An Agent-based IoT System for Intelligent Energy Monitoring in Buildings

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Abstract—**The new power system paradigm demands a more active end-consumer participation in smart grids environment. To achieve this participation, new demand side management solutions should be developed and analyzed. Moreover, the massive dissemination of internet of things devices inside buildings are a reality in nowadays. This paper proposes a multi-agent system for microgrid representation that integrates internet of thing devices to boost the energy management in today's buildings. The paper will present the proposed multi-agent system as well as an environmental awareness smart plug. The case study in this paper will present the data acquisition from a real building using a combination of market internet of things smart plugs, the proposed environmental awareness smart plug and a load emulator.**

Keywords—energy management; environmental awareness; multi-agent system; smart plug

I. Introduction

The power system paradigm has been changing in the last years and will continue to change in future years, resulting in the dissemination of smart grids [1]. The centralization of generation will end, appearing decentralized generation [2]. The end-consumers will be called to actively participate in the smart grids, changing completely their roles [3].

The use of Demand Response (DR) enables the end-consumer participation in smart grids. DR programs enable the direct participation of end-consumers, or through the aggregation of end-consumers [4]. The end-consumer's response to each program is defined by the user and contracts that he/she owns. DR programs intend to integrate the end-consumers using two types of remuneration [5]: incentive-based; and price-based.

The active participation of end-consumers requires actions and reactions from them. Therefore, Demand Side Management (DSM) is commonly used to respond and manage the consumption and generation balance in the end-consumers side [6][7]. DSM can act as smart and autonomous solutions that can manage entire facilities by optimizing electrical loads and generators [8].

To model this new paradigm with all the players involved is possible to use Multi-Agent Systems (MAS). These systems can model a microgrid or even a smart grid with all their players [9][10]. A MAS is a good option to model the interaction between agents and the players of a smart grid; giving the individual agents characteristics, such as, reactivity, pro-activeness and social abilities [11].

The devices inside a building are owned by the building users and, in this paper, they will be seen as being properties of the building, without having individual goals.

The massive dissemination of Internet of Things (IoT) devices enables the control and monitoring of buildings. Therefore, the use of this devices in the energy management solutions can benefit the systems and avoid the acquisition of new loads and hardware.

The main contribution of this paper is the proposal of a MAS for microgrid representation that integrates IoT devices for energy management inside the buildings. The proposed MAS was developed for low-performance hardware, such as, single-board computers. These enables the installation of the agents in low-cost hardware and small enough to be placed inside the electrical switch board of the building. These features are similar to the VOLTTRON project [12]. However, the proposed MAS uses high penetration of IoT devices to perform energy management solution inside the buildings. This is the biggest contribution of this work.

This paper also presents an environmental awareness smart plug. This smart plug enables the systems to understand the environment where the load is. Giving more information to the system is possible to improve the energy management of a building.

After this first introductory section, the proposed MAS will be presented in Section II, with relevance to the overall architecture and the communication protocols. Section III will describe the IoT devices used in this work. Section IV will present an environmental awareness smart plug used in the MAS. The case study is presented in Section V, as well as its results. Finally, Section VI presents a brief of the results achieved.

II. Multi-Agent Sytem

MAS can be used to model smart grids, where each agent is able to represent each smart grid player. The possibility of cooperative and competitive agents enables the representation of competitive players - multiple aggregator - and cooperative players - two members of the same microgrid. In this paper is proposed a MAS that models microgrids, using agents which interact with IoT devices for energy management.

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The Microgrid Intelligent Management System (µGIM) is a MAS for microgrid management. It's a system thought for low-power and low-cost single-board computers able to have a continuous operation, even without external connection. Each agent interacts with the others, but is responsible for the building that it represents. Therefore, each agent has the capability to work in offline and provide energy management solutions for its building.

A. *Overall Architecture*

Fig. 1 shows the architecture of µGIM applied in a microgrid environment. One of the µGIM priorities is the integration of massive IoT devices to provide energy management solutions. In Fig.1 is possible to see the separation between the devices inside the building and the microgrid players represented by the agents. The devices used in this work are one of three types: IoT device available on the market, EnAPlug that is a IoT smart plug with environment awareness capabilities [13], or Virtual to Reality (V2R) emulator that is able to emulate electrical loads [14].

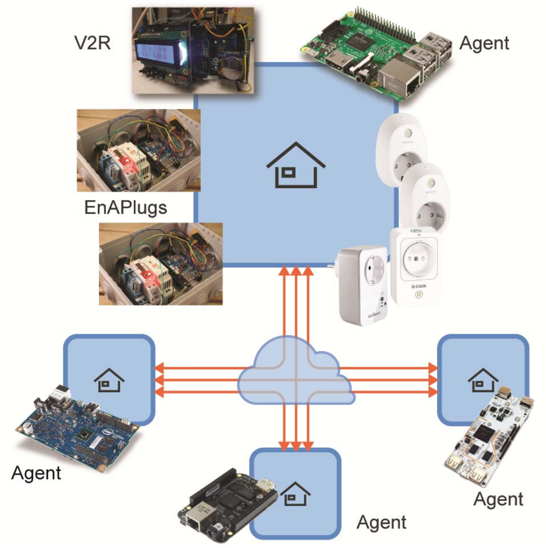

Fig. 1. µGIM architecture for microgrid

Each agent of µGIM represents an abstraction layer that separates the inside of the building from the outside. The loads of a building should be managed by the agent itself and should not be manage by external agents. However, this is not the case in Direct Load Control (DLC) events, where the agent makes some loads available to external players, such as, aggregators. The agent also deals with the communication to other players, such as, DSO and aggregators.

The agent of µGIM should be autonomous enough to provide energy management to its building. However, the agent is controllable and configurable by the users of the building. The users can and should set the agent to represent their goals and beliefs. And the agent should understand them and provide the solution that most fit to the users' desires.

The use of IoT devices gives eyes and hands to the agent. With these devices the agents can see the building and act on the building. The use of massive IoT devices in todays market should be take into consideration in energy management systems, because they can empower the systems and avoid the installation of specific hardware.

B. *Communication Protocols*

Each agent must be able to interact with external devices, such as, IoT devices. This interaction will provide the agent with data and means to act in their world – being its world the building that it represents. To provide enough information to the agent, multiple and suitable sensors should be integrated inside the building. For actuation and energy management is needed energy monitoring devices and actuators.

To provide the ability to integrate such devices and sensors, the agent must provide the appropriate communication protocols that are most common in the IoT world. In order to reduce develop work, for this paper it was used Home Assistant – that is an open-source home automation platform [15]. Home Assistant already has multiple communication protocols and the ability to directly communicate with IoT devices commonly available on the market. It also provides a RESTful API for external communications. This allows the control of Home Assistant from a third party, like µGIM agents. The direct control decreases the limitations of using the proprietary cloud services – usually large time period readings and lack of APIs.

Besides Home Assistant, µGIM uses RS-485 with Modbus/RTU protocol to enable the direct communication with energy analyzers and inverters. Each agent also has the ability to directly communicate using Modbus/TCP, that is handy for communications with Programmable logic controller (PLC). New protocols can be and should be developed because the number of protocols available are directly connected with the number of devices that can be connected to the agent. Therefore, the more the better.

III. IoT Devices Used

For this work, it was used some IoT devices that can be found on today's market. They enable the integration of electrical loads in the µGIM system.

A. *Smart plugs*

The use of smart plugs, especially the ones with energy metering, are a good option for energy management systems. Enabling load control without the need of new controllable loads. This work uses four smart plugs: D-Link DSP-W215, Edimax SP-2101W, TP-Link HS100, and TP-Link HS110.

The most relevant parameters of the used smart plugs are presented and compared in Table I. In this analysis is consider the European market, and the prices available in the Spanish Amazon. This information was collected on January 15, 2018.

The switch control capability is common in all the presented smart plugs. Is possible turn on or off the load through a smartphone, using the manufacture mobile application. The wireless communication protocol used is barely the same, the adoption of Wi-Fi protocol is natural since its massive dissemination in buildings and residentials. The metering capability has a big impact on the price, in this case the lack of this capability allows the HS100 to be the cheapest analyzed smart plug.

TABLE I. SMART PLUGS SPECIFICATIONS

Parameters	Smart plugs			
Brand	D-Link	Edimax	TP-Link	TP-Link
Model	DSP-W215	SP-2101W	HS100	HS110
On/off control	✓	✓	✓	✓
Metering	✓	✓	✗	✓
Internal sensors	✓[a]	✗	✗	✗
External sensors	✗	✗	✗	✗
Communication	IEEE 802.11n	IEEE 802.11b/g/n	IEEE 802.11b/g/n	IEEE 802.11b/g/n
Voltage	100-240 VAC	100-240 VAC	100-240 VAC	100-240 VAC
Current	16 A	16 A	16 A	16 A
Price[b]	€38.22	€51.75	€23.99	€39.95

a. Only temperature sensor of the device.

b. From Spanish Amazon (https://www.amazon.es/).

B. *Limitations*

The main limitation of market available smart plugs, is the lack of sensors. Despite of switch control and metering, smart plugs do not have external sensors that could understand the environment around. Considering a desk lamp, if the user is not around, the lamp could be turned off. In other words, smart plugs could be smarter using external sensors to understand the load's environment.

IV. ENAPLUG

To overcome the current limitations of smart plugs, this work integrates EnAPlugs for some of the electrical loads. EnAPlug is an environmental awareness smart plug composed by multiple sensors that enable the understanding of the environment [13]. This enables the system to understand the environment were a specific load is, and not only its consumptions or operation state – if it is on or off. EnAPlug is an open-source project that can be requested to the authors. At this moment, the code is only available through direct requests.

Using mainstream hardware, such as, Arduino and Arduino shields, is possible to build our own EnAPlug to use in laboratory or in real scenarios. The concept of EnAPlug is simple, understand the environment of a load using suitable sensors that measure variables related to the load or load functionality. For instance, if a common smart plug is used in an energy management system, for residential use, the system is able to cut the heater consumption. But to do that there are some variables that the system should know, such as, the temperature of the room where the heater is. Other variable that can be handy is the presence of people inside the room. These variables are not available in smart plugs available on the market today, to have these variables there is two options: buy IoT sensors that answers to our requirements, or build an EnAPlug with the sensors that we need.

Fig. 2 shows the architecture of EnAPlug. From left to right we have the following:

- *Load* – the load is the electrical appliance that EnAPlug will control and measure, it can be a discrete load (on/off) or a variable load (with several consumptions levels);
- *Metering* – this block is responsible for the load measuring regarding electrical parameters, for this propose, the presented work uses a single phase energy analyzer, such as Circuitor CVM-1D Series that provides a total of 25 energy related parameters and allows loads until 31 A. The only requirement for this block is the usage of an energy analyzes with RS-485 and Modbus/RTU communications;
- *Actuator* – this block is the actuator that corresponds to our control desires, the simplest actuator is a relay that can turn on/off a load. However, more complex actuators can be used using communication protocols or infrared emitters to control the load. Is also possible to accommodate more than one actuator in this block, for instance, a relay with an infrared emitter;
- *Microcontroller* – this is the 'brain' of EnAPlug, is responsible for: read the energy analyzer, give the signals to the actuator, process all the signals from the sensors, receive and interpret the control signals and publish all these information in the server database. In this work it was used an Arduino Mega 2560 Rev3. However, other Arduinos or even other microcontrollers can be used. The Arduino was only used to simplify the implementation of EnAPlug and the integration of sensors;
- *Sensors* – the number of these blocks are chosen by the developers. Theoretically, is possible to have a huge number of sensors measuring everything. However, the concept of EnAPlug dictates that the sensors should measure variables with impact on the work or workflow of the load, for instance, a refrigerator should not measure the CO2, but it should be measure variables, such as, inside temperature, outside temperature and the time the door is open. The sensors to use depend on the goal that the developer has and the microcontroller capabilities regarding processing power, communications ports and libraries available;
- *Control Signal* – the control signal is sent using TCP/IP protocol (wired or wireless), that gives instructions to EnAPlug regarding the load state, for instance, to turn on or off the load;
- *Server and Database* – EnAPlug is connected to an online server; that can be in the user's private network or in the public network. The server and database block is responsible to publish all the sensors data, the energy metering data and all the control signals that EnAPlug receive. For this work, the data was publish using a 5 second period. Similar to Control Signal block, it is used TCP/IP protocol, that can be used in wired or wireless networks.

The integration of EnAPlug in μGIM gives a more detailed and complete understanding to the agents in comparison with IoT solution available on the market. This provides the agent with better data and therefore improves the energy management algorithms.

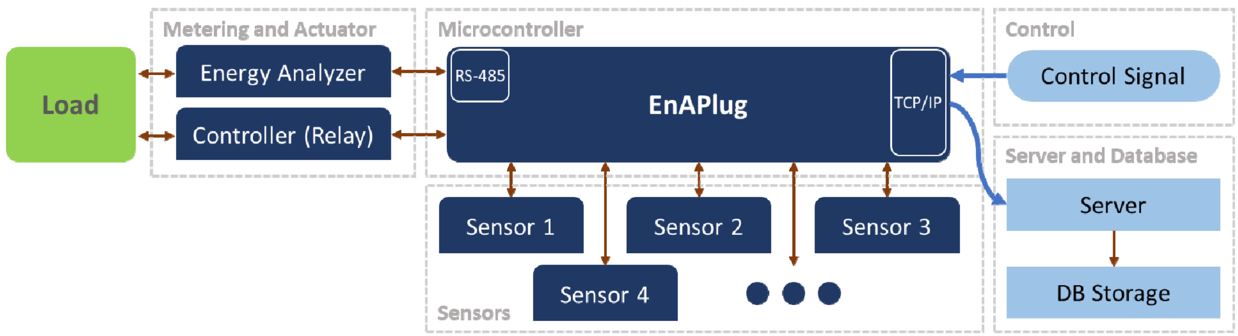

Fig. 2. EnAPlug architecture

V. CASE STUDY

For this case study it will be demonstrate the capabilities of a µGIM agent to acquire all the data from the smart plugs, EnAPlugs and the V2R – that are load emulators. All the data are acquired directly from the devices. It will not be used the cloud service of the IoT devices. This will speed up the communications with the IoT devices and enable the agent to control the devices even without internet connection.

The presented work uses two EnAPlugs in an office building: one for a refrigerator and other for a water heater. The EnAPlug installed in the water heater has a temperature sensor in the water pipe measuring the temperature of the water and give information regarding the time that the hot water was used. The EnAPlug installed in the refrigerator has an inside temperature and humidity sensor, an outside temperature sensor to measure the room's temperature and a door sensor that provides information regarding the opening of the door

The case study presents the reading data from 02:00 p.m. to 03:00 p.m. using a reading period of five seconds. However, other reading periods can be chosen and used in µGIM. The presented agent is installed in an office building with:

- 1 V2R emulating a fan heater,
- 4 IoT smart plugs that measure the lamps, one fan heater, one television and one monitor. The fan heater do not have metering because it was used the TP-Link HS100 - a cheaper and common smart plug for residentials,
- 2 EnAPlugs measuring one water heater and one refrigerator, using external sensors,
- 1 energy analyzer that measures all the sockets that do not have individual metering from EnAPlugs or IoT smart plugs.

The µGIM agent of the building reads all the data from the installed devices every 5 seconds. The collected data is presented in Fig. 3. As can be seen, IoT devices can be used to perform metering in a building, enabling energy management solutions in the building.

Three major problems from using massive market available IoT devices are: the lack of direct communication with the device, the metering period, and the few information provided by the smart plugs. The presented work shows the possibility of direct communication with IoT devices and their capability to provide metering data in small periods. The lack of information provided by smart plugs cannot be easily solved, to overcome this issue, this work uses EnAPlugs.

Fig. 4 shows the metering provided by one EnAPlug connected to the refrigerator of the case study. The measurements were taken between 00:00 p.m. and 01:00 p.m. with a 5 seconds time period.

The use of EnAPlug provides a lot more data than a conventional smart plug. The Fig. 4 presents electrical measurements of voltage, active power and reactive power of the refrigerator. Regarding the sensors, Fig. 4 shows the inside humidity in the refrigerator (that increases when the motor stops running, stopping the air ventilation), the inside temperature in the refrigerator (that decreases while the motor is consuming), the outside temperature and the door usage. These measurements enable the understanding of the load and the smart control of the load for energy management methodologies [16].

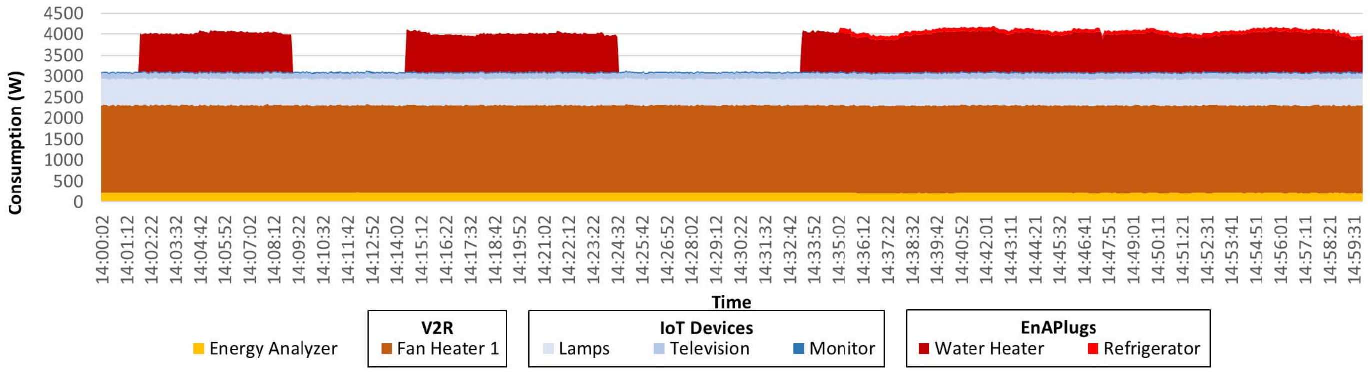

Fig. 3. Metering from 02:00 p.m. to 03:00 p.m.

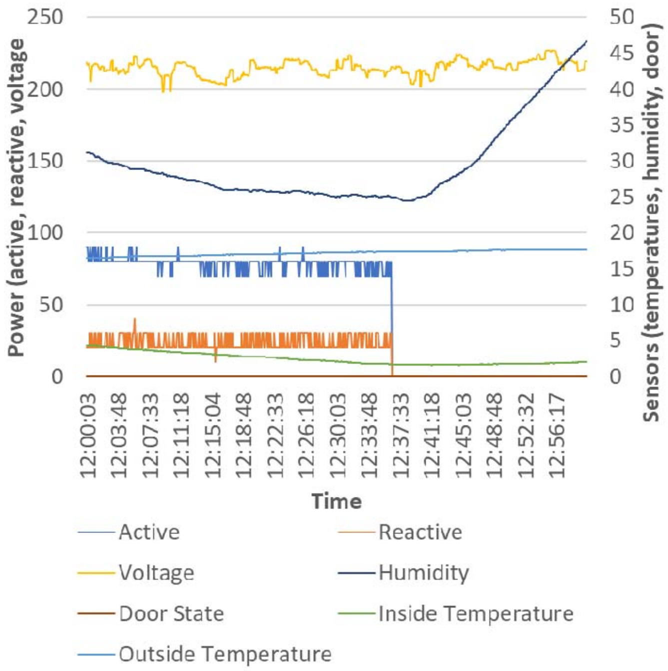

Fig. 4. EnAPlug metering (energy and sensors)

VI. Conclusions

This paper presents a multi-agent system that models microgrid and management, using internet of things devices to provide the metering and control of the buildings. The case study presents the results of the integration of internet of things devices in an agent installed in an office building.

The case study was a success, providing metering every 5 seconds. Previous tests also work with 1 second period measurements. This enables the use of internet of things devices for energy management. This paper uses direct communication with the devices, avoiding the use of proprietary clouds owned by manufactures.

This paper also proposes and presents an energy awareness smart plug that can provide energy management systems with more information regarding the load environment. This feature enables a better understanding of the load and therefore, can improve the energy management algorithms and techniques.

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