Multi Agent-based Smart Home Electricity System Considering Electric Vehicle

Amin Shokri Gazafroudi[1*], Juan Manuel Corchado[1,2]

1. Dept. of Computer Science and Automation, University of Salamanca, Salamanca, Spain, 37008

2. Osaka Institute of Technology, Asahi-ku Ohmiya, Osaka 535-8585, Japan

For correspondence:

shokri@usal.es

PhD Student, Dept. of Computer Science and Automation

University of Salamanca, Salamanca

Spain, 37008

Abstract: This paper proposes a Multi-Agent system that models the Smart Home Electricity System (MASHES) to manage electrical energy. The considered system consists of different agents, each with different tasks in the MASHES. The performance of the proposed Home Energy Management System (HEMS) is evaluated using a JADE implementation of the MASHES.

Key-words: Home energy management system, multi-agent system, electric vehicle, energy scheduling.

1. Introduction:

These days, new visions have been discussed to deal with challenges due to increment of renewable energy sources. One of the most consensual solutions is known as Smart Grid (SG) [1]. In this scope, home can transact the generated energy locally [2]. Various researches have been presented for optimal scheduling of smart homes and SGs. In [3], a decision support tool based on a dynamic fuzzy method has been presented. In [4], authors defined an intelligent system to control SGs in the distribution scale of the network. In [5], each smart home has been considered as an independent agent that can purchase, sell, and store electricity. In [6], home energy management system has been defined as an intelligent Multi-Agent System (MAS). In [7], a MAS has been used in the distribution network scale, while agents consist of home agents and retailer agents. In [7], minimizing the payment cost of electricity is the aim of the authors. In [8], a method has been proposed to apply the local energy resources optimally through minimizing the energy loss. In this paper, the MASHES is defined as a multi-agent system where each agent has different tasks in the system. Energy scheduler of the MASHES is responsible to manage inside electrical energy as well as the smart home can trade electrical energy in the electricity market.

The rest of this paper is organized as follows. Section 2 introduces the MAS structure of the smart home. Then, the proposed home energy management problem is described in Section 3. Section 4 states the simulation results. Finally, Section 5 provides the conclusions.

2. Multi Agent-based Smart Home Electricity System (MASHES):

The physical system of the MASHES is seen in Fig.1. There are two layers in the MASHES. First layer is the electricity system which is displayed by black lines. Also, second layer is the communication system that is shown by blue lines. MASHES includes different agents that each of them has different tasks in the system. These agents or group of agents consist of Electrical Loads (ELs), Distributed Energy Resources (DERs), Energy Storage Systems (ESSs), Information Provider (IP), Local Electricity Market (LEM), and Energy Scheduler (ES).

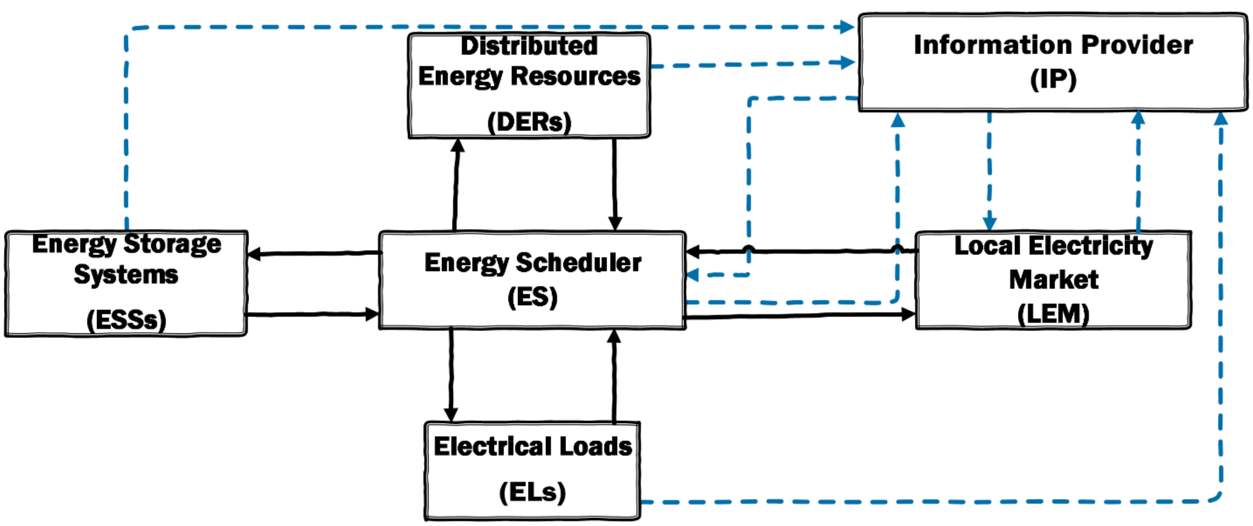

Figure 1 – The physical system of the Multi Agent-based Smart Home Electricity System (MASHES).

ELs are a group of agents that consume electrical energy. ELs can be introduced as an organization basis for different agent kinds in the MASHES. On the other hand, DERs are a class of agents that are in charge of producing electrical energy in a home. Likewise, ESSs -e.g. Electric Vehicles (EVs) and batteries- are the agents that store electricity. IP is another agent that senses and records environmental information from all the agents. LEM is defined as an external agent of a home. In other words, smart homes should be able to connect to the LEM to transact electricity. Finally, ES is a virtual organization of agents who predict and manage energy in the MASHES. The ES includes two agents, one is the Predictor System (PS) and the other one is the Home Energy Management System (HEMS).

3. Home Energy Management (HEM) Problem:

In this section, the proposed HEM problem is defined. The HEMS is responsible to solve the HEM problem and make optimum decisions for the system. In this paper, the Objective Function (OF) is to maximize the expected profit of the provided energy services. As seen in (1), the OF includes five parts. The first part represents the revenue from selling the energy produced by PV system to the power market. The total cost of energy consumption is presented in the second term. The profit from selling the energy produced by EV to the electricity market is represented in the third one. The forth term represents the value of energy which is not served. Finally, the spillage cost of PV system is represented in the last one. It is noteworthy that uncertainty of outdoor temperature and the must-run services are ignored for simplicity in this paper. Also, uncertainty of the PV power generation is modelled based on the prediction interval band. Hence, the amounts of these variables are determined based on the outputs of the PS.

$$EP = \sum_{t=1}^{N_t} (\lambda_{pv_t}.P_{pv,out_t} - \lambda_{net}.P_{net_t} + \lambda_{ev_t}.P_{ev,out_t} - \sum_j \left(VOLL_j.L_{j\ \ t}^{shed}\right) - V_{pv}^S.S_{pv_t}) \quad (1)$$

The power balance equation is represented in (2a). Besides, the power flow limitation through the distribution line is stated in (2b).

$$P_{net_t} + P_{pv,in_t} + P_{ev,in_t} = \sum_j L_{j\ \ t} - \sum_j L_{j\ \ t}^{shed} \quad (2a)$$

$$-f_{max} \leq P_{net_t} - P_{pv,out_t} - \lambda_{ev_t}.P_{ev,out_t} \leq f_{max} \quad (2b)$$

Additionally, all appliances have specific constraints to be modelled in the HEMS. The power output of PV system, P_{pv_t}, is obtained based on (3a).

$$P_{pv_t} = P_{pv_t}^p - S_{pv_t} \quad (3a)$$

$$P_{pv_t} = P_{pv,in_t} + P_{pv,out_t} \quad (3b)$$

$$0 \leq S_{pv_t} \leq P_{pv_t}^p \quad (3c)$$

From (3a), P_{pv_t} is the power output of the PV panels, $P_{pv_t}^p$is the predicted power output of the PV system, and S_{PV_t} is the spillage power of the PV system. Eq. (3b) represents that total power output of the PV system equals its power output which consumed in the home and the amount of power generation that is transact with the power market. The spillage amount of PV system is the amount of power generation that is spilled in period t because of the technical and economic issues. This amount is positive or equal to zero, and is limited to the predicted power generation of PV system as presented in (3c).

In this paper, an EV are only modelled as an ESS. There are different factors that should be considered to model the effect of the EV utilization in the HEM problem. These factors are mobility patterns and battery characteristics of the EV.

$$P_{ev\,t} = -P_{ev,b\,t} - \omega_t^c + \omega_t^d \tag{4a}$$

$$C_t^{ev} = C_{t-1}^{ev} + \omega_t^c . \eta_{H2V} - \frac{\omega_t^d}{\eta_{V2H}} - \frac{\omega_t^m}{\eta_{V2T}} \quad , \quad \forall\, t = 2, \ldots, N_T \tag{4b}$$

$$C_t^{ev} = C_i^{ev} \quad , \quad \forall\, t = 1$$

$$P_{ev,d\,t}^{min} . \eta_{V2H} . (1 - u_t^{ev}) \le \omega_t^d \le P_{ev,d\,t}^{max} . \eta_{V2H} . (1 - u_t^{ev}) \tag{4c}$$

$$P_{ev,c\,t}^{min} . \eta_{H2V} . u_t^{ev} \le \omega_t^c \le P_{ev,c\,t}^{max} . \eta_{H2V} . u_t^{ev} \tag{4d}$$

$$0 \le \omega_t^d \le (C_t^{ev} - P_{ev,d\,t}^{min}) . \eta_{V2H} \tag{4e}$$

$$0 \le \omega_t^c \le (P_{ev,c\,t}^{max} - C_t^{EV}) . \eta_{H2V} \tag{4f}$$

$$P_{ev,d\,t}^{max} - C_{t-1}^{ev} \le P_{ev,b\,t} \le P_{ev,c\,t}^{max} - C_{t-1}^{ev} \quad , \quad \forall\, t = 2, \ldots, N_T \tag{4g}$$

$$P_{ev\,t} = P_{ev,in_t} + P_{ev,out_t} \tag{4h}$$

The power generation of EV is represented in (4a) and (4h). Eq. (4b) represents the state of charge balance equation in an EV, and C_i^{ev} is the initial state of charge in the EV. Maximum and minimum limitations of the EV's discharge current are represented in (4c) and (4e). Also, (4d) and (4f) define constraints of the EV in the charging state. Also, (4g) enforces power limitations of the EV.

As mentioned before, ELs are one group of agents in the MASHES. ELs include loads that can be controllable/shiftable. Eqs. (5a) and (5b) represent maximum and minimum limitations of the ELs' power and energy consumed. Also, (5c) defines the electrical load shedding, $L_{j\,t}^{shed}$, constraint of the Els. Eqs. (5d) and (5e) enforce equal and unequal constraints of the ELs. The interested readers are referred to [9] to know more information about the modeling of different loads.

$$L_{j\,t}^{min} \le L_{j\,t} \le L_{j\,t}^{max} \tag{5a}$$

$$U_{j\ t}^{min} \leq \sum_{t=1}^{N_t} L_{j\ t} \leq U_{j\ t}^{max} \quad (5b)$$

$$0 \leq L_{j\ t}^{shed} \leq L_{j\ t} \quad (5c)$$

$$f_a(M_t\ ) = 0 \ ; \quad a = 1, \ldots, N_a. M \in \{L_j, \theta_{out}, \theta_{in}\} \quad (5d)$$

$$g_b(M_t\ ) \leq 0 \ ; \quad b = 1, \ldots, N_b. \quad (5e)$$

4. Results:

The performance of the proposed HEM problem is evaluated in three cases based on the utilization situation of the EV. Also, the physical system from [10] is utilized. However, some modifications of the system parameters are applied to the system too. Detailed information of this test system is available in [9]-[12]. The physical system parameters are:

- PV system: Maximum power produced by PV system is 2-kW.
- EV: The EV can store between 1.77 and 5.9 kWh, and maximum charging/ discharging rates are 3 kW. Charging and discharging efficiencies are 90%.
- Space Heater: Maximum heating power equals 2 kW to maintain the temperature of the house within ±1 of desired temperature (23℃). The thermal resistance of the building shell is equal to 18℃/kW and C equals 0.525 kWh/℃.
- Storage Water Heater: The energy capacity of the storage water heater is 10.46 kWh (180 L) which has 2 kW heating element.
- Pool Pump: The pool pump is utilized for pool maintenance which its rated power is 1.1 kW, and it can run for maximum 6 hours during the day.

As highlighted, there cases are defined to assessed our proposed system's performance as described in the following:

- Case 1: EV is not considered in the HEMS.
- Case 2: EV is considered in the system and is available at home in all hours.
- Case 3: EV is not available between 7 A.M. and 5 P.M. (more realistic case). In this case, it is considered that EV should be full charge at 7 A.M., and its charging state will be at minimum level at 5 P.M.

Table 1 presents the expected profit of the system in these three cases. As seen in Table 1, the expected profit of the system in case 1 is less than other cases. On the other hand, the expected profit in case 2 has the highest amount because the EV is available in all hours. Hence, it plays as a battery in the system in case 2. However, in the real case, it is clear that EV will not be available in all hours in the home. Hence, case 3 has been defined in this study. Moreover, Table 1 states that considering the EV in the HEMS increases the exchanged electrical energy between the home and the power grid. EV increases the amount of energy that is sold to the power market.

Likewise, the bought energy from the power grid will be increased to provide the electrical consumption of the EV in the charging mode. However, the expected profit of the system considering the EV will be increased because the price of electricity that is sold to the power market is more than the price of the bought electricity.

Table 1 – Impact of the EV on the expected profit, bought/sold energy.

	Expected Profit ($)	Bought Energy (KWh)	Sold Energy (KWh)
Case 1	20.285	39.86	8.41
Case 2	93.551	55.105	44.41
Case 3	50.73	39.86	23.41

In addition, Fig. 2 shows the charging and discharging power curves of the EV in case 2 and 3. As shown in Fig. 2, in case 3, charging/ discharging power of the EV in time period 7 A.M.-5 P.M. equals zero because the EV is out of the home, and it cannot be included in the HEMS.

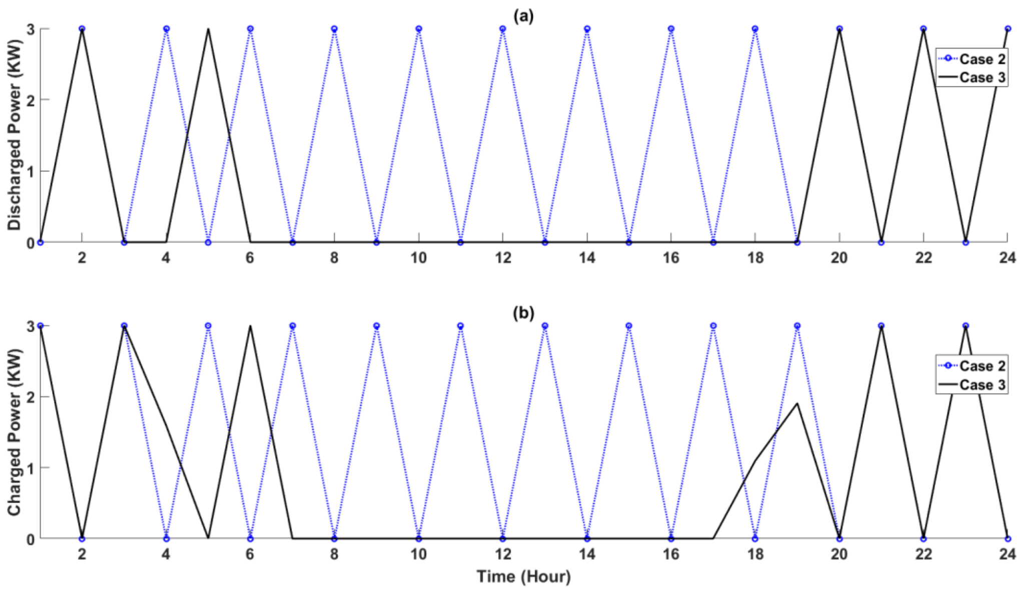

Figure 2 – Charging/Discharging power curve of the EV.

5. Conclusions:

In this paper, the multi agent-based smart home electricity system has been introduced. Also, home energy management system has been described considering the EV. To assess performance of the system, three cases have been considered, and their effects on the expected profit of the system, the bought and sold energies have been studied.

According to the proposed case study, the EV has a positive impact on the expected profit of the HEMS, and bought/sold energy. We do not consider transportation problem in this work. Hence, multi agent-based HEM and transportation systems will be defined simultaneously in our future work.

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