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Multi Agent System Design for PV Integrated Home Management

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Abstract- This paper focused on an energy management cooperation concept for a dwelling photovoltaic/battery system. The application of multi-agent system (MAS) was investigated as a key technology to provide a distributed flexible micro-network control. Indeed, in a multi-agent technique each function of the system is assigned to a separate agent, providing thereby a higher modularity and greater autonomy compared to a traditional system. The agents are usually tightly linked and communicate typically through messaging. The main task in this work was the design of a dynamic system of smart building loads and energy producing equipment, modelled by simple agents that communicate within a MAS approach. The major aim was to set up an intelligent habitat system which components are able, to make decisions and optimize energy consumption through intercommunication, without affecting the inhabitant comfort. To validate the elaborated design, different simulations were performed. The results show that this approach is able to reach optimal configurations.

Keywords PV, Multi-agent system, Demand Side Management strategy, Dynamic behaviour.

1. Introduction

The concept of the intelligent network is a new generation of distribution systems that has grown nowdays due to the emergence of new monitoring, automation and communication equipment. This evolution has enhanced the emergence of intelligent methods for power quality improvement, price monitoring at all times, energy source management and demand management [1].

Since the power grid must always be stable and all operations have to be achieved safely, a detailed planning strategy for predictable levels of renewable energy sources (RES) / demand deployment is recommended during the integration of new loads such as the electric vehicle. This intelligent management strengthens the existing network infrastructure [2]. The same technological evolution has been proceeded from the macro grid level to the micro grid one. It may affect the micro-network especially as the housing sector accounts for a significant part of energy consumption. In this case, a home automation system appears as the solution of the huge energy consumption problem. This solution has an economic impact since electricity cost drops by 18% if only 40% of the devices were controlled [3].

Considering the multiple advantages of this new research trend, several studies have been developed to propose energy management algorithms of dwelling integrating eventually photovoltaic systems. The main objective was to reduce the electricity cost through minimizing the daily energy consumption without affecting the residents’ comfort [4]. Several authors have therefore developed some management methods such as the so called "restricted method" based on predefined rules [5]. Complying to the organization of the supervision system, they developed predictive management algorithms based already on known data.

Ref. [6-8] use the Mixed Integer Linear Program (MILP). This algorithm is applied to manage the household appliances. An efficient mathematical study can determine the best dwelling model taking into account weather forecasts and energy efficiency criteria. Various other studies focus on the demand side management (DSM) approach to adapt energy consumption to production needs. Acting on the load profile allows maximizing the benefits of renewable energy in order to ensure the minimum system cost [9,10]. The DSM technique leads to minimize energy consumption during the peak hours and to alter it at the off-peak hours. Shedding and shifting are the main techniques used by the DSM and solved by different energy management algorithms [11,12]. Several authors rely on the Multi-Agent-System approach (MAS) to show the possibility of making decision in the habitat context and allow embedding communication with the different home appliances [13-15].

As a definition, the MAS approach is a loosely coupled network of software agents that interact to solve problems. So it consists of intelligent agents whose behaviors are in harmony knowing that several researchers have specialized in their behavioral study [16]. They found an interaction model between them in order to improve the reactive management of the renewable energy sources [17] and master response services to the consumer's residential demand [18].

The multi-agent systems control can be carried out according to three associated structures: centralized, decentralized and distributed structures. The centralized system [19], is characterized by a master / slave approach. In fact, the master controller is responsible for collecting information from all agents, generating control signals and returning them to the slave agents. The high bandwidth of the centralized intercommunication between central controller and slave agents leads to a system malfunction even when there is an exposure of a single failure point. In a decentralized control system, each agent reaches its own satisfaction through the embedded individual controllers without a communication network [20]. In spite of the limitation of the information exchange, it is possible to ensure that the modules share a common control objective by proving a global reference signal. However, the responsibility of each controller for its own data weakens the appropriate adaptation and may change of information and objectives in the global system-level data. The third control system is that of the distributed system [21-23]. Based on embedded controllers in each agent, the communication between each agent and its neighbors takes place via a cyber network in order to achieve the overall control objective. This communication network type enhances the reduction of communication infrastructure costs and makes it scalable when compared to a fully connected network.

Thanks to its reliability, the multi-agent technique can be exploited in diverse areas. For example, a distributed multi-agent infrastructure for reactive power management with wind power generation has already been used in [24]. The main goal was to maintain the dynamic voltage stability through a DC bus voltage control. The MAS architecture can be also applied to a cluster of Building Energy Systems (BESs). It is integrated in [25] for the programming concept of domestic heating devices. The purpose of this work was to use a planning ability that takes into account the dwellers' wishes on the one hand and achieve a system level objective (SLO), on the other. In the domestic field, this approach focuses on demand and delay management [26, 27], as well as the energy production and storage control [28]. So, to promote the efficient exploitation of this home management system, a satisfaction concept has already been discussed in [29].

In this context, this paper investigated a new distributed MAS approach for power management in smart household application of integrated renewable energy sources.

The remaining contribution of this paper can be distributed over five sections:

- ✓ After the introduction section, a building energy control incorporated in a Multi-Agent approach was proposed in section 2. It consists of a number of intelligent agents that simultaneously coordinate with their neighboring agents and represent various behavioral models to provide information about energy and its flow through the different physical processes. Using the various agents' generated clustered data, the main objective of this system was to improve the renewable sources exploitation and production in order to provide high quality household services.
- ✓ In section 3, the UML diagram has introduced in order to organize the relation between all agents which each one is defined by a specific service SRV(i).
- ✓ Relating on the service notion, a dynamic behavioral modeling of a chosen residential micro-grid is investigated within a multi-agent-system approach during the section 4. The studied system consists of photovoltaic arrays and a centralized battery bank for residential application.
- ✓ In section 5, a proposed algorithm is implemented to provide an optimal solution of the loads electricity distribution in each case without affecting the consumers' comfort. Simulation results have demonstrated that the proposed multi-agent system is efficient and convenient as it is able to find an optimal target configuration considering the simple negotiation strategies.
- ✓ The key outcomes of this study have been stated in the conclusion section.

2. Energy Control in a Building Application

The smart building is a complex entity that consists of a number of data sources, data storage and data consumers that must be carefully managed. To control the mobilization and deployment of equipment and tools effectively, we started by mastering the complex interactions between loads operation signals, exploring new modeling techniques and describing the requirements for new simulation tools to control the dynamic coupling between power energy devices.

As a solution, a Multi-Agent System approach was investigated to size, model and simulate a complex system called a "multi-agent home automation system", which relies on various coupled agents, each of which with a specific task, typically communicating via messaging. Each of these agents is responsible for solving the problem of controlling its energy consumption. Indeed, an agent is either real (loads, sources…) or virtual (software…) entity with an autonomous behavior. It is capable of acting and interacting with other agents by sending / receiving messages.

The agent/agent communication protocol provides a standardized Agent Communication Language (ACL) with such nomenclature as:

$\mathrm{SRV(i)}$: Service associated to agent *i* (*i*=1…N)
i: number of agents
ad : Agent which needs energy.
A : Other agent.
STi : Beginning date of the service *i*.
ETi : The end time of the service *i*.
Pi : Required power profile for $\mathrm{SRV(i)}$.

This lexical has been designed to facilitate a high level cooperation and interoperation among the agents and consists of [13]:

- Continuously monitoring the agent satisfaction level (for example, the temperature of the central heating).
- When its satisfaction level falls below a critical value, it informs the other agents by sending messages as follows: $\mathrm{Request}_{\mathrm{SRV(i)}}\left(\mathrm{ad,\ A,\ STi\ ,\ ETi,\ Pi}\right)$.
- It analyzes them and makes proposals in return after receiving requests from the other agents. The typical message has the following syntax: $\mathrm{Propose}_{\mathrm{SRV(i)}}\left(\mathrm{A,\ ad,\ propositions}\right)$
- When it receives answers to its own requests, it chooses the most interesting proposal. This is the third step in our ACL system: $\mathrm{Accept}_{\mathrm{SRV(i)}}\left(\mathrm{ad,\ A,\ proposition}\right)$

Figure1 summarizes the interaction concept between two agents.

3. Studied System Presentation

The aim of this paper was to develop an architectural solution for a better electrical control strategy based on MAS approach for a residential grid connected PV/battery system. The cluster ensures the interaction between the following elements: production sources, capacities, storage system and means of communication, to achieve the following goals:

- Energy optimization thanks to the proximity between a local electricity production and the consumers, which leads to an immediate loss minimization related to the consumed energy.

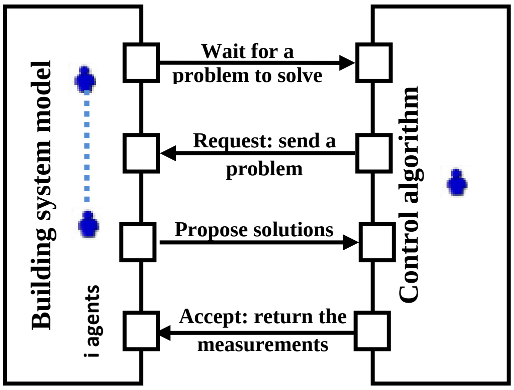


Fig.1. Standard ACL communication protocols

- Economic valorization through the energy resale and the provision of system services
- Increase the installation reliability to work in standalone mode.

We proposed, then, a new concept for programming home appliances scheduling the building clusters energy system using MAS architecture. This architecture is made up of agents that ensure specific tasks, interact and communicate to achieve the control strategy goals. Moreover, the agents are associated with an equipment and energy source production and therefore can be piloted. Figure 2 presents the overall structure of the proposed system, which consists of various household equipment supplied by the PV and the storage system as sources of energy and connected to the grid.

The first idea was to associate each agent with a specific service. However, this generic notion allows defining two main categories of services: temporary and permanent.

Each service has to satisfy the user's desired requirements. This notion is translated by the performance degree through a satisfaction function.

3.1. Service concept

A home control system is integrated into the building to provide new energy management functions. These functions make it possible to synchronize and coordinate the various energy activities by exploiting new interfaces that are dedicated to the communication components. Thus, we can talk about the concept of energy services within the same building. In fact, each household equipment can be presented as a service $\mathrm{SRV(i)}$ which is capable of continuously describing its behavior and relations with the energy resources and the other loads [6].

To organize the relation between all the services, the UML diagram is used and schematized by figure 3.

3.2. UML diagram

The UML diagram presents the classes and interfaces of the services as well as the different relationships between them. It consists of four main elements:

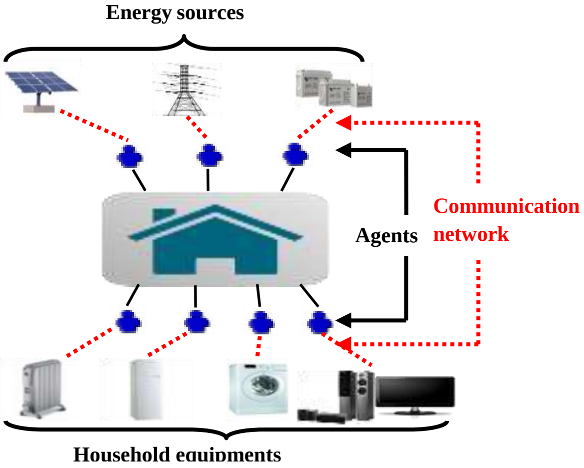


Fig.2. Architecture of the system

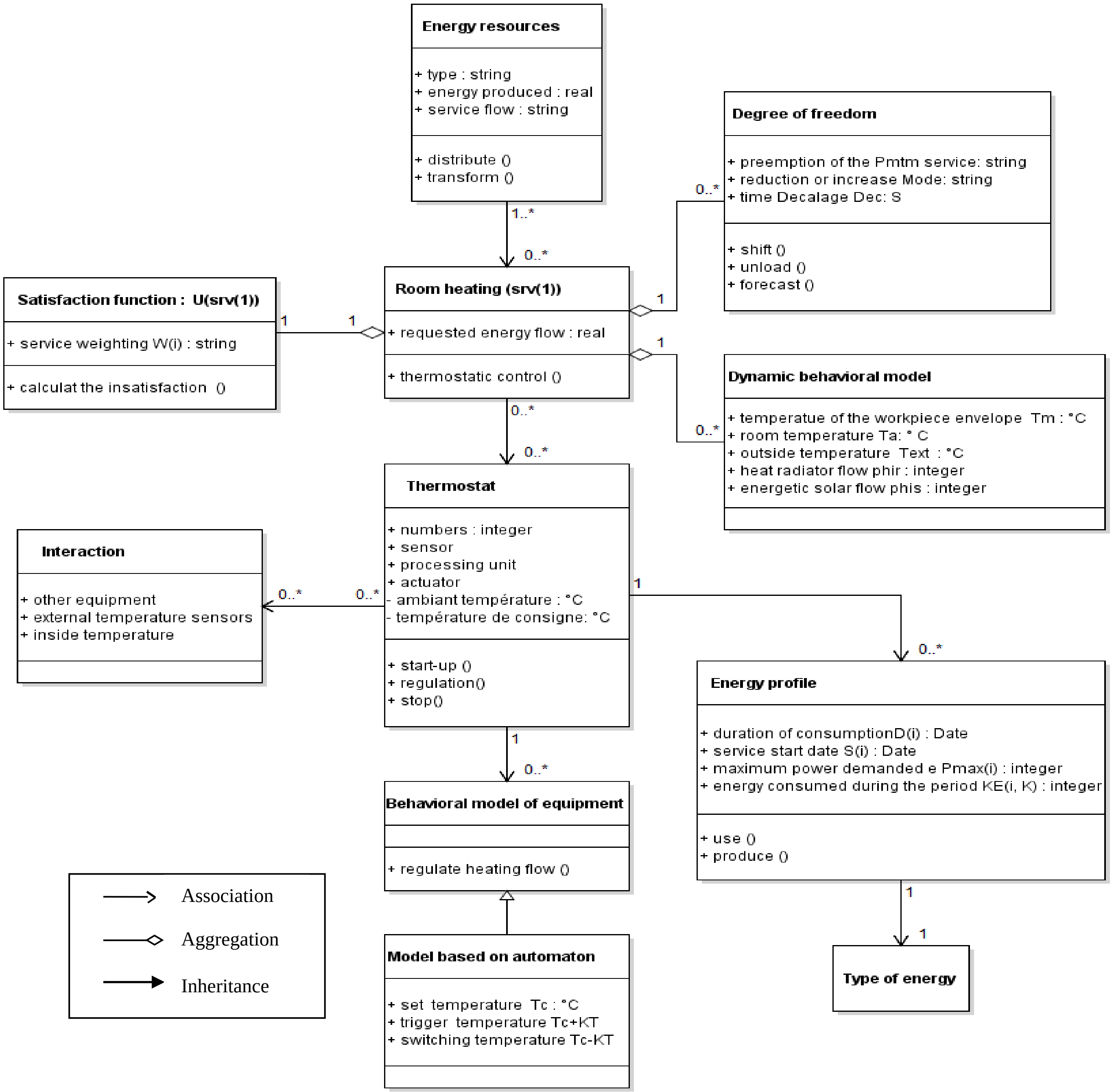


Fig.3. UML diagram of heating service *SRV*(1)

- The studied service name (e.g heating service, cooling service…).
- The energy provider element.
- Interactions between the equipment parts: exchanges of energy flow or information.
- Managing the different energy activities, the behavioral system model plays a very important role for the exploitation of the system freedom degrees. There are four types of models: the continuous dynamic models, the finite state models, the hybrid model and the static model [6].

4. Modeling Services

4.1. Modeling service performance: Satisfaction function

In home automation, the "users comfort" is one of the most important aspects to be taken into consideration. The concept of comfort can be directly linked to the concept of a satisfaction function. Thus, a problem formulation of satisfaction has been proposed [6, 13 and 29]. Satisfaction functions have been defined by equipment as well as by energy sources and expressed between 0% and 100%.

The satisfaction function of a permanent agent (e.g: heating service) is represented by figure 4. It can be estimated by the linear function which depends on the characteristic variable $x_c(t)$ of each service according to its range limits x_{cmin} and x_{cmax}.

The satisfaction function of a washing machine which is considered as a temporary agent can also be estimated by the linear function which depends on the shift of the service from the end date desired by the user as shown in figure 5. RET_i, DET_i, EET_i and LET_i are respectively, the end time service, the desired end date, the earliest end date and the latest end date. A behavioral model is used to define consumption/production of energy for this service. In this part, a finite state automaton defines the service operation steps described in part (4.2.2.).

The satisfaction function of a support service is presented by a linear function with a negative coefficient of proportionality as shown in figure 6.

4.2. Loads behavioral models

The objective of this part was to find a general formalism for the modeling of different elements of the studied residential system. These models describe the continuous or discrete evolution function of each service.

4.2.1. Dynamic models

Two dynamic models were considered for this selected home automation application: the heating model and the refrigerator model.

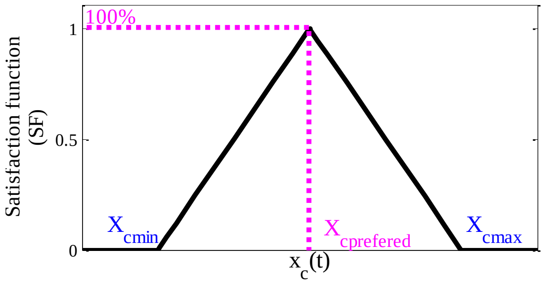


Fig. 4. Satisfaction function of permanent service.

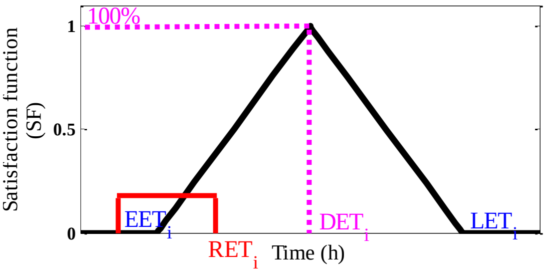


Fig. 5. Satisfaction function of temporary service.

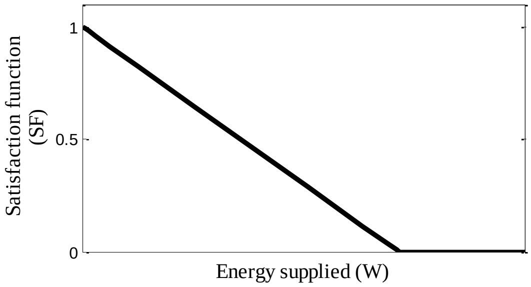


Fig. 6. Satisfaction function of energy source.

- Heating service model: The heating environmental model of the room is considered as a continuous thermal model. It can be described by the following state space system [6]:

$$\begin{cases} \dfrac{dx_c(t)}{dt} = A_C x_c(t) + B_c U_c(t) + F_c P_c(t) \\ y_c(t) = C_c x_c(t) \end{cases} \tag{1}$$

Where

$x_c(t)$ represents the state variables which are the temperature values.

$U_c(t)$ contains the control input variables such as energy flow.

$P_c(t)$ contains known but uncontrolled input variables such as outside temperature and solar radiation.

To model the internal dynamics temperature for a heating room service, a first order system state is proposed by an analogy with an RC electrical model. Considering that the heat capacity of the walls is relatively low, the heating model dynamic equation is resolved in equation (2), and described as shown in figure 7:

$$\begin{cases} \dfrac{d}{dt}\begin{bmatrix} T_{in}(i,t) \\ T_{env}(i,t) \end{bmatrix} = A_c \begin{bmatrix} T_{in}(i,t) \\ T_{env}(i,t) \end{bmatrix} + B_c\left[P_{rad}(i,t)\right] + F_c \begin{bmatrix} T_{out}(i,t) \\ \Phi_s(i,t) \end{bmatrix} \\ T_{in}(i,t) = C_c \begin{bmatrix} T_{in}(i,t) \\ T_{env}(i,t) \end{bmatrix} \end{cases} \tag{2}$$

With: $A_c = \begin{pmatrix} \dfrac{-1}{r_{in}c_{env}} & \dfrac{1}{r_{in}c_{env}} \\ \dfrac{1}{r_{in}c_{in}} & \dfrac{r_{in}+r_{env}}{r_{in}c_{in}r_{env}} \end{pmatrix}$, $B_c = \begin{pmatrix} 0 \\ \dfrac{-1}{c_{in}} \end{pmatrix}$, $F_c = \begin{pmatrix} 0 & 0 \\ \dfrac{1}{r_{env}c_{in}} & \dfrac{w}{c_{in}} \end{pmatrix}$ and

$C_c = \begin{bmatrix} 1 & 0 \end{bmatrix}$

The dynamic temperature variation of the heating service $SRV(i=1)$ at a given time t depends on the following variables:

- T_{in}, T_{out}, T_{env} indoor and outdoor temperature and middle envelope of the component temperature, respectively.
- c_{in}, c_{env} are the thermal capacity inside the casing and housing.
- r_{in}, r_{env} are the thermal resistances.
- w is the equivalent surface of the window.
- P_{rad} is the consumed power by the heat generator.
- Φ_s is the energy flow generated by solar radiation.

After taking into consideration the presence of the user in the room $\mathrm{occ(t)}$, it is recommended to use a thermostat in order to control the temperature inside the room T_{in}. The constraint associated to the thermostat model is:

$$\begin{cases} T_{min} \le T_{in}(i,t) \le T_{max} & \text{if} \quad \mathrm{occ(t)} = 1 \\ T_{in}(i,t)\ ;\ T_{out} & \text{if} \quad \mathrm{occ(t)} = 0 \end{cases} \tag{3}$$

The simulated heating model is based on real output temperature data T_{out} collected for the studied city on a winter day as shown in figure 8.

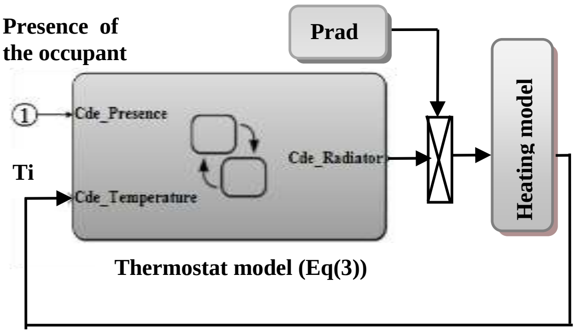


Fig.7. Heating model

The main objective is to satisfy the inhabitant comfort in the most unfavorable conditions.

As shown in figure 8, the scenario analysis interferes considerably with the desired limits temperature T_{max} (22°C) and T_{min} (17°C) of the studied heating system [4]. In fact, when the heating service is on, the temperature profile inside the room should oscillate between T_{min} and T_{max}. Otherwise, T_{in} sustains T_{out}.

Figure 9 shows the hourly plot of a chosen scenario of habitat presence in the household during 24 hours. The purpose was to carefully monitor the user's demand in his presence. From the above case study, it is obvious that the start-up of the radiator is simultaneously conditioned by two constraints as indicated in figure 10: the presence of the inhabitant in the living room and the absence of T_{in} inside the satisfaction temperature interval $\left[T_{min}, T_{max}\right]$. Indeed, although the inhabitant presence was reported in from 12pm to 1pm, the radiator worked only when T_{in} p T_{min}.

- Refrigeration model: This service is similar to the heating system in its behavioral model since it is also considered as being a thermal service. The heat exchanges are modeled by equation (4), and validated in figure 11 and figure 12:

$$\begin{cases} \dfrac{d(T - T_{out})}{dt} = -\dfrac{1}{\tau}\left(T - T_{out}\right) + \dfrac{k}{\tau} P_{refrig} \\ \dfrac{d(T - T_{out})}{dt} = -\dfrac{1}{\tau}\left(T - T_{out}\right) \end{cases} \tag{4}$$

Where:

T is the inside cooling temperature.

T_{out} is the outdoor temperature.

P_{refrig} is the compressor power.

k is the refrigerating factor of the refrigerator.

τ is the time constant [S].

When the inside refrigerator temperature exceeds 4°C the compressor starts, the refrigerator consumes 100 Watts. When the temperature drops below 2°C, the compressor stops.

4.2.2. *Finite state machines*

A one finite state machine dedicated to a service of washing machine, denoted $\mathrm{SRV(i)}$, has been studied in this application.

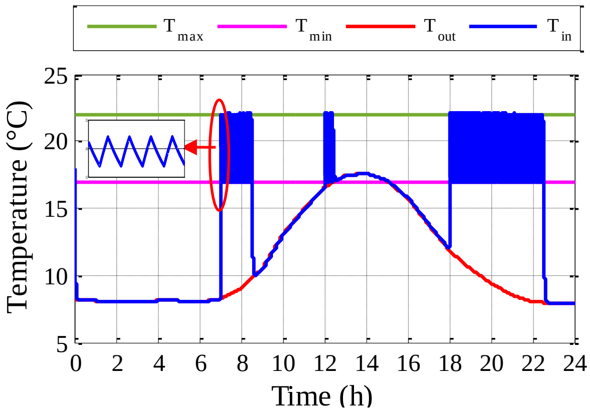


Fig. 8. Temperature evolution inside the room

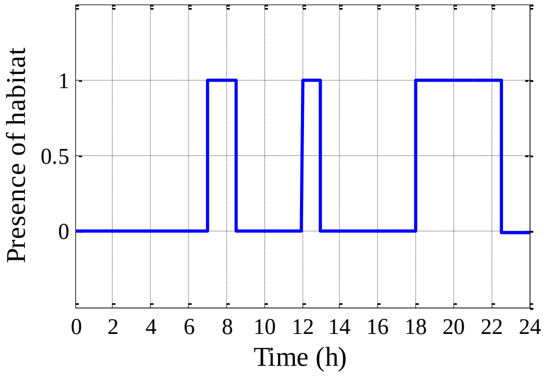


Fig. 9. Presence sensor signal

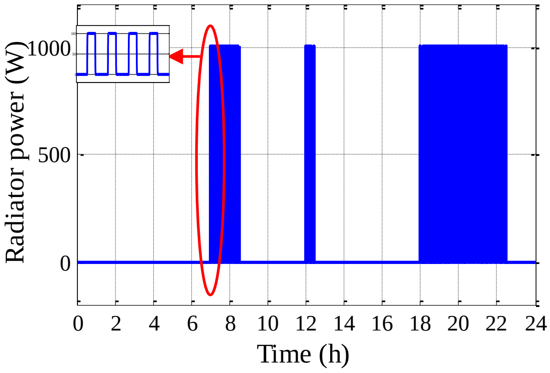


Fig.10. Radiator operation

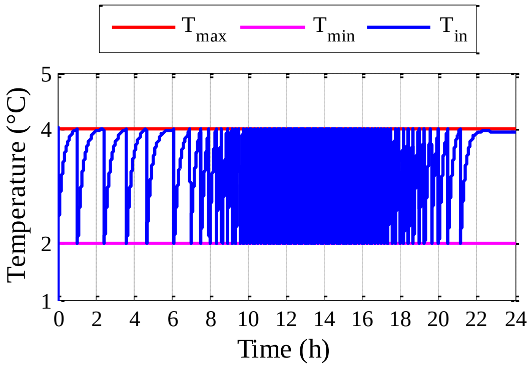


Fig.11. Temperature variation inside the refrigerator

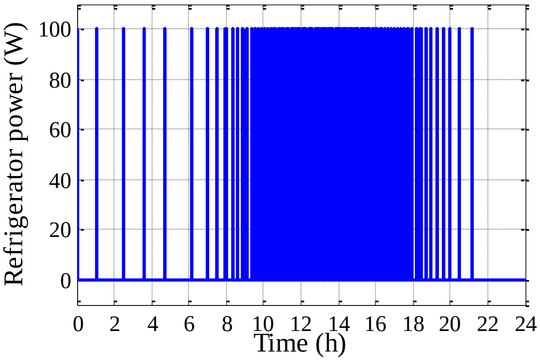


Fig.12. Compressor operation

This domestic appliance comprises three main operation steps {E}:

- The heating water step, characterized by high energy consumption which varies according to the water temperature.
- The washing and rinsing step which is characterized by low power consumption
- The Wringing step.

These steps occur automatically following a typical transition procedure {T}. The start date of the operation is fixed according to the energy availability during the day and the desired end time interval $\left[EET_i, LET_i\right]$ as described in section (4.1.). Each step (j) of the washing service is modeled by a quantity P_j consumed during the period $ET_j - ST_j$. ET_j is the end date of step j and ST_j is the start date of step j [7, 13]. The operation steps of the washing machine are linked together in a predefined order in which the transition to the next step is activated by the end of the previous step as shown in figure 13.

The washer electricity consumption is mainly used to heat the water. For this reason, the duration and the required power of each cycle varies according to the used water temperature as shown in Table 1 and Table 2 [30].

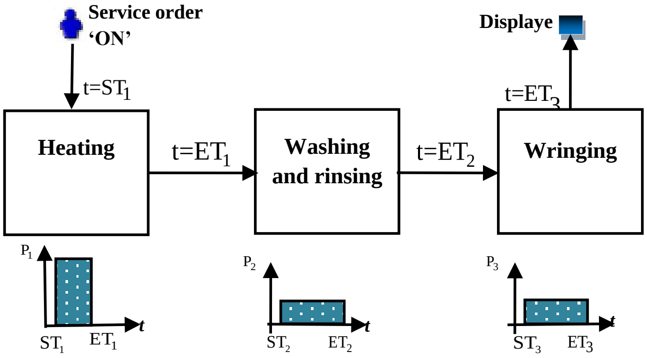


Fig.14. Behavioral operation of washing machine

Figure 14 shows the simulation results of this model using a temperature of 60°C.

Table 1. Duration of each cycle (min)

Temperature (°C)	30-40°C	60°C	90°C
Cycle duration (min)	70	90	130
Heating	15	20	30
Washing and rinsing	40	50	80
Wringing	15	20	20

Table 2. Required power of each cycle (W)

Temperature (°C)	30-40°C	60°C	90°C
Power (W)	1100	1400	1600
Heating	76%	87%	92%
Washing and rinsing	11%	6%	4%
Wringing	13%	7%	4%

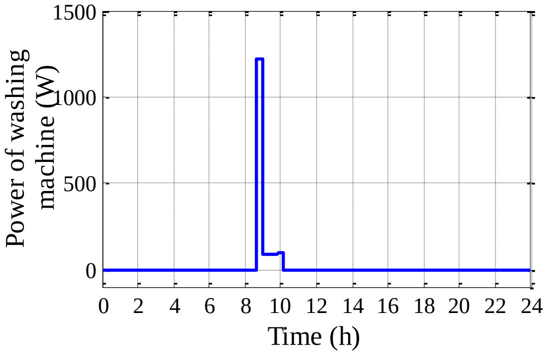


Fig.13. Power profile of a washing machine with 60°C

4.2.3. Hybrid model

Various services combine the finite automaton model with the continuous dynamic model. In fact each finite state is modeled by a differential equation. The storage service is considered to be a hybrid service represented by figure 15.

$SOC_{batt}(t)$ and $P_{batt}(t)$ define respectively the battery state of charge and the controlled battery power exchanged. As defined in equation (5), the dynamic battery model depends on the efficiency factor $\eta_{ch.batt}$ that relied on the battery power during the charging step $P_{batt+}(t)$ and the efficiency factor $\eta_{dis.batt}$ that relied on the battery power during the discharging step $P_{batt-}(t)$ whereas the loss *factor* $\eta_{loss.batt}$ is constant [28]:

$$\frac{dSOC_{batt}}{dt} = \eta_{ch.batt} P_{batt+} + \eta_{dis.batt} P_{batt-} - \eta_{loss.batt} SOC_{batt} \quad (5)$$

The state of the storage system has to give satisfaction at all times the following constraints:

$$\begin{cases} SOC_{min} \le SOC \le SOC_{max} \\ 0 \le P_{batt+} \le P_{batt\,max} \\ P_{batt\,min} \le P_{batt-} \le 0 \end{cases} \tag{6}$$

Where SOC_{min}, SOC_{max}, $P_{batt\,min}$ and $P_{batt\,max}$ represent respectively the battery SOC lower limit value, the battery SOC upper limit value, the discharge minimum power and the maximum power for charging a battery [11].

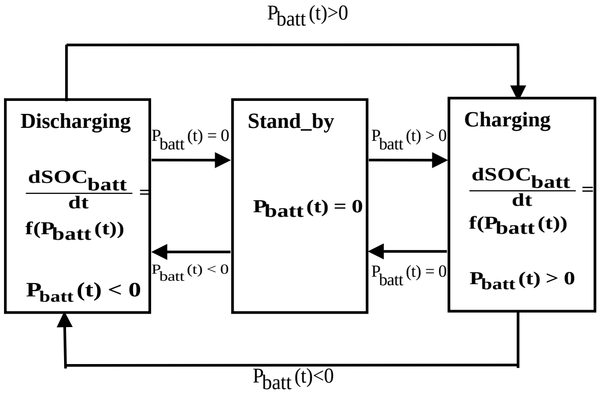


Fig. 15. Hybrid model of a battery

Figure 16 shows the electrical behavior of a battery bank consisting of 4 batteries connected in series with 12 V each and a total capacity of 450 Ah. The battery state of charge is conditioned by the limits $SOC_{min}=0.4$ and $SOC_{max}=0.9$ which cannot be exceeded. The power variation range within the battery oscillates between -1500 W and 1500 W.

As indicated in figure 17, according to the imposed power profile by the proposed multi-agent-management-system, the battery can be charged or discharged. If the $P_{batt}(t)$ power is negative: $P_{batt}(t) = P_{batt-}(t)$, the battery discharges to cover the required energy lack and consequently the state of charge $SOC_{batt}(t)$ decreases. Since the priority loads must always be satisfied in whatever condition, the storage system must be carefully sized to avoid being completely discharged and reaching the lowest state of charge SOC_{min}. To ensure a balanced power system, the excess of the generated renewable energy after satisfying the loads has to be stored in the battery without exceeding the maximum state of charge level limit SOC_{max}. Violating this constraint leads to send the difference power to the public grid.

4.2.4. Static model

The renewable energy source commonly used in household appliances is the PV source. As it is indicated in equation (7), the PV output power under the nominal conditions of solar irradiation P_{pv} is expressed as a function of the PV area, solar radiation conditions and its efficiency [4, 10, 31].

$$P_{pv} = \eta . A_p . N_p . E \tag{7}$$

Where:

η : The energy conversion efficiency.

A_p : The area of single PV panels.

N_p : The number of PV panels.

E : The solar radiation value.

For 2 KWc of photovoltaic power under standard measuring conditions with a PV area of 2 m² and an efficiency $\eta = 12.5\%$, the generated PV power follows systematically the irradiation evolution during the whole day as it is indicated in figure 18 And figure 19.

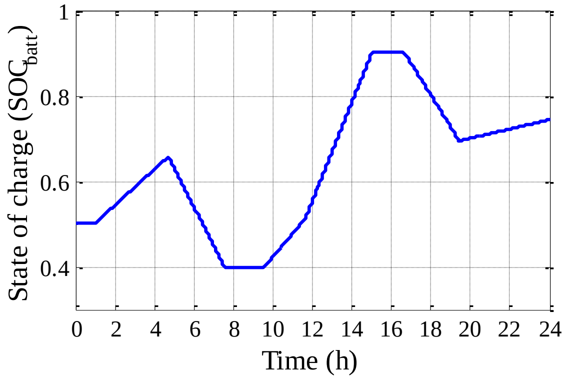


Fig. 16. Storage system SOC

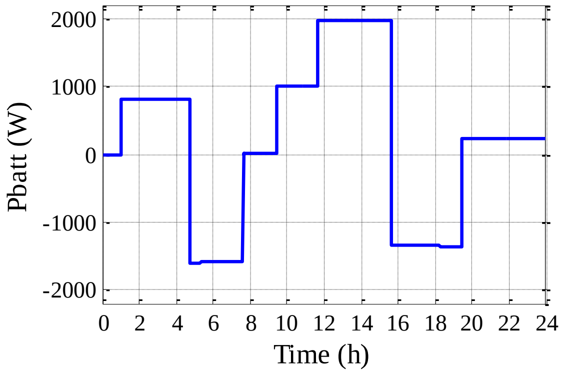


Fig. 17. Battery power profile

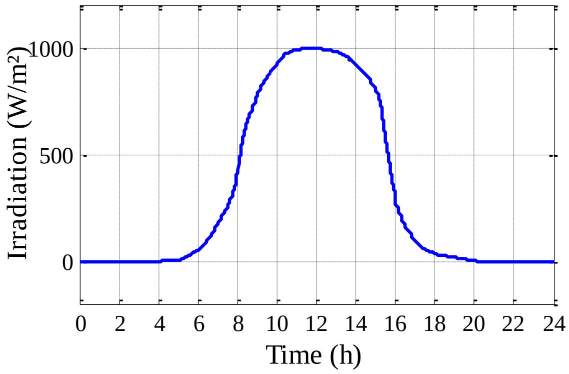


Fig.18. Irradiation profile

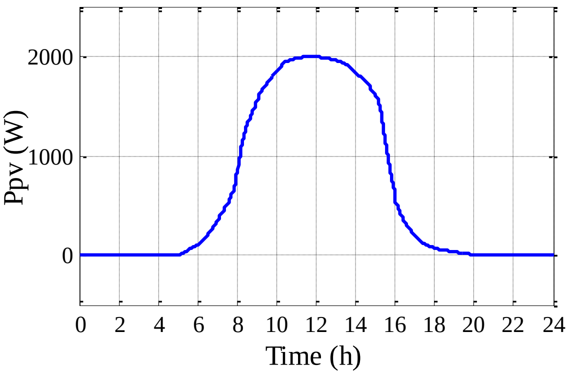


Fig. 19. PV profile

5. Case Study

In this work, a typical Tunisian home with a minimum annual average electricity consumption of 4000 KWh and benefiting from the PRSOL ELEC support mechanism [32] has been studied. In this case, the consumer will benefit from a PV power station of 2 KWc. Then the simulated model is based on theses collected actual measurements according to the customer's energy satisfaction. The chosen loads are classified in order of priority according to their service identifier and power identifier, as shown in table 3. The studied energy storage system is made up of 450 Ah storage capacities dimensioned only for priority loads P_{1_1} and P_{1_2} with one-day autonomy. P_1 is defined as the sum of the priority loads P_{1_1} and P_{1_2}: $P_1 = P_{1\_1} + P_{1\_2}$.

P_{2_1} is defined as the selected power that the washing machine operates with. It can be equal either to P_{2_11} or P_{2_12} or P_{2_13}. P_{2_1} and P_{2_2} are supplied only by the PV panel in a priority order. The simulation was carried out over a period of 24 hours.

The main objective of applying the MAS strategy was to ensure the reliability of power flow distribution between different agents through the communication protocol. As shown in figure 20, the permanent agents (radiator or refrigerator) send their consumption profiles which are fixed according to the user request ($\text{Request}_{SRV(1\_i)}$, i=[1,2]) to the source agent (photovoltaic panels). Thus, the source agents decode the received message, evaluate their power availability ($P_{pv} > P_1$), make the decision about operation, give the order to start the equipment and calculate the new power measurements ($\text{Propose}_{SRV(1\_i)}, i = [1,2]$).

In case of insufficient renewable energy ($P_{pv} < P_1$), the agent associated with the storage system will be responsible for compensating the missing priority loads demand only. Therefore, the storage system has been sized to satisfy only the priority loads in whatever condition. When the battery is completely charged ($P_{batt+} = P_{batt\,max}$ and $SOC_{batt}(t) = SOC_{max}$), the surplus of photovoltaic production will be injected into the AC grid The balance between the generation/demand powers must be carefully controlled. In fact, after taking into consideration the required energy of the priority loads, the remaining energy should satisfy the no-priority loads SRV(2_1i), i=[1,2,3] and SRV(2_2) in order of priority. P_2 is defined as the sum of the no- priority loads P_{2_1} and P_{2_2}: $P_2 = P_{2\_1} + P_{2\_2}$.

Figure 20 shows that the insufficient available power to satisfy the no priority loads (washing machine or home cinema TV) may undergo a total or partial shedding ($P_{pv} - P_1 < P_2$).

As indicated in figure 21, the PV agent interferes considerably in the power distribution of the priority loads (refrigerator and heating system). The startup order of service SRV(1_i), i=[1,2] is given by resetting to state 1.

However, if the instantaneous photovoltaic power is not enough to supply the refrigerator or the heating system, the daily consumption requirements switch the storage system on to be satisfied (between 7 pm and 24 pm for example). Figure 22 shows the state of charge of the battery ranging from 1 for a charged battery, to -1 for a discharged one.

At 10 a.m., the PV panels receive a message from home cinema TV asking for power profile of 500 W during 2 hours ($\text{Request}_{SRV(2\_2)}$) as shown in figure 23. The importance of MAS communication appears at 10:30 a.m. when the user gives an order through his smart phone to connect the washing machine as indicated in figure 23.

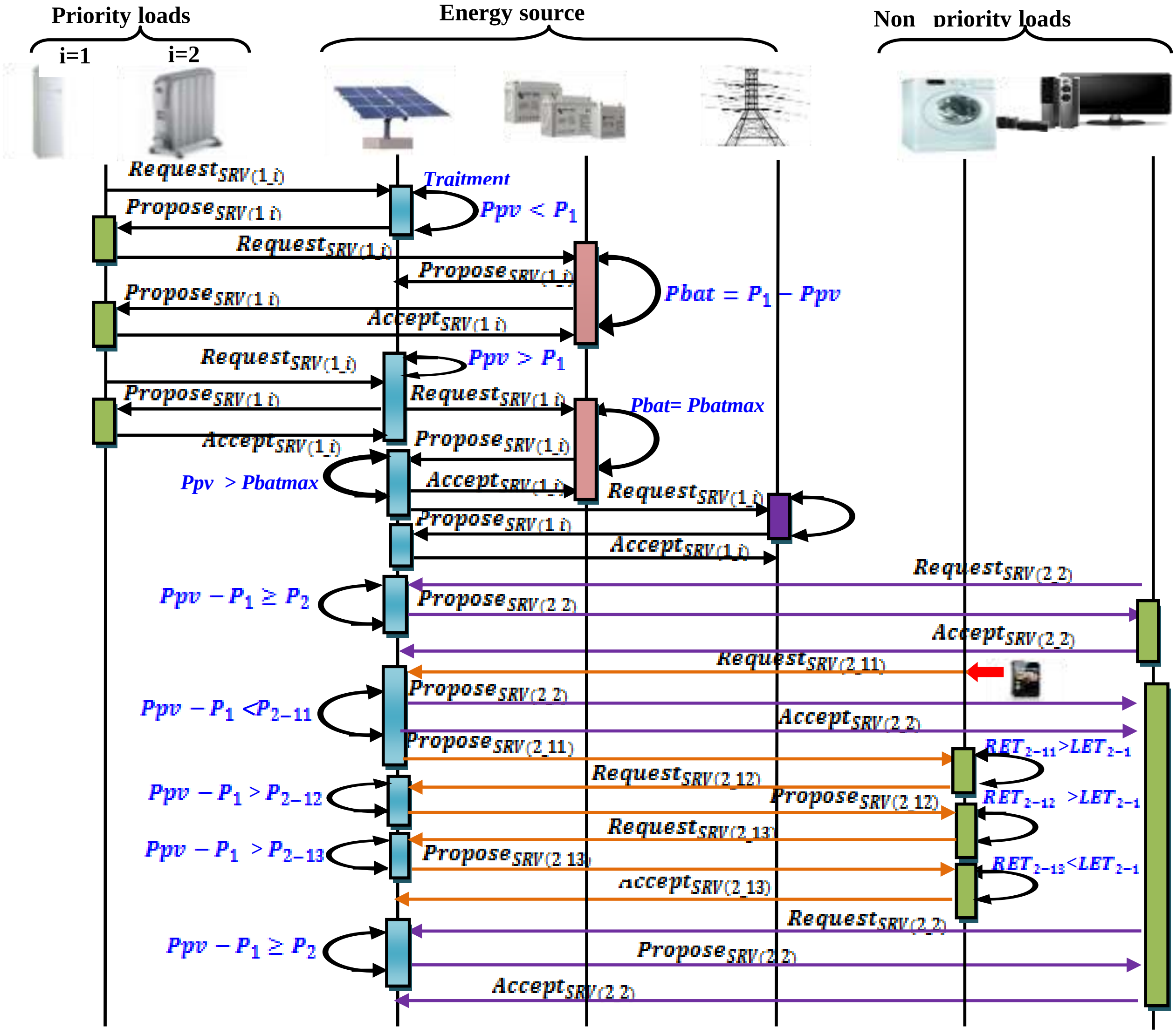
Since the washing machine has a higher priority than the TV and to ensure more cooperation, the PV agent announces in this figure that it is unable to satisfy the TV demand during 15 min because the consumption requirements exceed the production capacity of the energy source $P_{pv} - P_1 < P_2$. As a result, the TV operation mode reset to state 0 at 10.30 a.m. and restarts to 1 at 10.45 a.m. Obviously, the startup order of these no-priority services is well respected in figure 24, to validate the exchanged power balance of the studied system. Indeed, two constraints have to be taken into consideration: the availability of the requirement power profile $P_{2\text{-}11}$ and the desired latest end time of washing machine operation cycle LET_{2_1}.

According to the previously defined washing machine behavioral operation in section (4.2.2.), if the available photovoltaic power is lower than that chosen by the user (i.e. $\text{Request}_{SRV(2\_11)}$ =1472W), a modulation order will be sent by the PV agent according to other proposed profiles ($\text{Propose}_{SRV(2\_12)}$, $\text{Propose}_{SRV(2\_13)}$).

Table 3. Variation of power services consumption

Charge	Service identifier	Power identifier	Type	Power (W)	Duration (h)

Refrigerator	SRV(1_1)	P_{1_1}	Permanent	100	24
Heating system	SRV(1_2)	P_{1_2}	Permanent	1005	4
Washing machine	SRV(2_11)	P_{2_11}	Temporary	1600	2.17
	SRV(2_12)	P_{2_12}	Temporary	1400	1.5
	SRV(2_13)	P_{2_13}	Temporary	1100	1.17
plasma TV 94+ home cinema	SRV(2_2)	P_{2_2}	Permanent	500	2



P_1 : Priority loads power
P_2 : No-priority loads power
P_{2-11} : The first desired power profile
P_{2-12} : The second desired power profile
P_{2-13} : The third desired power profile

LET_{2-1} : The desired latest end time of washing operation
RET_{2-11} : The first real end time of washing operation
RET_{2-12} : The second real end time of washing operation
RET_{2-13} : The third real end time of washing operation

Fig. 20. Sequence diagrams in UML shows the negociation protocol between agents

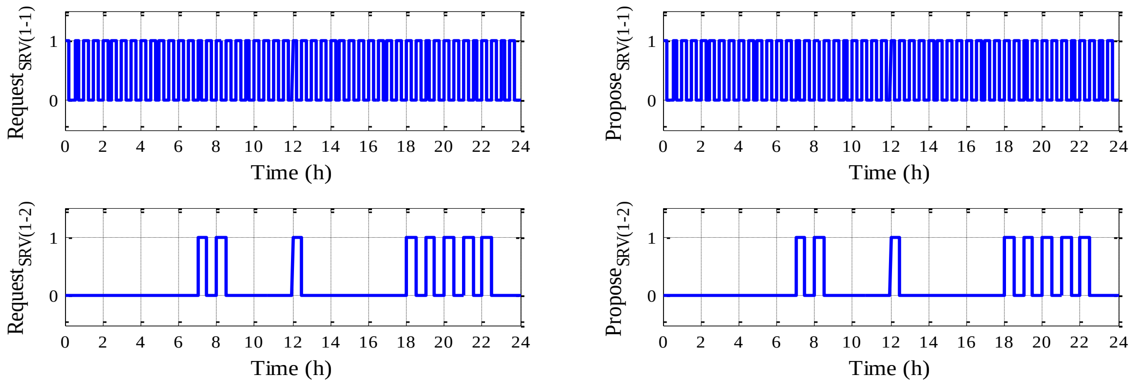


Fig. 21. Requested/proposed profiles of priority loads

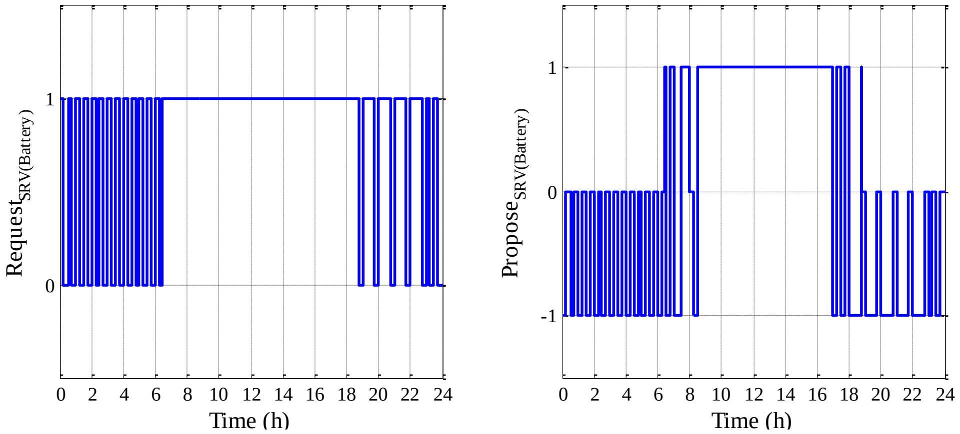


Fig.22. Requested/proposed profiles of storage system

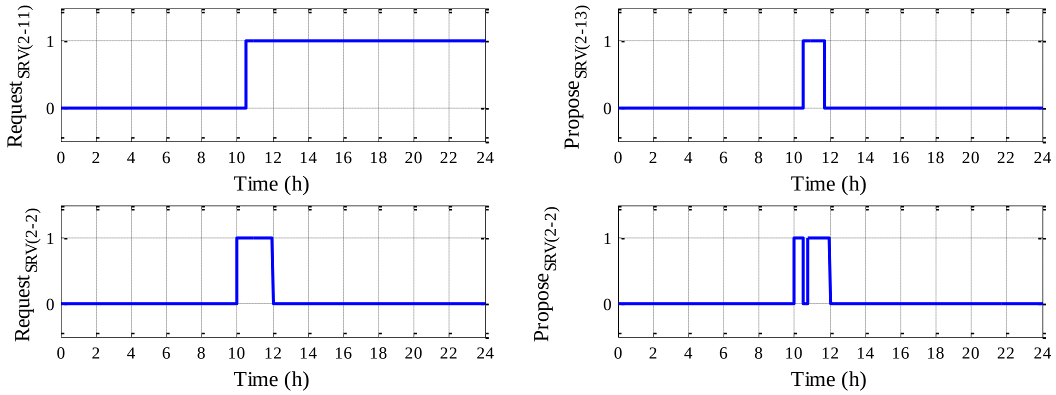


Fig. 23. Requested/proposed profiles of no-priority loads

As defined in section (4.2.2), to prove the proposed strategy effectiveness, it is recommended to achieve the operating mode at RET_{2_11},RET_{2_12} or at RET_{2_13} in the desired functioning end time $[EET_{2\_1}, LET_{2\_1}]$. In this case, it is obvious to adopt the latest possible end time LET_{2_1} during the customer's presence at home (e.g. 12 a.m.).

As the single supply source for non-priority loads, the PV generator remains unable to satisfy both the TV and the washing machine at 10 a.m. during 15 minutes. So, the TV will be forced to switch off during this period in view of its lower priority order compared to the washing machine.

Figure 25 illustrates the exchanged power flow between the produced photovoltaic power, the battery power and the priority loads powers. The charging and discharging process of the storage system fluctuate in accordance with the PV power generation and the priority loads requirements. Relating on figures 24 and 25, all components power profiles fluctuation can be subdivided into 3 major parts:

- From midnight to 7 a.m.: the priority loads are supplied by the storage system owing to the absence of photovoltaic irradiation.
- From 7 a.m. to 6 p.m.: the PV generator should supply all loads requirements respecting the chosen priority order. The photovoltaic surplus energy will be injected in the storage system to charge it. So, between 10 a.m. and 12.30

p.m., the charging battery shape decreases when the house hold appliances operate.

- From 6 p.m. to midnight: the storage system will be discharged again to satisfy the user's power demand. The reliability of this management appears since the priority loads are satisfied at all times by different energy sources (PV or storage system).

6. Conclusion

In this paper,as first step, an integrated solution of energy management cooperation concept for small residential applications has been developed and successfully implemented using Matlab/Simulink. A new modeling method was used taking into account the Request/Propose (RP) services rather than the standard physical model. Indeed, with the behavioral design, incorporated in the multi-agents concept, the controls as well as the management of the global system have been simply implemented. Furthermore, each component response can be observed separately by referring to its own characteristics, which enhances the system pertinence. To provide the RP (Request/Propose) services for micro-grid support, this research has explored the viability of multi-agent approach to adequately enhance the efficient coordination of distributed energy resources at different household devices. The effectiveness of the proposed multi-agent system lies in its exploitation in a connection model network. It is worth noting that this new technique can monitor the target configuration and the switching sequence applying local information and communication network. This makes that the proposed technique a promising approach to be used in various complex areas. The obtained simulation results validate the multi-agent system performance. In fact, discussed and demonstrated in the simulation results, the combined application of management strategy techniques and MAS system gave rise to an intelligent application which acts and interacts as a distribution manager of produced energy during the peak hours without affecting the consumers' comfort.

In the second step, the results should be validated in real time using a common controlling platform with several domestic sensors, actuators, controllers and communication protocols.

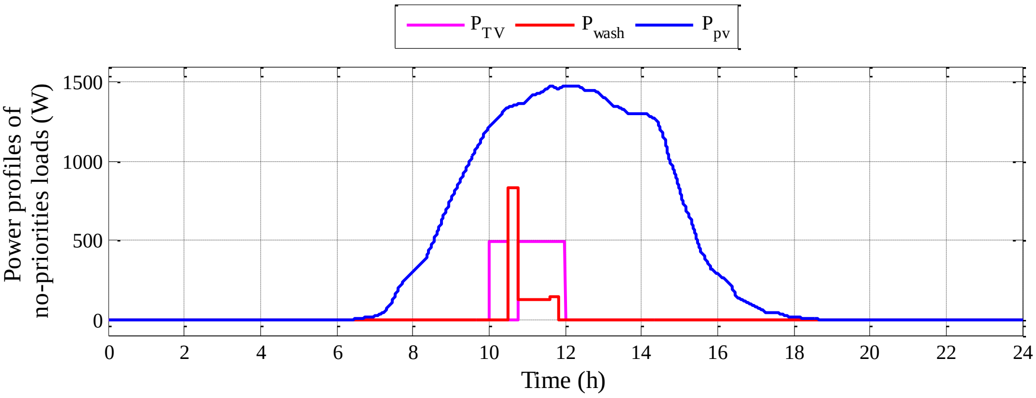


Fig.24. Power profiles evolution of no-priorities agents: washing machine and TV

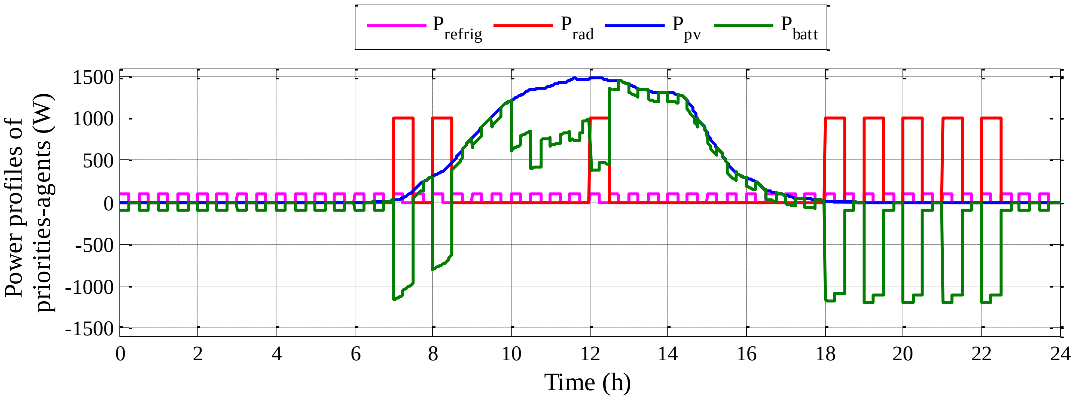


Fig.25. Power profiles evolution of priorities agents: heating and cooling services

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