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Energy Management for Embedded Microgrid using Multi Agent System

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***Abstract*—With the use of the renewable energies the electricity generation has evolved into a distributed way which has facilitated the establishment of islanded microgrids, sometimes mobile, such as in the electric vehicles. In this paper, an intelligent energy management model based on Multi Agent Systems technique is proposed for an islanded microgrid. It supplies a racing sailboat using only renewable energy sources; which complicates the energy management work since several constraints must be considered, such as the sailing speed of the sailboat and the intermittence of energy sources.**

***Keywords*— Microgrid, Multi Agent System, Energy management.**

I. Introduction

The integration of renewable energies in the electrical grid has increased the complexity of the grid and changed its structure. In fact, the dispersion of renewable energy sources on different sites has made possible the distributed energy production and the bidirectionality of the energy flow in electrical grids. The integration of distributed production in the grid can be facilitated by the establishment of microgrids based on geographical location. The management of microgrids becomes more complex if it is not connected to the main grid. In this case we speak about islanded microgrids which can supply fix or mobile systems. The electric cars, flying devices and ships are some examples of mobile systems. When they are at a standstill, the electric vehicles can be connected to the grid in order to be charged.

Currently, a lot of researches are carried out on Artificial Intelligence (AI) techniques inspired by the human reasoning (Fuzzy Logic), the natural selection (Genetic Algorithms), the functioning of the human nervous system (Artificial Neural Networks - ANN), and the social behavior of some species (Multi Agent Systems - MAS). The application fields of these techniques are continuously growing, both in research and industry. The application of some of these techniques in the management of complex systems has already been the subject of various research works. They have been applied in medicine, in order to assist the healthcare professionals for detection and diagnosis of disease and for surgery. In [1] an approach based on ANN and Internet of Things (IoT) for electrocardiogram analysis and cardiac disease detection was proposed. In [2] authors combined deep learning algorithms with augmented reality to develop surgical navigation system. In addition, AI techniques have been exploring the software engineering field to solve several software engineering problems. In [3] for example, the application of ANN, machine learning and data mining in the automated software reuse for software construction and global software development was discussed. In the field of electrical engineering, AI was applied to solve several issues. In [4], authors have proposed an error diagnosis analysis model of electric energy meter based on deep learning. A fault library has been collected and used to predict the cause of electric energy meter error, ensure the learning effect and improve the generalization ability and robustness of the model in the case of less sample spaces. In [5] a substation inspection tour has been monitored thanks to an intelligent video surveillance system using image classification algorithm based on deep learning. The proposed solution lets to: 1/ the intelligent control realization of field personnel and operation behavior, and 2/ the automatic confirmation and alarm of abnormal situation such as foreign body, smoke and flame detection in station area.

AI solutions were also proposed in order to solve the electrical grid / microgrid issues such as:

- Energy prediction: The intermittence of the renewable energy generation requires a preliminary estimate of the amount of energy to be produced and consumed in order to supply loads. In this respect, artificial learning (machine learning, deep learning, ANN, etc.) has been widely applied and has proven its effectiveness to predict: 1/ the solar or wind energy to be produced by PV panels or wind turbines respectively [6-8], 2/ the

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solar radiation or wind speed to be introduced as input to estimate the PV or wind energy production respectively [9-11] and 3/ the energy consumption in order to estimate the electric profile of the system to be studied [12, 13],

- Energy management: The energy management issues in microgrid depend on its operation mode. In connected mode the problems to raise are: the geographical constraints optimization to supply loads, the energy cost negotiation when buying energy from the main grid, the choice between selling or storing in batteries the energy excess, etc. In islanded mode, the problems to raise are: the decision making to disconnect some loads when there is a lack of local power generation, consequently the decision making about which loads to disconnect and at what time; the demand side management which means the consumption shifting relative to the production when it is possible, etc. The proposed AI based models to solve these issues have applied different techniques such as ANN [14], artificial bee colony [15], fuzzy logic [16] and MAS [17].

The objective of the work presented in this paper is to take advantage of the development of AI techniques to ensure the operation of a microgrid embedded on a racing sailboat. It is supplied using only renewable energy sources such as wind turbines, photovoltaic panels and a hydro-generator in addition to a storage system (battery). This challenge requires the design of an energy management advanced system which must ensure a balance between production and consumption, taking into account the estimation of the daily electrical energy available to determine when and how much energy to store on one hand, and the race constraints on the other hand. The Energy Management System (EMS) proposed in this work is based on the Multi Agent Systems (MAS) technique.

The rest of the paper is organized into four sections. In Section II the model of the considered microgrid is presented. In Section III the proposed MAS and agents are identified. Simulation results are shown for three operating scenarios in Section IV. Finally, a conclusion is drawn in Section V.

II. Microgrid elements modelling

The sailboat microgrid is organized around a DC bus and the considered loads are lights, navigation and communication systems, computer and white goods.

This DC microgrid was simulated under Matlab-Simulink environment and its structure is shown in Fig. 1.

A PV array and a hydro-generator are considered for the energy production. The energy storage is ensured by Lead-Acid batteries which are protected by a charger. Based on their characteristics, the loads are classified into three types:

- Primary loads, there are the critical loads, which must not be disconnected from the microgrid, namely: the communication and navigation systems and security lights.
- Secondary loads, there are the loads which can be disconnected without compromising the security of the boat and without disturbing the progress within the race, such as the interior lights.
- Inertial loads, there are those that must be supplied for a specified time during the day, but it does not matter when, because they have internal batteries or other possibility of energy storage (heat or cold storage). This type of load can be disconnected if necessary, as for example: laptop, mobile phone, fridge, etc.

In addition to supplying loads properly, the objectives to achieve for the system design and operation are also related to the race, mainly the speed optimization of the sailboat; among others by decreasing its weight (design) and limiting the use of the hydro-generator (operation).

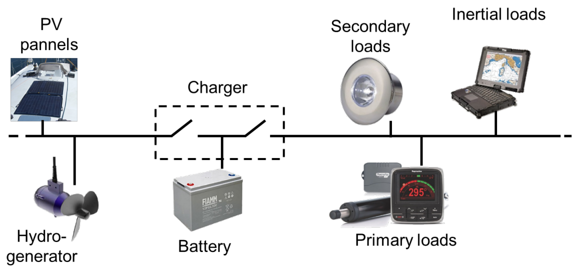

Fig. 1 Structure of the microgrid embedded in the sailboat

III. Proposed MAS for the sailboat microgrid management

The proposed MAS for the sailboat microgrid management is presented in Fig. 2. Two types of agents are considered: A - agents associated to physical devices. There are hardware agents whose the main objective is to protect microgrid elements Their structure is mainly based on sensors (current and voltage) and effectors (switches), B - computing and IHM agents. There are software agents.

A) One agent is assigned to each element of the microgrid:

- distributed generation elements: PV agent (A_PV) and hydro-generator agent (A_hydro-generator),
- energy storage and management storage elements: battery agent (A_battery) and charger agent (A_charger),
- loads: Since loads belonging to the same group have the same properties and priority order, they can be controlled by the same agent. Therefore, one agent is proposed for each load type: primary loads agent (A_primary loads), inertial loads agent (A_inertial loads) and secondary loads agent (A_secondary loads).

B) In addition, the MAS includes:

- prediction agent (A_prediction): it applies an artificial learning based to an ANN to predict daily solar radiation and then estimate the production of the PV generator. The prediction solar radiation ANN model considered in this work has been developed in our pervious work published in [18],

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- supervisor agent (A_local supervisor): it manages the power balance in real time, supervises the energy over the day; and ensures the protection of the microgrid elements,
- IHM agent (A_interface): it ensures the interaction between the system and the user. This is performed by a periodic updates and visualization of the system state.

In the implementation of a microgrid, two connection types are necessary: 1) electrical connections to ensure the energy flow and 2) connections for communication that can be wired or wireless. Both are presented in Fig. 2.

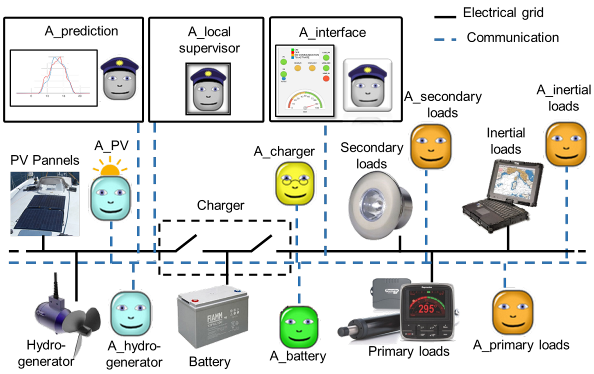

Fig. 2 Proposed MAS model

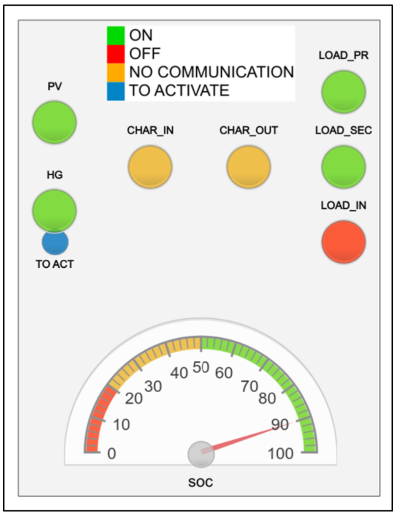

Fig. 3 User interface of the MAS

The interface managed by the IHM agent is presented in Fig. 3. It consists of:

- a gauge which indicates the State Of Charge (SOC) of the battery, ranging from 0 to 100%. It is assumed that information about the SOC is of major importance for the skipper,
- seven LEDs, each corresponds to a switch state, and indicates the connectivity of the associated element using a color.
- an additional LED which switches to blue to indicate to the skipper that the hydro-generator must be started. It must be noted that the launch of the hydro-generator in water is done manually.

IV. Operating Scenarios and Simulation Results

To validate the efficiency of the proposed EMS, it is interesting to compare the microgrid operation with and without the contribution of MAS. In this respect, three scenarios are exposed in this paper: two scenarios present the basic operation of the microgrid, and one scenario presents the contribution of MAS in the microgrid operation.

Although the Simulink model was developed to operate in a Multi Agent context, it is possible to obtain the basic operation of the microgrid by disabling the communication.

A) Scenario 1: Microgrid basic operation ensured by the charger

In this scenario, it is the charger which manages the connection / disconnection of the production and the consumption sides in order to protect the battery and increase its lifespan. The scenario was run for 24 hours with the following microgrid characteristics:

- peak PV power = 2250W, the PV power changes according to solar radiation,
- hydro-generator power = 200W, it is assumed that the hydro-generator is permanently put into water, and when it is not disconnected by the charger, it provides a constant power,
- capacity of the battery = 200 Ah, initial SOC = 50%,
- average power consumed by loads = 450W. The three types of loads are permanently supplied, and the consumption profile includes a random part,

Depending on SOC, the charger disconnects sources at 100% and reconnect them at 95%; and disconnects loads at 20% and reconnect them at 25%.

The variation of the SOC and the charger currents during the run of scenario 1 are presented in Fig. 4 and 5 respectively. The sources are disconnected several times from 15000 to 32000 seconds (from 4 am to around 9 am) because the battery is fully charged. During these disconnections solar energy is lost as the PV panels are disconnected so they cannot supply electrical power to the microgrid. The hydro-generator is also disconnected at these intervals while still in water, which can slow down the sailboat's progress.

The loads are also disconnected several times from 65000 to 85000 seconds (from 6 pm to around midnight) because the battery is too low. All the loads are disconnected at the same time, even the primary loads, because the charger is not able to differentiate them.

The total available energy (PV + hydro-generator, 13.584 kWh) is greater than the energy required to supply loads (10.8 kWh). With a greater battery capacity, the energy can be collected but it is not possible since the studied microgrid is embedded on a racing sailboat. In fact, increasing the capacity of the battery causes an increase in its weight and thus a degradation of the sailboat speed. Furthermore, the quick connection and disconnection of loads is a dangerous

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phenomenon that will damage them. To consider these constraints the scenario 2 is proposed.

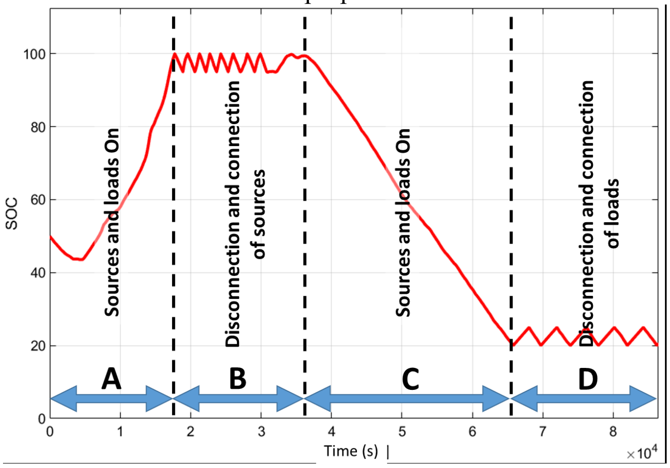

Fig. 4 SOC variation during scenario 1

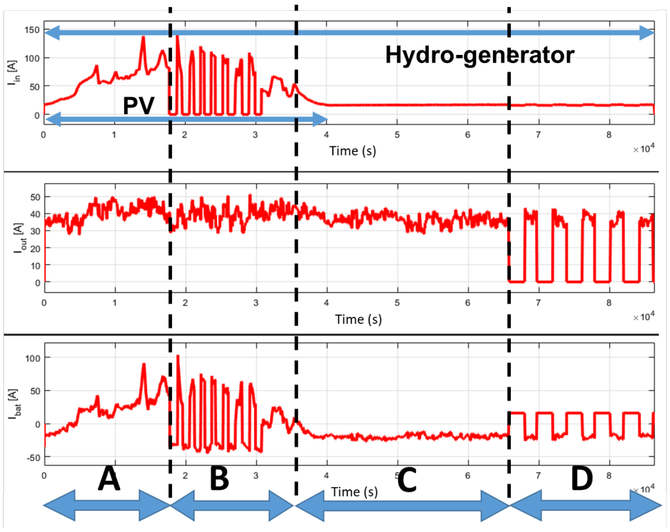

Fig. 5 Charger currents variation during scenario 1

B) Scenario 2: Microgrid optimized operation

This scenario is run with the same duration and parameters of the scenario 1 with some differences that will be mentioned below. Its principle is based on:

- reinforce the energy consumption when PV produces energy i.e. when there is solar radiation. Therefore, the inertial loads are supplied during the day. To perform it, it is assumed that they are permanently connected to the microgrid, but they consume energy only for 12 hours. Their average power is set at 400W. For primary and secondary loads, average power is set at 150W and 100W respectively, 250W in total,
- put the hydro-generator into water at night, for 12 hours (this action is made by the skipper). To maintain the same amount of energy as the first scenario, the produced power is doubled to 400W.

The variation of the SOC and the charger currents during the run of scenario 2 are presented in Fig. 6 and 7 respectively. An appropriate choice of the operating intervals of inertial loads and hydro-generator avoids the disconnection of sources and loads without increasing the storage capacity. However, this scenario has two drawbacks:

- the charger connects / disconnects all loads and / or all sources. In case of power lack, even if there is enough energy to supply primary loads, the charger disconnects them by closing the loads side switch. It is the same problem in case of power excess, the charger cannot disconnect one generator and let the other one running,
- The hydro-generator is disconnected from the microgrid only when the skipper recovers it from water (no specific switch to this device). If, for example, the skipper is sailing in adverse weather conditions, he will not have time to recover it, this can damage the battery.

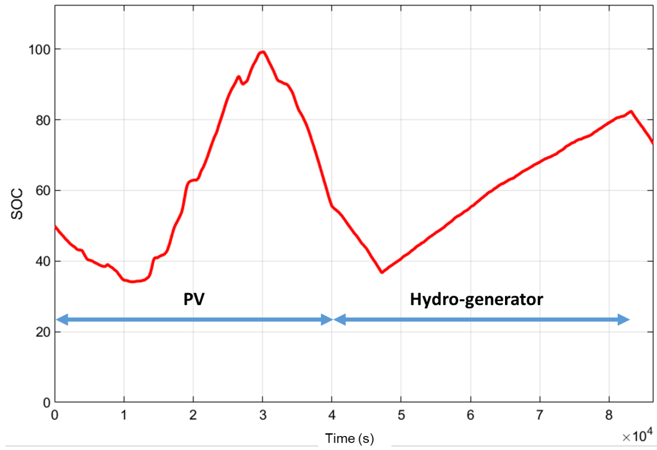

Fig. 6 SOC variation during scenario 2

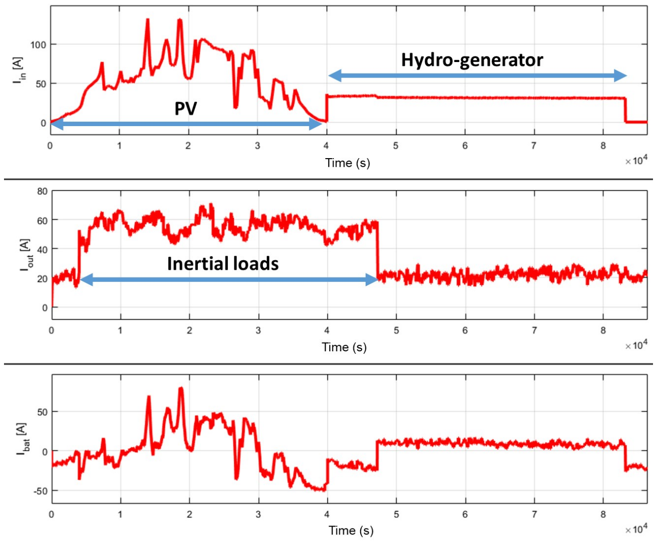

Fig. 7 Charger currents variation during scenario 2

C) Scenario 3: Microgrid operation with MAS

In this scenario the microgrid energy management is based to the proposed MAS. It is run with the same duration and parameters of the scenario 2. The secondary loads connection

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and disconnection SOCs are set at 85% and 80% respectively. The primary loads are permanently connected and the inertial loads work with the same principle of scenario 2. It is assumed that the communication between the supervisor agent and all other agents is active.

As presented in Fig 8, the final SOC of the battery is greater than the initial one. The available energy has not been consumed because the secondary loads are disconnected throughout the period when the SOC is less than 80%, so they are supplied approximately for half the time (41613 seconds, around 11½ hours). The PV panels are disconnected twice as well as the hydro-generator (Fig 9).

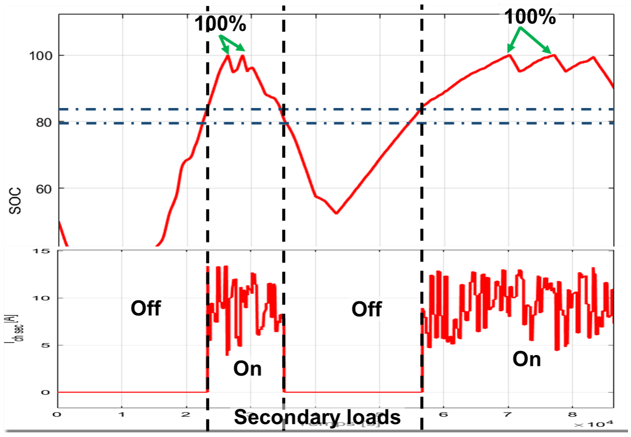

Fig. 8 SOC and secondary loads current variation during scenario 3 (secondary loads connection / disconnection SOCs set at 85% / 80% respectively)

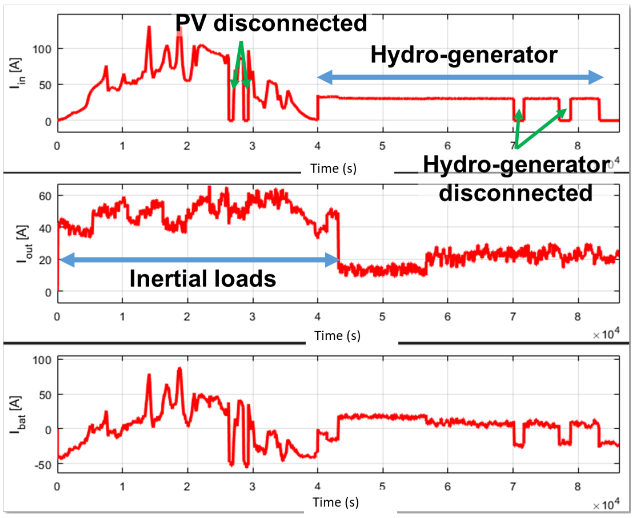

Fig. 9 Charger currents variation during scenario 3 (secondary loads connection / disconnection SOCs set at 85% / 80% respectively)

To improve the system energy efficiency relating to the secondary loads supply, the supervisor agent is configured to connect and disconnect them at 45% and 40% SOCs levels respectively. The obtained results are presented in Fig 10 and Fig 11.

The secondary loads are supplied during 71523s (around 20 hours), the SOC reaches its maximum once, so the PV panels are disconnected once, and the hydro-generator is permanently connected. In this case a suitable consumption of the available energy is observed, and the battery is not completely discharged. In other cases, for example when the hydro-generator is not launched by the skipper in water to operate during the 12 hours of night, the battery can be discharged while the PV panels cannot produce energy. That is why it is appropriate to set SOCs connection and disconnection levels at high values to ensure both primary loads supply and microgrid safety.

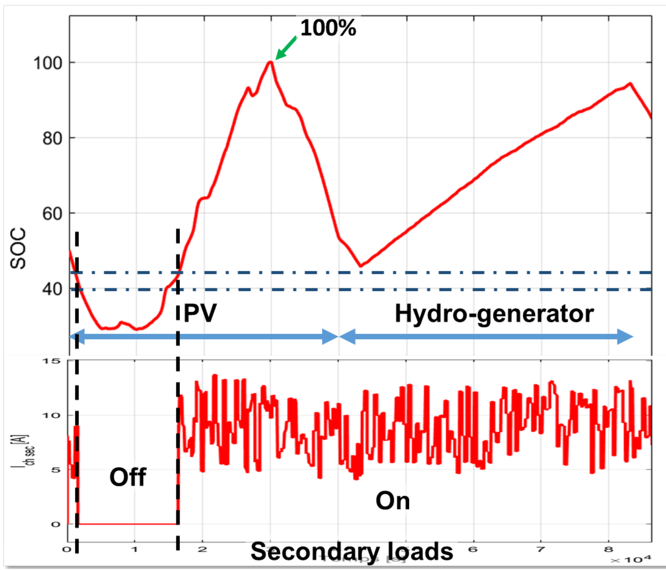

Fig. 10 SOC and secondary loads current variation during scenario 3 (secondary loads connection / disconnection SOCs set at 45% / 40% respectively)

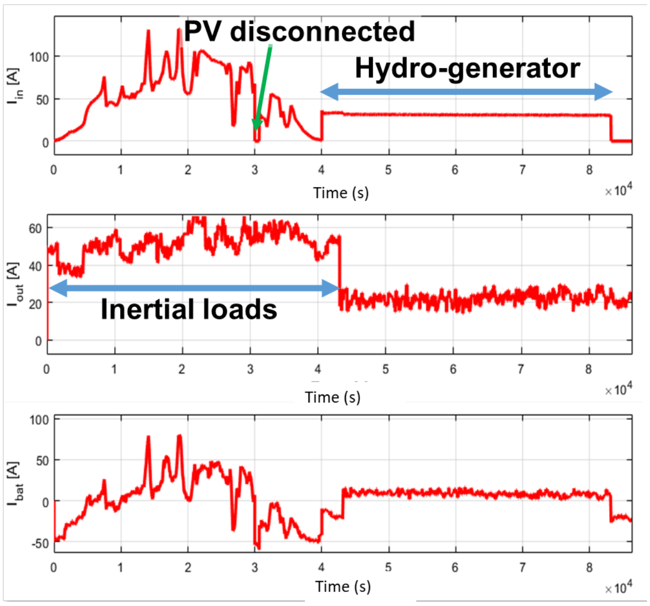

Fig. 11 Charger currents variation during scenario 3 (secondary loads connection / disconnection SOCs set at 45% / 40% respectively)

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The simulation results show that the application of MAS for the management of the studied microgrid improves its energy efficiency. Indeed, the distributed nature of MAS and the interaction between agents allow:

- supply all types of loads as much as possible, which ensures the service continuity of the microgrid,
- control the SOC variation continuously and effectively, which helps to protect the battery and increase its lifespan,
- take advantage of the availability of PV production as much as possible, which optimizes the launch of the hydro-generator in water and therefore improves the sailing speed of the sailboat,
- promote the use of renewable energies, which despite their intermittent nature, constitute a safe source of electricity.

V. CONCLUSIONS

In this paper an intelligent EMS is proposed for an islanded microgrid embedded on a racing sailboat. The energy management is performed using the MAS technique. One agent is proposed to control and protect each microgrid element and load type, since the loads have been organized into three types: primary, inertial and secondary. In addition, a supervisor, a prediction and an IHM agents are added to ensure the connection / disconnection of each element to / from the microgrid in order to protect them, predict the energy to be produced by the PV panels, and ensure the user interface real time update respectively. Three simulation scenarios were run to compare the basic microgrid operation with the contribution of MAS in the microgrid operation. The obtained results validate the EMS performances. In fact, the proposed model allows increasing the efficiency and the security of microgrid devices taking into account the constraints related to the race conditions.

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