making for DR testing and validating. The presented model were executed by a real-time digital simulator (OP5600) using several real and laboratory hardware resources by Hardware-In-the-Loop methodology. In the case studies, the reactions of a small and medium prosumers have been investigated while the CSP makes various decisions for participating in a real-time DR event. The presented results are the real measured data from the loads and generators, which validate the concepts of the CSP by enabling the small and medium prosumer to participate in a DR event.

4.5. DLC tariffs definition using clustering algorithms

The distributed energy resources, when managed by an aggregator, are represented as a unique resource with characteristics that reflect the aggregated resources (Battistelli, 2014), (Roos, 2014). An aggregator managing a given number of resources or region, implies a simplification of processes to the operators, since the number of resources to be considered is reduced and energy negotiation and trade can be made (Vergados, 2016). Also, if balance responsible parties (BRPs) exist, the activities developed by the aggregator can also provide useful services to the BRPs (Rahnama, 2014). In fact, several countries of the European Union (EU) have introduced and accepted the concept of aggregators operating in their energy systems providing service mainly to consumers (Smart Grid Task Force, 2015).

The usefulness of an aggregator is specially seen as a flexibility provider, through the gathering of active consumers that can participate in the aggregator's demand response programs (Smart Grid Task Force, 2015). In this way, aggregators can manage several demand-side resources and obtain flexibility from these, that can be negotiated in the energy markets auction, through bilateral contracts. Regarding production-side resources, the aggregator assumes the role of a virtual power plant, as referred before (Rahmani-Dabbagh, 2016), (Faria, 2016). These resources often belong to consumers (prosumers) and thus have small capacity.

In the present section, it is proposed a methodology to support the aggregator in its activities, with focus on the participation of aggregated distributed energy resources in energy markets, and on how the aggregator can benefit from this participation while promoting their inclusion.

4.5.1. Proposed Model

In this section, it is explained the proposed methodology and all its components, regarding the scheduling, aggregation, and remuneration activities performed by the aggregator. The proposed methodology is shown in Figure 34. At the end of the methodology, the output results are the energy and cost of each group of resources made, according to the specifications of the aggregator. With this information, the aggregator can negotiate in the market by bidding the available energy amount at a given price. However, the selling price must be equal or higher than the cost of each group to obtain profits or at least recover what was spent on distributed resources. The activities of the aggregator are divided in two types: upper-level and bottom-level activities (Spinola, 2017).

The scheduling of resources considers external suppliers and two types of distributed energy resources, namely, distributed generators and active consumers. For the production-side resources, the methodology considers a linear cost function for both distributed generators and external suppliers. Regarding active consumers, it is considered that these can be enrolled in three different types of DR, namely, load reduction, curtailment, and load shifting. In this way, only the reduction and curtailment energy amounts obtained are considered by the aggregator to be scheduled and therefore negotiated in the energy market. The load shifting model is based on (Faria, 2015). In the case of the demand-side resources, the cost considered is also linear for reduction and curtailment, while load shifting is free.

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

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

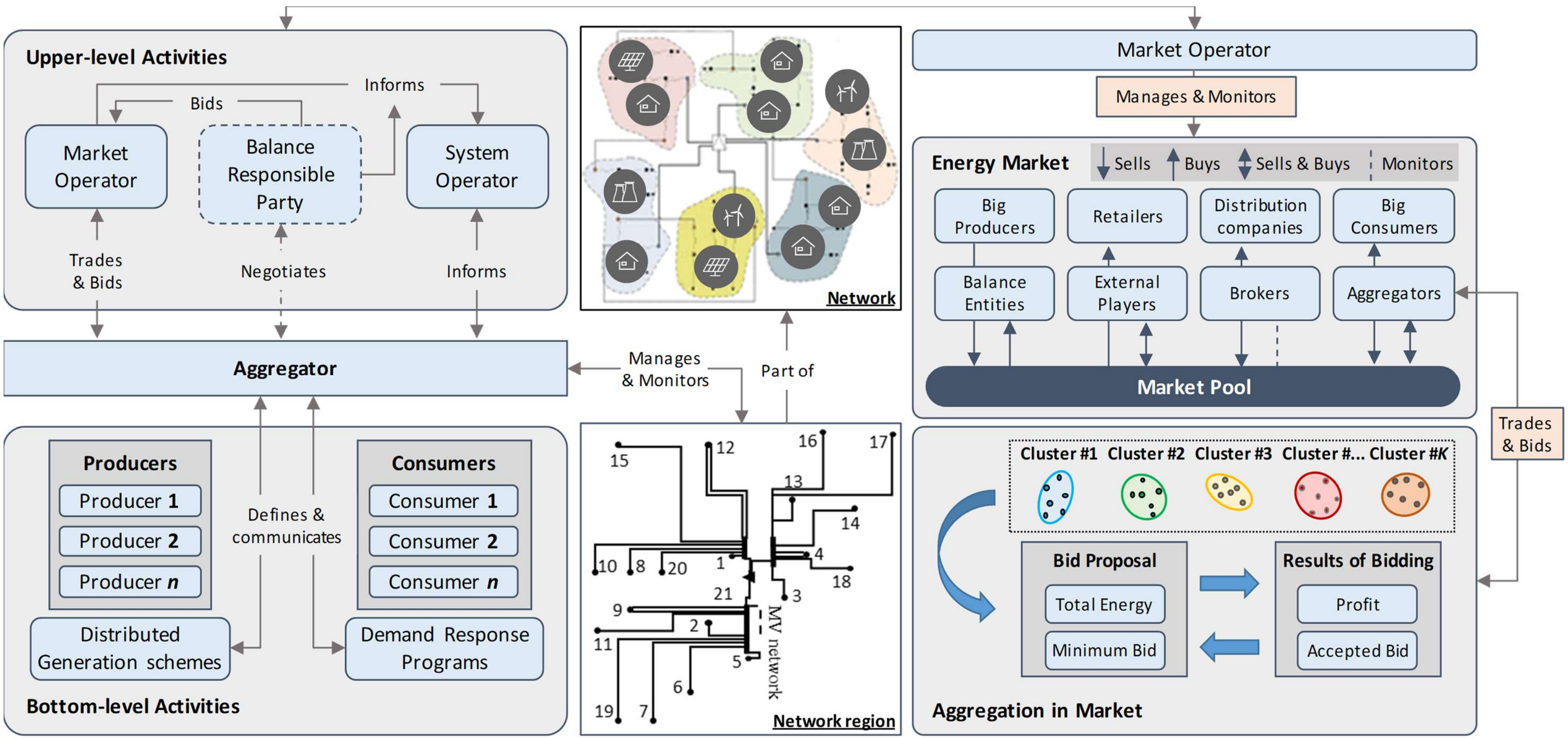


Figure 34. Scheme of the proposed methodology (Spinola, 2017).

The scheduling optimization reflects a mixed-integer linear problem (MILP), since it involves continuous and discrete variables. In this methodology, it is not considered that the aggregator is responsible for the technical verification of the network, i.e. this is assumed to be the operator's role. Equation (37) presents the objective function implemented for the aggregator's cost minimization. The resources considered for the objective function are: the energy bought from the external suppliers ($P_{(s,t)}^{Sup}$), the energy obtained from distributed generators ($P_{(p,t)}^{DG}$), and the demand flexibility (reduction - $P_{(c,t)}^{Red}$, curtailment - $P_{(c,t)}^{Cut}$, shifting - $P_{(c,t,d)}^{Shift}$.

$$
\begin{aligned}
& MinOC = \sum_{s=1}^{S} P_{(s,t)}^{Sup} \cdot C_{(s,t)}^{Sup} + \sum_{p=1}^{P} P_{(p,t)}^{DG} \cdot C_{(p,t)}^{DG} \\
& + \sum_{c=1}^{Cs} \begin{bmatrix} P_{(c,t)}^{Red} \cdot C_{(c,t)}^{Red} + P_{(c,t)}^{Cut} \cdot C_{(c,t)}^{Cut} \\ + \sum_{d=1}^{T} P_{(c,t,d)}^{Shift} \cdot C_{(c,t,d)}^{Shift} \end{bmatrix} \\
& \forall t \in \{1,...,T\}
\end{aligned}
\tag{37}
$$

The constraints of the proposed optimization problem consist of:

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

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

4.5.2. Case Study

This section presents the description of the case study used to validate the proposed methodology. The considered network is composed by 21 buses, representing a university campus, as described in (Silva, 2015b). The network has 20 consumers classified by their average consumption, and 26 production generators classified by type of source.

The energy cost of both distributed generation and external suppliers, is considered constant in all periods. All producers, except the external supplier, can participate in aggregation for energy markets. Regarding the consumers, these are divided into five types: Domestic (DM), Small Commerce (SC), Medium Commerce (MC), Large Commerce (LC), Industrial (ID). This type of assignment is performed based on their average daily consumption. Figure 35 presents the consumer's details considering their linear cost, by type of resource. The maximum reductions are 6% of the initial load for reduction, and 10% for curtailment and shifting.

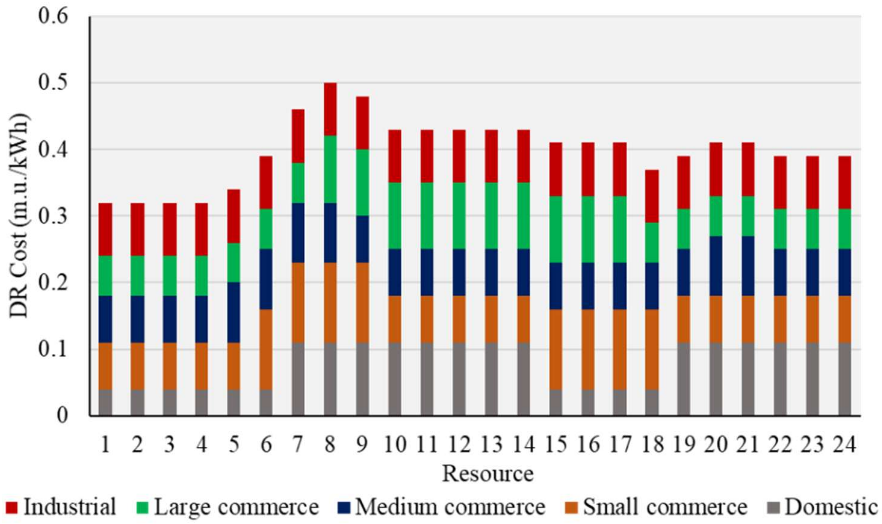


Figure 35. Linear cost for load reduction and curtailment.

To simulate the participation in the energy market by the aggregator, a market place must be considered. A market pool ensures that several entities can propose energy bids, including aggregators. This kind of market ensures competition between participants, and therefore improves the outcome from the consumer's perspective. Therefore, a summary of the results obtained for the scheduling, aggregation, and remuneration processes is described in below, and more detailed information is available on (Spinola, 2017).

The results concerning the market negotiation are focused on describing how the aggregator can use the results obtained to present a bid. First, the scheduling results for generation are presented in Figure 36. It is considered an energy shortage from the external suppliers in the first 4 periods, being these able to support only 10% of their capacity, around 50 kWh.

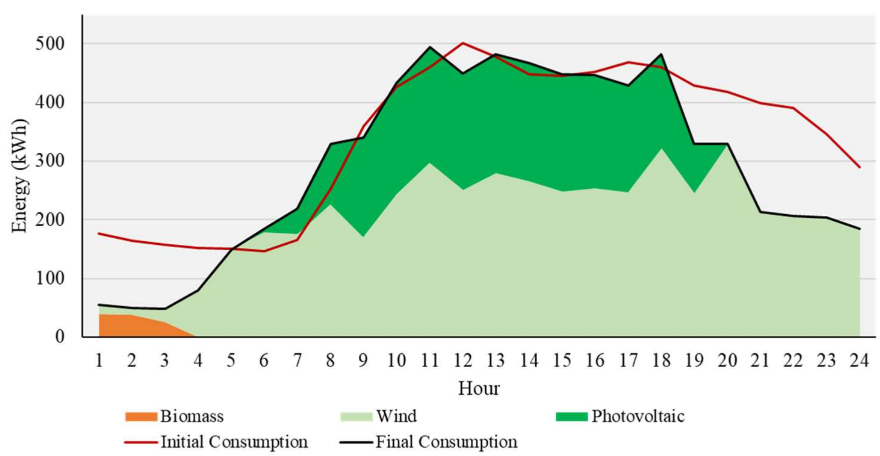


Figure 36. Generation scheduling with initial and final consumption.

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

The demand side management adjust the remaining energy differences between production and consumption when distributed generation is not sufficient. Moreover, during the periods of energy shortage from the distributed generators, load shifting is used to move consumption from those periods to more favorable ones, thus avoiding the buying of energy from the grid, which is more expensive. Moving on to the energy market's results, in Table 7, the results for the aggregation and remuneration of the resources are shown, regarding period number 12. The total energy and number of resources are outputs of the aggregation process, while the minimum bid tariff is from the remuneration process.

Table 7. Remuneration and aggregation results.

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

The results presented in Table 8 show that the aggregator could profit from the distributed resources energy sell in the energy market of around 489,62 kWh, a total of 24,10 monetary units. It is possible to conclude if a higher energy amount were sold, the aggregator would be able to rise considerably its profits from the negotiation. It is also relevant to notice that this evaluation is for a single period, for example, a given hour of the day as the case study presented suggests. Again, the profitability of the aggregator is also dependent of the offers and capability of negotiation in the energy market by the aggregator and existing competition. Using the proposed model, the operation of the aggregator becomes profit, from its market participation, even with a small-size region (20 consumers and 25 distributed generators). By controlling a larger region or number of resources, the aggregator gains more energy capacity for clustering, and as mentioned before, market negotiation.

Table 8. Financial balance for the aggregator.

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

As mentioned before, the aggregation was made considering only the resources that participated in the aggregator's scheduling in each of the periods. Each period's aggregation therefore, considers the characteristics and scheduling of the resources in that time. Further on, a comparison is made regarding the influence of load shifting in the costs. The comparison is made between the total costs of the aggregator in the current scenario, and in one when instead of load shifting availability, there is enough energy available from the external suppliers. In Table 9, the results of the scenarios comparison show that the influence of load shifting availability affects considerably the total costs of the aggregator, since these are mostly balanced by the contributions that distributed generators and external suppliers provide for the scheduling.

Table 9. WS and WOS comparison.

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

In the scenario without load shifting the generation from external suppliers is raised in 50 kWh in the first four periods, obtaining a total of 100 kWh. This is performed so that energy balance can be obtained without load shifting.

Results showed that the aggregator can perform the scheduling regarding the distributed energy resources contribution, implementing different types of operation programs, mainly, in the through demand-side resources. In this way, the aggregator can obtain the network balance and the participation of each resource. Aggregation and remuneration results demonstrated that the methods used, affect the outcome of profit for the aggregator, and thus further study and development is needed. However, the aggregator can obtain the operation balance and a fair usage of distributed energy resources for its activities by using this methodology.

5. Conclusion

The execution of Direct Load Control (DLC) equires consumers' loads equipped with remote control capabilities. This problem can be solved by using solutions available on the market, or by developing new and dedicated hardware for remote load control. The capability of load monitoring can also be used/implemented to improve the control of the load during DLC event, especially for critical loads. This report presents some of the possible solutions to integrate pre-existing loads in DLC contracts. The usage of pre-existing loads rather than new loads increases the number of consumers able to participate in DLC events and make it possible to execute DLC events in our days.

This report demonstrates some use cases developed within the scope of DREAM-GO project. The use cases show the capabilities and advantages of using DLC in buildings. For this demonstration is used computational multi-agent systems, real scenarios and real-time simulations. The optimization model of section 4.3 was evolved and implemented in one GECAD/ISEP building, according to section 4.3.2, making it possible the continuous study and improvement of the optimization model using an uncontrollable environment with more than 16 researchers working there daily. The air conditioners in use are pre-existing equipment that did not have remote control (besides the normal infrared control), for the implementation of the optimization model it was developed hardware that mimics the infrared control. This hardware is controlled by a programmable logic controller that receives the DLC events and acts on the air conditioners.

The use of pre-existing loads in DLC events is possible and desired. The retrofitting of building’s loads is possible and can bring large economic advantages. The upgrade of buildings will enable them to participate in demand response programs and reduce their electrical bill without the need of new constructions or equipment replacements. This will accelerate the future and opens the door for smart grids and microgrids to be implemented today in buildings of yesterday.

References

(Abrishambaf, 2015) O. Abrishambaf, L. Gomes, P. Faria and Z. Vale, "Simulation and control of consumption and generation of hardware resources in microgrid real-time digital simulator", 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM), 2015.

(Abrishambaf, 2016) O. Abrishambaf, L. Gomes, P. Faria, J. Afonso and Z. Vale, "Real-time simulation of renewable energy transactions in microgrid context using real hardware resources", *2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, 2016.

(Abrishambaf, 2017) O. Abrishambaf, P. Faria, L. Gomes, J. Spínola, Z. Vale and J. Corchado, "Implementation of a Real-Time Microgrid Simulation Platform Based on Centralized and Distributed Management", *Energies*, vol. 10, no. 6, p. 806, 2017.

(Alexander, 2008) M. Alexander, E. K. Agnew, and M. L. Goldberg, "New Approaches to Residential Direct Load Control in California", 2008

(Bakr, 2015) S. Bakr and S. Cranefield, "Using the Shapley Value for Fair Consumer Compensation in Energy Demand Response Programs: Comparing Algorithms", *2015 IEEE International Conference on Data Science and Data Intensive Systems*, 2015.

(Battegay, 2015) A. Battegay, N. Hadj-Said, G. Roupioz, F. Lhote, E. Chambris, D. Boeda, and L. Charge, "Impacts of direct load control on reinforcement costs in distribution networks," Electr. Power Syst. Res., vol. 120, pp. 70–79, 2015.

(Battistelli, 2014) C. Battistelli and A. J. Conejo, "Optimal management of the automatic generation control service in smart user grids including electric vehicles and distributed resources," Electr. Power Syst. Res., vol. 111, pp. 22–31, 2014.

(Canizes, 2015) B. Canizes, M. Silva, P. Faria, S. Ramos, and Z. Vale, "Resource scheduling in residential microgrids considering energy selling to external players," Power Systems Conference (PSC), 2015 Clemson University. pp. 1–7, 201

(Cappers, 2013) P. Cappers, J. MacDonald, C. Goldman and O. Ma, "An assessment of market and policy barriers for demand response providing ancillary services in U.S. electricity markets", Energy Policy, vol. 62, pp. 1031-1039, 2013

(Ceseña, 2015) E. Martínez Ceseña, N. Good and P. Mancarella, "Electrical network capacity support from demand side response: Techno-economic assessment of potential business cases for small commercial and residential end-users", *Energy Policy*, vol. 82, pp. 222-232, 2015.

(Conejo, 2010) A. J. Conejo, M. Carrion, J. M. Morales, \Decision making under uncertainty in electricity markets", Inter. Series in Oper. Res. and Manage. Science, Springer, 2010.

(DALI, 2017) Digital Addressable Lighting Interface [Online], www.dali-ag.org/discover-dali/dali-standard.html, visited: 30/06/2017

(DASH7, 2017) DASH7 Alliance [Online], www.dash7-alliance.org, visited: 30/06/2017

(Dave, 2013) S. Dave, M. Sooriyabandara and M. Yearworth, "System behaviour modelling for demand response provision in a smart grid", Energy Policy, vol. 61, pp. 172-181, 2013.

(Smart Grid Task Force, 2015) EG3 Report - Smart Grid Task Force, "Regulatory Recommendations for the Deployment of Flexibility," 2015.

(Ericson, 2009) T. Ericson, "Direct load control of residential water heaters," Energy Policy, vol. 37, no. 9, pp. 3502–3512, 2009.

(Facchinetti, 2011) T. Facchinetti and M. L. Della Vedova, "Real-Time Modeling for Direct Load Control in Cyber-Physical Power Systems," IEEE Transactions on Industrial Informatics, vol. 7, no. 4. pp. 689–698, 2011.

(Fang, 2012) X. Fang, S. Misra, G. Xue and D. Yang, "Smart Grid - The New and Improved Power Grid: A Survey", *IEEE Communications Surveys & Tutorials*, vol. 14, no. 4, pp. 944-980, 2012.

(Faria, 2011) P. Faria and Z. Vale, "Demand response in electrical energy supply: An optimal real time pricing approach", Energy, vol. 36, no. 8, pp. 5374-5384, 2011.

(Faria, 2015) 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.

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

(Fernandes, 2014) 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, Oct. 2014.

(FIPA, 2016) Foundation for Intelligent Physical Agents (FIPA), FIPA Agent Management Specification, 2004. [Online]. Available (30/06/2017): www.fipa.org/specs/fipa00023/SC00023K.html

(Fotouhi, 2017) M. Fotouhi Ghazvini, J. Soares, O. Abrishambaf, R. Castro and Z. Vale, "Demand response implementation in smart households", Energy and Buildings, vol. 143, pp. 129-148, 2017.

(GAMS, 1999) GAMS Release 2.50. A users guide. GAMS Development Corporation, 1999 [Online], http://www.gams.com, visited: 30/06/2017

(Gomes, 2014) L. Gomes, P. Faria, H. Morais, Z. Vale and C. Ramos, "Distributed, Agent-Based Intelligent System for Demand Response Program Simulation in Smart Grids," *IEEE Intelligent Systems*, vol. 29, no. 1, pp. 56-65, 2014.

(Gomide, 2007) F. Gomide and W. Pedrycz, "Notions and Concepts of Fuzzy Sets," Fuzzy Systems Engineering: Toward Human-Centric Computing, 2007.

(Guo, 2017) P. Guo, V. Li and J. Lam, "Smart demand response in China: Challenges and drivers", *Energy Policy*, vol. 107, pp. 1-10, 2017.

(IEEE, 2017)	IEEE PES Intelligent Data Mining and Analysis [Online]. Available (30/06/2017): http://sites.ieee.org/psace-idma/data-set.
(ISEP, 2017)	Meteo ISEP Website [Online], http://meteo.isep.ipp.pt, visited: 30/06/2017
(JADE, 2017)	Java agent development framework (jade) at http://jade.tilab.com/
(Jozi, 2016)	A. Jozi, T. Pinto, I. Praa, F. Silva, B. Teixeira and Z. Vale, "Energy consumption forecasting based on Hybrid Neural Fuzzy Inference System," 2016 IEEE Symposium Series on Computational Intelligence (SSCI), Athens, 2016.
(Kim, 1999)	J. Kim, N. Kasabov, "HyFIS: adaptive neuro-fuzzy inference systems and their application to nonlinear dynamical systems," Neural Networks, Volume 12, Issue 9, November 1999, Pages 1301-1319, ISSN 0893-6080.
(LZQJ-XC, 2017)	LZQJ-XC product information [Online], http://www.emh-metering.de/en/products/lzqj-xc1, visited: 30/06/2017
(Modbus, 2017)	The Modbus Organization [Online], http://modbus.org, visited: 30/06/2017
(Oliveira, 2012)	P. Oliveira, T. Pinto, H. Morais, and Z. Vale, " MASGriP - A Multi-Agent Smart Grid Simulation Plataform", in IEEE Power and Energy Society General Meeting, San Diego, USA, 2012.
(Pandzic, 2015)	H. Pandzic, Y. Dvorkin, T. Qiu, Y. Wang, and D. S. Kirschen, "Toward cost-efficient and reliable unit commitment under uncertainty", IEEE Trans. Power Syst., vol. 31, no. 2, pp. 1-13, June 2015.
(Pedrasa, 2009)	M. Pedrasa, T. Spooner, and I. MacGill, "Improved energy services provision through the intelligent control of distributed energy resources," in Proc. 2009, IEEE Bucharest power Tech conf.
(PEPCO, n.d.a)	PEPCO, "Energy Wise Rewards Maryland." .
(PEPCO, n.d.b)	PEPCO, "Energy Wise Rewards Thermostat: Homeowner's Manual." .
(Pipattanasomporn, 2012a)	M. Pipattanasomporn, M. Kuzlu and S. Rahman, Demand Response Implementation in a Home Area Network: A Conceptual Hardware Architecture", Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES.
(Rahmani-Dabbagh, 2016)	S. Rahmani-Dabbagh and M. K. Sheikh-El-Eslami, "A profit sharing scheme for distributed energy resources integrated into a virtual power plant," Appl. Energy, vol. 184, pp. 313–328, 2016.
(Rahnama, 2014)	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.
(Ramos, 2011)	S. Ramos, H. Morais, Z. Vale, P. Faria and J. Soares, "Demand response programs definition supported by clustering and classification techniques", *2011 16th International Conference on Intelligent System Applications to Power Systems*, 2011.
(Rocky Mountain Institute, 2006)	Rocky Mountain Institute, "Demand Response: An Introduction - Overview of programs, technologies, and lessons learned." p. 46, 2006.

(Roos, 2014) A. Roos, S. Ø. Ottesen, and T. F. Bolkesjø, “Modeling Consumer Flexibility of an Aggregator Participating in the Wholesale Power Market and the Regulation Capacity Market,” Energy Procedia, vol. 58, pp. 79–86, 2014.

(Rudd, 2014) K. Rudd, G. Di Muro and S. Ferrari, "A Constrained Backpropagation Approach for the Adaptive Solution of Partial Di_erential Equations," IEEE Trans. on Neural Networks and Learning Systems, vol. 25, no. 3, pp. 571,584, Mar. 2014.

(Ruiz, 2009) N. Ruiz, I. Cobelo, and J. Oyarzabal, “A Direct Load Control Model for Virtual Power Plant Management,” IEEE Transactions on Power Systems, vol. 24, no. 2. pp. 959–966, 2009.

(Santos, 2015) G. Santos, T. Pinto, H. Morais, T. M. Sousa, I. F. Pereira, R. Fernandes, I. Praca, and Z. Vale, “ Multi-Agent Simulation of Competitive Electricity Markets: Autonomous systems cooperation for European Market modeling”, Energy Conversion and Management, vol. 99, pp. 387-399, July 2015.

(Santos, 2016a) Santos, G.; Pinto, T.; Praça, I.; Vale, Z. An Interoperable Approach for Energy Systems Simulation: Electricity Market Participation Ontologies, Energies 9(11), 878 (2016)

(Santos, 2016b) G. Santos, T. Pinto, I. Praca, and Z. Vale, “MASCEM: Optimizing the performance of a multi-agent system”, Energy, vol. 111, pp. 513-524, Sep. 2016.

(Shokri Gazafroudi, 2017a) A. Shokri Gazafroudi, F. Prieto-Castrillo, and J. M. Corchado, "Residential Energy Management Using a Novel Interval Optimization Method," Accepted: 4th International Conference on Control, Decision and Inf. Tech., April 2017.

(Shokri Gazafroudi, 2017b) A. Shokri Gazafroudi, T. Pinto, F. Prieto-Castrillo, J. Prieto, J. M. Corchado, A. Jozi, Z. Vale, G. K. Venayagamoorthy, "Organization-based Multi-Agent Structure of the Smart Home Electricity System," in Proc., 4th IEEE Cong. on Evolut. Comp., June 2017.

(Shokri Gazafroudi, 2017c) A. Shokri Gazafroudi, F. Prieto-Castrillo, T. Pinto, A. Jozi, Z. Vale, "Economic Evaluation of Predictive Dispatch Model in MAS-based Smart Home," in Proc., 4th IEEE Cong. on Evolut. Comp., June 2017.

(Shokri Gazafroudi, 2017d) A. Shokri Gazafroudi, O. Abrishambaf, A. Jozi, T. Pinto, F. Preito-Castrillo, J. M. Corchado, and Z. Vale, "Energy Flexibility Assessment of a Multi Agent-based Smart Home Electricity System," in 17th edition of the IEEE International Conference on Ubiquitous Wireless Broadband ICUWB-2017, Salamanca, Spain, 12-15 Sep. 2017.

(Silva, 2015a) 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,” PowerTech, 2015 IEEE Eindhoven. pp. 1–6, 2015

(Silva, 2015b) M. Silva, F. Fernandes, H. Morais, S. Ramos, and Z. Vale, “Hour-ahead energy resource management in university campus microgrid,” PowerTech, 2015 IEEE Eindhoven. pp. 1–6, 2015.

(Soroudi, 2013) A. Soroudi, “Robust optimization based self scheduling of hydro-thermal Genco in smart grids", Energy, vol. 61, pp. 262-271, Nov. 2013.

(Spinola, 2017) J. Spinola, P. Faria and Z. Vale, "Model for the integration of distributed energy resources in energy markets by an aggregator", 2017 IEEE Manchester PowerTech, 2017.

(Teixeira, 2017) Brígida Teixeira, Francisco Silva, Tiago Pinto, Gabriel Santos, Isabel Praça, Zita Vale, TOOCC: Enabling Heterogeneous Systems Interoperability in the Study of Energy Systems, PESGM 2017 – IEEE Power and Energy Society General Meeting, Chicago, USA, 16-20 July, 2017

(Vergados, 2016) D. J. Vergados, I. Mamounakis, P. Makris, and E. Varvarigos, “Prosumer clustering into virtual microgrids for cost reduction in renewable energy trading markets,” Sustain. Energy, Grids Networks, vol. 7, pp. 90–103, 2016.

(Wang, 1991) L. X. Wang and J. M. Mendel, "Generating fuzzy rules by learning from examples," Intelligent Control, 1991., Proceedings of the 1991 IEEE International Symposium on, Arlington, VA, 1991, pp. 263-268.

(Zigbee, 2017) Zigbee Alliance [Online], www.zigbee.org, visited: 30/06/2017

(Z-Wave, 2017) Z-Wave [Online], https://products.z-wavealliance.org, visited: 30/06/2017