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Research paper

Energy Management Applied To Non-Autonomous Photovoltaic Station For Hybrid Vehicle Loading

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ABSTRACT

Among the major challenges of the widespread use of electric and hybrid vehicles is the unavailability of platforms and loading stations in a sufficient manner. For this reason, people think about having semi-autonomous individual stations. In this article, we propose a type of semi-autonomous station that can be multifunctional thanks to an adaptive algorithm for managing various energy flows, by incorporating a controller based on fuzzy logic, which can take the role of an optimization system with two inputs (sunlight and battery charge state) and an output that represents the energy allowed to be used to meet other energy needs.

1. INTRODUCTION

The optimization of energy sources (conventional or renewable) for better management and control of the demand for electrical loads was the objective of several research projects in different fields, to better understand the need for energy management, especially after the development of several new types of decentralized systems for the production of electrical energy.

Among the solutions offered to reduce the use of fossil sources, we find renewable energies (in particular wind, hydraulic, and photovoltaic energy, in our case we will be interested in photovoltaic energy). Still, unfortunately, the direct dependence of their sources on climatic conditions leads to the instability and intermittency of energy production, which cannot be prevented [1], especially in the case of imbalance or the presence of a defect [2]. To resolve this serious problem, which is hampering the widespread

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exploitation of renewable energies, the integration of a storage device remains necessary for proper exploitation of random and intermittent production [3-5]. The studies conducted in recent years on storage systems have demonstrated that it is unnecessary to have large capacities for long autonomy periods, which can exceed 2 and 3 days at most [6,7]. The research is much more focused on modeling the different elements of the energy chain [9–11], optimizing photovoltaic source power [12], especially through the different MPPT commands developed [13], and improving devices for adapting the power supply of electrical loads according to their needs through a renewable source (photovoltaic) [14]. Another important area of research focuses on the development and improvement of systems and strategies for managing energy flows to ensure optimal operation [15-17], whose objective is to facilitate the intensive integration of photovoltaic energy into public networks, especially through the use of systems for smoothing peak consumption points based on the integration of storage systems [18-19]. The management of energy flows in the photovoltaic field is considered a contemporary branch of research. According to [20], a new generation of battery management devices has been developed by the Fraunhofer-Institute of Solar Energy, which leads to a great improvement in the reliability and lifespan of battery banks. These management devices, particularly during loading and unloading operations of the battery group allow the adoption of modern operating strategies that remain impossible to use with old systems coupled with conventional batteries. The authors in [21], presented a method that is based on the exploitation of a predictive model of battery charging states for implementing the control algorithm, which allows optimal energy management for an autonomous photovoltaic system. Another energy management approach based on the control of DC-DC converters (un-directional and bi-directional) for an autonomous photovoltaic system was proposed in [22]. The authors in [23], proposed an energy flow management strategy that integrates the control of maximum power point search (MPPT), controlling the power of electrical loads, and the control of rapid battery charging by applying a variable current.

Electric vehicle charging stations have experienced great progress in recent years. The authors in [24-27] proposed some strategies for controlling an electric vehicle charging station for appropriate energy management and voltage regulation in a stand-alone microgrid. In [28], a robust two-stage energy management of a hybrid charging station was proposed for a system composed of an electrolyze, a fuel cell, and a hydrogen storage with the integration of a photovoltaic source. The authors in [29] adopted a real scenario for a multi-vector energy management system including an electrolyze for charging electric vehicles. In [30], the authors propose an autonomous charging station based on solar energy coming from building envelopes for drones.

This paper aims to address the matter of electricity production from photovoltaic conversion adapted for various housing applications, such as charging stations for hybrid or electric vehicles. This involves incorporating innovative electrochemical storage technology systems that use lithium-ion batteries. To achieve highly efficient and multifunctional systems, an optimization search method is used, based on fuzzy logic controller. In the case of the semi-autonomous charging station proposed in this work, a bidirectional exchange of energy flows with the grid will be carried out permanently. While trying to inject as much excess power as possible into the grid (especially during peak hours) or import the deficit in the event of a shortage, as shown in Figure 1.

2. SIZING OF THE MAIN ELEMENTS IN THE PHOTOVOLTAIC CHARGING STATION

Sizing an electric/hybrid vehicle charging station based on renewable energy (Especially for a photovoltaic source) is a relatively difficult task due to a large number of parameters (related to climatic and operating conditions) and also several elements that must be taken into consideration, namely photovoltaic generators, storage elements, static converters, MPPT control, the type of electric charger to be used and the electrical wiring, etc. In this article, we will just focus on the sizing of the most important elements in such a station, which are the capacity of the storage elements (batteries) and the power of the photovoltaic panels to be installed. For an individual, non-autonomous photovoltaic charging station, the storage capacity is estimated at approximately 54 *kWh* per day with average sunshine of around 5.23 *kWh/m²J* (The case of the Tindouf region in Algeria), similarly, the vehicle roof will be easily occupied by the installation of two generators with an average power of 219.67 Watts for each.

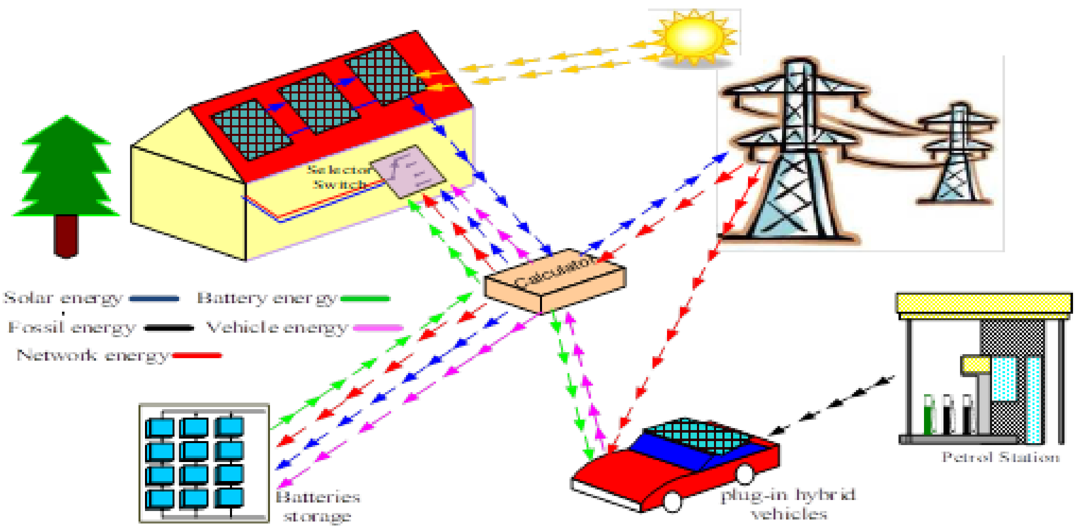

Fig 1. The principle of energy flow exchange between a hybrid vehicle and the various possible sources

So that the sizing can be effective for a long time, we adopt a global correction coefficient *K*, which takes into account: the instability of site climatic conditions (around ± 5%), the different angles of solar radiation received (approximately 5%), pollution of panels during exposure (around 5%), the lifespan and aging of the modules (approximately 5%) and also the efficiency of the most fragile element in the installation, the batteries (around 10%). Generally speaking, the corrective coefficient is often taken between 0.65 and 0.75 [24]. For our application, we take *K*=0.75, in this case, the capacity of the batteries that must be installed is approximately 72 *kWh* (54 *kWh*/0.75), by combining in series and parallel 12 (4×3) Intensium3 modules from battery supplier VL45E.

The number of photovoltaic generators calculated for the average sunshine and the number of batteries mentioned previously will be estimated at 63 modules.

3. OPTIMIZATION AND MANAGEMENT OF PHOTOVOLTAIC ENERGY PRODUCED

Ensuring better optimization of photovoltaic source power with efficient management of all energy flows is the primary objective for each participant in this field, to not only ensure proper charging of vehicle batteries but also to diversify and expand the uses of the station to domestic uses and injection into the public network. To make this reasoning a reality and improve energy efficiency, the use of a management system based on fuzzy logic, based on instantaneous and continuous detection of climatic conditions (real-time control), can be a very effective solution.

For such management, several techniques can be used, such as genetic algorithms [29], optimization by particle swarm and/or swarm of salps [32], neural networks with machine learning techniques [33], and fuzzy logic controllers [34]. In this work, we opted for fuzzy logic for forecasting weather conditions because of its robustness, flexibility, and simplicity of implementation in the control model.

A controller based on fuzzy logic, as shown in Figure 2, is made up of three parts: fuzzification or coding the real input variables into linguistic variables; the inference rules table that represents the decision-making element; and finally, we find defuzzification, which represents the phase of decoding the linguistic result obtained into a real result (fuzzy controller output). The controller proposed in this article has two inputs, the first is the sunlight captured in real-time by the GPVs which is renamed by the abbreviation *S(k)* and the second input will be the state of charge of the batteries represented by *SOC(k)* (The choice of sunlight comes from its very significant influence on the power produced compared to that of the temperature). The fuzzy controller in this application presents as output, the power that can be allowed by the controller for uses in various secondary functionalities (domestic uses and/or injection into the public network) other than battery charging (the main function of photovoltaic panels).

To avoid any instability of the controller, the type of membership functions is triangular without overlapping (Figure 4). The membership intervals with the inference rules are determined experimentally, after several findings (calculations and simulations), so that better exploitation of solar resources will be guaranteed throughout the lighting period, to ensure efficient loading, favorable and permanent for the batteries, and a maximum backup for secondary uses.

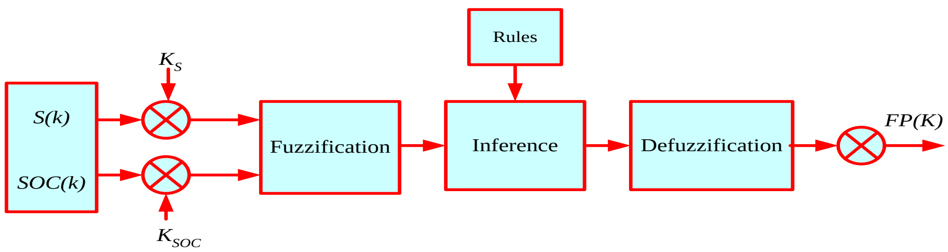

Fig 2. Block diagram of a fuzzy logic

The two linguistic inputs used by the fuzzy controller consist of seven fuzzy sets each, resulting in a total of forty-nine rules. These rules can be found in Table 1.

Table1. Fuzzy rules bases

S \ SOC	S	M_1	M_2	M_3	B_1	B_2	B_3
S	Z	Z	Z	Z	Z	Z	Z
M_1	Z	Z	Z	Z	Z	Z	S
M_2	Z	Z	Z	Z	Z	S	M_1
M_3	Z	Z	Z	Z	S	M_1	M_2
B_1	Z	Z	S	M_1	M_2	M_3	B_1
B_2	Z	S	M_1	M_2	M_3	B_2	B_3
B_3	M_1	M_2	M_3	B_1	B_2	B_3	B_3

The set of rules from the inference table is represented on the control surface generated by the fuzzy logic controller output with seven intervals (LFC7), as shown in the following Figure 3:

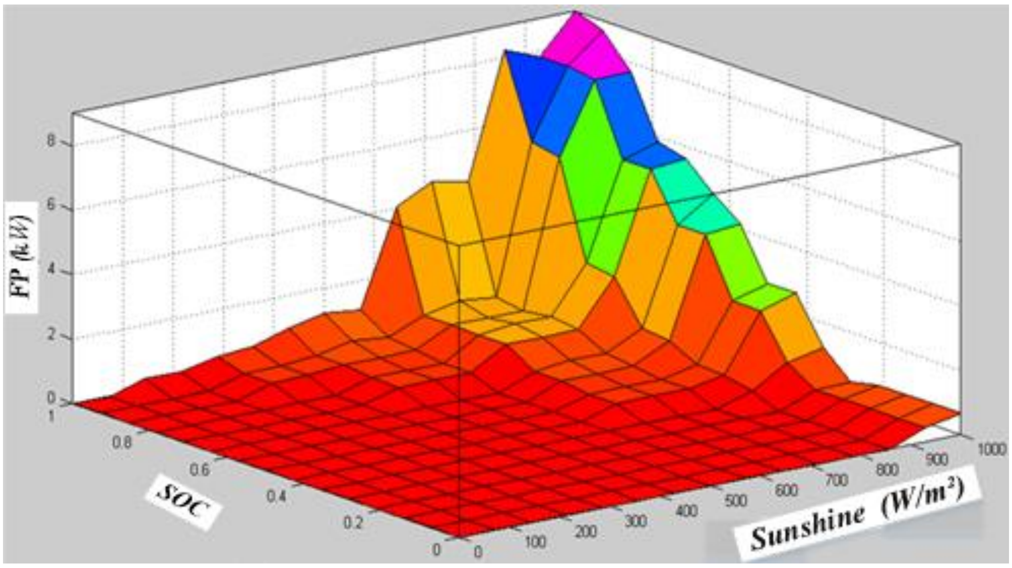

Fig 3 Control surface generated by the output of the fuzzy controller (FLC7)

Figure 4 shows us the inputs *S(k)* and *SOC(k)*; and output *FP(k)* membership functions of fuzzy logic controller. Inputs are sunshine and battery group state of charge and the output of our controller is the allowable power.

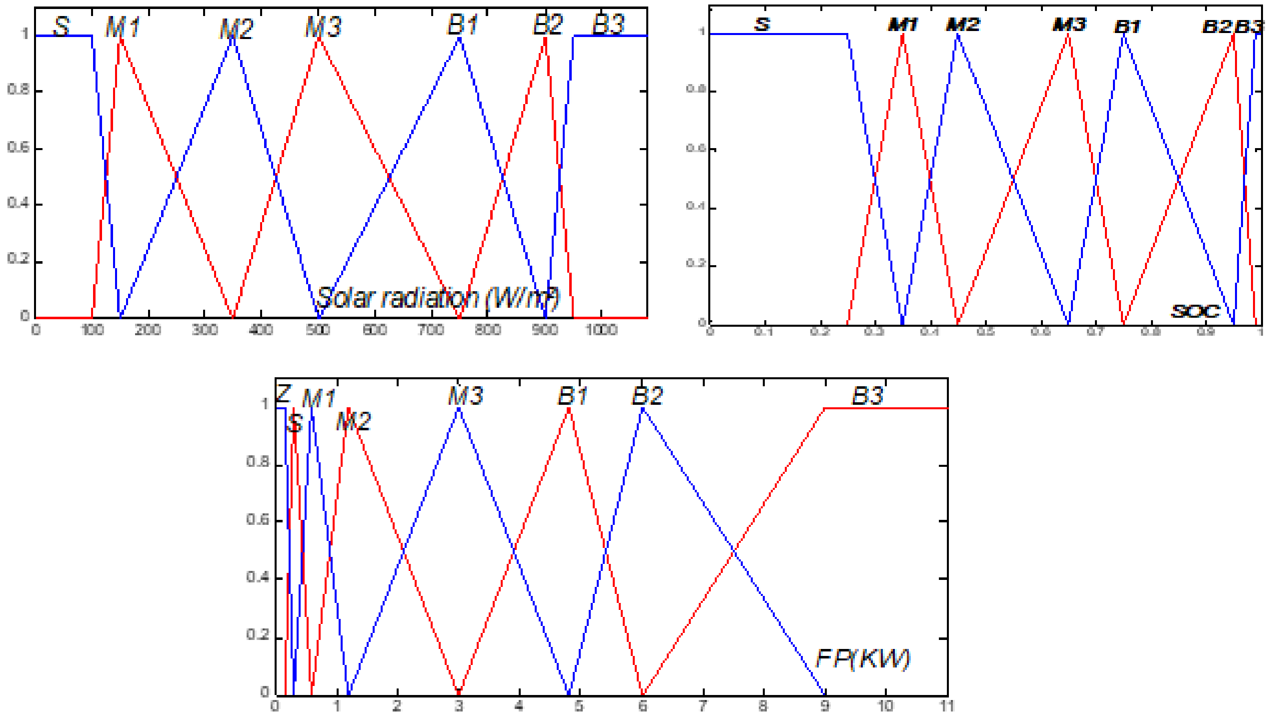

Fig 4. Membership function of the three linguistic variables chosen for sunshine, for the charging state of the station's batteries, and the power authorized at the output

3.1 Overall station energy management algorithm

To facilitate the reading and exploitation of the flowchart of the overall algorithm developed, for the management of the different energy flows existing in the power plant (which was considered multifunction), a list of abbreviations has been adopted as follows:

- P_{pv}: Power produced in real-time by the station's photovoltaic panels;

- *FP*: Power allowed by the fuzzy controller for subsequent uses other than the main function;
- *DP*: Power required to satisfy domestic needs;
- P_{en}: Power exchanged in both directions with the grid in real-time;
- *PB*: Push button which is used to activate or deactivate battery group charging depending on the requested power by the station firstly, and the user's will, secondarily. For example, if there is no need to charge the vehicle as the on-board battery bank is almost charged or the energy already stored will be sufficient or will not be used, therefore all the energy produced by the photovoltaic generators will be used for other functions;
- D_{en}: Public grid availability detector knowing that:
  - D_{en} = 1, the vehicle-battery system can absorb energy through the public grid;
  - D_{en} = 0, the non-possibility of absorbing energy from the public grid for different causes such as outages or load shedding.

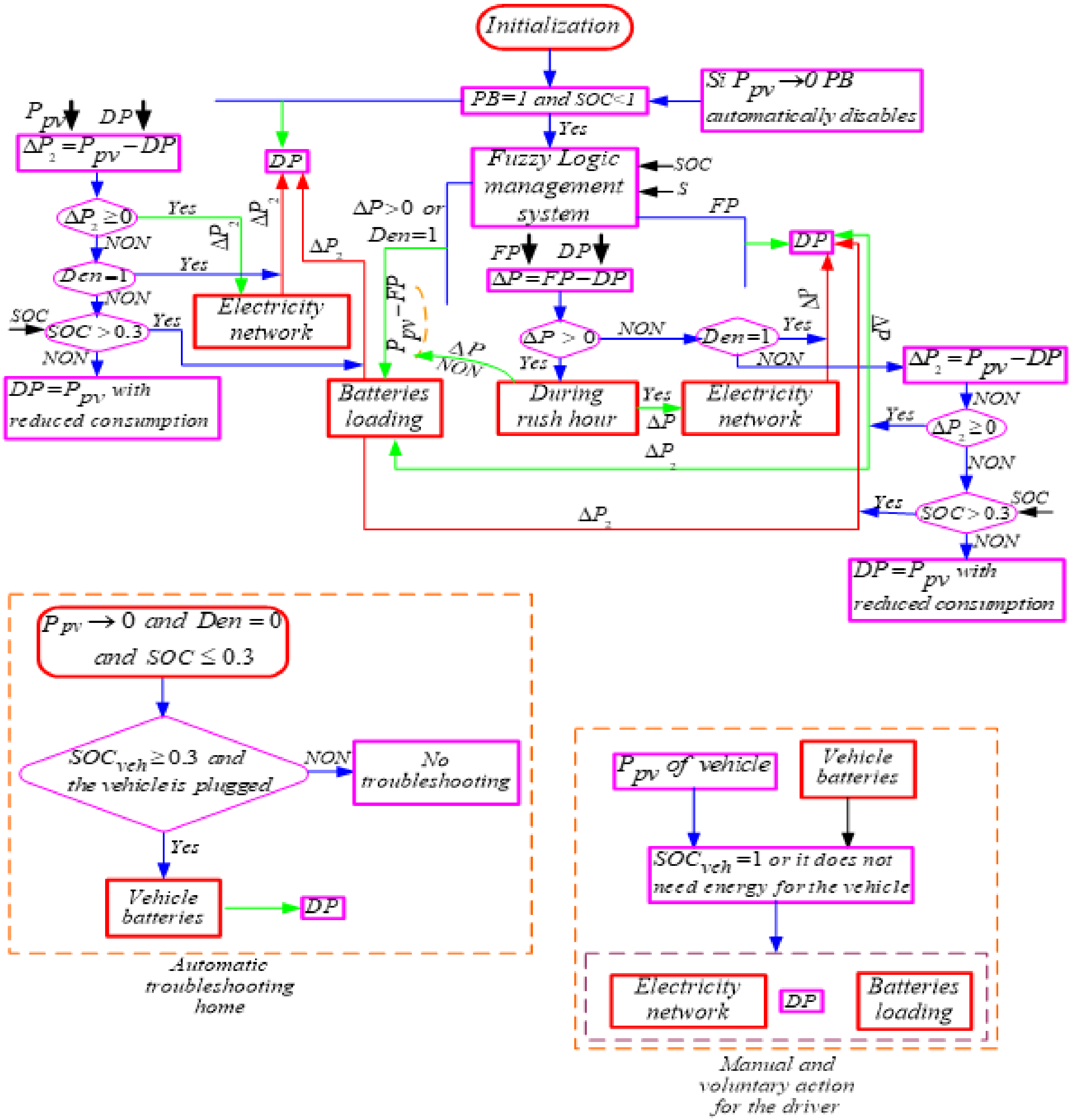

Fig 5. Flowchart of energy management

In the case of the application proposed in this paper, we introduce two secondary functions that we find very useful for an almost semi-autonomous station. In addition, to charging vehicle batteries, the system implemented will be able to ensure, depending on its capacity, part or all of the domestic needs, and if there is still excess energy, an injection into the public grid is permitted. In this context, and to enable the energy manager to respond to all the desired energy requirements, the fuzzy controller will be assisted by another adaptive algorithm, whose objective is to benefit from all the photovoltaic energy that can be produced, by permanently forcing the system to exchange the energy flows in the maximum of the directions indicated in Figure 1, according to the various conditions of the following two cases:

- Case 1: For (*PB*=1 and *SOC*<1):
  - If domestic needs exceed the power authorized by the fuzzy controllers (*DP* > *FP*), the deficit *ΔP* will be absorbed through the public grid;
  - If domestic needs are lower than the power authorized by the fuzzy controller *(DP < FP)*, the excess *ΔP* will be injected into the grid during peak hours (where the cost of electrical energy is high) if it is off-peak hours (where the cost of electrical energy is low) the *ΔP* will be reused for charging the batteries;
- Case 2: For (*PB*≠0 where *SOC*=1), i.e. all the power produced by the photovoltaic panels is authorized by the fuzzy controller for secondary uses ($FP=P_{pv}$), according to the following conditions:
  - If domestic needs exceed the power authorized by the fuzzy controllers (*DP* > *FP*), the deficit *ΔP* will be absorbed through the public grid;
  - If domestic needs are lower than the power authorized by the fuzzy controller *(DP < FP)*, the excess ΔP will be injected into the public grid.

To better adopt this work, a margin of maneuver is left to the driver's will according to his estimates, either to use the energy stored in the vehicle's on-board batteries and that produced by the two panels installed on its roof or not, to ensure domestic needs in the event of absences from all other sources, this operation will be during parking periods according to the owner's plans, through a manual system.

4. SIMULATION AND INTERPRETATION OF RESULTS

To validate the efficiency of our algorithm, tests are carried out (the vehicle is disconnected for cases A to C). The maximum power measured by a PV module is 219.67 Watts with a current I_{ph} =8,214 A, for N_s =54 cells under normal conditions. The series and parallel resistances of the PV module are respectively

$$R_s = 221{,}10^{-3}\ \Omega \text{ and } R_p = 415.405\ \Omega.$$

4.1 In the first case, it is assumed that the power required for domestic needs is low and cannot go beyond 1*kW*, however, the batteries are completely discharged (SOC_0=0), for favorable climatic conditions (an average day).

The simulation results are shown in Figure 6, showing that:

- The public grid ensures all domestic energy needs throughout the morning until *t=5.52* (which corresponds to 11:31 p.m.), from this moment until *t=5.88h* part of the domestic needs are provided by photovoltaic power allowed by the fuzzy controller (*FP*), and from the moment *t=5.88h* until the end of the day, the power requested by domestic loads is provided entirely by the fuzzy manager;

- During the period from *t=6h* to *t=8h* which coincides with peak hours (where the price of electrical energy is high), any excess power (*FP*) provided by the fuzzy manager setup is injected into the public network, and from the moment t=8h during off-peak hours (where the price of electrical energy is low), all the excess will be reused to force the charging of the batteries until *SOC*=1;

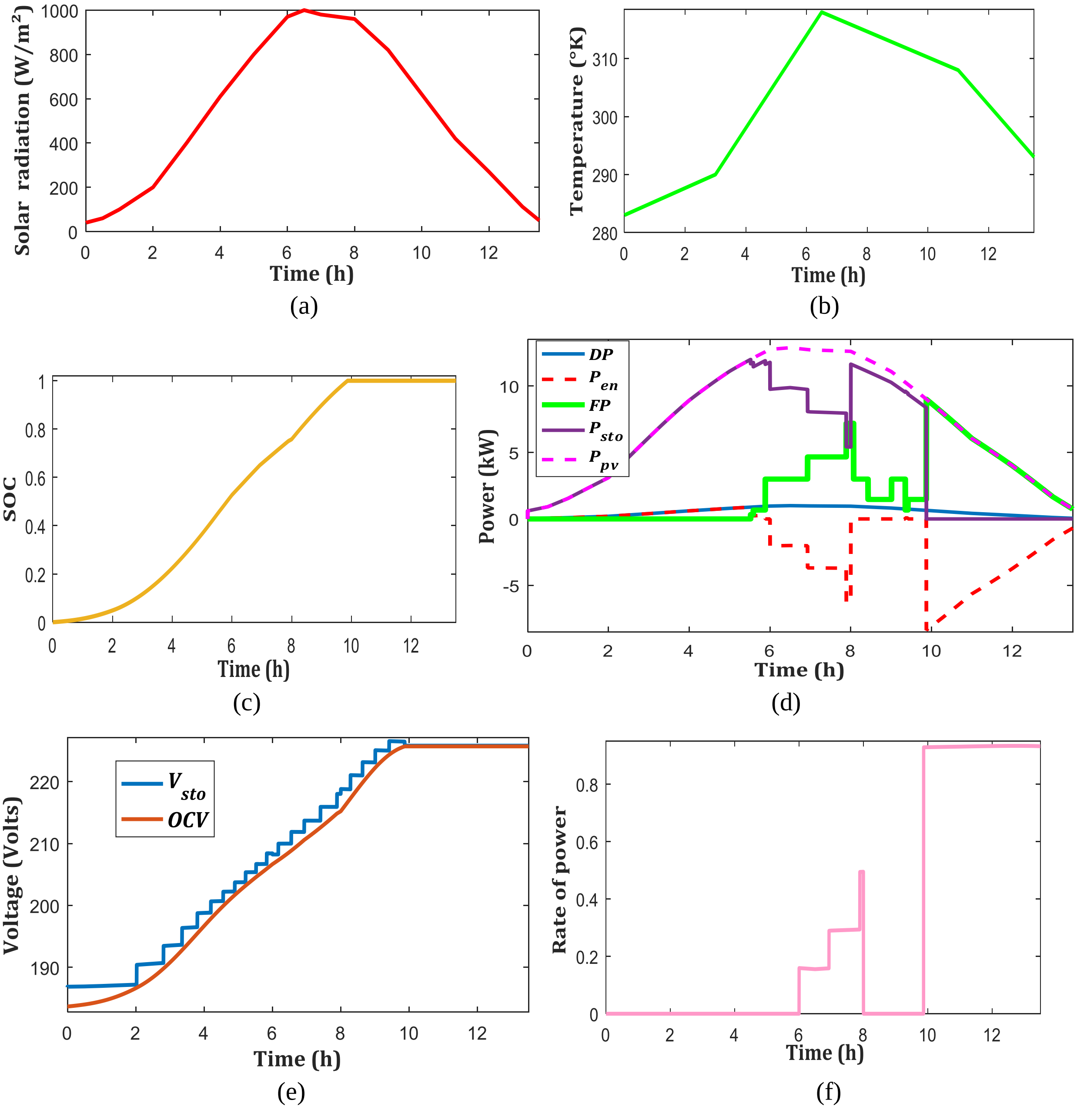

Fig 6. (a) Real-time sunshine profile, (b) Temperature profile in real-time, (c) Charging state of the storage batteries within the station, (d) Power required to satisfy domestic needs, Power exchanged in both directions with the public grid, Photovoltaic power permitted by the fuzzy controller, Power used to charge the station's batteries and power produced by the photovoltaic panels in real-time (e) Voltages at the battery terminals when empty and charging, (f) Rate of power injected into the public network relative to that produced by photovoltaic panels

4.2 The same conditions in case A are taken except SOC_0=0.9 (For example, if the station is loaded)

The results obtained are illustrated in the following Figure 7:

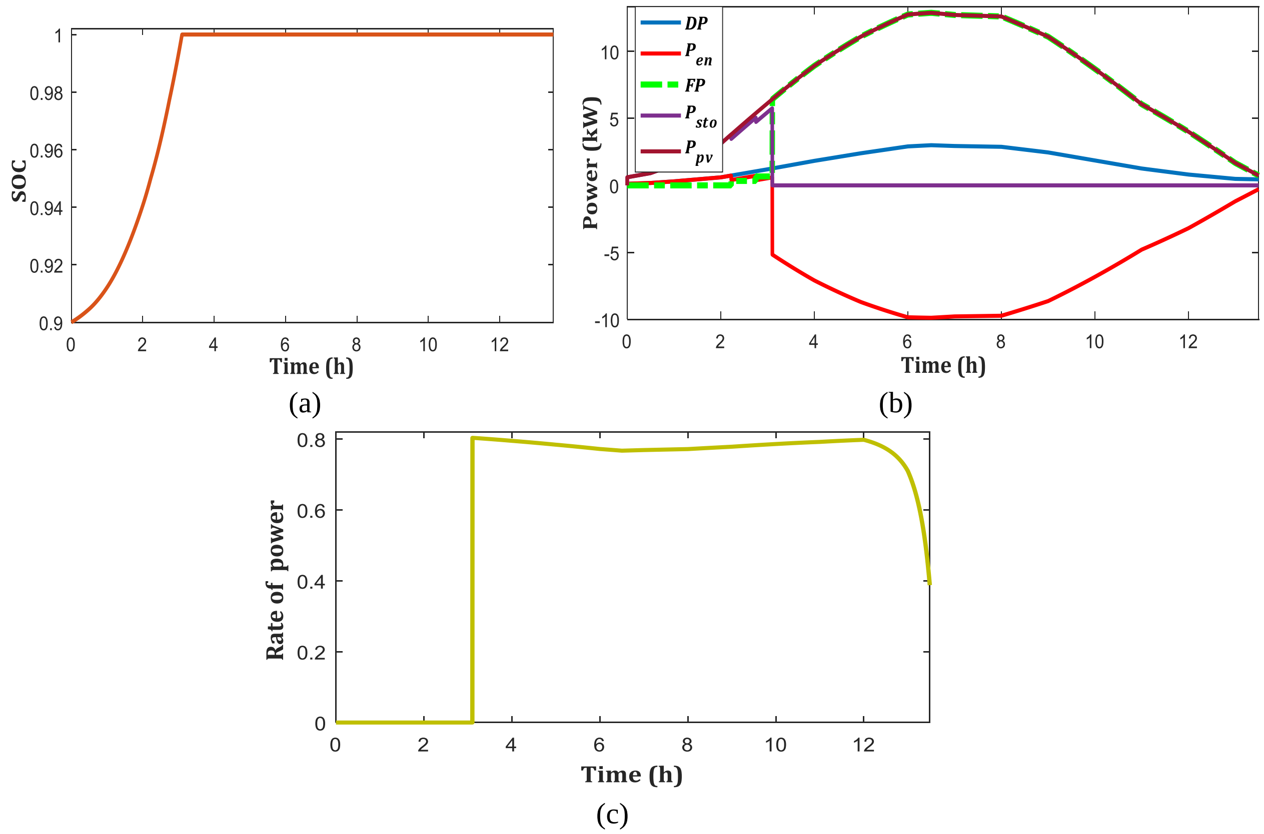

Fig 7. (a) Charging state of the storage batteries within the station, (b) Power required to satisfy domestic needs, Power exchanged in both directions with the public grid, Photovoltaic power permitted by the fuzzy controller, Power used to charge the station's batteries and power produced by the photovoltaic panels in real-time (c) Rate of power injected into the public network relative to that produced by photovoltaic panels

From Figure 7, we notice that the fast charging of the batteries allows the fuzzy controller, during the majority of the day, to use the totality of the PV energy for supplying domestic needs and send the surplus to the grid; the rate of power injected into the grid is improved over almost 7 hours.

4.3 In this case shading defects are introduced on the PV panels:

The defects cause the reduction of the PV energy production during the appearance of the defects, SOC_0=0.3 and D_{en}=0 (due to a cut or an overload), on the other hand, the export of energy is allowed to help out a neighbor during peak hours (transition to the "Smart City" or the micro-grid), for example.

The simulation results are shown in Figure 8. From Figure 8.c, the most important observation that can be drawn concerns the power absorbed by domestic loads, which is fully guaranteed by the energy produced by PVG most of the time, in parallel from t=8.624h, the deficit is ensured by the energy stored in the battery farm, since the import of power from the grid is not permitted.

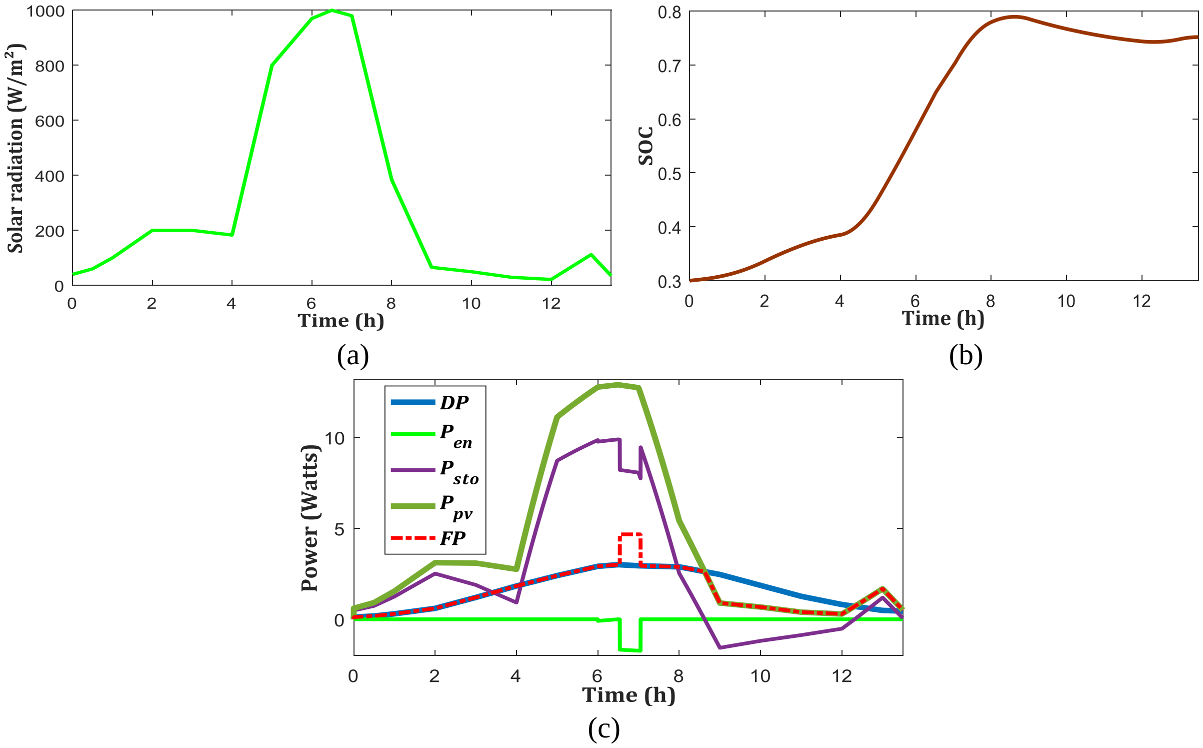

Fig 8. (a) Real-time sunshine profile, (b) Charging state of the storage batteries within the station, (c) Power required to satisfy domestic needs, Power exchanged in both directions with the public grid, Photovoltaic power permitted by the fuzzy controller, Power used to charge the station's batteries and power produced by the photovoltaic panels in real-time

4.4 Another test will be carried out, in the case where the photovoltaic panels are completely disconnected or their power supplied is negligible compared to other power flows:

In this case, the power required to cover domestic needs is the same as the previous case C, likewise the initial state of charge of the batteries SOC_0=0.3, D_{en}=0, but in this case assuming that the vehicle is connected to its charger terminal with the overall energy system (SOC_{veh0}=0.7). The results obtained are illustrated in Figure 9:

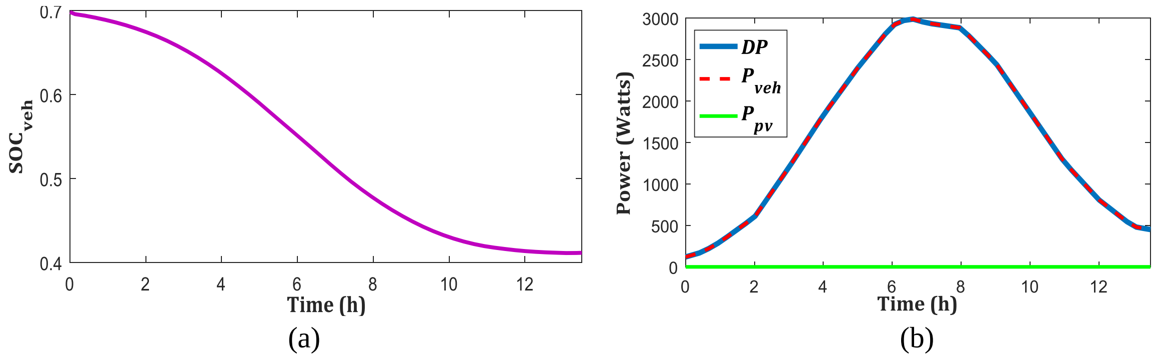

Fig 9. (a) Charging state of the storage batteries within the station, (b) Power required to satisfy domestic needs, Power supplied to the system by the vehicle's on-board storage batteries, and power produced by the photovoltaic panels in real-time

The aim of this test (Figure 9) was to show the robustness of the energy manager in all possible cases so that we can talk about a multifunction system that can be generalized in a smart home. In this last case, the power flow from the photovoltaic generators is negligible so the power authorized by the fuzzy manager will necessarily be negligible, since the public network is inaccessible and the station's batteries have reached the minimum acceptable threshold (SOC_0=0.3), so the solution was the connected vehicle which will play the role of the power source for domestic needs, according to its available energy capacities and the operating constraints imposed.

5. CONCLUSION

The overarching objective outlined through this article was to size an energy system (For very unfavorable climatic conditions) and develop an adaptive algorithm to optimize the circulation and exchange of energy flows in a semi-autonomous individual charging station, intended mainly for charging hybrid or electric plug-in vehicles, in this sense a manager based on fuzzy logic has been implemented to give more flexibility to energy management in all directions, through determining the power that can be used to power the various systems outside of the station's batteries. The massive establishment of such stations can remarkably reduce the overload of public networks, especially during peak hours. Therefore, improves the security and operating economy of the public grid, and also reduces the vehicle operating cost, especially if the high cost of electrical energy during peak hours is taken into consideration with the unavailability of fuel in certain regions.

Several simulations were carried out to test the adaptation of the proposed manager with the operating conditions and the targeted objectives, the results obtained show that:

- The global management algorithm proposed with the incorporation of a fuzzy controller which operates with climatic conditions detected (sunshine and temperature) instantly and permanently (real-time command), presents very remarkable flexibility and robustness, especially when we find that every Watt that can be produced by photovoltaic panels is captured and used in a very efficient way;
- Almost regular use of photovoltaic energy in various functions other than the main one is ensured by the fuzzy controller without having a significant negative influence on the charging process and the final state of charge of the batteries;
- Another advantage of using fuzzy manager is to participate in the control of the station's battery charging process in a very efficient manner, especially for high loading states (*SOC* is between 0.9-1), to avoid any form of overheating or degradation of battery performance (With the presence of a fuzzy controller in the manner adopted in this work, the device for controlling the battery's state of charge, can be eliminated, in the majority of cases);
- The simulations carried out showed that a simple individual charging station for electric and/or hybrid plug-in vehicles can become a multi-function installation with several additional tasks if the system for managing and controlling energy flows is effectively adopted.

So, with the presence of adequate management systems, these small individual installations can remedy some unforeseen impacts of charging hybrid vehicles on the electrical network in addition to the economic advantages which bring, in particular, the integration and combination between the principle of cogeneration and the notion of "Smart Home Energy", while estimating the allocation of smart-city or micro-grid systems.

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