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Application systems from Portugal and Brazil to Demand Response programs

Filipe Fernandes[a*], Luiz Leite Rosa[b], Hugo Morais[a],
Nelson Kagan[b], Zita Vale[a]

[a]*GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering – Polytechnic of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal*
[b]*NAPREI/ENERQ – Smart Grid and Power Quality Laboratory, Polytechnic School - University of São Paulo, Av. Prof. Luciano Gualberto, 380, 05508-010 São Paulo, Brazil*

Abstract

In a near future, the house management systems should be significantly increased making more complex system. The total consumption, distributed generation, electric vehicles and the participation in demand response programs should be managed in an effective way by house management systems with most important objectives: consumption efficiency, the energy bill minimization, and the required comfort levels according with operation context. The operation of the house management systems should provide support to the grid operator through the participation in demand response programs.
The paper presents two application systems in testbed laboratory that allow the simulation of the end consumer in research activities of Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development in Portugal and Smart Grid and Power Quality Laboratory in Brazil, namely, the SCADA House Intelligent Management and Load Emulator respectively. The application systems are able to participate in demand response programs to reduce the electricity consumption based in interaction with an external entity.

Keywords: Demand response, domestic consumer, energy resources, house management system, load emulator.

[*] Corresponding author.
E-mail address: fijgf@isep.ipp.pt.

1. Introduction

Smart Homes (SH) can be defined as a house which comprises a network communication between all devices of the house allowing the control, monitoring and remote access of all application and services of the management system. The advanced functions should be included in management system, such as the management of electric vehicles, the interface with external operators, security functions, health care prevention, among others [1], [2], [3]. Otherwise, a home to be considered smart should include three main elements: the internal communication network that can be implemented in different ways: wire/wireless, dedicated/shared and/or low voltage/high voltage (Power Line Carrier), home automation composed by actuators and sensors devices that allow the controlling and monitoring of the house, and intelligent control systems [4]. The intelligent control systems are all the systems able to read sensors information, to process this information in an intelligent way, and to send control actions to the actuators.

Figure 1 presents a model of a SH developed to manage the energy usage of a domestic consumer considering the micro-generation, the storage systems, the connection with the grid and the control of smart appliances.

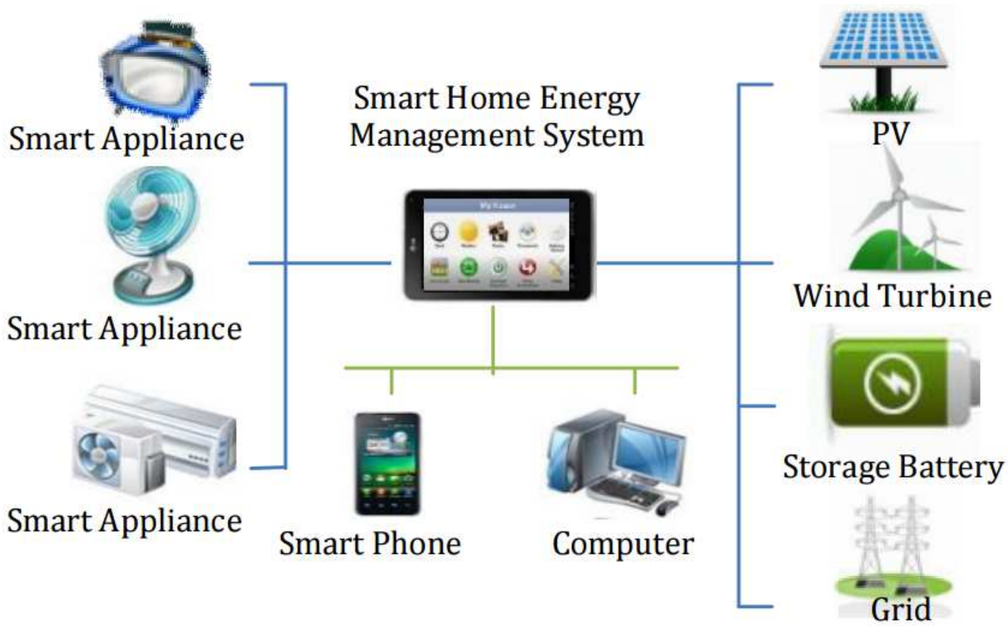

Fig. 1. Model of the Smart Home system for energy management [5]

In the new vision, the SH systems should be extended to integrate external communications to interact with services aggregators and utilities, and the automatic participation in Demand Response (DR), making decisions according these interactions. In DR events, the house management system should reduce the electricity consumption based not on internal information, but on the interaction with an external entity [6].

All of the energy resources of the domestic consumer should be considers in a House Management System (HMS), namely, the management of the electrical consumption, the

micro-generation units, the electric vehicles and the consumer participation in the DR programs. To improve the performance of the HMS systems, it is necessary to include the ability to autonomously acquire knowledge about the user's behavior adjusting the consumer's profiles according the preferences during the management process improving the global system performance, and also the consumers comfort [7], [8]. The improvement of the HMS systems will be very important to the control of devices during a DR event in order to reduce the electricity consumption without changing a lot the comfort levels [9].

The present work focuses on two application systems in testbed laboratory that allow the simulation of the end consumer in research activities of Knowledge Engineering and Decision Support Research Center in Portugal and Smart Grid and Power Quality Laboratory in Brazil, namely, the SCADA House Intelligent Management and Load Emulator respectively. The application systems are able to participate in DR programs to reduce the electricity consumption based in interaction with an external entity. A survey of existing studies in the literature of house management systems developed by several authors is also performed in this work to better understand the complexity of the management systems in end consumers with participation in DR programs..

The first section presents the introduction of the paper. Section 2 presents the application of the demand response programs in the house management systems context according with existing studies in the literature. Section 3 shows the models develops in Portugal and Brazil in research activities with laboratory application. Finally, Section 4 presents the main conclusions of the work.

2. Demand Response in house management system context

The present section includes house management works developed to the participation of domestic consumers in DR programs and shows some examples of DR programs applied in domestic consumers.

A House Management System (HMS) is developed to address the user´s active participation and the contribution for a better efficiency of the system to manage the domestic consumer energy [10]. Actually, several HMS solutions are proposed for companies and organizations although some barriers to the massive use of HMS. Nevertheless, the barriers represent opportunities to the development of new methodologies to integrate in the HMS including the participation of domestic consumer in DR programs.

In the future power systems the DR programs can be an important energy resource. Actually, the industrial and large commerce consumers are the main focus of the DR programs. However, small consumers, including the domestic consumers, allow more flexible response in DR events [11].

In the context of HMS, the participation in DR events is an important functionality in the future management system of small consumers. The DR functionality allows taking monetary advantages directly depending on the type of DR program. The future HMS should be able to automatically manage DR events considering the consumers' point of view, regarding the consumption/prices off sets, and the loads preferences [12].

To try to develop adequate programs for different situations, several types of DR programs have been proposed by different systems operators. The Direct Load Control (DLC) programs one of them. In [13] is developed the Energy Management Controller (EMC) system to control some loads of a SH considering DR programs. The structure of the system is presented in Figure 2. In this way it is possible to turn off the loads defined

according with the DR programs. In this case, the user has a DLC contract to participate in DR programs. Also it is presented in [14], the load curtailment in the DR programs where the program can vary between 15 minutes and more than 5 hours.

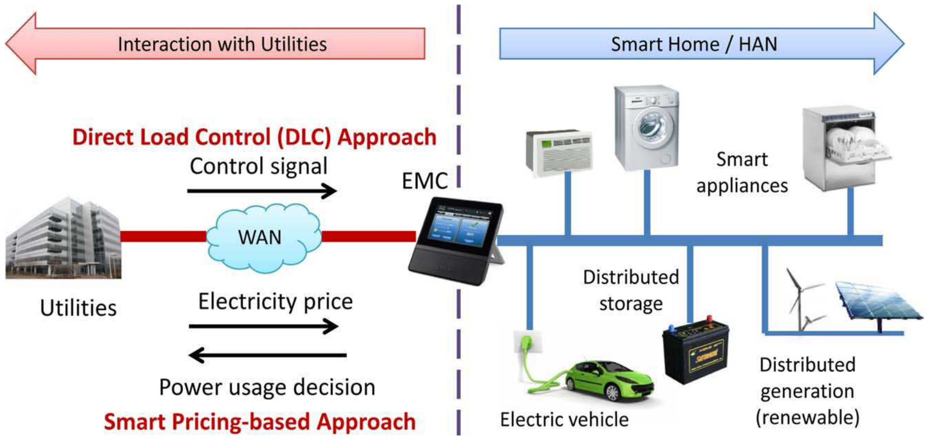

Fig. 2. Intelligent management system of a house with grid communication [13]

Another type of DR programs and the most popular ones is the Time-of-Use (TOU) programs. According with higher electricity price the TOU program encourage consumers to decrease the consumption [15]. Figure 3 presents the existing communications in intelligent management system for the house energy developed by [15].

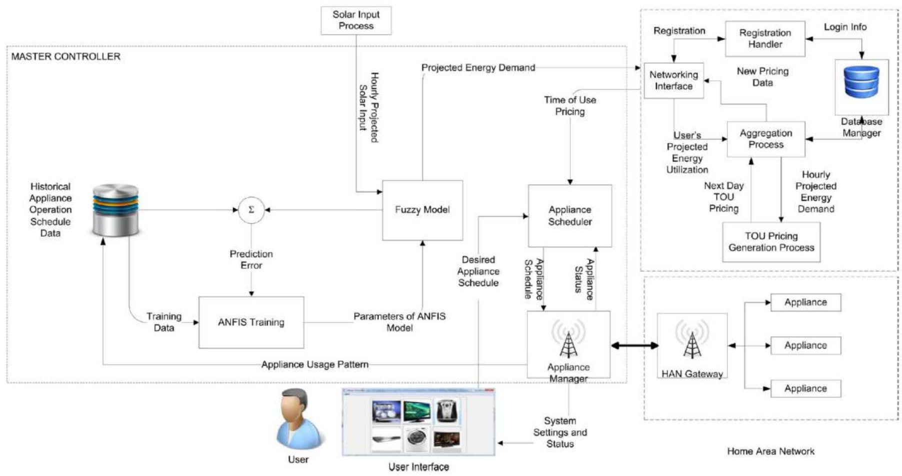

Fig. 3. Communication structure of HMS system [15]

The participation in DR programs can be managed by the curtailment service provider (CSP), an aggregator entity. One of the distinct characteristics of the CSP is the ability to manage the participation of several consumers in DR events, making some guaranties to the system operators, and providing services to the consumers.

In [16] it is proposed a communication architecture composed by different layers,

considering a layer to implement the interface between the HMS, and the system operator energy management system (EMS). The loads management was implemented in another layer using a mixed-integer programming in order to minimize the operation costs considering the DR opportunities. A default priority loads and consumption limits in the house use is proposed in [17].

Other application is presented in [18], an intelligent multi-objective energy management system (MOEMS) is proposed for a domestic consumer equipped with smart appliances (washing machine, dishwasher, tumble dryer and electric heating) to participate in DR programs. In the simulation results, the MOEMS system allows to reduce residential energy use and improve the user's comfort by optimal management of power consumption and generation.

In [5], it is developed an optimal dispatching model of Smart Home Energy Management System (SHEMS) including intelligent residential loads and micro-generation resources. The multi-objective optimization is based in control strategies with DR participation adjusting the parameters of optimal dispatching model in this system. The model is applied in domestic consumer photovoltaic system, wind turbine, storage battery and TOU prices according with DR program. The energy management system and optimal dispatching model obtain good results for the smart home live in a comfortable and economical way.

To reduce peak consumption and to increase the efficiency of the power grid, the DR and dynamic retail pricing of electricity are important contribution in a smart grid context. DR allows to reduce electricity consumption and consequently, the energy costs for domestic consumers. In this context, the work presented in [19] develops a control strategy for the Heat and Ventilation Air-Conditioning systems (HVAC) to respond to real-time prices for peak load reduction. The work proposes the Dynamic Demand Response Controller (DDRC) that allows change the set-point temperature of the HVAC systems according with electricity retail price changed each 15 minutes. Also it is developed a detailed single family house model using OpenStudio and Energyplus. The DDRC system applied in residential HVAC systems allow to reduce the consumption and energy bills only with a single variation in thermal comfort.

The architecture of the dynamic system developed is presented in Figure 4.

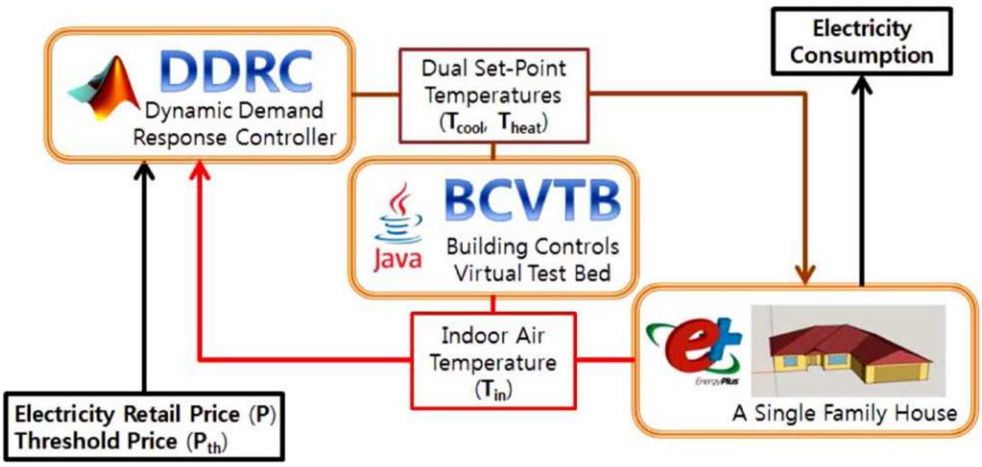

Fig. 4. Architecture of dynamic DR controller [19]

3. Models of Demand Response application systems: Portugal and Brazil approach

The present section explains the house management platform developed in Polytechnic of Porto, Portugal (sub-section 3.1) and the load emulator developed in Polytechnic School - University of São Paulo, Brazil (sub-section 3.2). Both systems have the capacity for the participation in DR programs with main goal to reduce total consumption of the end consumers according with real data of loads and generation resources.

Figure 5 presents the countries of the developed systems with important functionalities to participate in DR programs, simulation of an end consumer and use of real data to determinate consumption profiles.

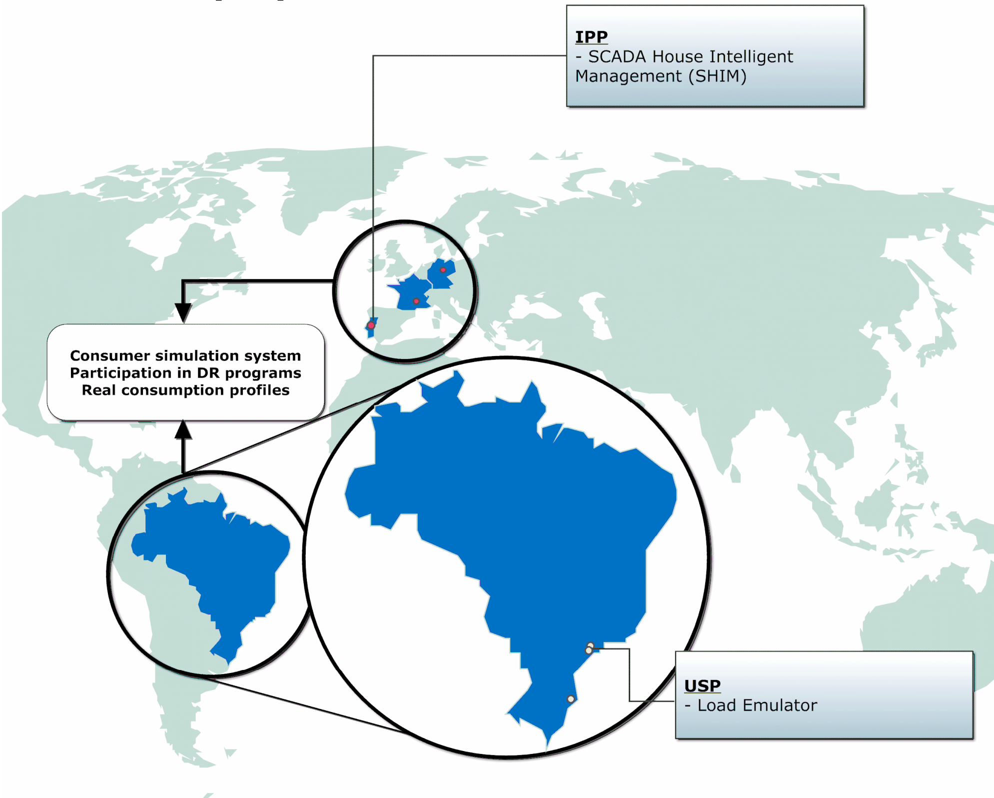

Fig. 5. Application systems developed in each country to participate in demand response programs

3.1. SCADA House Intelligent Management platform – Portugal

The Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development (GECAD), located at the Institute of Engineering – Polytechnic of Porto (ISEP/IPP) develops a testbed platform with the main goal of testing, simulating, and validating new algorithms and methodologies to apply into house/buildings' management. SCASA House Intelligent Management (SHIM) has real equipment such as several types of

loads, distributed generation (photovoltaic panels, wind generator), and storage systems that allow the simulation of the electric vehicles' behavior.

Figure 6 presents the architecture of the SHIM platform composed by three parts with different modules,

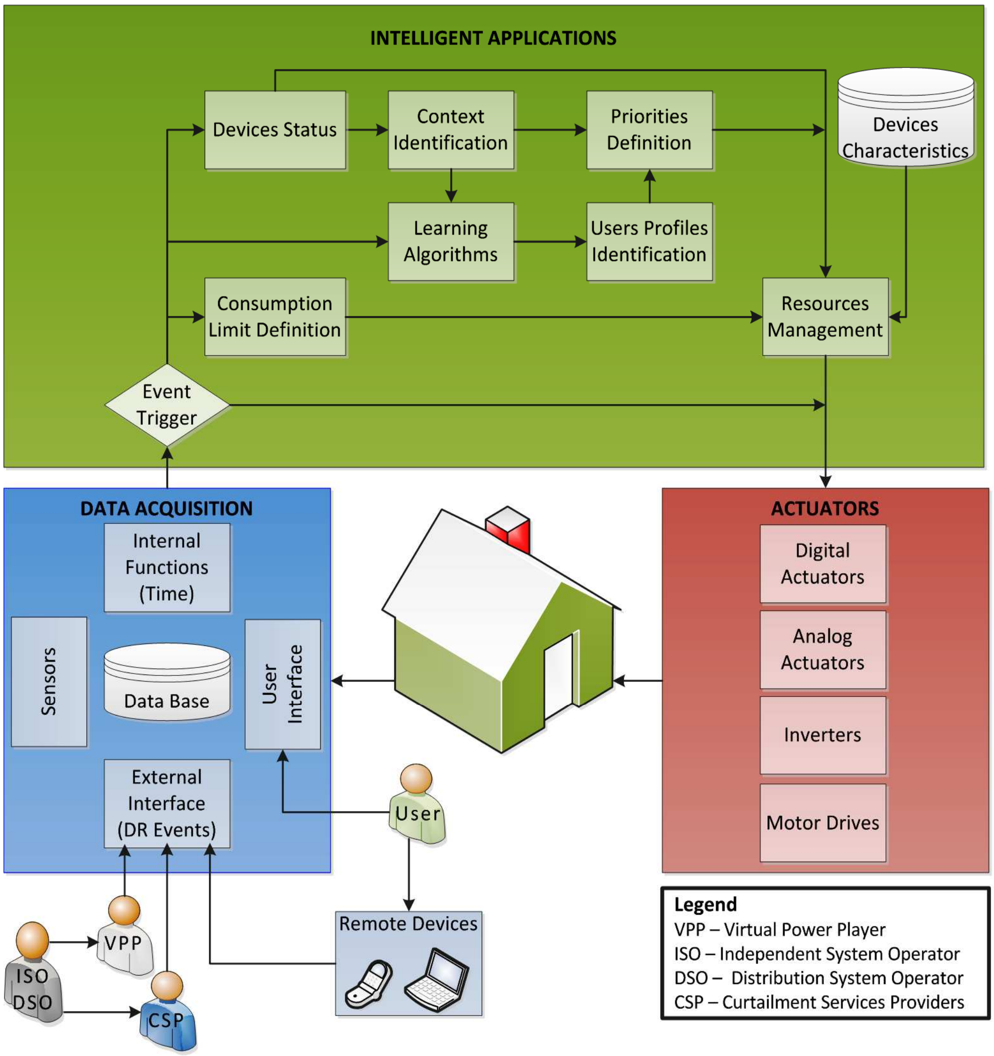

Fig. 6. General diagram of SHIM platform developed in GECAD [6]

Each module is composed by algorithms to be used in different situations, namely the Data acquisition, the Actuators, and the Intelligent Applications:

- In the data acquisition part, four sub-modules are included, namely the sensors, the user interfaces, the external communications, and the internal functions. The sensors module aggregates all types of sensors and meters in the house, and also in the devices inside the house. The user interfaces module allows the communication with different platforms, namely Windows, Android, and touch panels using the Modbus

or TCP/IP protocol. The external interface allows the system remote access and the interaction with service providers' entities (in the existing platform this interaction is simulated in the MASGriP platform) [20]. The DR events are introduced in the system through this module. The internal functions module integrates several functions in the SHIM system, such as the time synchronization. In the proposed methodology, the time synchronization is important to run the optimization algorithm each minute. The internal functions module also integrates a negotiation function used to evaluate the participation in DR events, and a data acquisition function to determine comfort levels, the system efficiency, the estimated energy bill or the detection of abnormal functioning devices.

- A database was included to store all the information provided by other modules.
- The part of the actuators integrates all types of interfaces with real hardware, namely digital actuators, the analog actuators, inverters, motor drives, among others. This module also includes the internal network management considering different protocols.
- The intelligent applications part integrates all the advanced functions in SHIM systems, namely the identification of the context, the definition of priorities, learning algorithms, the users' profiles identification, and the resources' management. The modules also need information on the equipment' functioning characteristics, and the actual status of each device. A trigger allows detecting new events to run all the algorithms. If the event was an order given by the user, the event trigger sends this order directly to the actuators, and in a second step, it sends the order to be processed by other modules. If the event was a DR program, for example, the system does not need to execute any control action before the information is processed. With this mechanism, SHIM avoids delays between orders and actions.

3.2. Load Emulator – Brazil

The Smart Grid and Power Quality Laboratory (NAPREI/ENERQ), located at the Polytechnic School - University of São Paulo (USP) aims to develop a testbed system with the main goal of simulating and validating consumption characteristics of end consumers through a Load Emulator allowing the participation in DR contracts. To the Load Emulator can be added micro-generation profiles according real resources presents in laboratory such as, photovoltaic systems in micro-scale.

Figure 7 shows the main modules to represent the functions of the Load Emulator and the communication with measurement centers of the grid and also the SCADA systems.

The Load Emulator has two important modules, External and Internal interface with different functions. At the top of the figure are shown the following grid systems:

- Distribution Management System (DMS): DMS is to monitor and control the distribution network. The application has open computing environment and can be configured to be integrated in SCADA systems.
- Meter Data Collector (MDC): MDC is to collect data from meters and transfer to the MDM. To collect data the meters use the MESH or GPRS communications.
- Meter Data Management (MDM): MDM is software of the measuring center management. The system allows obtaining the information for billing.

The External Interface is used to allow the communication between the Load Emulator and the grid status. The External Interface has three sub-modules with the following objectives:

- DR programs: This function allow save the DR contracts of the end consumer with grid operator. In this case, the DR contracts can be based on the price or based on the incentives. The participation in DR programs can be achieved by aggregating entity, the public service entities, or by a regional network operator.
- Energy Price: This function is primarily important for DR programs based on price allowing emulator to know the price of energy at the moment.
- Smart Meter: This feature allows to know total consumption of the emulator. Therefore it is possible for the consumer and the service provider, to know for example, if the consumer is meeting with the limits of consumption that exists in some DR programs. Also, it can be added the total generation in the case of the consumer with micro-generation.

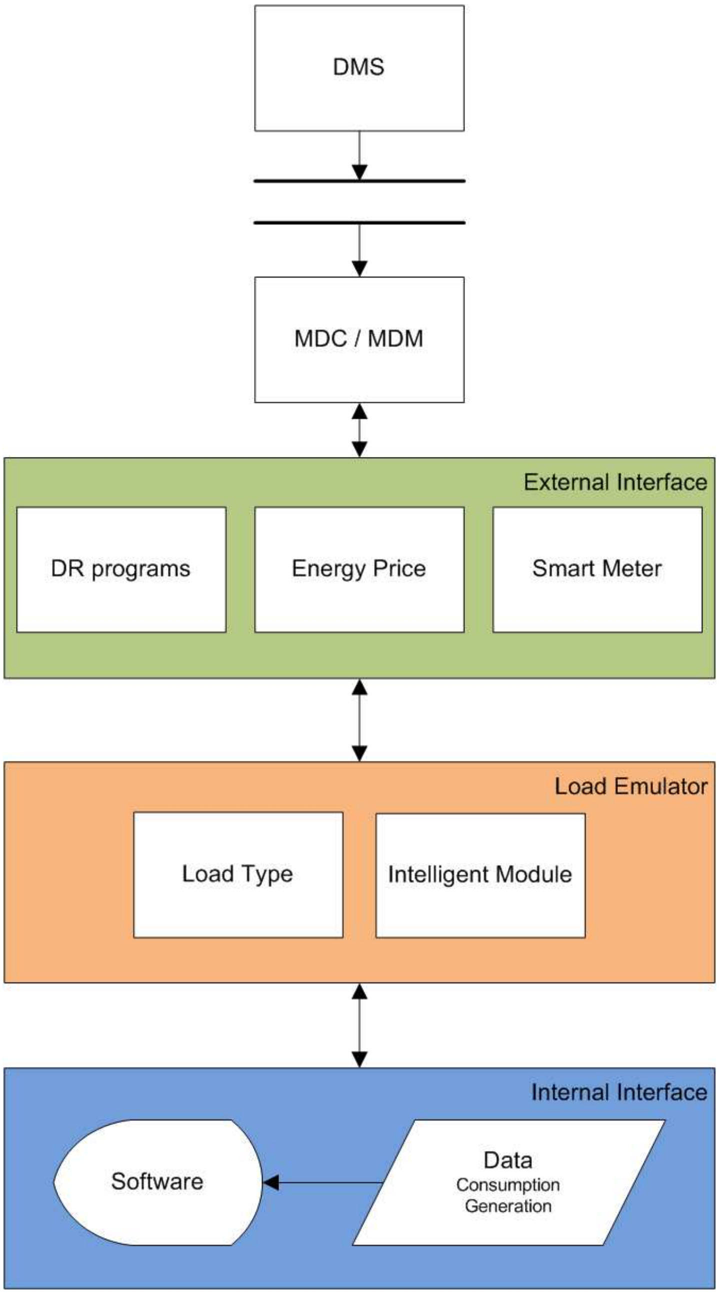

Fig. 7. General diagram of Load Emulator developed in NAPREI/ENERQ

The Internal Interface of the Load Emulator is used to allow the simulation of the load according with consumption real data or, in the case of the consumer with micro-generation, the simulation of the generation. The Internal Interface has the following functions:

- Load/generation profile (voltage, current and power): Allow to know the profile for each resource (load or generation).
- Load/generation state (on/off, power): Allow to know the actual state for each resource where it is possible to change the state, for example, to reduce the total consumption to participate in DR events. The function allows controlling all resources as turn on or turning off, and/or reducing or increasing.
- Total consumption: Allow to know, according with individual consumption of each load, the total consumption of the end consumer. This value is communicated with smart meter of the external interface.
- Total generation: Allow to know, according with micro-generation (photovoltaic and/or wind), the total generation of the end consumer if exists this capacity. This value is communicated with smart meter of the external interface.
- Time/hour: Obtain the date and hour of the simulation scenario in emulator.
- Communication with Load Emulator: Through this communication is possible to emulator know the consumer state (loads and micro-generation units), its current consumption and production, the state of the all loads and generation resources.
- External data: Through this feature it is possible to introduce values of consumption and generation for the loads and generation resources respectively. So as to create a scenario, for example for 24 hours (event generator). The values used will be based on real data.

The Load Emulator is a simulator of the end consumer in a laboratory and depends directly of the Internal Interface data to define the power profiles. The module of the Load Emulator has the following functionalities:

- Load Type Definition: The function is used to select the load type of the end consumer (domestic, Small/Medium/Large commerce or Medium/Large industry)
- Intelligent module: This module will allow the emulator manage existing resources, for example loads. In moments when power consumption is limited by DR programs, the emulator can optimize consumption (function in optimizing the implementation of the priorities of each developed load).

To enable the connection between the Load Emulator and two interfaces (internal and external) is important develop an efficient and secure communication with main characteristics:

- Internal Interface Communication: The communication with internal interface is used to obtain the load/generation resources data. To the communication it can be used the TCP/IP protocol.
- External Interface Communication: The communication with external interface is used to define the DR contracts, to obtain the energy prices and to communicate with the grid the energy/power measurement. To the communication it can be used the TCP/IP protocol.

4. Conclusions

The paper exposes the house management systems developed by several researchers' activity presented in literature to allow the participation on demand response programs. The main goal to the participation of the end consumers, particularly domestic consumers, in demand response programs is to obtain a consumption reduction in context with the operation grid. In other words, this capacity of the house management systems supports the grid operator in the management of the grid.

The paper presents two application systems of different countries enabling the interaction between the power consumption of the end consumer with grid through participation in demand response programs. Both systems are performed in laboratory and use real data information to obtain more realistic results. It can be adapted for end consumer with integration of micro-generation system allowing the management at the same time of consumption and generation power. In the case of Portugal, the Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development develop the SCADA House Intelligent Management. In the case of Brazil, the Smart Grid and Power Quality Laboratory develop the Load Emulator.

The two proposed systems are especially useful for simulation of the end consumer according real data profiles enabling the tests of the participation in demand response programs in a grid context.

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