Contribution of renewable energy hybrid system control based of multi agent system coordination

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***Abstract*— In recent years, renewable energies are considered among the best alternatives to fossil fuels which are characterized by limited supplies and polluting in nature.**

Following the discontinuity nature of renewable in their energy production, we propose a hybrid renewable energy (photovoltaic, wind) with energy storage which are distributed kind and open, in order to meet the load at all times.

Traditionally multisource systems are managed by centralized approaches and following the limit of these approaches we propose a decentralized approach is multi-agent system "MAS" to ensure proper control and coordination between all system components.

The paper presents the idea of the overall system design, the agents of models associated with system components. An example is presented to discuss the agent's behavioral characteristics of the coordination process. The approach adopted can improve the system operation overall and economic efficiency.

Key words- Renewable energy, Photovoltaic, Wind, Energy storage, Hybrid renewable system, Centralized and decentralized approaches, Multi agents systems "MAS"

I. INTRODUCTION

Renewable energies constitute an alternative to fossil energies for several reasons: they disturb less generally the environment, do not emit a gas with greenhouse effect and do not produce waste, they are inexhaustible, and they authorize a decentralized production adapted at the same time to resources and needs local [1].

The development of clean energies such as wind and photovoltaic has motivated many experts to study wind, photovoltaic, storage, power generation, and energy-coordination, control systems. However, the operation process of large-scale wind, photovoltaic, storage, and power-generation units often suffer from low operation efficiency, nonstability, and lack of energy-coordination control strategies. Various countries have successively conducted a number of demonstration projects showing operation control importance of the energy production and storage [2, 3, 4, 5, 6].

Such tests are done in the peak and valley adjustments [7] and in the adjustment and improvement of power quality [8]. In terms of energy control and coordination, the United States, Spain, and Denmark can optimize wind power and photovoltaic power under existing economic leverage on the basis of perfect electric power market mechanisms. By contrast, developing countries with backward market mechanisms are inexperienced in energy-coordination control. Therefore, the design of the energy system control and coordination can be applied to renewable energy large-scale units to optimize output according to the distribution characteristics of natural resources.

Furthermore, the equipment characteristics of the power-generation are conducive for improving the reliability and economic system for promoting the development of energy sustainability.

Traditional control coordination energy grid (wind–photovoltaic and energy storage), use a centralized energy management strategy based on intelligent control algorithm. With the increasing construction of wind farms and photovoltaic, as well as the increasing adoption the systems of energy storage, the defects of the centralized energy control method in flexibility and extensibility hinders the operations of large-scale power-generation systems for wind, photovoltaic, energy storage. The multi agents system responds intelligently and flexibly to changes in environment. This approach has been widely applied in various aspects of the energy system [9, 10, 11].

To date, the MAS based in control and energy strategy coordination mainly includes the optimal scheduling based on the intelligent algorithm and the competition coordination based on free market trading. The system optimization objectives and the equipment constraints, provides the equipment operation parameters and real-time load demand and the energy control and coordination in the intelligent algorithm.

The design solution the behavior of the agent with the operation characteristics of the equipment and realizes a large MAS system based on the JADE environment, thus proving the rationality of the MAS in the control and coordination energy of the hybrid system renewable-energy. By using high fault tolerance, openness and adaptability as the objectives. [12] Adopts the bottom-up approach to design a MAS-based distributed power-generation management system and verifies by simulations that this system is more efficient in handling problems than centralized energy management systems. [13] uses high energy density, power density, and combustion efficiency as the objectives to design a MAS-based hybrid-power energy-coordination plan and proves the high efficiency and robustness of the system by simulations. [14] Uses the minimized operation cost as the objective to design the energy-coordination strategy of distributed power-generation under an isolated environment based on MAS. The system uses three-stage energy dispatching strategies to maximize the use of renewable energies, to meet the demands of each independent system, and to minimize operation costs.

Each equipment bids for the tendering control unit achieves energy coordination based on the competitiveness of the bidding unit. For instance, [15] sets the market operator as the internal consultation control center under a microenvironment in the energy market. [16] Establishes three layers of control system under the micro network environment, and other agents to manage the internal consultation process in the energy market.

II. Hybrid Energy System Configurations

The basic components of the hybrid energy systems mainly comprise renewable energy generators (Alternative Current "AC" / Direct Current "DC" sources), non-renewable generators (AC/DC sources), power conditioning unit, storage, load (AC/DC) and sometimes may include grid. A general hybrid energy system configuration has been depicted in Fig.1 as shown below.

The various configurations which can be further summarized into Direct Current "DC" coupled, power frequency Alternative Current "AC" coupled, high frequency Alternative Current "AC" coupled and hybrid coupled system (comprising of both AC and DC bus) [17, 18]. The selection of a particular configuration depends on the application type.

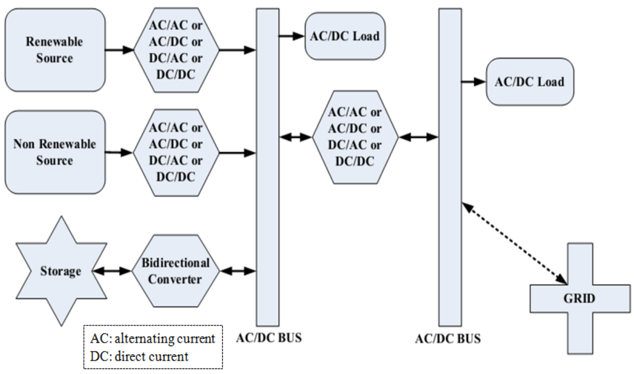

Fig. 1. Basic components of hybrid energy system "HES"

III. Evaluation Criteria for HES

Selection of evaluation criteria is one of the important works necessary for designing “HES” for a required locality given in [19].

[20] Used ELECTRE for assessing an action plan to diffuse renewable energy technologies at regional level. [21] Explored the energy planning approach for ranking the projects. [22] Analyzed the possible energy alternatives depending on their physical, environmental, economical, political and other uncontrollable aspects. [23] Developed a multi-criteria decision analysis (MCDA) tool to allow ranking of different scenarios relying on their performance on 13 criteria covering economic, job market, quality of life of local populations, technical and environmental issues. Various criteria involved in designing of HES are shown in Fig.2.

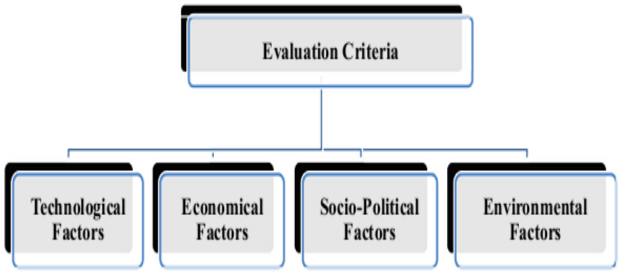

Fig. 2. Factors impacting the selection of the renewable energy system

IV. Description of the System Studied

The system studied, is composed of two energy sources (Photovoltaic, Wind), a battery bank, a load and controller equipment, see Fig.3

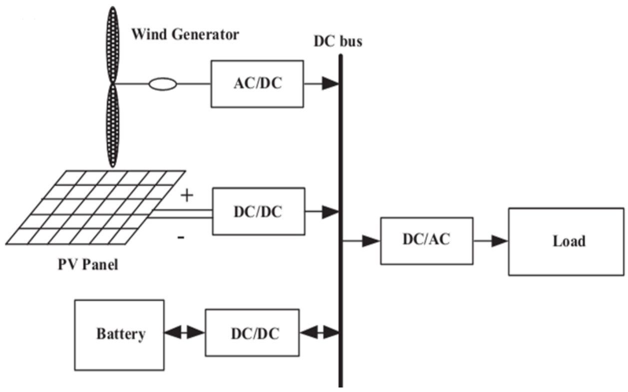

Fig. 3. Synoptic diagram of the Multi Sources System studied

V. Energy Management Problems

The management or the energy control is a rather broad concept which indicates the whole of the techniques making it possible to decrease power consumption in a preoccupation of financial economies and a reduction of the ecological print [24, 25]. We propose a three application distinction fields of the energy management: Production and storage, Transport and distribution and Consumption, see Fig.4.

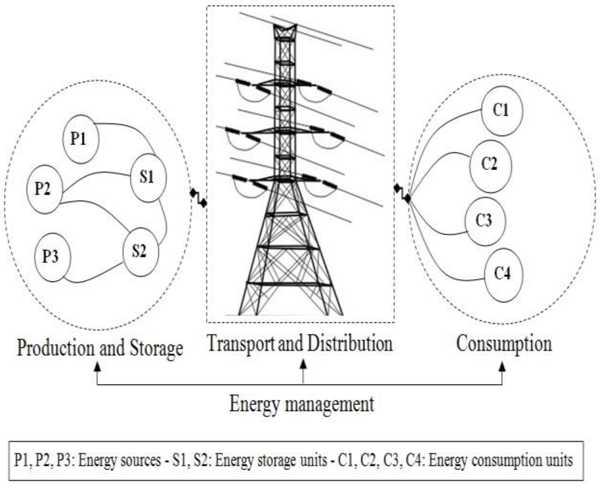

Fig. 4. Classification of the application fields of the energy management (Electrical engineering aspect)

Production and storage are energy sources of energy management, the transport and distribution part relating to the electricity routing between the energy sources and the consumers. Finally, the energy management for consumption for the main purpose of reducing different consumption consumer.

VI. Towards a Decentralized Approach for the Energy Management

Considering the nature of the hybrid systems which is open and distributed the downward approach limited, a rising approach can be, by opposition and seem preferable for this type of problem.

Indeed, the designer knows, in the majority of the cases, how each element must react separately. With the rising approach, the management of energy emerges starting from relatively simple rules laid down according to the constraints of each element. This approach can be structured around the paradigm of the Multi Agents Systems “MAS”.

Multi Agent Systems design methodologies are many and varied [26]. We present our "MAS" is appropriate to the systems nature and the energy management problem of a hybrid system

A. Agent

1) *Definition:* there is no unique definition of what is an agent. This term is used in a rather vague way [27]. The majority of works refers to this definition:

An agent is an autonomous entity, located in an environment, endowed with reasoning and able to communicate with these similar, see: Fig.5.

Ferber [27] proposes a more complete definition for an agent: “We call agent a physical or virtual entity: which is able to act, which can communicate, which owes resources, which is able to perceive, which has only one partial representation of this environment, which has competences and offers services and which can reproduce”.

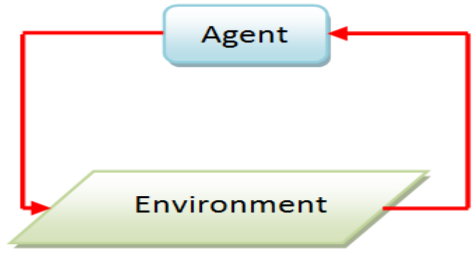

Fig. 5. Agent Interaction with its environment

2) *Agent types:*

Several types of agents, according to the capacities, will be described as reagents, cognitive or hybrid.

B. Multi-agent system

1) *Definition:* “MAS” can be defined a whole of the agents located in a common environment and interact according to a certain organization.

Ferber [27] define “MAS” as: “being a system made up of the following elements: an environment `E', objects set `O `, an `A' agents set, a relations number `R', an operations number `Op' and operators, see: Fig.6.

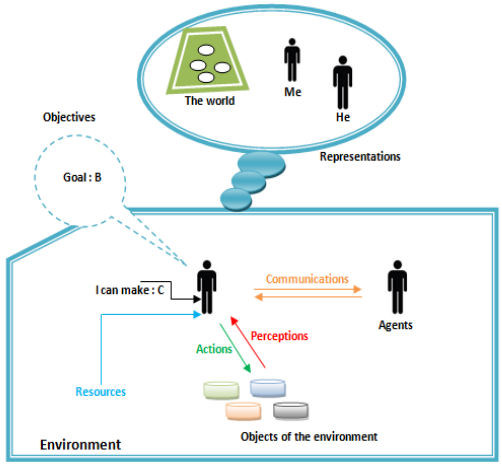

Fig. 6. Representation of an agent in interaction with its environment and other agents

2) *The SMA characteristics:* the SMA has a decentralized vision. Each agent is responsible for its knowledge and its actions (autonomy), the tasks realized and competences to do it are distributed on the agents.

VII. Multi Agent Systems design “MAS”

A. Basic structure of Agent

Fig. 7 shows the internal structure of the typical Agent.

Agent feels the change of environment through the perception module and responds to the environment through the action module. Inference and decision making are the core modules of Agent on the basis of the local model/algorithm library and knowledge library. During the Inference process, the constraint condition, task standard, current token location and abilities of other Agents will be combined to make decisions after negotiation with other Agents. In the decision-making process, it realizes the experience accumulation and organization and achieves the purpose of learning.

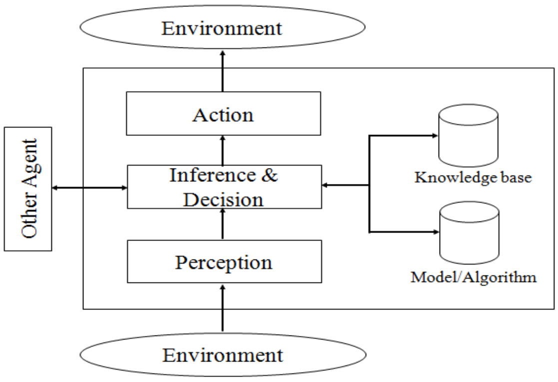

Fig. 7. Basic structure of Agent

1) *Knowledge base*: is a technology used to store complex structured and unstructured information used by a computer system.

2) *Algorithm base*: contains all the instructions that solve a problem in an accurate and timely manner.

B. Entities, properties and operations

Following the system description and the goal to reach by this latter, we conclude the entities: Photovoltaic generator, wind Generator, Battery, Load, Data external and Management.

Among the system properties we mention: Battery nominal voltage (V_{bat}), Battery full capacity (Cap_{bat}), Discharge coefficient ($C_{déch}$), Battery loading output (η_{cha}), Battery loading minimal limit ($SOC_{bat-min}$), Battery loading maximum limit ($SOC_{bat-max}$), Batteries discharge output ($\eta_{déch}$), …

The system is also characterized by the operations we cite: Battery loading, Battery unloading,…

C. The agent's development list

Our idea consists in releasing a whole of axioms; thereafter we conclude our "MAS" agents list.

- Any system entity must be related at least to a system task.

$$\forall e\ E(e) \Rightarrow \exists\ t\ Task(t) \wedge Connected(t,e) \qquad (A1)$$

- For any system task, it must exist at least an agent to carry out it.

$$\forall t\ Task(t) \Rightarrow \exists\ a\ Agent(a) \wedge executed(a,t) \qquad (A2)$$

- If an agent cannot carry out a task, it can delegate the task to another agent belonging to its dealing network.

$$\forall a,t\ Agent(a) \wedge Task(t) \wedge (\neg\ Competence(a,t)) \Rightarrow$$
$$\exists\ a_1 Querable(a_1,t) \wedge Acquaintance(a,a_1) \qquad (A3)$$

- If agents want to reach the same resource, we need the presence of another agent to manage the resource sharing between them

$$\forall a_1,\ldots,a_n \bigwedge_{i=1}^{n} Agent(a_i) \wedge Resource(r) \bigwedge_{i=1}^{n} Uses(a_i,r) \Rightarrow$$
$$\exists ag\ Agent(ag) \wedge ResourceSharing(ag,r,a_i,\ldots,a_n) \quad (A4)$$

From the entities list quoted previously and the axioms (A1), (A2), (A3) and (A4) we conclude the agents list, see Fig.8

TABLE I. SYSTEM AGENTS LIST

Agent name	Shortened name	Agent type
Photovoltaic Agent	AgentPv	Hybrid agent
Wind Agent	AgentWind	Hybrid agent
Battery Agent	AgentBat	Hybrid agent
Load Agent	AgentLoad	Reactive agent
Updated Agent	AgentUpd	Reactive agent
Management Agent	AgentMan	Cognitive agent

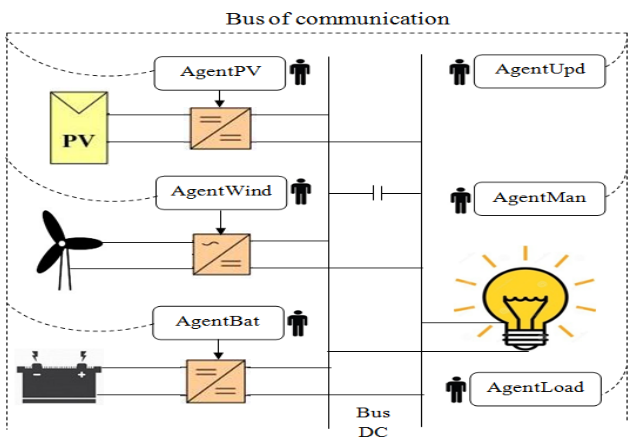

Fig. 8. The system structure ordered by "MAS"

The Multi Agents Systems "MAS" are based on their operation on the reasoning more precisely for the cognitive and hybrid agents.

D. Characteristics of Agent

1) *AgentWind: "*AgentWind" and "AgentPv" represent the control units of the wind turbine and the photovoltaic panel, respectively. As the wind turbine and the photovoltaic panel operate at a low levelized cost, in the principle of maximizing the use of renewable energy, the characteristics of "AgentWind" and "AgentPv" are designed to be participating in the bid-ding actively until all the available equipment operate to the maximum power output. At the same time, they can initiate the energy coordination task when the power out-put changes.

The wind generator output power characteristics can be expressed [28]:

$$\begin{cases} P_w(V) = P_n \dfrac{V - V_{dem}}{V_n - V_{dem}} \quad if \quad V_{dem} \le V \le V_n \\ P_w(V) = P_n \quad if \quad V_n \le V \le V_{\max} \\ P_w(V) = 0 \quad if \quad V > V_{\max} \quad or \quad V < V_n \end{cases} \tag{1}$$

With: P_n : Rated power of wind generator, V_{dem} : Boot speed to which the turbine starts producing energy. V_n : Wind rated speed, V_{max} : Maximum speed for which production is stopped for safety reasons and wind is feathered.

2) *AgentPv:* The output power model of the PV module is deter-mined by solar radiation and environmental temperature [29], as follows:

$$P_{pv} = \eta_{pvg} A_{pvg} G_t \tag{2}$$

With: Gt : Solar radiation (W/m2), A_{pvg} (m^2): Photovoltaic generator surface, η_{pvg} : Overall efficiency, it is given by:

$$\eta_{pvg} = \eta_r \eta_{pc} \left[1 - \beta \left(T_c - T_{cref} \right) \right] \tag{3}$$

With: η_r : Reference performance module is η_{pc} yield characterizing the state of the latter charge is equal to 1 in the case of using the MPPT (Maximum Power Point Tracker) control strategy. β is the temperature coefficient is assumed to be constant and for photovoltaic cells based on silicon β is in the range 0.004 to 0.006 (1 / ° C). T_{cref} is the cell reference temperature (° C) T_c is the temperature of the cell given by:

$$T_c = T_a + \left(\frac{NOCT - 20}{800} \right) G_t \tag{4}$$

with: T_a (°C) ambient and NOCT (° C) represents the nominal operating temperature of the photovoltaic cell.

3) *AgentBat: "*AgentBat" in the system can monitor the state of charge (SOC) of the battery and manage the charge and discharge of the batteries. AgentBat in the system can monitor the state of charge (SOC) of the battery and manage the charge and discharge of the batteries.

4) *AgentLoad:* "AgentLoad" is responsible for monitoring the evolution of the load in real time and rank priorities (see fig.9) the load depending on the importance and can cut the least important load when the power generation unit can not meet the entire demand.

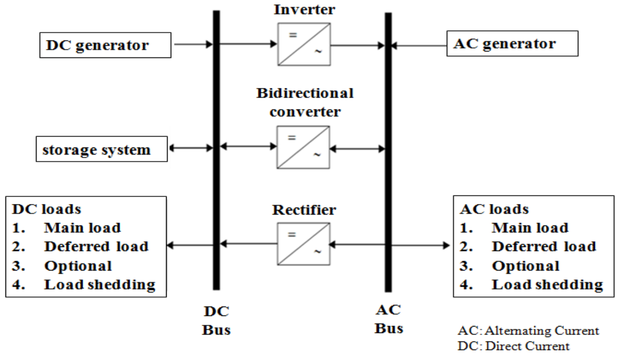

Fig. 9. Loads in a hybrid system

5) *AgentMan:* ensure proper coordination among the system agents

6) *AgentUpd:* resonsable recover all the news concerning the environmental objects of the external world (outside environment)

VIII. Interactions extract between the agents of our "MAS"

We distinguish two interactions categories:

- Interaction for the energy management, see fig.10:

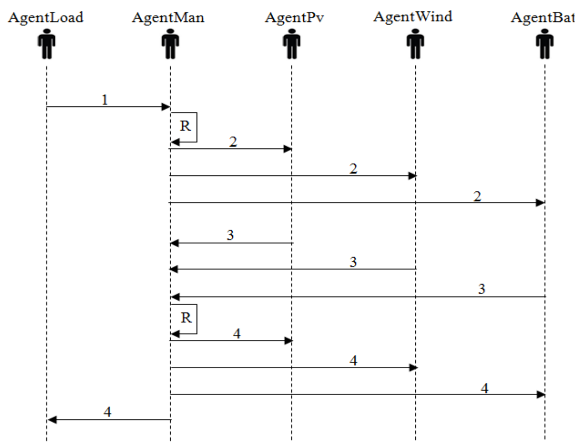

Fig. 10. The interactions extract between the members of the "MAS" Company for the energy management

TABLE II. LIST OF COMMUNICATIONS FOR ENERGY MANAGEMENT

Communication number	Description of communication
1	"AgentLoad" informs "AgentMan" on the load in energy
2	"AgentMan" requires sequentially "AgentPv", "AgentWind", "AgentBat" the production state of photovoltaic and wind generator and energy storage state
3	The three agents "AgentPv", "AgentWind", "AgentBat" answers "AgentMan"
4	"AgentMan" selects the best choice to ensure the proper management and gives instructions to agents: "AgentPv", "AgentWind", "AgentBat" to carry out the various instructions and informs "AgentLoad" on their request
R	Represent the manager agent reasoning "AgentMan"

- Interaction for updated data system, see fig.11:

TABLE III. LIST OF COMMUNICATIONS FOR SYSTEM UPDATE

Communication number	Description of communication
1	"AgentUpd" informs the agents "AgentPv", "AgentWind", "AgentBat" on the weather new data, techniques or of installation site.
R	Representing the reasoning agents: "AgentPv", "AgentWind" and "AgentBat"

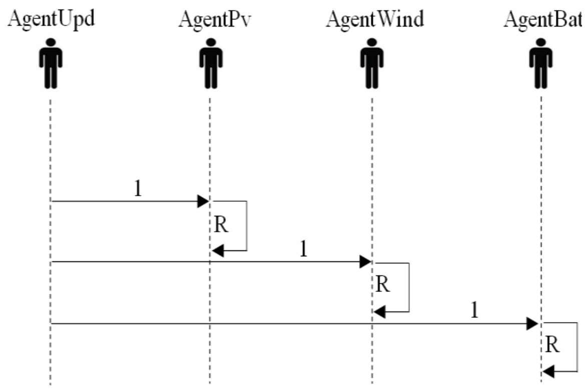

Fig. 11. The interactions extract between the members of the «MAS» Company for updated data

IX. The Reasoning in Multi Agents Systems "MAS"

Multi-Agent Systems based in its operation on the reasoning engines and inference rules [30]. An inference rule takes the following form:

$$\text{if } (C_1 \wedge C_2 \wedge C_3) \text{ then } (A_1) \Leftrightarrow$$

if the "C_1", "C_2" and "C_3" conditions are true then "A_1" action is realizable

We quote some rules of inferences associated with our system:

$$\text{if } (Soc_{\text{bat-min}} \le Cap_{\text{bat}}(t) < Soc_{\text{bat-max}}) \wedge (E_{\text{load}}(t) = \text{"0"}) \wedge \left(E_{\text{Pv}}(t) > 0\right) \vee \left(E_{\text{wind}}(t) > 0\right) \text{ then "battery loading"}, \forall t \qquad \text{(R1)}$$

$$\text{if } (E_{\text{pv}}(t) = E_{\text{wind}}(t) = \text{"0"}) \wedge (Cap_{\text{bat}}(t) > Soc_{\text{bat-min}}) \wedge (E_{\text{load}}(t) > \text{"0"}) \text{ then "battery unloading"}, \forall t \qquad \text{(R2)}$$

$$\text{if } \left(E_{\text{load}}(t) = 0\right) \wedge \left(Cap_{\text{Bat}}(t) = Soc_{\text{bat-max}}\right) \text{ then "two generators in stopped state"}, \forall t \qquad \textit{(R3)}$$

With: $Cap_{bat}(t)$: Battery capacity at t moment, $\text{SOC}_{\text{bat-min}}$: Minimal limit in battery unloading,

$\text{SOC}_{\text{bat-max}}$: Maximum limit in battery loading, $\text{E}_{\text{Pv}}(\text{t})$: Energy produced in photovoltaic generator at t moment, $\text{E}_{\text{wind}}(\text{t})$: Energy produced in wind generator at t moment, $\text{E}_{\text{load}}(\text{t})$: requested energy at t moment.

X. Communications Implemented Through "JADE"

"JADE" (Java Agent Development framework), is the platform to use more for the development of multi agents systems and which is in conformity with standard FIPA (Foundation for Intelligent Physical Agents), it is to develop by the language JAVA and the interaction between the agents made through communication protocols, see fig.12

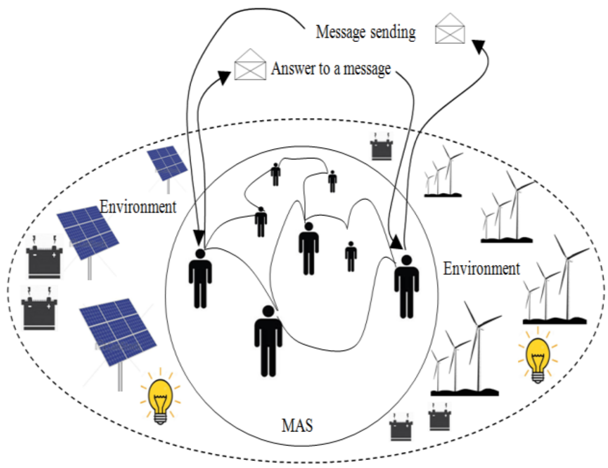

Fig. 12. Interaction form between two agents, formulated by the "JAVA" language

We quote an example of communication between two agents: "AgentPv" and "AgentBat".

"AgentPv" Produced of energy then send them to "AgentBat" for battery loading operation. As long as the battery is not full, it informs "AgentPv" that it is ready to receive more energy. As soon as the loading level is equal with the maximum limit, "AgentBat" informs "AgentPv" and stops. As soon as "AgentPv" receives the message of stop, it also stops.

We quote maintain the algorithm which summarizes the communication described previously, see fig.13

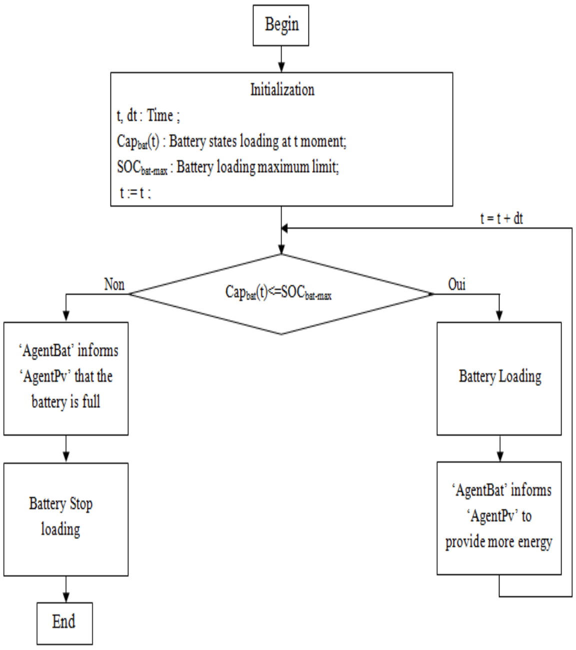

Fig. 13. The algorithm which represents a communication between "AgentPv" and "AgentBat"

XI. Conclusion and Prospects

The work done is a start to a long process, it revolves around a contribution to the creation of a Multi Agents System that ensures control and energy management in a multi sources system (photovoltaic, wind) with energy storage, in this article we performed the following work:

- Description of the system concerned with the study;
- Description of the problem of energy management;
- Set the choice of the most appropriate approach to the problem of energy management and nature of the system involved in the study;
- Propose some axioms for the development of the list of agents with the type of each;
- Present the reasoning aspect in multi-agent system in our study;
- Describe some interactions between members of the "MAS";

The possibility of using this system is the great interest, namely the optimal management of renewable energy sources multiple system that characterize an area to enjoy and energy more efficiently.

In terms of outlook, several aspects remain to be developed. Among which we mention:

- Revisit the proposed design;
- Develop the reasoning of our SMA by proposing inference rules;

Nomenclature

V_{bat}	Battery voltage nominal
$Cap_{bat}(t)$	Battery capacity Full
$C_{déch}$	Discharge Coefficient
η_{cha}	Battery loading Output
$SOC_{bat-min}$	Battery loading Minimal limit
$\eta_{déch}$	Batteries discharge Output
$E_{Pv}(t)$	Photovoltaic energy produced at t moment
$E_{wind}(t)$	Wind energy produced at t moment
$E_{load}(t)$	The load or the energy requested at t moment
$SOC_{bat-max}$	Battery loading Maximum limit
AC	Alternative Current
DC	Direct Current
P_w (V)	Output power
P_n	Rated power of wind generator
V_{dem}	Boot speed to which the turbine starts producing energy
V_n	Wind rated speed
V_{max}	Wind maximum speed
G_t	Solar radiation (W/m^2)
A_{pvg}	Surface of the photovoltaic generator (m^2)
η_{pvg}	Overall efficiency
P_{pv}	Output power of photovoltaic generator
MPPT	Maximum Power Point Tracker

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