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# A simulation energy management system of a multi-source renewable energy based on multi agent system

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**ABSTRACT**

The intermittent nature of renewable energies sources makes their control difficult. One of the solutions to overcome this handicap is to promote hybridization (multi-source system). To ensure continuity of service, a storage system must be coupled to the system. To do so, artificial intelligence based models are developed to respond optimally to the dilemma of energy supply and demand. These models allow the management of the energy flow between the sources (photovoltaic, wind, battery, super capacitor, and generator) and the variable loads by controlling electronic switches according to the availability of the sources. The artificial intelligence algorithm used in this study is multi agent system (MAS). The simulation results and validation tests shows the effectivenes of the proposed approach.



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## 1. INTRODUCTION

In the last decacdes, the world has recognized the problems of global warming due to greenhouse gas emissions. Renewable energy is one of the solutions to reduce these emissions [1-2]. The use of renewable energy sources involves the use of storage devices due to the intermittent nature of the sources [3]. In addition, backup sources, such as diesel engines or fuel cells (FC), are often added to the system to increase system reliability. The complete system is called a hybrid energy system (HES), since it combines at least one renewable source and one storage element, either it can be connected to an electrical grid or supplying an isolated load (standalone system) [4]. In order to extenuate the randomness of a given renewable energy field (wind, solar ...) a hybrid combination of two or more different technologies with a storage system can improve the performance of thesystem [5]; this hybrid solution constitutes an interesting possible solution minimizing energy losses by an optimal use of electric energy obtained from renewable energy sources [6-8].

In a hybrid energy system, it is obligatory to have an energy management system (EMS), especially the renewable energy has an intermittent behavior and the system is located on an island. several EMShave been found in the literature, there are classical [9] and intelligente control strategies. In [10-11] the authors present an intelligent supervisor based on fuzzy logic controller to keep the power balance in a hybrid system. In reference [12], the authors combine the Fuzzy inference system with genetic algorithme to maximize the profit generated by the energy exchange with the grid. This technique proved to be very effective in improving the overall interpretability of the solution found, yielding a lighter rule base. These methods are based on the centralized systems and they focus their attention only on the global reaction of the system. For that a distributed management system based on the paradigm of multi agent system must be integrated. With development of this technique in recent years, it has been implemented to the field of hybrid system for EMS. In [13], the authors propose a multi agent system for energy management of a multi source renewable energy and they enumerate the advantage of this method like adaptability to a distribueted system, higt level of flexibility and finaly the MAS are proactive in seeking to meet their goal that's means the agent can go for the information they need to make decisions. Althougt, this contribution must be developed at the level of the rule. In [14], the MAS were proposed to solve every practical choice for grid outage management of a micro-grid. And in [15-16] the distributed control and management of the microgrid based on MAS was presented and implemented in java agent development framework (JADE). All the above researches imply that the MAS can provide the following agvantages: flexibility that's means we can add or remove element without rewriting the program, they are fault tolerance. Hight performance comparing to centralized energy management. The system is not conceived as a single element to control but as a set of entities that nevertheless collaborate effectively.

For the advantage of MAS given above, we popose an energy management system based on MAS and load shedding to balance between supply and demand of energy. This proposed solution allows us to protect the batteries against deep discharge and over charging, reduce the use of the generator set and satisfied the load demand. The system consists of two renewable energy sources (photovoltaic pannel and wind turbine), an energy storage system (batteries and super capacitor) to ensure the continuity of service and a conventional source (the generator set) used as an exceptional rescue resource. Both sources of renewable energy will charge the batteries then these batteries will provide energy to the consumers (loads). These batteries are emptied by the different loads of consumers. The aim of energy management is to maintain a constant charge level in the batteries and ensure sufficient and continuous pressure for the users. This is to keep the batteries charged all the time for a permanent supply of the load, while the super capacitors are used to store the excess energy and also compensate the response time of the generator (too long to start).

This paperis organized as follows: In section 2, we present the architecture of the system. In section 3, we explain the proposed method with multi agent system. The implementation of our proposed approach is presented in section 4. The results obtained and discussions are given in section 5. Finally a conclusion and our perspectives are presented in section 6.

## 2. SYSTEM PRESENTATION

The system on which we applied our strategy of artificial intelligence MAS based energy management is located in Mohammedia city; Morocco country, Africa continent. With the following latitude and longitude coordinates: 33°41'9.85"N, 7°22'58.73"W. The system shown in Figure 1 consists of:

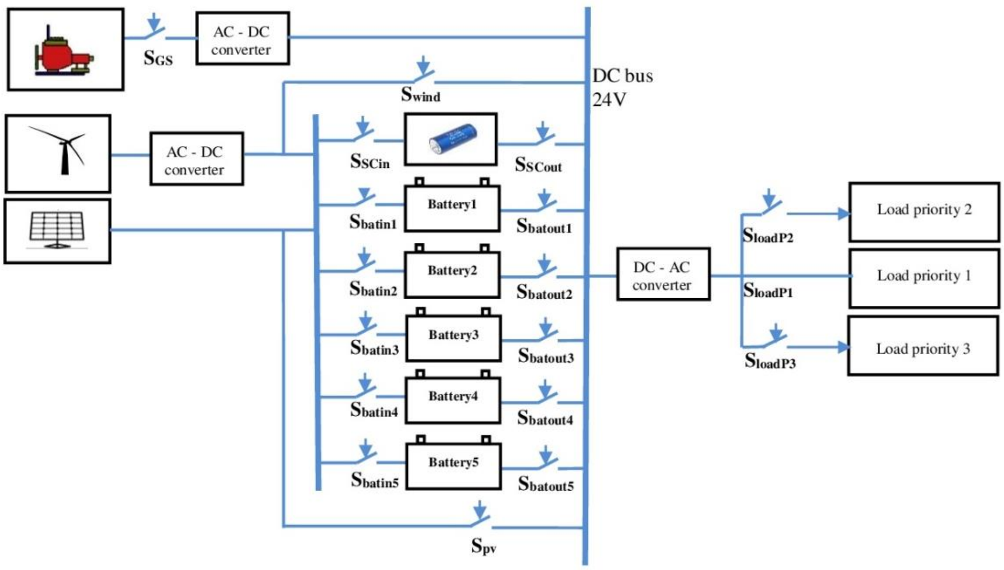



Figure 1. Synoptic diagram of multi-source renewable energy system

- Two sources: a photovoltaic panel (PV) and a wind turbine
- Energy storage system “batteries and super capacitor”
- Emergency source “generator set”
- The loads consist of three priority.

For the state of charge (SOC) of the battery, it must stay between 60% and 90%, to avoid damaging the battery. While in our case, it may happen that there is neither wind nor sun plus the conventional source is down, so we will need the total charge of the battery. It is therefore proposed that solar battery [17] which can undergo a large number of charging/discharging cycles and withstand a discharge depth reach 60%. In this work, we propose a model of multi agent system for a hybrid system integrating PV, wind, batteries, super capacitor and the generator set. Various variables were chosen to keep the controller efficient in terms of Processing of rules and decision making; this controller takes into account the energy supplied by the sources and the power demanded by the loads.

## 3. MULTI AGENT SYSTEM (MAS)

A distributed method MAS is used to improve the performance metrics of the system. The choice of the method depends mainly on the fact that our system can be modified and rebuilt, without the need of a detailed modification of the application [18], our study is extended to a large scale system, which is the exchange of excess energy produced between neighbors instead of drawing energy from the conventional source [19]. Flow control in a multi source energy system must be distributed; it must be seen as a set of different elements to achieve a given objective [20].

### 3.1. Principle

The idea of "agent" and "multi-agent system" appeared in the late 1980s. The goal of the MAS domain is to make artificial entities that simulate human behavior and the way humans interact with each other and with the environment. The domain of MAS is in strong connectionwith the field of distributed artificial intelligence. The concept agent has been defined by several researchers [21-22], there is no universal definition of the agents, and each one proposes a more or less convergent definition. The main characteristics of an agent: is the located entity, able to act in an environment, which has a more or less complex representation of its environment and interacts with it as well as with other entities. In addition, an agent has a set of goals that he seeks to accomplish and has a set of resources.

A multi-agent system (MAS) is a system that consists of a set of agents, located in an environment and interacting according to certain relationships, collectively capable of achieving goals that are difficult to achieve by an individual agent. MAS are also the self-organizing system because it gives the best solution of a given problem without intervention. According to Ferber Jacques [23], a multi agent system consists of the following as shown in Figure 2:

- An environment "E".
- A set of objects "O".
- A set of agents.
- A set of Relationships.
- A set of operations.

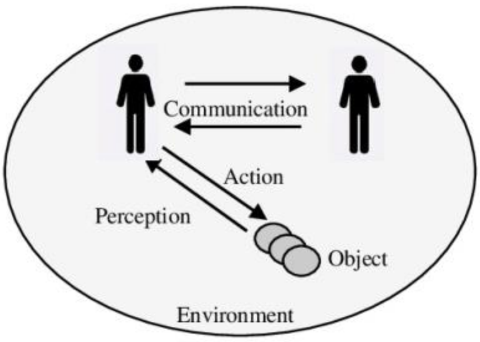



Figure 2. Architecture of multi agent system

### 3.2. Communications implemented through “JADE”

In this paper, we used java agent development environment (JADE) to manage our system because it is a platform among the five functional parallel multi agent platforms, easy to install, contain a detailed documentation. JADE is a multi-agent platform written in the java programming language which is a stable language. This technology offers many features that facilitate the construction of a MAS, which complies with the foundation for intelligent physical agents (FIPA) standard. It is a standards organization of IEEE computer society.

FIPA defines a model for an agent platform and a communication language for agents. All platforms to be compliant with FIPA should follow this pattern and understand the language, and JADE is no exception [24]. Compliance essentially requires four features, as shown in the Figure 3:

– ACC "Agent Communication Channel" is a mechanism that allows agents (and the platform itself) to communicate with each other.
– AMS "Agent Management System" is a way for agents to be registered in the platform and to be contactable for a contact.
– DF "Directory Facilitator", which is a kind of public service in which agents publish the services they offer, provides a Yellow Pages service.
– FIPA agent communication language (ACL) support, which is a common language for all agents to communicate with. JADE implements all these features (and some others) and is therefore a platform compliant with FIPA.

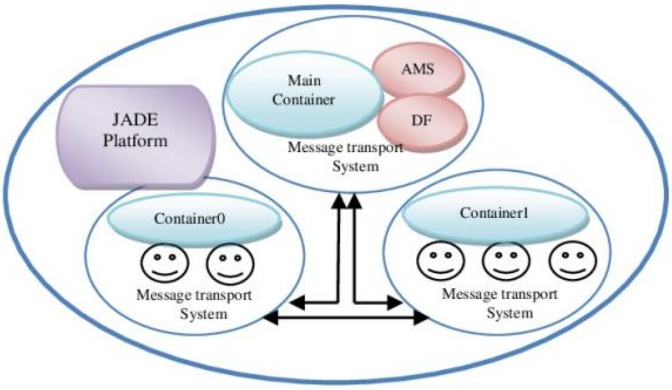



Figure 3. JADE platform

### 3.3. Interactions between agents

Our system consists of seven agents; the load agent “AgentLoad”, the photovoltaic agent “AgentPv”, the AgentWind, the batteries agent “AgentBat”, the super capacitor agent, the executing agent and theSwitches agent who are responsiblefor opening/closing the switches. These agents are implemented using multi-agent programming and coded in the JADE platform. The methodologies for designing MAS are many andvaried [25]. Here it is presented a simple procedure, as shown in the Figure 4:

1. The entire agents are identified in theplatform with an ID and a name.
2. The source agents could publish their service in theagent directory facilitator.
3. The Execution Agent asks for “request” to the loadagent and energies agents.
4. Each agent will respond with a message to informexecution agent on the quantity of energy toprovide.
5. The execution agent while choosing the bestproposal and he will be inform the switches agent.

Each element of the system constitutes an agent (energy source agents, energy storage agents, switchesagents, energy-consuming agents and an agent thatcontrols the environment), each agent has its own roleand its own constraints as well as its interactions on theenvironment. The main objective of energy management using MASis to achieve a high level of flexibility, since we can addelements or delete others without any modification of theprogram [21], also our system does not stop running if anelement is down.

In our program on the JADE platform we have created five containers:

– Main container which contains the AMS and DF agents, it is a main container, it must be started first.
– Container0: demand of power.
– Container1: contains the execution agent who receives information from other agents (load agent, PV agent, wind agent, batteries agent, super capacitor agent) and he sends to his role an inform message to

control and activate the switches by an energy management algorithm, the flowchart of the Figure 5 describes the details of the proposed energy management algorithm.
- Container2: contains the sources of energy, those will publish their services to choose the source ready to provide energy to the agent load.
- Container3: contains the switches, each agent inside controls its switch.

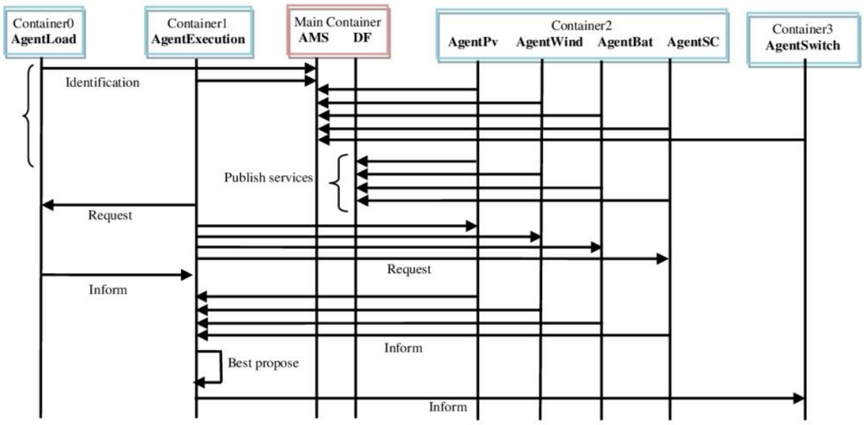



Figure 4. Interactions between agents

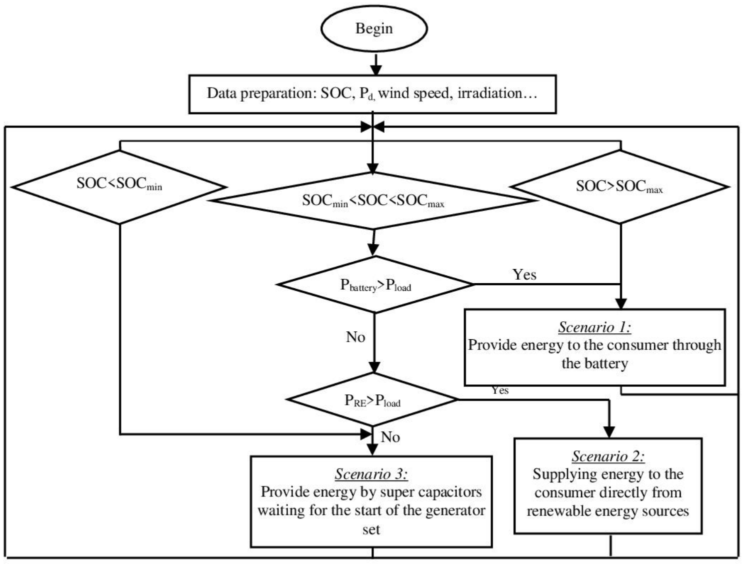



Figure 5. Flowchart of the energy management algorithm

## 4. REALIZATION

### 4.1. Hardware system design

After the simulation of our system on eclipse java, we will proceed to the programming step to implement our method of MAS, for this we have at our disposal the choice between two technologies either PIC Microcontroller or Raspberry Pi. The Raspberry Pi with its processor superior to that of the PIC, a RAM equivalent to that one of a laptop, and its 40 GPIO pins push them to be one of the most developed technological programming cards. The Raspberry Pi, is easy to use due to its Raspbian operating system based on Linux, its accompanying software (Python for example) and its graphical interface which can be exploited by connecting a keyboard, a mouse and an HDMI cable connecting the Pi to a screen. A comparative table between the PIC and a model of Raspberry (Raspberry Pi 2B) highlights the characteristic differences between these two technologiesas shown in Table 1.

### 4.2. Software system design

Java language is used to create our multi agent system, in order to transfer the executed program on eclipse to our raspberry pi, we will convert it to JAR files and then send it through an secure shell (SSH) connection.

### 4.3. Proposed system

The proposed system is capable to manage between different renewable energy sources using raspberry Pi through the control of the switches. The schematic diagram of the proposed system is illustrated in Figure 6.

Table 1. Characteristics of the PIC and Raspberry

| Characteristics | Raspberry Pi 2 | PIC(16F877) |
|---|---|---|
| Processor | 900MHz | 20Mhz |
| RAM | 1Go | 368octets |
| Flash | Micro SD | 8Ko |
| I/O | 40 | 33 |
| Ethernet | 10/100 | N/A |
| USB Master | 4USB 2.0 | N/A |
| Audio/ Video | HDMI | N/A |

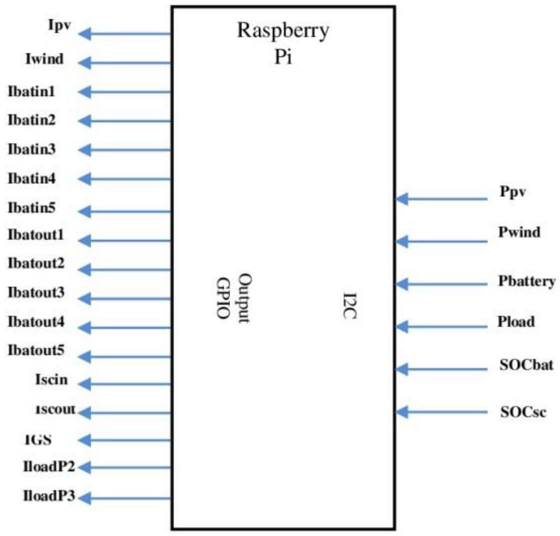



Figure 6. Schematic diagram of the proposed system

The inputs of Raspberry Pi are the powers provided by the sources of renewable energy which are analog data, whereas raspberry accepts only numerical data for that we thought to integrate a digital analogconverter which will convert our couple (Vi, Ii) in numerical value (8bits). Our system presents four powers plus the batteries state of charge; to do so we need 72 inputs (raspberry has just 26 inputs) for that we use a current sensor linked with the I2C serial interface that is available on the raspberry. The proposed system diagram consists of switches controlled by the GPIOs. The pins are considered as switches that the Pi can enable or disable (output). The whole system is simulated on JADE platform and coded using java.

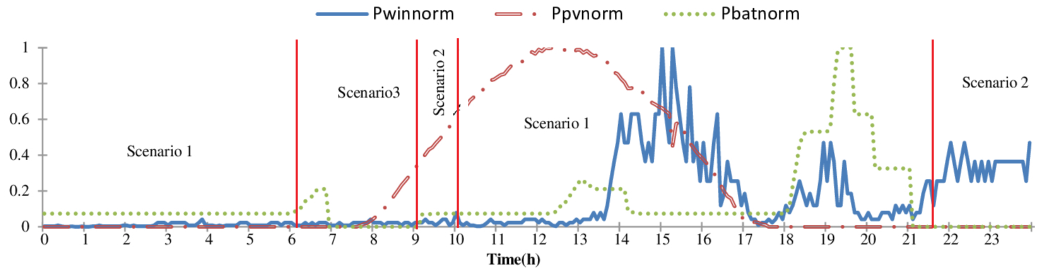
## 5. RESULTS AND DISCUSSIONS

In this work, we focused on the use of distributed architecture based on the agents while exploiting collective intelligence and parallel processing of data. Our system consists of a set of agents that interact with each other; among these agents we have an executing agent (central agent) presenting a set of conditions, the Figure 7(a-d) and Figure 8 below illustrates the results of the energy management program implemented on the central agent. The energy management of the different sources is ensured by a manager who controls the opening and closing of the switches according to the weather conditions.

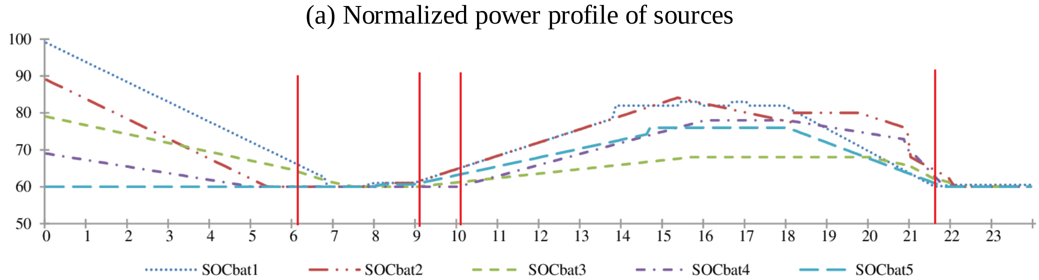
We simulated the hybrid system, giving as input the powers provided by the renewable energy sources (PV, Wind turbine) in Figure 7(a), the state of charge of batteries and supercapacitor in Figure 7(b-c), the load power profiles in Figure 7(d) and we visualize the state of the relays as output. Figure 8 present the switches command signal, it is clear that in the morning the renewable energy sources are exhausted for that our energy management system provide energy by the batteries by closing the switches "$I_{batout1}$,$I_{batout2}$,$I_{batout3}$,$I_{batout4}$,$I_{batout5}$".

At 7 am the batteries is discharged, in this moment "$I_{GS}$" is closed, the generator starts until the batteries restart its charge near renewable energy sources and exceeds its $SOC_{min}$, likewise at 22 pm. When SOC of the batteries drops above 90%, the switch "$I_{batin}$" is closed to charge it. In case of a sharp load changes, as example at 6am,12am, 18pm and 19pm , we call the super capacitorby closing the switch "$I_{SCout}$". Finally, the excessprovided by the renewable energy sources are stored inthe super capacitor by closing the switch "$I_{SCIN}$".

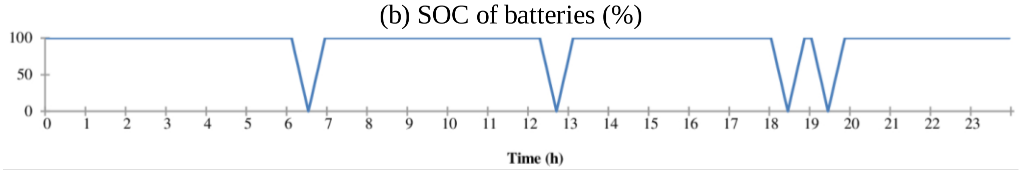
The load shedding system is called when the batteries are decharged and the renewable energy systems are exhausted. Between 6 a.m. and 9 a.m, the EMS open the switches "$I_{loadP2}$ and $I_{loadP3}$" to maintain the balance of the system. The results of the simulation show that the energy management strategy MAS satisfies the specified objectives and that this method manages the system according to the rules described in the flowchart above.



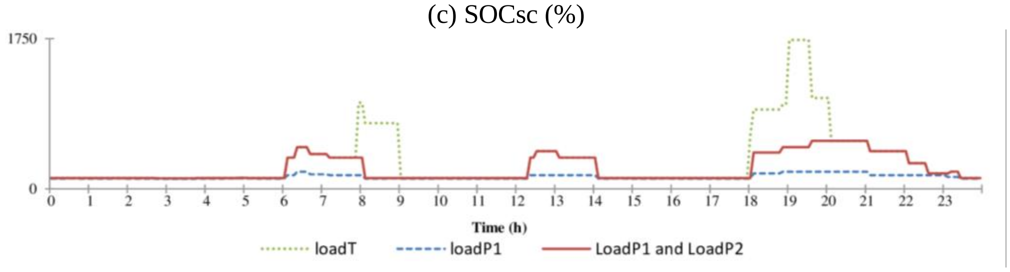

(a) Normalized power profile of sources




(b) SOC of batteries (%)




(c) SOCsc (%)




(d) Load profile (W)

Figure 7. (a) Power profile of PV, Wind turbine and batteries during 24hours (b) SOC of batteries (c) SOC of supercondensator and (d) load power profiles.

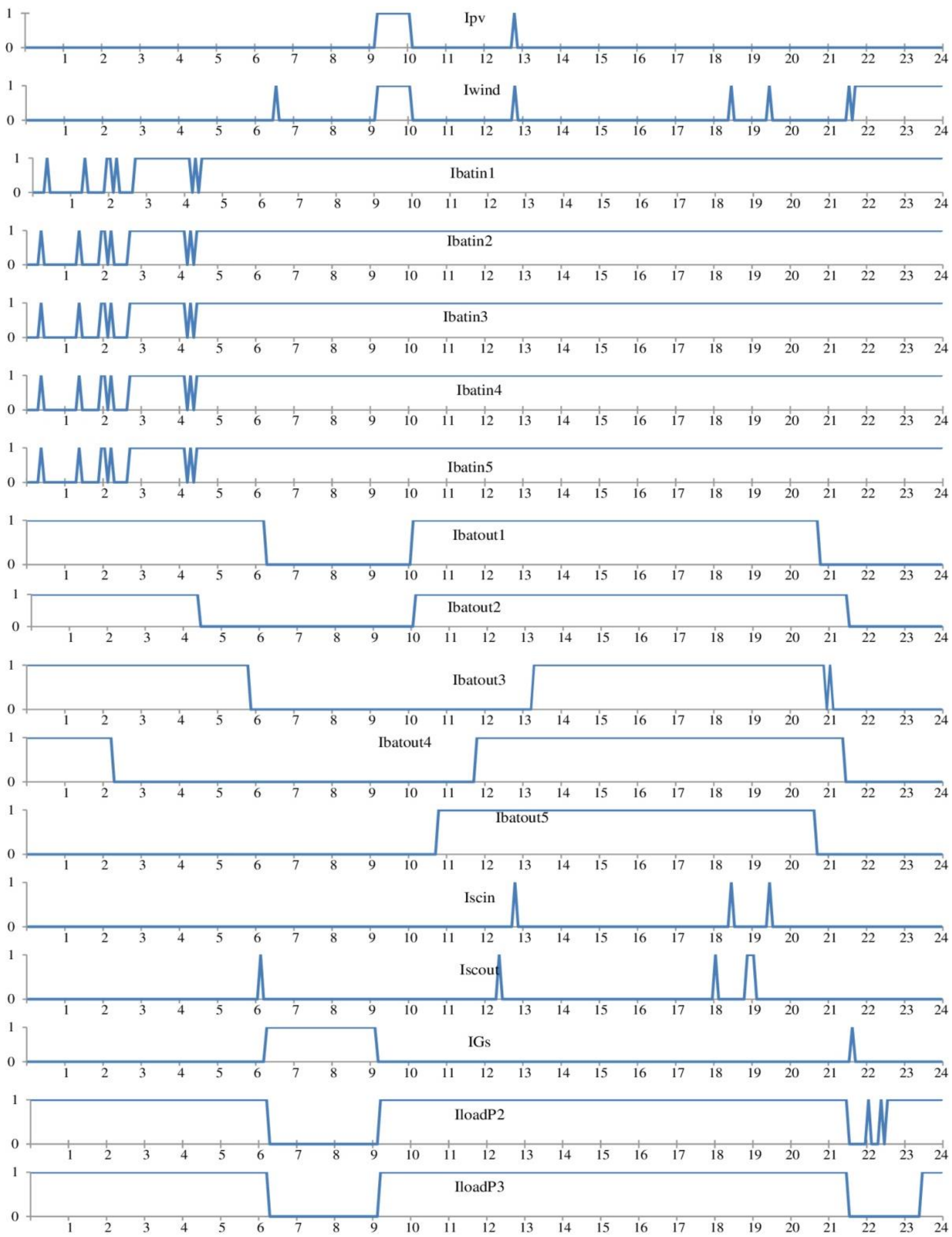



Figure 8. Switches command signal during 24hours

## 6. CONCLUSION AND FUTURE WORKS

In this article, we proposed a distributed method basedon multi agent system to manage our multi-source system, the latter consists of a set of controlled switches, each agent of the platform controls an element of the system with an executing agentwho plays the role of the central agent able to control the switches, this agent is guided with a simple algorithm composed of a set of rules in the form "IF condition1 AND condition2 AND .... THEN conclusion". The proposed method was detailed and also simulated through the multi agent platform; the reaction of the system proves the fault tolerance that mean our system does not stop running if an element is down and the simplicity of design and reliability of the system through the principle of dialogue and cooperation between agents. This energy management solution is a beginning for a work, in terms of prospects we will developed this solution by integrating the artificial intelligence to control the executing agent and develop his performance. A multi agent system is used for large scale distributed systems. It is planned to apply this MAS approach to the energy management of a set of houses; the principle ofthis management is to allow the exchange of energy between a set of producers and consumers. This technique of energy management is called energysharing.

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