Multi Agent Architecture For Smart Building Energy Management

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***Abstract*— The aim of the work presented in this paper is the energy management in residential microgrids. The study focuses on Multi Agent System approach based on sensors and actuators network. The system operation requires a large amount of data both for its architectural description and for its real time control. Dealing with this, the fundamental step in the energy management is the organization of data in order to construct the suitable relational database model. The second step is to analyze the system architecture and identify the agents to use for the system. When data are structured and Multi Agent System is modelled, the energy management algorithms are developed and validated taking into account the data availability and the agents properties.**

Keywords— Smart building, Microgrid, energy management, Multi Agent System, sensors, actuators.

I. Introduction

The residential microgrid concept has observed a growing interest in recent years, because of the large part that it represents in global consumption. In European Union (EU) for example, about 50 % of final energy consumption is used for heating and cooling; among which 80 % is used in residential buildings [1]. Therefore, achieving the EU's energy and climate goals requires significant investment in improving the energy efficiency of buildings. In old buildings, the most significant energetic reduction can be achieved through the refurbishment. However, several other techniques can further improve the result such as energy management.

In this context, one of the objectives of the European project REZBUILD, "Refurbishment decision making platform through advanced technologies for near zero energy building renovation", is to develop an ecosystem for the renovation of residential buildings, based mainly on the integration of new construction technologies. In addition, an energy management system will be implemented once the renovation completed. Energy management is an important task which needs the availability of pertinent data and the development of complex models and control algorithms.

Several research works have focused on the study and design of Energy Management Systems (EMS) dedicated to microgrid in general or residential microgrid. Different techniques are proposed depending on the microgrid structure, operation mode (connected to the main grid or islanded), available data and management objective. In [2] authors proposed an EMS based on JuMP-Julia for Mathematical Programing (MILP) with Gurobi Solver for a set of inter-connected microgrids. The optimization problems consider the following constraints: Load demand, Photovoltaic generation and import/export energy price. The EMS performances are validated for three microgrid's operation modes: grid-connected, grid-disconnectable and stand-alone. In other works, Model Predictive Control (MPC) was used for the energy management. In [3], MPC approach was proposed in residential microgrid. The optimization includes the aging of the components, the price of the electricity and the operational constraints. The management objectives are: minimizing the electricity bought of the power grid, maximizing the economic profit of the microgrid, satisfying user demand and extending the lifespan of batteries. The different system constraints were satisfied contributing to the Demand Side Management (DSM). Researchers who used MPC technique in energy management went further to improve the computational time and scalability of the current MPC based control schemes [4]. This is achieved by decoupling the economic dispatch and unit commitment problems and resolving them distinctly. The management algorithms consider the prediction of loads consumption, the present and predicted prices of energy and the availability of renewable energy. Artificial Intelligence techniques have also been used in the literature and have shown their efficiency in energy management. In [5] an EMS based on Artificial Bee Colony (EMS-ABC) was implemented for economic dispatch in a residential microgrid. The main objective of the EMS-ABC was to minimize the production cost and the market clearing price. This was reached using an optimal generation scheduling and consumption shifting in demand response. In [6], authors proposed an energy management approach based on Fuzzy Logic Control in a residential microgrid. The objectives are: improving battery lifespan and reducing the grid power fluctuation. The work principle consists in calculating the State-of-Charge (SOC) of battery and rate of change of the Grid/Load power in order to predict the required percentage rate of battery discharge. This prediction leads to improve the grid fluctuations, realizing a smooth grid power profile and keeping the battery in safety. In [7], authors have been also interested to the energy management in residential microgrid using fuzzy logic. However, they proposed a different strategy of management which aims to maintain a flat consumption of the main loads in priority. Since the principle power source in the studied microgrid is a PV generator, the main objective is to compensate the intermittent nature of the PV. An intelligent battery management system has been proposed considering a fuzzy controller whose rules are defined by the behavior of the people living in the houses, the intermittent energy available from the PV generator, the SOC of the battery and the maximum power. The battery lifespan was not been taken into account in this research work.

Assuming that the microgrid consists of a set of heterogeneous entities, which interact with each other's in a distributed way, these characteristics match with the Multi Agents Systems (MAS) working. A MAS has been proposed in [8] to manage the energy sources of a microgrid. The role of MAS in this research work is to determine periodically (every 30 minutes) the microgrid's operation mode taking into account the fluctuations in the market price and power balance between generation and demand. In the proposed MAS, a microgrid controller agent manages the switch between operations modes. Power sources are controlled by a power generator agent, loads by a load agent, and batteries by a storage agent. Since the MAS and the microgrid have been each developed in a different environment, an interface agent was proposed. In previous works we have proposed a MAS for the energy management in an embedded microgrid (sailboat) [9]. The approach consists to implement a MAS wherein each microgrid element is controlled by an agent which can connect / disconnect it from the microgrid, based on a decision from the supervisor agent or a self-decision when an emergency occurs, or the supervisor agent is unreachable. In this respect, the main contribution of this paper is to implement a Multi Agent software and hardware environment for the energy management in residential microgrid in the REZBUILD project context. The EMS is embedded in a calculation unit which is connected to a communication network in order to ensure the data flow needed for the microgrid control. The data flow is organized, with other important data, in a relational database which has a significant role in the MAS energy management.

The rest of this paper is structured as follows; section II defines the concept of MAS and agent properties and features. Section III describes the physical architecture of the system. Section IV presents the organization of the proposed database model. Section V presents the Multi Agent approach for the microgrid energy management and identifies the proposed agents with their specifications. Section VI illustrates the validation of the EMS operation based on two performed scenarios. Finally, section VII gives conclusions and future works.

II. Multi Agent System

In order to study the feasibility of applying a Multi Agent approach in the energy management of the microgrid, it is necessary to define the Multi Agent Systems and to characterize the concept of agent.

A Multi Agent System (MAS) is a system consisting of several interacting agents with each other's and with the elements of their environment. The interest of the MAS use comes from the agent properties and abilities. In fact, an agent is an autonomous software or hardware entity, which acts on itself and on its environment. In the Multi Agent context, an agent is able to communicate and collaborate with the other agents. Its behavior is the result of its observations, its knowledge, and its interactions with the other agents and the entities of its environment [10].

The most important specification of agent is that it is autonomous. The agent autonomy is its ability to act without direct intervention of another entity (agent or human) on one hand, and to control its actions and its state on the other hand. Moreover, agents can be classified, according to their autonomy level, into three types:

- reactive agents, behavior based on stimulus-response, with a limited autonomy,
- cognitive agents, "thoughtful" behavior, resulting from a choice among a set of possible actions, this choice is the result of reasoning,
- hybrid agents, behavior using both properties of cognitive and reactive agents.

Another important specification, which concerns software agents is the mobility. Mobile agents mainly target applications distributed over long distance networks, since they allow the execution to be moved to the servers and thus reduce the cost of access to these servers. The objective can be to locate a resource or to reconcile data treatment to reduce bandwidth consumption or to adapt a remote service to the needs and capacities of the client. The mobility is controlled by the agent, and not by the execution system.

III. Physical Architecture

The studied microgrid is a residential one operating in grid-connected mode. It consists of classic residential loads, which are supplied by PV local production and main supply. Energy storage can be present in the microgrid in thermal form, considering the presence of the water heater in the system. The microgrid control requires the availability of pertinent raw or treated data and the ability to act on loads. Therefore, the microgrid must be equipped with sensors, actuators, calculation unit, and a communication network allowing the information flow between all these components. The elements of the studied system in this research work are:

- Sensors: analogic such as temperature, ambient light, power, energy, current and voltage; and binary such as occupancy, window and door opening.
- Actuators for: light, heating, air-conditioner, electric shutter, local power production.
- Calculation unit: EMS.

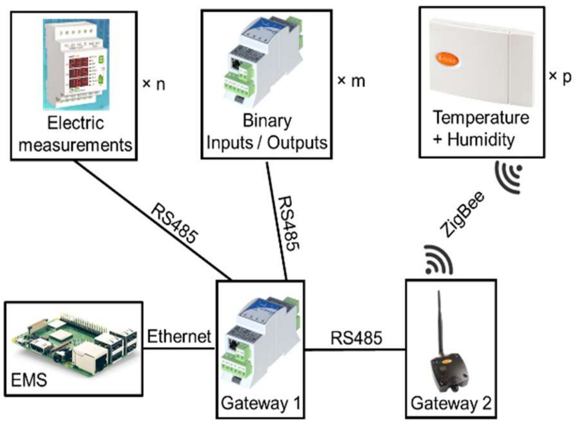

Fig. 1. Communication between the system elements

The physical architecture of the system is presented in Fig. 1. The communication between the EMS and the different elements of the network is ensured by an Ethernet connection type using a gateway (Gateway 1). A second gateway (Gateway 2) using a ZigBee connection is applied to ensure the communication with wireless sensors. The used communication protocol is Modbus TCP.

IV. Data Organization And Database Construction Model

The development of energy management algorithms is based on the use of the microgrid characteristics and sensor measurements. Each measurement is obtained establishing communication with its source. Therefore, the system must have a database containing three types of data:

- Measurements got from sensors, these are data to be used or treated in order to perform the energy management. Measurements can be used for the decision making in real time or stored in the database in order to construct the training set to be used for the consumption and production predictions,
- Device specific data, these are the data needed for the description of the device specifications and the construction of the measurement request frames (Modbus frames in the studied case),
- Microgrid and house data, these are the data presenting existent microgrid elements (production, storage and loads), the circuit where they are connected, their location in the house and the characteristics of the house.

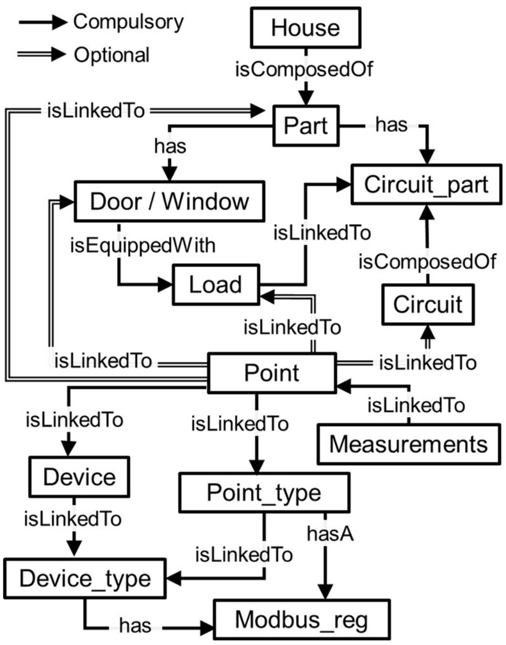

Fig. 2. Proposed relational database for the used microgrid model

Therefore, the database contains heterogenous data which are linked with each other. Links are presented based on an ontology concept [11] in Fig. 2. The ***House*** is composed of several ***Parts*** which have ***Doors*** and ***Windows***; which can be equipped with electric shutters and opening sensors. Each ***Part*** has ***Circuit_parts*** which are grouped in electrical ***Circuits***, each one protected by a fuse. Each ***Point*** has a type with specific properties and can be used for measurement or action purpose. Double line connections starting from the ***Point*** table are optional; just one link is active for each point. This link displays the physical connection between the ***Point*** and a sensor or an actuator. A ***Point*** is located in a physical ***Device*** and each ***Device*** has a type and can contain a number of ***Points***. The ***Modbus_reg*** is specific to the Modbus registers and their specifications; it is linked with ***Point_type*** and ***Device_type***. All measurements are stored in a ***Measurements*** table and linked to ***Point*** to identify the physical source and the properties of each measurement. The choice to use only one table for the measurements has been made for two reasons: 1/ If each point type is linked to an independent table, and considering the expendability of the microgrid and the sensors and actuators network, the adding of a new device will require the creation of a new table and consequently the change of the database structure when the system is running. 2/ One of the features of the EMS is the visualization of consumption and measurements curves. This is more convenient when all measurements are stored in one table because the visualization can be done for more than one device.

V. Multi Agent Approach For The Microgrid Energy Management

A. *Proposed Multi Agent architecture for energy management*

In accordance with the physical architecture of the microgrid on one hand, and the agent definition and specifications on another hand, a Multi Agent management approach is proposed, considering the following choice of agents:

- each sensor is a physical reactive agent which sends the measured physical quantity when it receives a request Modbus frame,
- each actuator is a physical reactive agent which must act on the associated load when it receives an order Modbus frame,
- each management algorithm is a mobile agent which can be embedded and executed on the calculation unit, the gateway if it has an intelligent unit, or on the server. The management algorithms depend on the available loads, actuators and sensors in microgrids. In the studied system the considered management algorithms are applied for heating, air conditioning, windows and lights. Examples of heating and light management agents will be presented in the next section,
- An additional software agent is added in order to manage the user interface.

B. *Management agents*

As mentioned previously, management agents are software mobile agents. Their most important properties are mobility and high communication and collaboration levels. In fact, to achieve its objective, the management agent must communicate with sensors agents and with associated actuator agents. The management of loads must consider the following parameters:

- the available data,
- the state of the communication network,
- the considered constraints.

We will insist here on a heating and a light management agent. They have been created in a specific room considering the availability of the following devices:

- sensors for temperature, occupancy, window/door opening, and ambient light,
- actuators for heating and for light.

The heating management algorithm is modeled in Fig. 3 and the light management algorithm in Fig. 4. Both consist of three phases which are executed periodically:

- data collect from sensors or database,
- data processing algorithm (decision making),
- sending of the order.

The main goal of management agents is to reduce the energy consumption taking into account the comfort of the house inhabitant. That is why the heating management algorithm connects the actuator when the temperature is less than the thresholds fixed by the habitant, and updates the thresholds by setting them to lower values when there is nobody in the room; these two actions have a comfort goal. However, the light management algorithm never put ON the actuator because its goal is mainly reducing the energy consumption; it considers that the habitant must act on the light to activate it if needed.

It is important to note that the management agents are designed in order to be able to adapt to the specific architecture and the devices available in the house. For each house part, instances of each management agent type are created and configured. For example, the number of heating management agent instances is the number of the heating devices.

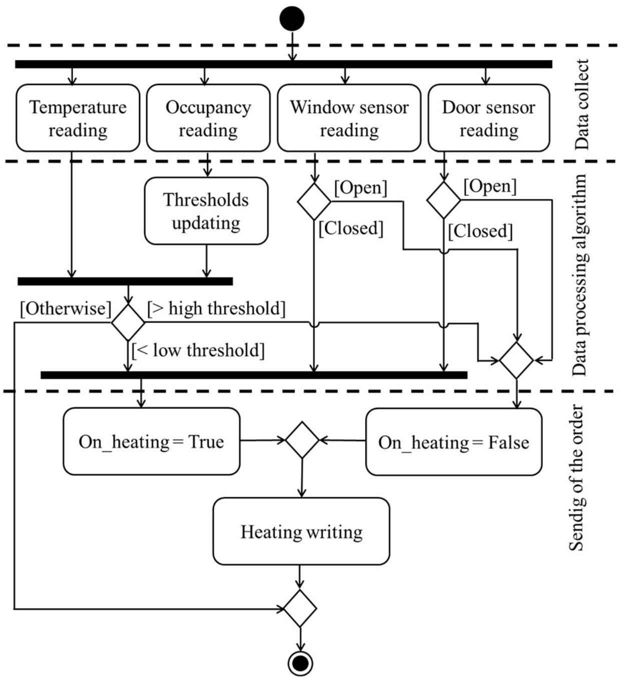

Fig. 3. Activity diagram of heating management agent algorithm

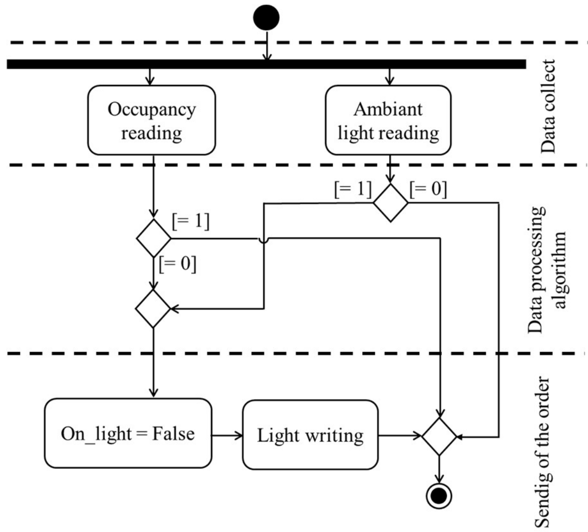

Fig. 4. Activity diagram of light management agent algorithm

C. *User interface agent communication*

The EMS has a user interface allowing the following functionalities:

- the visualization of the microgrid state (loads in use, electricity consumption curves, sensors measurements),
- the possibility of connecting / disconnecting loads.

The user interface agent is a software one which must have a high communication level because of its interactivity with both database and physical environment in real time.

For the microgrid state visualization, electricity consumption and sensors measurements curves (or last values) are obtained from the *Measurements* table of the database. It is assumed that this table is updated in real time by receiving periodically the sensors and actuators measurements and states.

To connect /disconnect loads from the user interface, the user interface agent communicates directly with the actuator agents.

The communication between agents and with their environment (database) is illustrated in Fig. 5.

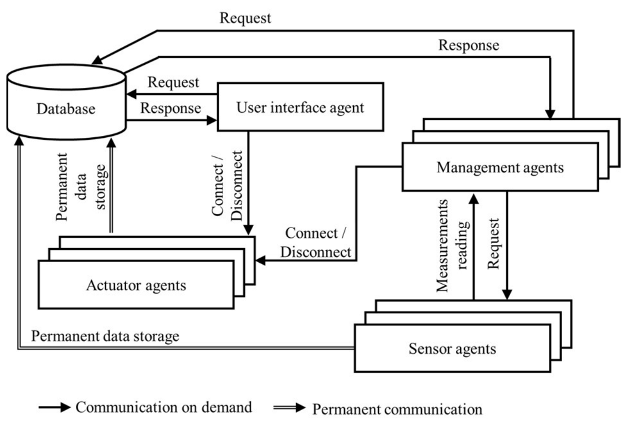

Fig. 5. Communication of agents in the MAS and with their environment (database)

VI. Validation of EMS Operation

In order to validate the proposed approach, a heating management agent has been implemented and embedded on a *Raspberry Pi system*. It considered the algorithm presented in V.*B section*. The tests have been carried out on a room demonstrator presented in Fig.6. A wireless temperature sensor has been used. To simulate the behavior of the other sensors (occupancy, window and door opening), three binary inputs have been considered. A heating device has been connected to one of the demonstrator outlets which is controlled by a binary output simulating the actuator agent. It is important to note that the device containing the binary inputs and outputs allows their wired connection directly with sensors and actuators and it will be used later in the buildings. The user interface agent and the database have been developed in the Django framework in order to allow web access to the system.

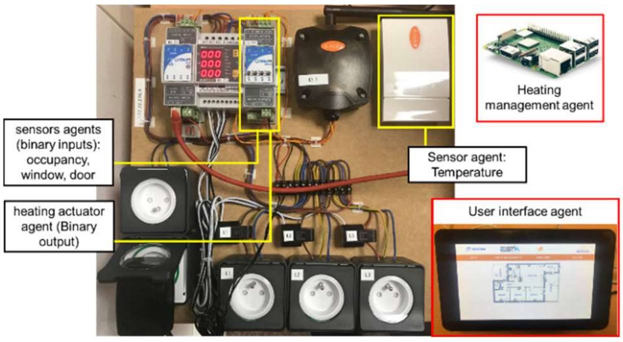

Fig. 6. Electrical part of the prototype: a bedroom management heating

Several scenarios have been performed with the demonstrator. For space limitations, only two scenarios are presented in this paper.

A. *Scenario 1: Testing the interaction between agents in real time*

The first scenario's principle is to validate the interaction between agents in real time. For that purpose, only one parameter has varied: the temperature. The states of the binary inputs presenting the occupancy and the window and door opening sensors were constant during the scenario's running. It was assumed that the room is occupied, and the door and the window are closed. The heating management agent has considered the same synchronization period as the temperature sensor which is equal to one minute. The temperature control is based on hysteresis control and the thresholds have been set at 23°C ± 0.25. Therefore, when the temperature is less than 22.75°C, the heating management agent sends an order to the heating actuator agent to connect the heating device. When the temperature reaches 23.25°C the heating management agent sends an order to the heating actuator agent to disconnect the heating device. Fig.7 illustrates a running of the scenario for one hour. It shows that the connection and disconnection of the heating device is synchronized in real time. At the start cycle the room temperature was around 17.3°C, therefore the heating device had been connected by the EMS for more than 30 minutes to reach the high threshold temperature value due to the thermal inertia of the heating device / room and the relative position between the temperature sensor and the heating device. For the same reasons, after switching on the heating, the temperature continues to decrease for a time lapse.

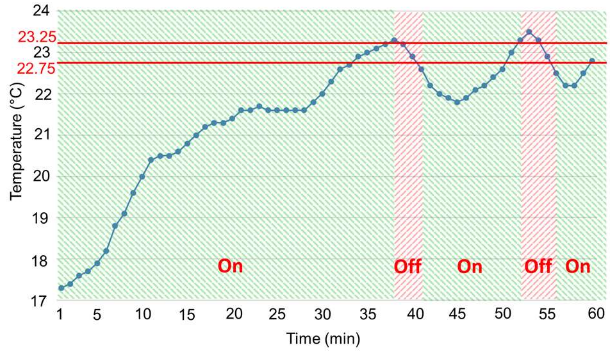

Fig. 7. Temperature variation and heating device state during the first scenario

B. *Scenario 2: Testing the EMS working in a real situation*

This scenario aims to simulate a real situation in order to validate the EMS functioning when it will be installed in the buildings. It is assumed that the door and the window are closed, and the occupancy in the room changes. The initial temperature thresholds are the same as the first scenario, with a decrease of 2°C when the room is not occupied. A running of the scenario for one hour is presented in Fig.8. From the minute 11 to 30 the binary input presenting the occupancy sensor has been set to 0. As shown in Fig.8 the heating management agent has updated the temperature thresholds and interacted with the heating actuator agent to decrease the room temperature around 21°C when there is no occupant.

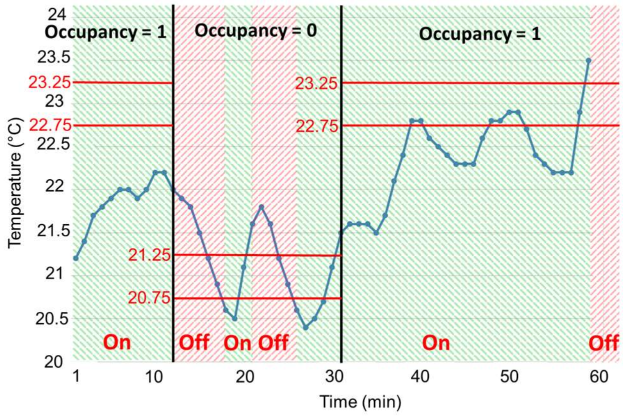

Fig. 8. Temperature and occupancy variation and heating device state during the second scenario

VII. Conclusion

This paper presents a Multi Agent approach for the energy management of residential connected microgrid. The system architecture consists of classical microgrid elements along with communication network ensuring the data flow using Modbus protocol. A database model was developed in order to organize the data flow with other important data for the EMS operation. Proposed agents are essentially physical agents for the communication network elements and mobile software agents for each management algorithm and the user interface. To validate the proposed approach, two scenarios have been performed using a heating management algorithm for a room demonstrator. The first scenario validated the interaction between agents in real time, and the second aimed to simulate a real situation when the heating device is on and the occupancy of the room varies. In general, the EMS functioning has shown promising results. In fact, the real time response of the heating actuator agent and the interactivity of the agents lead to an efficient energy control allowing reduced energy consumption.

As a future work, we plan to extend the physical and software architecture of the system and to deploy it on the real REZBUILD buildings in order to validate the MAS model efficiency in the management of residential microgrids. The implemented algorithms presented in this paper are basic, but they will be used to validate the real implementation. The next step will be the integration of artificial intelligence algorithms prediction based on Artificial Neural Networks.

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