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An Intelligent Power Management Investigation for Stand-alone Hybrid System Using Short-time Energy Storage

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ABSTRACT

Stand-alone Hybrid systems become appreciating issues that ensure the required electricity to consumers. The development of a stand-alone Hybrid system becomes a necessity for multiple applications The enhance energy security. To achieve this objective, we have proposed an accurate dynamic model using Multi-Agent System (MAS) in which a solar energy System (SES) serves as the main load supply, an energy Backup System (ERS) is based on a fuel cell and Electrolyzer for long-term energy storage and an Ultra Capacitor (UCap) storage system deployed as a short-time storage. To cooperate with all systems, an Intelligent Power Management (IPM) based on a specific MAS is included. Thus, to prove the performance of the system, we tested and simulated it using the Matlab/Simulink environment.

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1. INTRODUCTION

The stand-alone hybrid system combines various renewable power sources is begin an attracting issues. These sources can be solar power, wind and Fuel Cells [1]. The main goal of the Stand-alone hybrid system is to produce as much Renewable power to ensure the load demand. Also, the stand-alone system uses a Boost or Buck converters, Energy management unit and storage system [2]-[3]. All these components can be linked in different configurations [4]-[5]. The solar system is known by a reliable power during a critical periods as at night. In this regard, the integration of storage components is necessary for continuous power supply and to provide the required powerfor the electrical load [6]-[7]. To solve the problems of power demand, several configurations have been proposed and have been integrated same alternative energy sources such as fuel cells, Ultra-Capacitor, electrolyte, hydrogen tank storage [8]-[10]. The PEMFC fits the required energy for start-up power cases [11]. It can save the required power when the solar energy appears insufficient to meet those requirements. To achieve this, the combination of PEMFC and Ultra-Capacitor is an attractive requirement and an attractive solution due to its flexibility and its structure modularity [12]-[13]. The solar energy component (SEC) is used to provide high pulse energy demands in a short time. In addition, it can be connected to the charge and discharge depending on the state of the solar PV, the PEMFC and the load. To improve the energy supply reliability, Hydrogen gases are well suited to seasonal storage applications as chemical batteries due to its leak density and it's high mass energy[13]-[15].

In the literature, many configurations have presented a stand-alone hybrid system using MAS that seems to provide an isolated site. For example, in [16], the authors proposed an efficient distributed power sources using a MAS. The proposed distributed management using MAS was ensured better system reliability. In addition the system was evaluated and tested using a simulation model. In [17], the authors presented a distributed multi-agent system in smart grid. A multi-agent framework was employed to coordinate with all agents. The system performance was validated through simulation results. While, in [18], the authors proposed a Renewable energy system using a multi-objective algorithm. The proposed algorithm was included to optimally allocate the renewable energy sources and to minimize the system cost. The system performance was indicated an improvement in the operational system conditions. Finally, a Stand-alone hybrid system was presented by the authors in [19]. An efficient energy management system was proposed based on a hierarchical control. The proposed management strategy was aimed to generate a reference power, to ensure the load demand, and to maintain the level of the hydrogen in the tank. The system performance was improved through various kinds' simulation results.

In this paper, we propose a stand-alone hybrid system comprising a solar system as the main source, a backup system as a second source. The proposed system aim to apply a MAS to ensure the system reliability and system performances. Through the developed algorithm the excess and deficit power cases are evaluated in details. Also, the proposed system is evaluated based on an experimental profile.

Compared to the related works cited above, our work is specified by developing a stand-alone system based on MAS with a few improvements regarding:

a. The system and its devices: An ultra-capacitor is integrated to enable the system. This latter, presents a response time (charging/ discharging) much higher than the battery.
b. The proposed EMUs: Compared to the previous EMUs, our purpose, aims to renew the classical strategies using a Intelligent Power Management.
c. The input system simulation: An experimental data profile extracted from the Tunisian meteorological database is considered to improve the system performance.

The remainder of this paper is divided into 5 sections: Introduction is presented in the section 1; Section 2 presents the overall proposed system; Section 3 outlines the Intelligent Power management analysis; Section 4 is devoted to the analysis of the simulation results and concluding remarks are discussed in Section 5.

2. STAND-ALONE HYBRID SYSTEM AND MULTI-AGENT SYSTEM DESCRIPTION

In this section, the autonomous hybrid system is presented and evaluated (see Figure 1). Each system was presented by its own agent. Each agent was deployed to gather information with other agents and MAS. All these elements are coordinated and manipulated through an intelligent energy management (storage / Recovery).The backup system is characterized by two operations modes which are the Electrolyser mode was used as energy storage and the PEMFC mode was used as for energy recovery. The system also controls the state of the tank and the UCap to activate the appropriate elements. Finally, the system is planted to meet DC load requirements for remote application.

The IPM is applied to power systems ensures cooperation with each other to optimize energy supply and demand. The IEM is a stand-alone system, comprising other agents that perform the complicated task together and coordinate with each other to optimize energy consumption. Share decisions should be handled locally. Mostly, each agent can independently supervise the energy supply and demand from its own unit. Indeed, each agent has the ability to recognize the event to react quickly to the corresponding task. When an agent fails, automatically, all agents will continue sharing responsibility and exchanging knowledge with other agents (see Figure 1).

2.1. Solar Energy Agent

The power supplied by Solar Energy System (SES) has been characterized by various fluctuations due to the climate change such as temperatures and radiation. A Maximum Power Tracker (MPPT) was used to monitor and maintain optimum operation of the solar system [20]-[22]. To monitor the power status, an Agent-Solar has been deployed. The current solar cell is expressed as follows:

$$I_{SES} = N_p I_{ph} - N_p I_s \left[exp(\frac{V_{SES}}{N_s V_q} + \frac{I_{SES} R_{sc}}{NpV_q}) - 1 \right] - \frac{N_p}{R_{sh}} \left(\frac{V_{SES}}{N_s} + \frac{I_{SES} R_{sc}}{N_p} \right) \quad (1)$$

2.2. Energy storage Agent

The energy storage system (ESS) was used to control and to supervise the hydrogen production and the tank storage state. The ESS is characterized by the use of a water electrolysis that deployed to generate hydrogen gases from decomposing the water molecules into hydrogen and oxygen. ESA was used the electrical current from the SEA to produce hydrogen gases [23]-[24]. The current circulating into the cell and the generated hydrogen generated rate are given by the following equation:

$$\begin{cases} V_{EL} = E_{rev} + U_{act,A} + U_{act,C} + U_{ohm} \\ Q_{H_2}^{P} = \dfrac{\eta_F^{ESC} N_C}{2.F} .I_{SES} \end{cases} \tag{2}$$

The hydrogen gases delivered from the Electrolyzer were stored for the long-term. The mathematical model of the hydrogen pressure can be determined, from the Van der Waals state equation, for real gases [25].

$$p_T = \frac{Q_{H_2}^{P} .R.T_T}{V_T} \tag{3}$$

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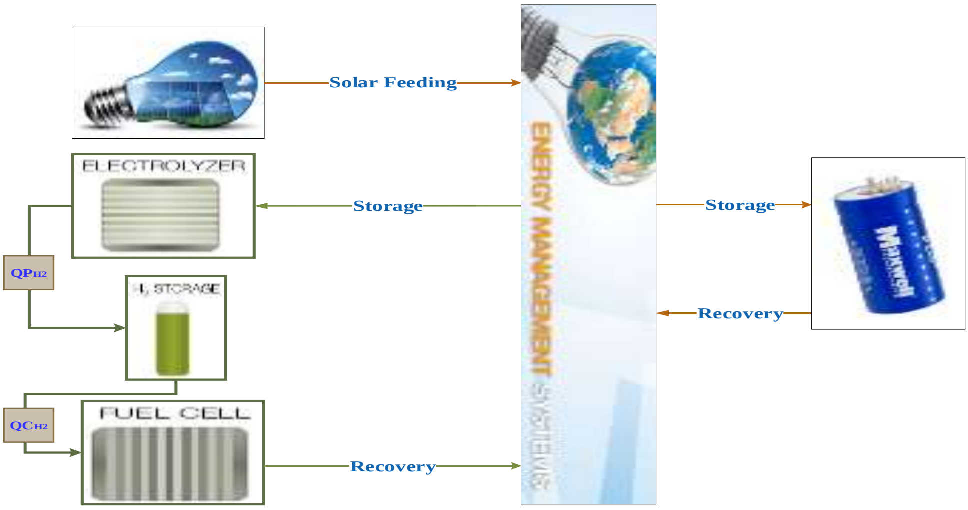


(a) Schematics of the considered autonomous hybrid system

(b) Mult-Agent-System

Figure 1. Descriptive model of the autonomous hybrid system

2.3. Energy Recovery Agent

The energy storage system (ERS) was used to control the hydrogen needed by the PEMFC. The ESS is characterized by the use of the PEMFC that deployed to convert the hydrogen gases. PEMFC was included as a second power source that is directly connected to the DC-DC Boost converter. It is a static energy conversion device that converts the direct chemical reaction of fuels into electrical energy [26]. The PEMFC output voltage and the hydrogen consumption variations can be defined as:

$$\begin{cases} U_{FC} = U_{rev} - (U_{act} + U_{con} + U_{ohm}) \\ Q_{H_2}^{C} = \dfrac{N_{CELL}}{2.F.\eta_{F}^{ERC}}.I_{ERS} \end{cases} \quad (4)$$

2.4. Ultra-Capacitor Agent: Short Time storage

The Ultra-Capacitor Agent was used as a short storage time. It was deployed to correct the power fluctuations of the ERA. The UCap model consists of an electric double-layer capacitance (C_{UCap}), an equivalent series resistance (Rs), and parallel resistance (Rp). The cap is chosen as an energy supplier. An efficient Agent was deployed to perform the UCap operations. Also, the agent was devoted to control UCap state of charge (SOC_{UCap}) that used to prevent the UCap from overcharging and undercharging [27]-[28]. The UCap voltage and its state of charge are given as follows:

$$\begin{cases} SOC_{UCap} = \left(\dfrac{U_{UCap}}{U_{UCap_{max}}}\right)^2 \\ U_{UCap} = R_{UCap}.I_{UCap}.\dfrac{1}{C_{UCap}}\displaystyle\int_0^t \left(I_{UCap} - I_{UCap}^{DH}\right).dt + U_{UCap}(0) \end{cases} \quad (5)$$

2.5. Electrical Load Agent

The electrical load demand was chosen to manage and to test the system performance. Indeed, the load power is considered as the referential power to optimize the components and to obtain the desired performance. The proposed system was treated according to an experimental data profile extracted from the Tunisia-meteorological database (see Figure 2).

3. INTELLIGENT POWER MANAGEMENT ANALYSIS

The energy management is a system of various rules is used to monitor, to control, and to optimize the performance of the autonomous system generation. In our case, the proposed IPM was integrated a Multi-Agent system. The MAS can provide a platform using the artificial intelligence and the mathematical tools to create an optimal agent interaction. In addition, each agent can detect its environment and acts on it. The multi-agent system was modeled using Agent/UML the language. This language is chosen to evaluate, explain the agent cooperation and to develop agent systems. The UML agent can provide various design representation types [29]. The Sequence Diagram of the autonomous system is given by the Figure 3.

The proposed system is evaluated according to the energy needs of a given load demand. For this reason, the IPM is proposed to ensure cooperation between the different system components according to the value of the control current which can identify the system state.

The current control is defined as the difference between the SES current and the load one ($I_{CTR}=I_{SES}-I_{Load}$). Hence, when the $I_{CTR}>0$, the system can provide an excess of power which can present by IEX. The excess power must be controlled and then stored. In the opposite case ($I_{CTR}<0$), the system declines a deficit power, given by I_{DEF}. So, the excess current (I_{EX}) and the deficit current (IDEF) are used as in input parameters that used to select which elements of the system will be either on or off. The describing algorithm given by the figure 4 can be ranged in several states:

State 1: (When $I_{EX}\neq 0$)

Firstly, the system checks the state of the tank storage in order to control the hydrogen production process.

State 2: (When $SOC_{H2}<SOC_{M}$)

The Electrolyzer is on ($D_{EL}=1$).

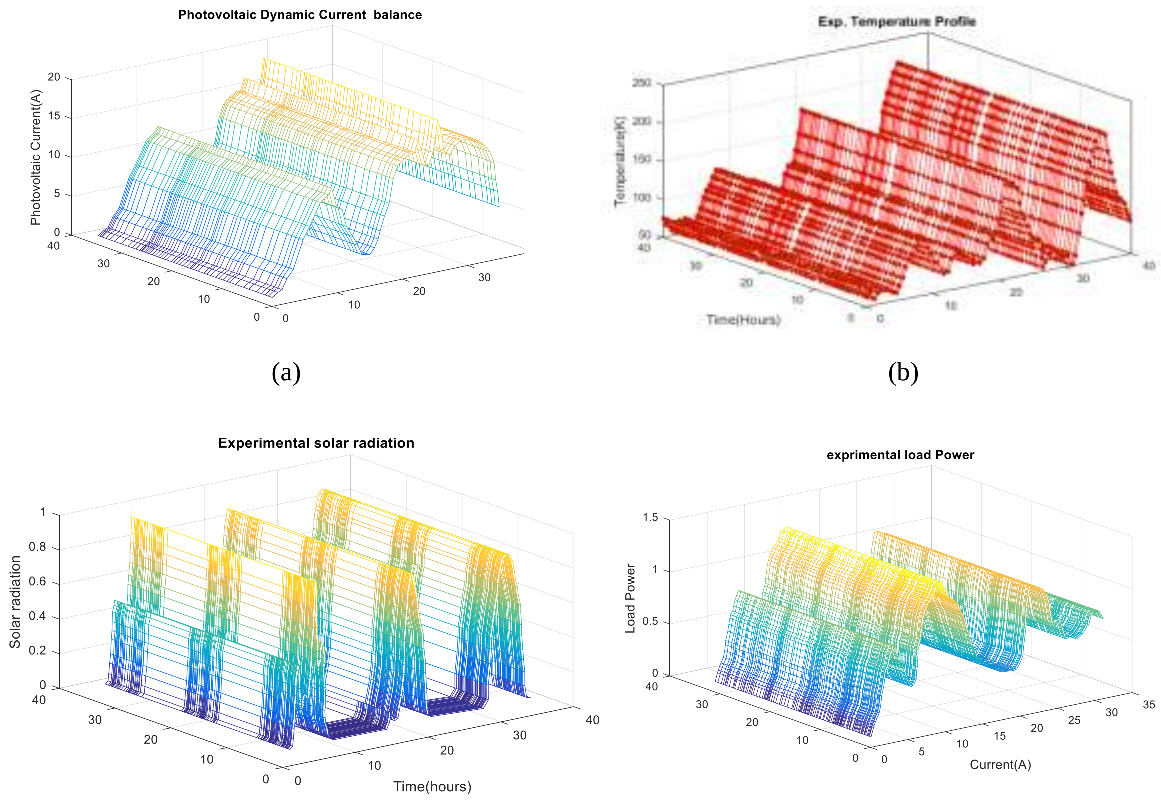
State 3: When $SOC_{H2}>SOC_{M}$

The ELectrolyzer is off element ($D_{EL}=0$). In this case, the system has to control the state of the UCap in order to rectify the energy storage process.

State 4: When :$SOC_{UCap}<SOC_{mx}$

The $_{UCap}$ is on ($D_{UC}=1$).

State 5: When SOC_{UCap}>SOC_{mx} and SOC_{H2}>SOC_{m}
The UCap is off (D_{UC}=0) and FC is on (DFC=1)
State 6: When SOCH2<SOCm
FC is on (DFC=1). In this case, the system can control the UCap state to maintain the load requirements.
State 7: When SOC_{UC}>SOC_{mn}
The UCap is on (D_{UC}=1).
State 8: When SOC_{UCa}p <SOC_{mn}
The UCap is off (D_{UC}=0).



(a) (b)

(c) (d)

Figure 2. Experimental Profiles Variations: Photovoltaic current profile (a); Temperature profile (b); Solar radiation profile (c); experimental load power (d)

4. RESULTS AND DISCUSSION

In this section, we evaluate the efficiency and performance of the proposed stand-alone hybrid power system by applying the MAS. The system evaluation is presented and explained in details through the below simulations. The simulations demonstrated the ability of the system to manage all problems related to energy demand or energy energy storage according to the MAS. This latter, improved and demonstrated the cooperation between all components and the IPM. To demonstrate the interaction of all the components, we used Matlab/Simulink that provides the ability to design the agent behaviors through the Stateflow Modeling space. The proposed system is simulated and evaluated according and experimental data profiles given by the above profiles (see Figure 2). According to the above experimental results, we have obtained the following results. All the input parameters of the stand-alone hybrid system are illustrated in Table 1

As can be seen, occasionally the system provides excess power and deficit power (see Figure 5). Indeed, the excess power generates the activation of the Elelyzerfor to produce hydrogen. Whereas the deficit of power generates the activation of the PEMFC for the consumption of hydrogen (see Figure 5 and 6).

The UCap intervenes to rectify the energy storage and energy recovery as follows:

a. Rectify the energy recovery when the tank is empty (SOC_{H2} = 0).

b. Rectify the energy storage when the storage of the tank is full (SOC_{H2} = 1).

The UCap behavior is given in Figure 5. The increasing value of SOC_{UC} indicates that the cap is activated in load mode while the decreasing value of the SOC_{UC} indicates that it is activated in unload mode. We must consider that the initial value of SOC_{UC} is about 55% and the critical value of the UCap load cannot be less than 5%. The decision taken by the supervisor agent who is assigned to the activation and deactivation of each system component is given by On/Off states (Figure 5).

Finally, the Figure 7 is dedicated to showing the overall efficient compared to the classical energy management. We can remark that the performance was shown by our proposed system is more important than that was showed by systems that use Classical power management. According to the result obtained, the system adopted by our work reaches a maximum of 35%.

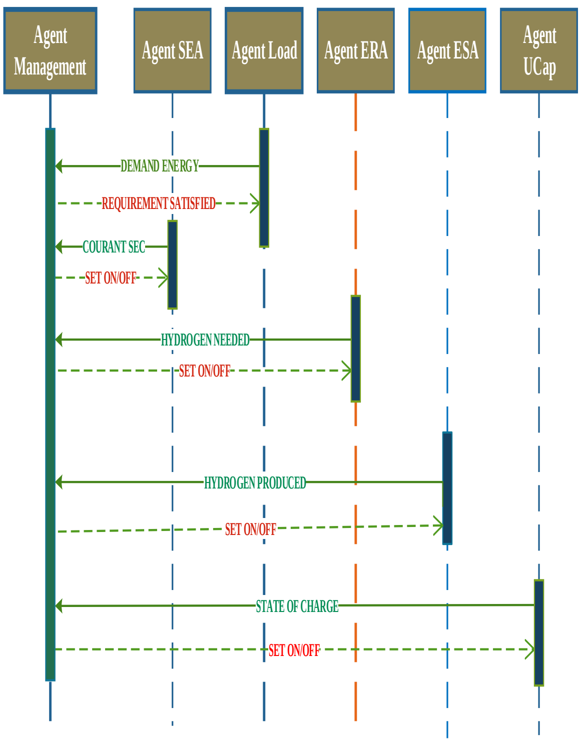


Figure 3. Sequence Diagram of the HES system

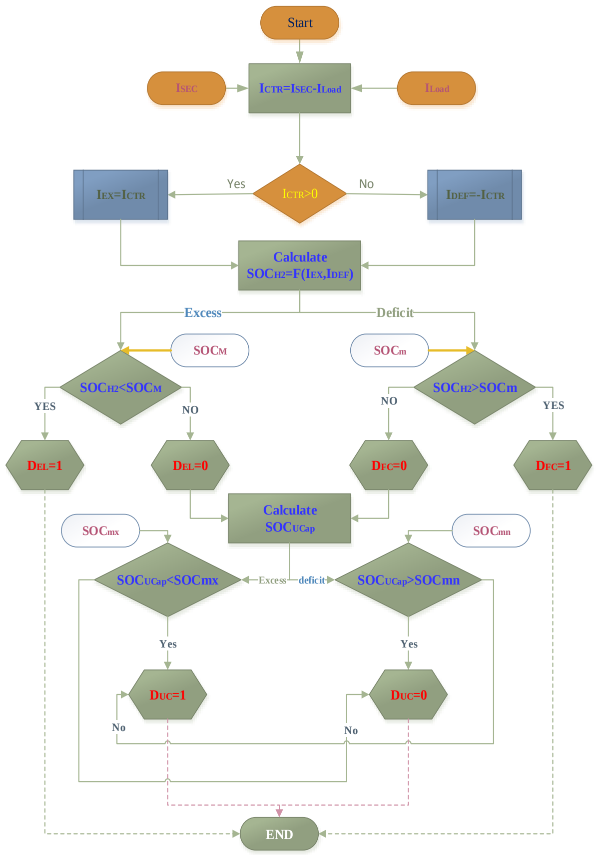


Figure 4. Operational Power Management

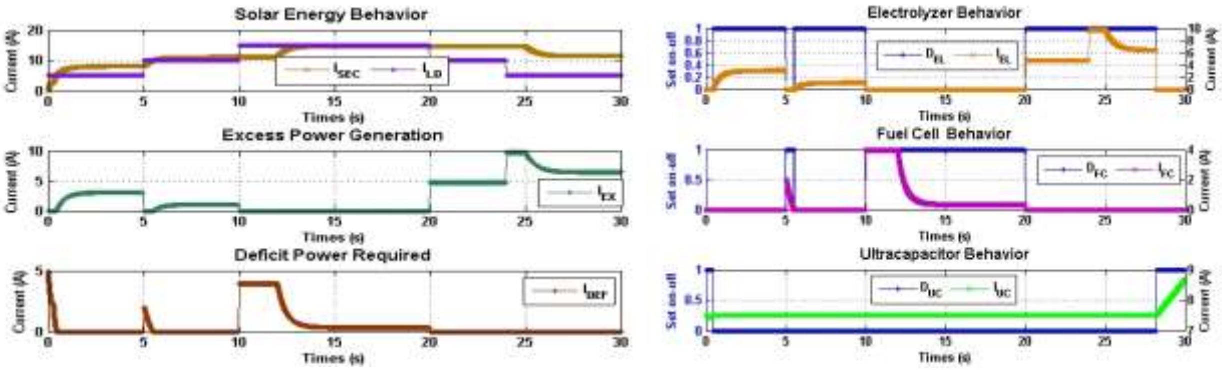


Figure 5. Curent profiles of the Stand-alone Hybrid system

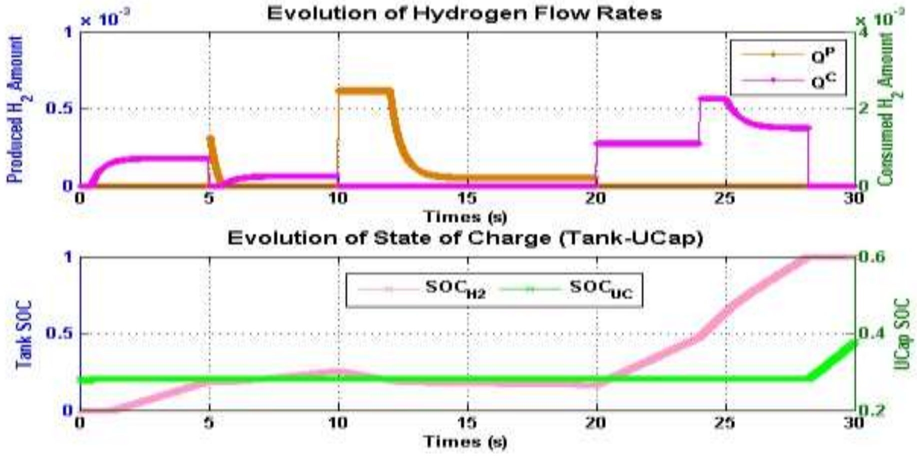


Figure 6. Hydrogen Profiles/State of Charge (SOC)

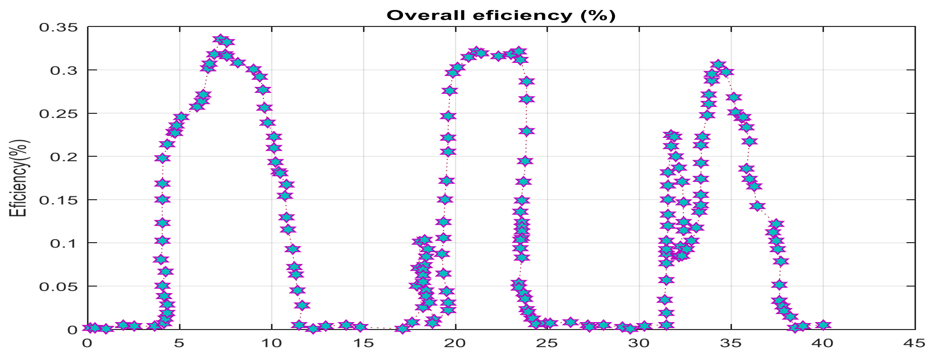


Figure 7. Overall stand-alone hybrid system efficiency

5. CONCLUSION

In this paper, we have treated the behavior of our proposed system using an IPM. The system discussion depends on the climatic conditions. Furthermore, we proposed an IPM, based on the current inputs of the sources and the decision coefficients that used to monitor the load demands. Finally, we have evaluated our contribution through simulations and we have shown the effectiveness and the toughness of the proposed approach. The MAS was accommodated with the interaction among different component agents. Hence, the deployment of these agents, keeps the optimal load demand. Finally, the obtained results proved the reliability of a stand-alone hybrid system based on renewable energy and hydrogen storage.

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