Agent-Based Self-Adaptive DC-DC Converter for Hybrid Energetic System Control

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***Abstract*—— The renewable energy resources production is entirely correlated to the fluctuant climate conditions and does not depend on the load requirement, therefore they behave as passive generators. The power electronics play a significant role to overcome these constraints. A DC coupled wind/pv/hydrogen/battery hybrid energy system is studied to show the role of power electronics in building actives RES generators. A distributed energy management is proposed to deal with the simultaneous operations of different hybrid system components. Furthermore, this paper proposes a self-adaptive DC-DC converters control by multi agent system. The simulation results are given by Matlab Simulink. The distributed control using multi agent system is performed by developing agent under Jade platform. While the communication middleware between Jade and Simulink is carried out by MacsimJX. Finally, the performance of the proposed control has been justified.**

Index Terms-- DC-DC converters; DC bus voltage control; Multi Agent System (MAS); Matlab Simulink; MaximJX; self-adaptive DC-DC converters.

I. Introduction

The hybrid energetic system (HES) is generally an energy system operating simultaneously several sources with different capacities and proprieties. It is principally based on renewable energy sources (RES) and distributed generators DG. Their distributed production should meet an increasingly variable demand. The RES depend strongly on meteorological conditions, thereby they cannot be considered as a continuous energy supply and therefore behave as passive generator. To balance between consumption and generation the RES should be coupled with other sources and storage systems. Diversifying the energy sources is now a real issue. Hybridizing the RES with the storage system and DG as cogeneration system can meet the distributed production requirements allowing the RES intensive integration. The HES ensure a long-term energetic availability and it is able to deliver a subscribed power when the RES act as active generators. The HES can be shown as a supply system consisting of small distributed energy systems [1-2]. However, the DGs and the storage technologies life cycle should be respected. To take full advantages of the HES a distributed energy management (DEM) is necessary. It deals with the simultaneous operation of the different generators, the storage system and DGs constraints, and the variable load demand. Furthermore; other requirements should be satisfied in the DEM, as voltage limit control, the produced energy cost, the system effectiveness, the energy quality improvement, the energy flexible use and the environmental issue. Thanks to DEM, the HES can produce and consume effectively depending on the capacity of each generator and the loads' needs.

The HES studied in this paper consists of PV generator and wind turbine as a RES and battery as storage technology system. This configuration can lead to prematurely lose battery life, because of the quickly battery charge and discharge. Many studies have dealt with the effective battery use [3-4]. Linking a hybrid generator to the RES and the battery as the Fuel cell (FC)-electrolyser combination generator is the HES suggested in this paper.

A custom role for power electronics is the development of HES, by meeting the distributed production constraints. Several studies have brought more interest to HES control containing DGs, RES and storage technologies. The Fuzzy logic and neural networks [5] were the subjects of many studies regarding the HES control, but the complexity and the difficulty in their implementation and comprehension can be their main inconvenient. Furthermore, these approaches can make the system non-scalable which conflicting with the distributed generation and therefore the future energy networks. This paper proposes a distributed energy management system based on the bus voltage control allowing simultaneously a flexible energy generation and consumption depending on the capacity of each generator and the variable demand by the bias of multi-agent system (MAS).

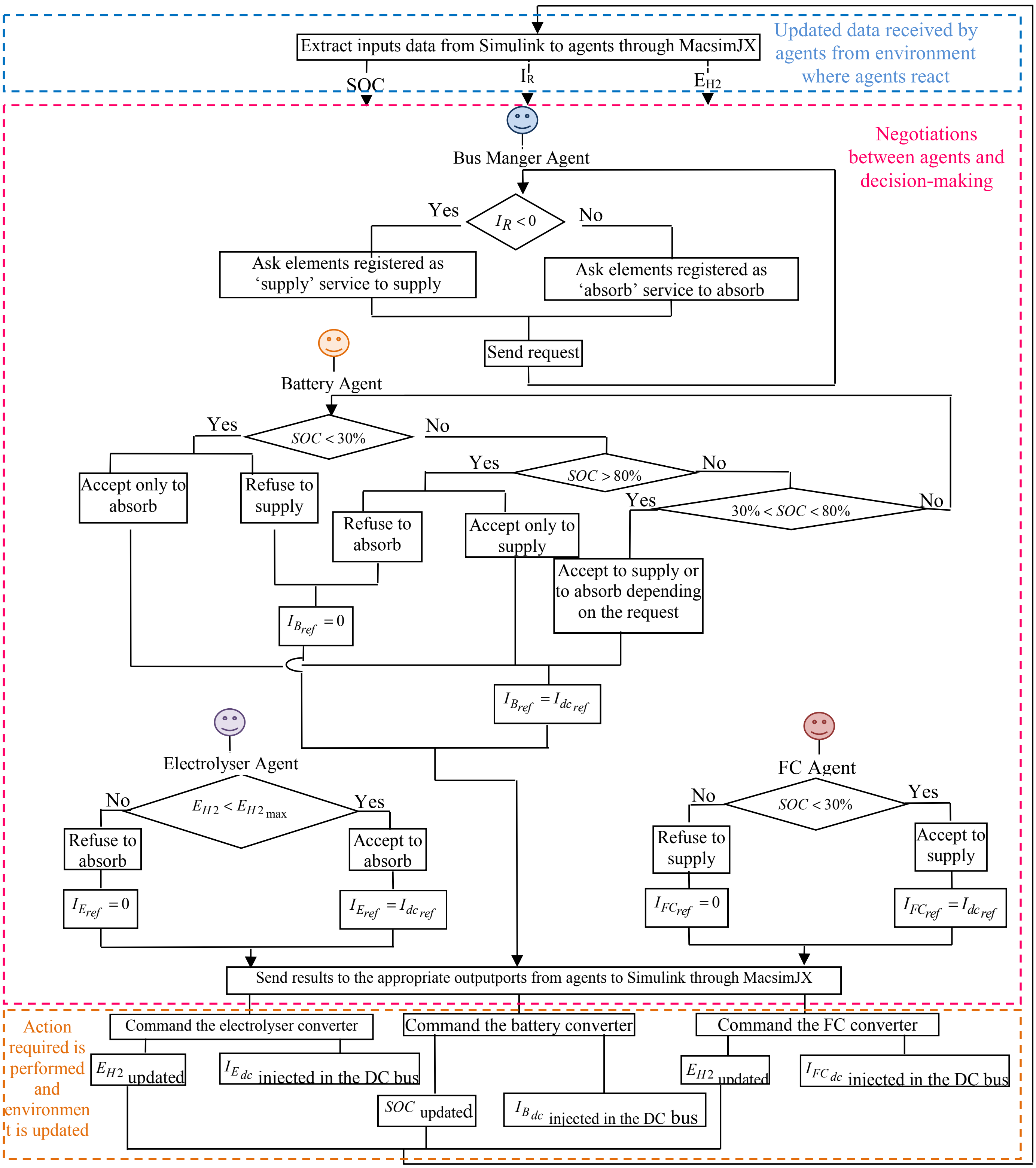

Fig. 1. Flowchart of the overall control scheme for the proposed HES

MAS is extensively suggested as a suitable approach to manage complex distributed systems with different capacities and different generation [6] such as HES. The goal of this paper is to introduce a self-adaptive DC-DC converter based on MAS paradigm.

The distributed energy management by MAS is given in section II and therefore the self-adaptive DC-DC converters are introduced. Section III meets the hybridization requirements by analysing the results of the HES control, section IV concludes the paper.

II. HES DISTRIBUTED ENERGY MANAGEMENT BY MAS

Many studies have developed approaches for DC bus control [7-8]. These studies are commonly based on master – slave method. It consists on choosing one element connected to the DC bus to be a centralized controller called master. It is responsible for controlling the dc bus voltage and transmitting the power references to the other source converters which are slaves and are current controlled [9].

In this paper a distributed DC bus voltage control is proposed. Where there is no master or slave element. All the elements tied to the DC bus are current controlled and there is no element designated to control the DC bus voltage. The DC bus receives the RES injected and the energy consumed, the difference between the both expresses the energy should be added to or omitted from the DC bus to maintain the DC bus voltage constant. The DC bus voltage must follow a fixed value called voltage reference. Thanks to a voltage controller the difference between the DC bus voltage measured and the voltage reference gives a current reference which is distributed between the battery, the FC generator and the electrolyser according to the distributed energy management strategy (DEMS) that generates a set-point of each one. Thanks to the corresponding converters and a current controller the power value able to balance the energy flow through the DC bus is injected. Thereby, no central controller is selected to control the DC bus, since the control is distributed among all elements that contribute together to the DC bus stabilization.

The voltage controller and the current controller play a major role in the bus voltage control. The voltage controller is based on a classic Proportional Integrator (PI) controller, while the current controller consists on bidirectional, boost, and buck converters connected to the battery, the FC and the electrolyser respectively and a classic PI controller.

The generation of set-points for the elements is achieved by the DEMS. The intelligent energy management using MAS concerns the communication, negotiations, and decisions between agents, in order to execute the best actions at the appropriate and required moment. Each agent has its own role that can be defined as behavior. Agents act together on their environment and react to events occurring in it. The main objective is to assign the decision-making to agents following the DEMS, and the executions of the required actions are made in Matlab Simulink environment. That allows designing self-adaptive DC-DC converters.

In this paper, three kinds of agents are considered. The HES studied is modeled under Matlab Simulink that enables the execution of all the mathematical calculations. While the DEMS is done by the MAS developed under Jade [10]. The communication between Matlab Simulink and Jade is established by MacsimJX. It is a tool for enabling models of systems created in Simulink to exchange data with MAS created using Jade. The junction of the two architectures is reported in [11-12]. By the following, the methodology used is described and illustrated in Fig.1.

The input signals express the data that each agent must know to react at any reaction required, in order to achieve the objectives and to meet all the challenges of the environment where the agents react. The SOC function is the battery agent input signal, E_{H2} is the FC and electrolyser agent input signal, and I_R is the bus manager agent input signal. These signals are sent from Matlab to agent developed under Jade thanks to

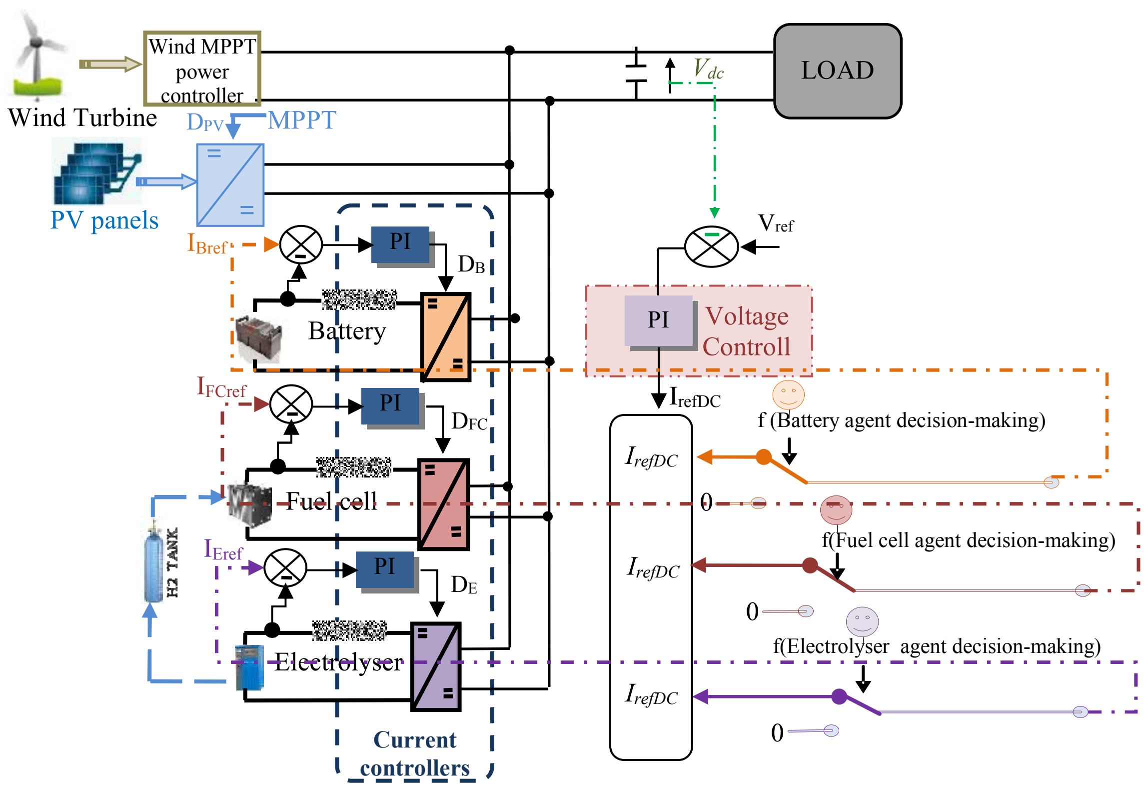

Fig. 2. HES control by MAS using self-adaptive DC-DC converters

MacsimJX for processing. Once the agents are finished processing these data, the agents' decision-making is sent to Simulink.

The agent decision-making expresses that the corresponding element and its associated converter modeled under Simulink will take over or not the current control and therefore the associated converters set point is equal to 'I_{refdc}' calculated during the voltage control or zero respectively. Fig.2 depicts the self-adaptive converters architecture allowing the HES control by MAS. It is shown that there is no central controller that collects data and assigns set points, each agent depending on received signals and messages; it controls autonomously the corresponding elements and associated converters.

III. Results and Discussion

The studied HES details are given in Table.1. The RES produce the electricity intermittently and not correlated with the demand. It results on two different kinds of processing which are the excess or the lack of energy through the DC bus as represented in I_R profile in Fig. 3. I_R expressed in (1), means the amount of current to supply or to absorb to balance the energy flow. It is a no controllable data because it depends on weather data and load demand. I_R is the current that the bus manager agent delivers for agents and receives from the HES modeled under Simulink.

TABLE I

HES components' specifications

Symbol	Specifications
DC bus	V_{dc}=48V,C_{dc}=50mF
Battery	V_{batt}=24V,Q_{batt}=12V/260Ah
Wind Turbine	P_W=10Kw
PV	P_{PV}=1kW,V_{PV}=24,4V,I_{PV}=7,58A,N_p=6,N_s=1
Fuel cell	P_{FC}=5kW, V_{FC}=24V, $N_{cell,FC}$=35
Electrolyser	P_E=5kW, V_E=26V, $N_{cell,el}$=24
Load	P_{load}=5 kW

$$I_R = I_{pv_{dc}} + I_{w_{dc}} + I_{D_{dc}} \quad (1)$$

The SOC of the battery was initially at 30%. It increases when the battery absorbs current, decreases when it supplies current and remains constant otherwise as it is shown in Fig. 4. The equivalent evolution of the energy of the stored hydrogen was initially set at 80kWh. It is shown, that E_{H2} increases when the electrolyser in operation producing hydrogen and it decreases when the FC consumes hydrogen and remains constant otherwise. The initial value was chosen near to E_{H2max}. All these measurements were taken to show

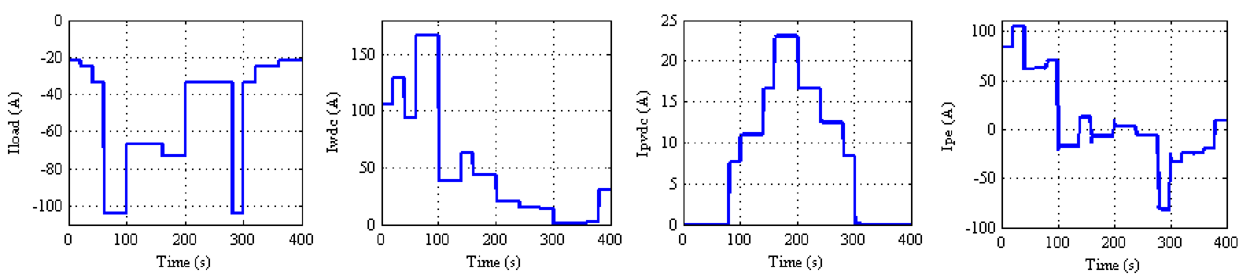

Fig. 3. Load demand profile, RES production and I_R resulting.

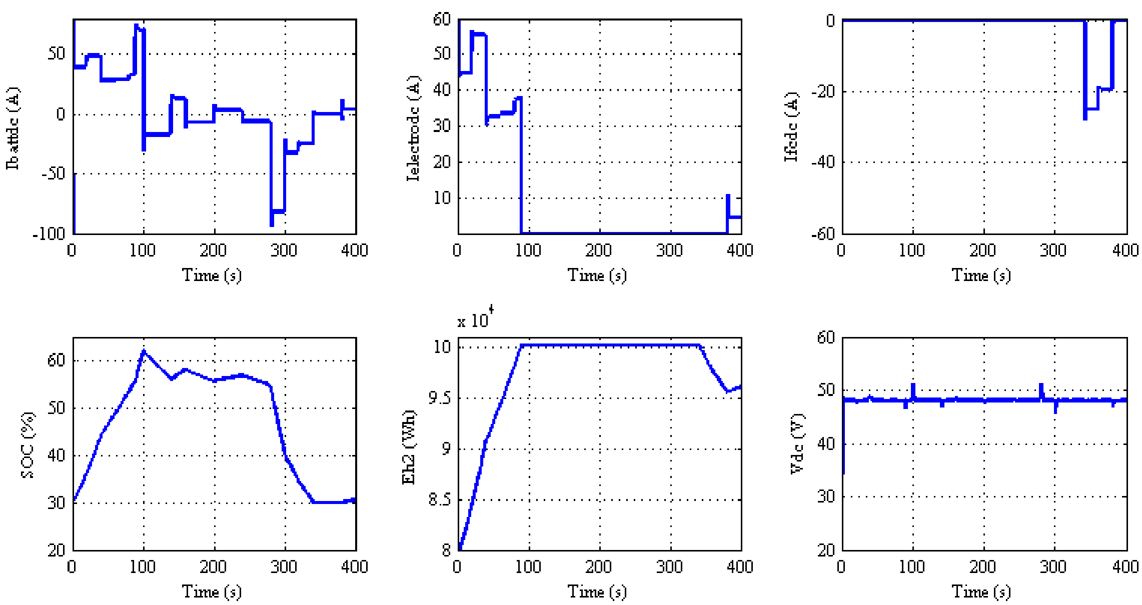

Fig. 4. HES reaction.

the capacity of each element to accept or to refuse taking over the required action depending on its own status. The scenario simulation time is about 400s. By the following, the reaction of each element to different variations and under various conditions is explained.

The PV generation and wind turbine exceeds the load demand as shown in Fig.3, from I_R profile. So a required quantity of current must be absorbed. At the beginning, it is shown in Fig. 4 that the summation of current absorbed by the battery and the electrolyser is equal to the current required to be absorbed i.e I_R. That means that the battery and the electrolyser absorb together the excess of energy long as the $E_{H2} < E_{H2max}$ and SOC<80%, by this way, if one of them fails or has no more capacity to absorb, the other takes over the control. By the following the battery and the electrolyser continues to absorb the excess of current. H_2 storage function and SOC increase simultaneously. However, if more minuteness is asked, it will be observed at 92s the system continues to ask to absorb and no changes have been recorded at the demand or generation energy, but the E_{H2} has reached its maximum limits as illustrated in Fig. 4. So the electrolyser suddenly stops to absorb and the battery continues to absorb the total of current required i.e I_R. This is very interesting during outages conditions to avoid general system failure. Thus one objective of the DEMS using MAS is reached: It is possible to distribute the current control action in order to avoid a general blackout due to a failure or inability of elements in current control. This notification indicates that the negotiation between agents is very useful to keep elements working for a long time. By this way, the cost of redemptions or maintenance is reduced, the material damage is avoided, and the stability of the system is maintained.

In the other side, when the generation of the RES does not satisfy the load demand, as result it is needed to provide the deficit of current. At the beginning the SOC of the battery was at 30%, it has increased when the battery has absorbed the excess of energy. Even if the FC is able to supply, it is shown that the battery takes over the current control. This is important to conserve a long life cycle for the FC which it depends on the hour of operation and number of start/stop cycles. At (341s) while it is always asking to supply, the SOC of battery has reached the lower limit, it stops supplying current and the FC is turned on to take over the current control, and continues supplying the missing of current as long as the SOC has not moved from the lower limit value. By the result, the hydrogen is produced and the E_{H2} becomes lower than E_{H2}max as indicated. That allows to the electrolyser to return to absorb as shown at the end of the simulation. Here the current control is distributed between the battery and the FC according to economic criteria, in order to conserve a long life cycle for the battery which it depends on the limit of the SOC function.

The DC bus voltage shall be maintained in a defined voltage reference which here is equal to 48V as shown in Fig. 4 otherwise the system will crash. That proves that the stability and the continuity of the system are ensured in the HES control using MAS.

IV. Conclusion

This paper has shown the significant role that plays the power electronics in the RES development and intensive integration. It is shown how the power electronics can turns the RES from passive to active generators and therefore they will no more follow the meteorological conditions and depend on the load demand in a HES thanks to the storage system and DG following an energy flow control. A hybrid storage system was presented in this paper, an electrochemical storage system is introduced by the battery and hydrogen storage is given by the FC-electrolyser conversion. A DC bus voltage distributed control was proposed in this paper to overcome the limitations of existing methods which depends on master-slave control method. Furthermore, a distributed control by MAS was studied in this paper and therefore a self-adaptive power electronic control is introduced. Finally a framework for co-simulation Matlab/Simulink and JADE was also proposed which has facilitated the implementation of the system, and enabled the physical HES modeling in Simulink and control agents are programmed in JADE.

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