Power supervision of an autonomous photovoltaic/wind turbine/battery system with MPPT using adaptative fuzzy logic controller

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ABSTRACT

In this work a power supervision of an autonomous photovoltaic/wind turbine/batteries system is presented. Measurements of weather conditions during different has been made. Due to the instantaneous changing of solar irradiance, temperature and wind speeds, maximum power point tracking (MPPT) is integrated. Due to its ease of use, the perturb and observe (P&O) algorithm is the most preferred, but has a great disadvantage of oscillations at steady state. The adaptative fuzzy logic controller (AFLC) method is also widely used for its advantages of fast response with better performance than the classical FLC and P&O strategies. An accurate sizing methodology was applied in the proposed sizing approach to calculate the PV and wind turbine generators number. To manage the various powers, supervision method is simple, easy realization and not heavy computation. A simulation study under MATLAB/Simulink has been made. The different results are given and analyzed.

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1. INTRODUCTION

Renewable energies specially wind and photovoltaic ones are clean and environmentally friendly. Nevertheless, their power output is intermittent, posing a threat to the electrical power system resiliency. So, adding storage is a practical method for balancing the demand and supply of energy by storing extra energy and producing it when needed. As a result, a hybrid system is created that is safer and environmentally friendly [1]–[4]. When the wind speed changes or solar irradiation deterioration, approaches are used to extract the optimal power. A wide variety of maximum power point tracking (MPPT) methods are used to track the maximum power point of photovoltaic panels [5]–[10] and wind turbines [11]–[17]. While they all aim to boost power, each performs differently from the others. While they all aim to boost power, each performs differently from the others. Because of its simplicity, the perturb and observe (P&O) method is the most widely employed to determine the MPP point for PV systems and wind turbine (WTb) generators, but this technique suffers from steady state oscillations [5]–[8]. Other methods have been employed to evaluate quick and effective MPPT strategies for PV systems, such MPPT algorithms. based on voltage and current [9], [10]. To provide quick and precise tracking, the fuzzy logic controller (FLC) adjusts the increment size. This method is widely used because of its advantages and fast response and has a better performance than the P&O, but the controller depends on speed and power variations. The adaptive fuzzy logic controller (AFLC) is primarily used to change the FLC duty-cycle for dealing with various external factors.

Depending on the wind speeds, a wind turbine system's output power varies. To track the wind turbine's maximum power point, several MPPTs algorithms have been established [11]–[17]. The most widely used tracking method is the P&O. Other algorithms like the fuzzy logic controller and the AFLC could be used. In this case, power and speed variations are the FLC's input controllers, and the reference speed variation is the output. The rules will be dependent on variations in speed and power in order to converge to the optimum point. FLC requires expert knowledge of the process; therefore, adaptative logic controller has been introduced.

In this work a study and power supervision of an autonomous photovoltaic/wind turbine system with batteries is studied. The optimization is made by the adaptative fuzzy logic controller (AFLC) method which is widely used for its advantages of fast response with better performance than the classical FLC and P&O strategies. The size of two generators can be determined using an accurate size approach. To manage the different powers, supervision method are applied [18]–[25]. In our work, the adopted method is the one already applied in our previous works [26]–[28]. The method is simple, easy realization and not heavy computation. The load power is always compared to the combined power of the two sources. When there is a lack of power, the batteries, if charged, supply the load alone or in compensation with the other sources. And if there is an excess of power, it charges batteries. To show the feasibility of the studied system, a simulation has been made under MATLAB/Simulink. The different results are given and analyzed.

2. PROPOSED STUDIED SYSTEM

The suggested system configuration is displayed in Figure 1. The main components are PV generator, wind turbine generator, the different converters (DC/DC, DC/AC) and storage batteries. The overall system is controlled using a proposed power supervision method. The optimization is based on the adaptative fuzzy logic controller (AFLC).

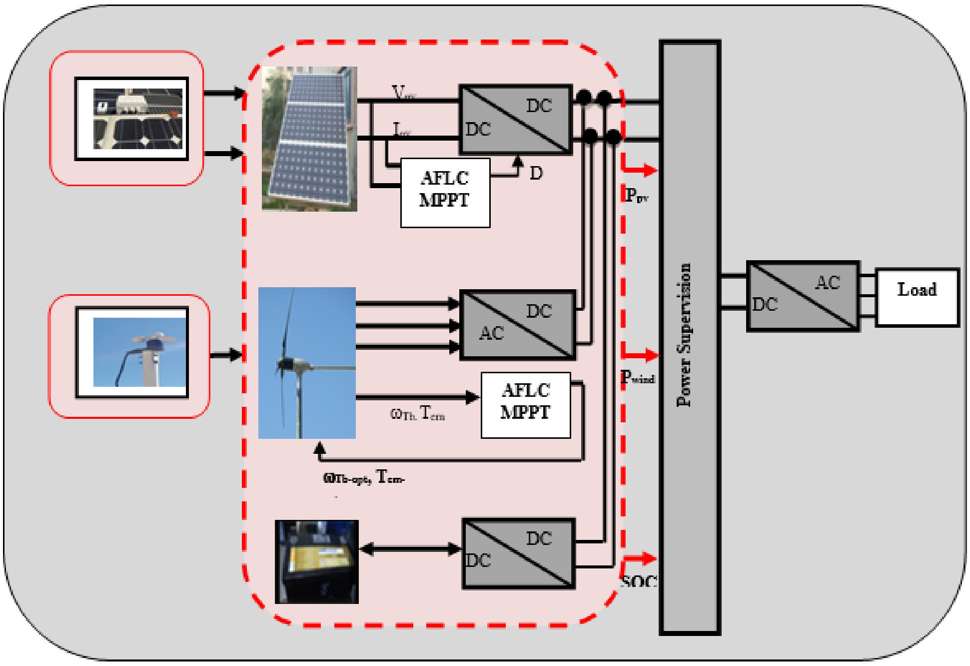


Figure 1. Studied system

3. PROPOSED DESIGN METHODOLOGY

The size of two generators can be determined using an accurate size approach used for multisource systems [1], [27]. The concept of fraction f and (1-f) between the two complementary energies was introduced. The main source is PV energy and wind energy is the secondary one. After calculations (Table 1), it is obtained the following results (Figure 2). The average consumed energy is given by:

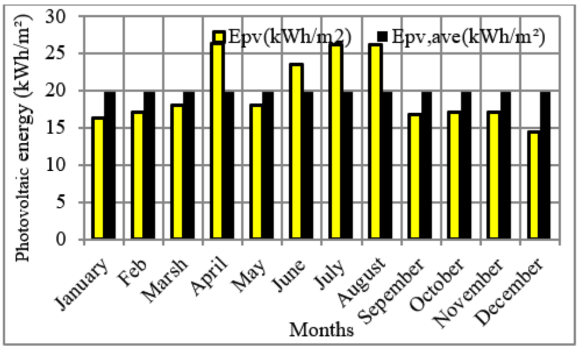
$$E_{load-ave} = E_{pv,ave}.A_{pv} + E_{wind,ave}.A_{wind} \quad (1)$$

Where: A_{pv} and A_{wind} are respectively PV and wind generators areas, N_{pv} and N_{wind} are respectively PV and wind generators number, $E_{pv,ave}$ and $E_{wind,ave}$ are respectively PV and wind generators average energy.

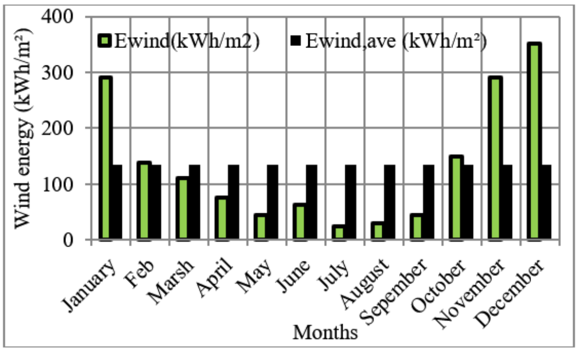
As the average load energy required is 476.86 kWh, the combination of 08 panels and 01 wind turbine is corresponding to the required load energy (486.02 kWh) but as it is necessary to have a hybrid system (PV/wind turbine) this solution is not considered and therefore the configuration of 08 panels and 01 wind turbine (Figure 3) is the closest to the required load energy (523.47 kWh).

Table 1. Calculations of the number of panels and wind turbine

f	N_{pv}	N_{wind}	$A_{pv}(m^2)$	$A_{wind}\,(m^2)$	$E_{Load\text{-}mean}$(kWh)
0.00	0.00	2.00	0.00	6.28	842.30
0.10	4.00	2.00	2.58	6.28	893.46
0.20	8.00	1.00	5.17	3.14	523.47
0.30	12.00	1.00	7.75	3.14	574.63
0.40	14.00	1.00	9.04	3.14	600.21
0.50	18.00	1.00	11.63	3.14	651.37
0.60	22.00	1.00	14.21	3.14	702.53
0.70	26.00	1.00	16.80	3.14	753.69
0.80	30.00	1.00	19.38	3.14	804.85
0.90	34.00	1.00	21.96	3.14	856.01
1.00	38.00	0.00	24.55	0.00	486.02

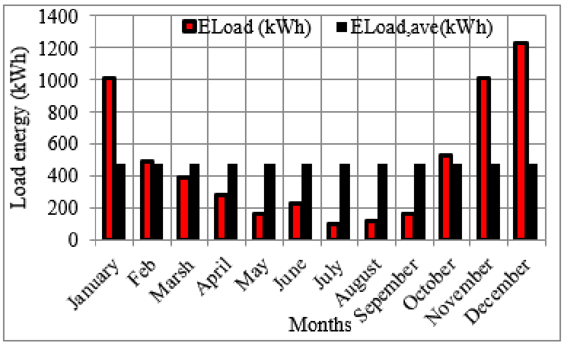


(a)

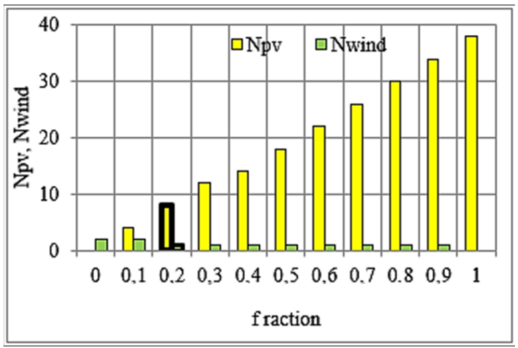


(b)

Figure 2. PV and wind energies and their average during a year (a) photovolaic energy and (b) wind energy



(a)



(b)

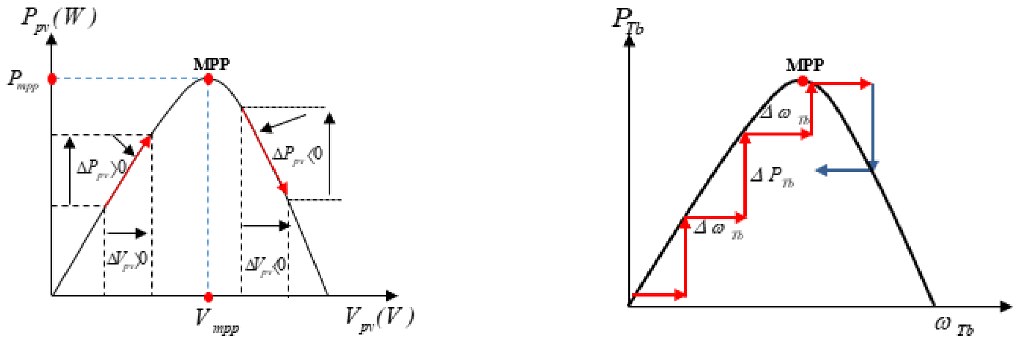
Figure 3. Load energy and its average during a year and number of components Npv and N_{wind}
(a) load energy and (b) number of components

4. OPTIMIZATION METHODS

To optimize the strategy in PV and wind turbine generators, three MPPT approaches (P&O, FLC and AFLC) are adopted.

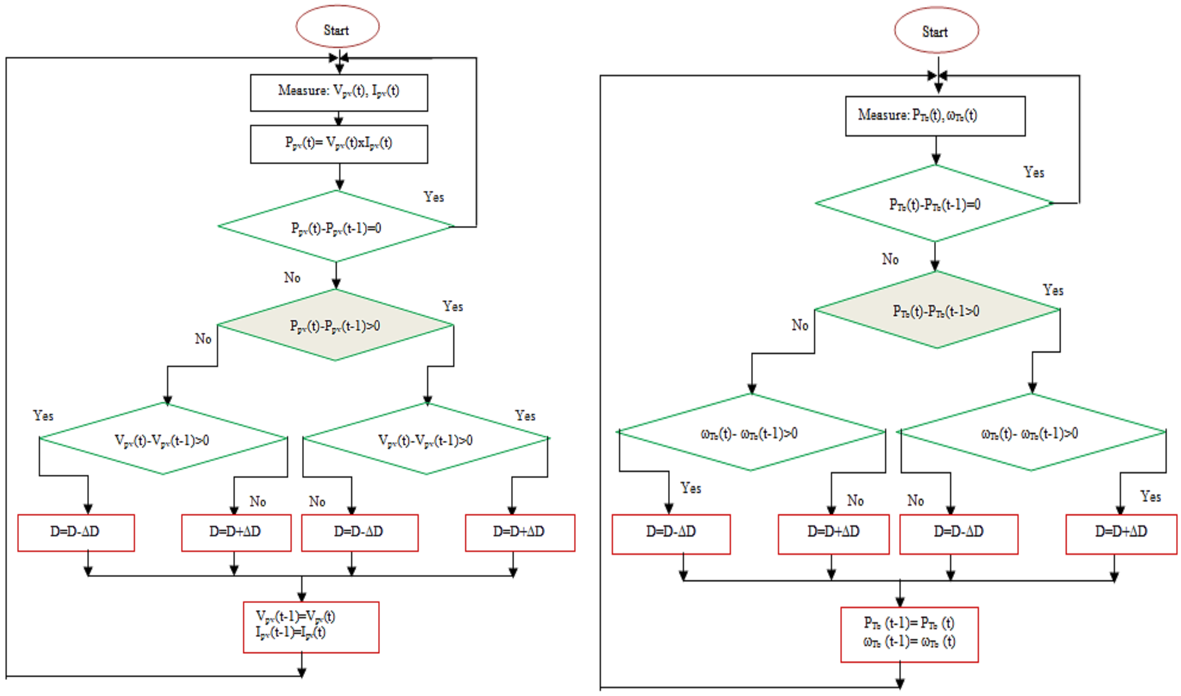
4.1. P&O method

Its algorithm principle is described in Figure 4 and explained in the flowchart as shown in Figure 5 [1]. Where: Ppv(t) and Ppv(t-1) are respectively photovoltaic power at t and (t-1), Ipv and Ipv(t-1) are respectively photovoltaic current at t and (t-1), $P_{Tb}(t)$ and $P_{Tb}(t-1)$ are respectively mechanical wind turbine power at t and (t-1), $\omega_{Tb}(t)$ and $\omega_{Tb}(t-1)$ are respectively mechanical wind turbine rotational speed and D duty cycle.



(a) (b)

Figure 4. P&O algorithm principle (a) photovoltaic and (b) wind turbine



(a) (b)

Figure 5. P&O MPPT strategy flowchart (a) photovoltaic and (b) wind turbine

4.2. Fuzzy logic controller (FLC)

In order to deal with extremely complicated or unfamiliar systems, L. Zadeh's work from 1965 marked the beginning of the use of fuzzy logic [29]. Zadeh represented and addressed imprecise or approximate knowledge. The control's main function is to extract and monitor a photovoltaic generator PVG's maximum power at various temperatures and solar irradiation conditions. The three basic steps of fuzzy logic's mechanism (Table 2) are fuzzification, fuzzy inference, and defuzzification [1], [30].

Table 2. Fuzzy controller rules in FLC

Error (e)	Change of error (Ce)						
	NB	NM	NS	ZE	PS	PM	PM
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

A sufficient representation of the knowledge is established using fuzzy interfaces or fuzzification. In this stage, the membership function is used to transform the input numeric values into linguistic variables (Figure 6). The FLC algorithm output, which is the change in duty cycle, is determined via defuzzification using the center of gravity technique.

$$D = \frac{\sum_{i=1}^{n} \mu(D_i) - D_i}{\sum_{i=1}^{n} \mu(D_i)} \quad (2)$$

The different equations for PV and wind turbine are [1].

$$\begin{cases} \Delta\omega_{Tb} = \omega_{Tb}(t) - \omega_{Tb}(t-1) \\ \Delta P_{Tb} = P_{Tb}(t) - P_{Tb}(t-1) \end{cases} \quad (3)$$

$$\begin{cases} \Delta V_{PV} = V_{PV}(kt) - V_{PV}(t-1) \\ \Delta P_{PV} = P_{PV}(t) - P_{PV}(t-1) \end{cases} \quad (4)$$

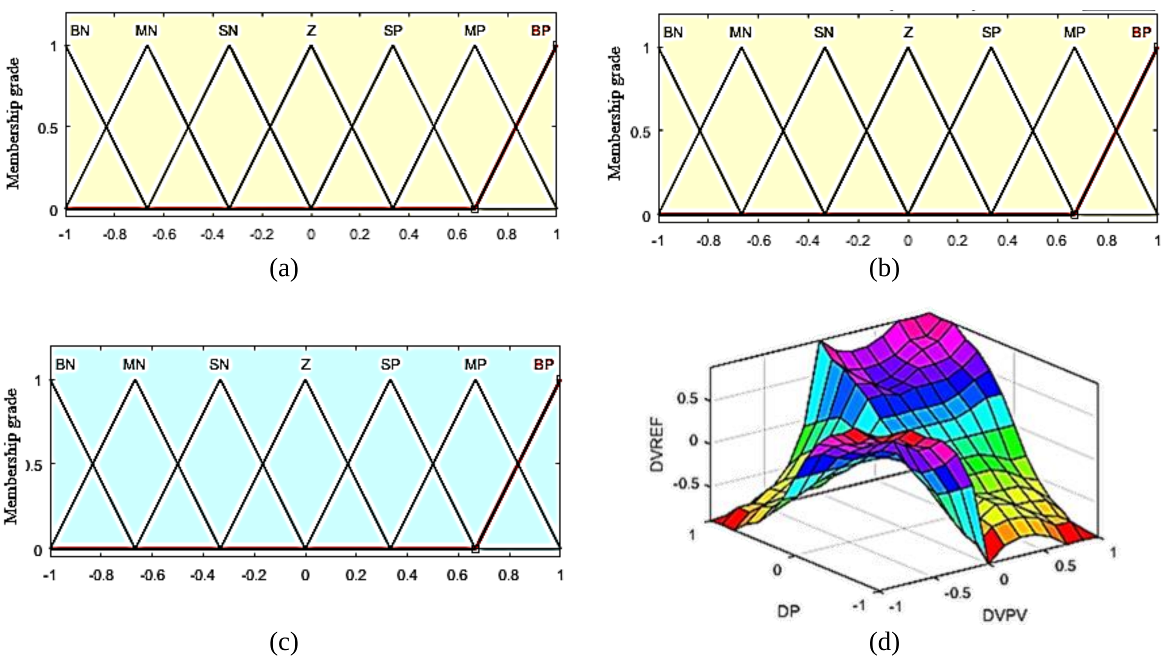


Figure 6. Membership functions and surface in FLC (a) input variable dP/dV, (b) input variable dP, (c) output variable DVref, and (d) surface function

4.3. Adaptative fuzzy logic controller (AFLC)

The AFLC, which is an upgraded version of the FLC is primarily used to change the FLC duty-cycle. The PV module's voltage and current are added to the preceding values to produce the average value. The structure of AFLC is given as follow (Figure 7). The AFLC method is made up of two parts: a fuzzy basic learning controller and a learning mechanism. This one is used to study the environmental parameters and to modify the FLC so that the global system response nearly to its optimal point.

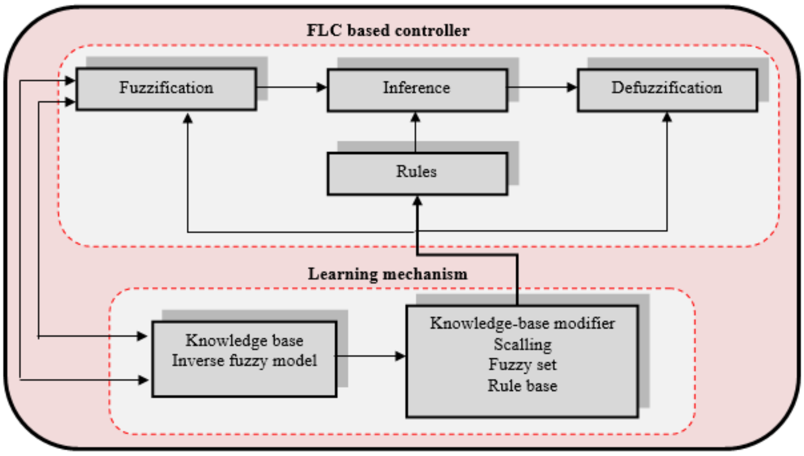


Figure 7. AFLC structure

The controller MAMDANI type is shown in Table 3 along with functions for membership in seven classes (Figure 8) [30]. The simulations are performed in MATLAB/Simulink using data from three separate days of real solar irradiance and wind speed profiles (Figure 9). Figure 10. illustrates the power obtained for the two generators using the three MPPT methods. When AFLC is used, very significant power benefits can be seen that are caused by the increasing of wind and photovoltaic power (black color). So, in the following of this work, AFLC will be applied in the optimization power.

Table.3. AFLC rules

Error (e)	Variation of error (Ce)						
	NB	NM	NS	ZE	PS	PM	PM
NB	NB	NB	NM	ZE	ZE	ZE	ZE
NM	NB	NM	NM	ZE	NM	PS	PS
NS	NB	NB	NB	NB	PM	PS	PM
ZE	NB	NB	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	PB	PB	PB	PB	PB	PB
PB	ZE	PB	PB	PB	PB	PB	PB

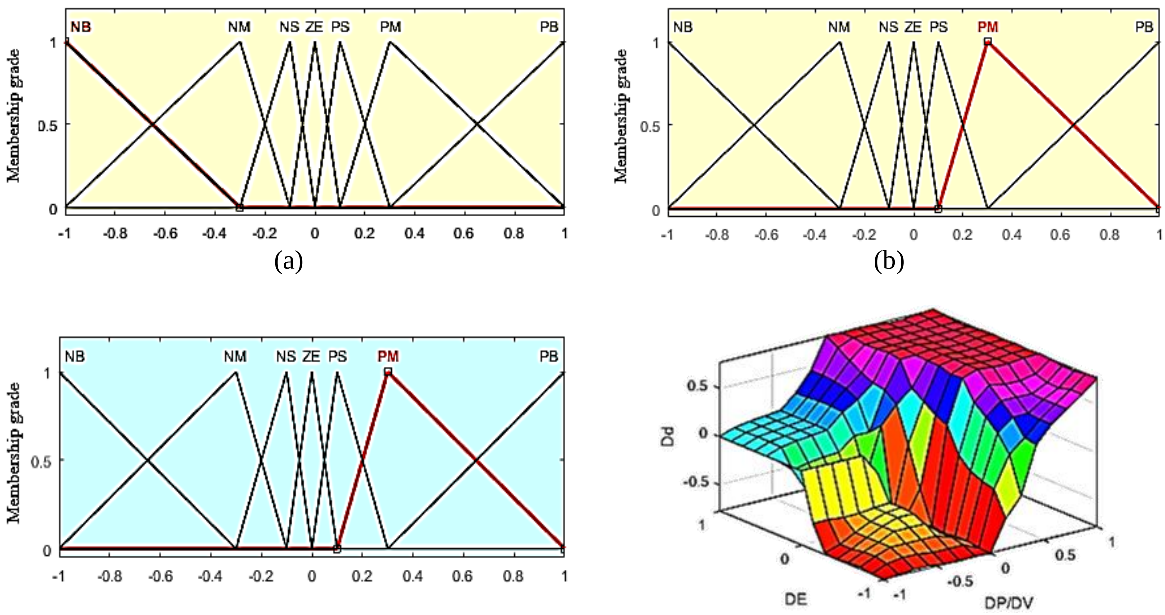


Figure 8. AFLC membership functions (a) input variable dP/dV, (b) input variable DE, (c) output variable Dd, and (d) surface function

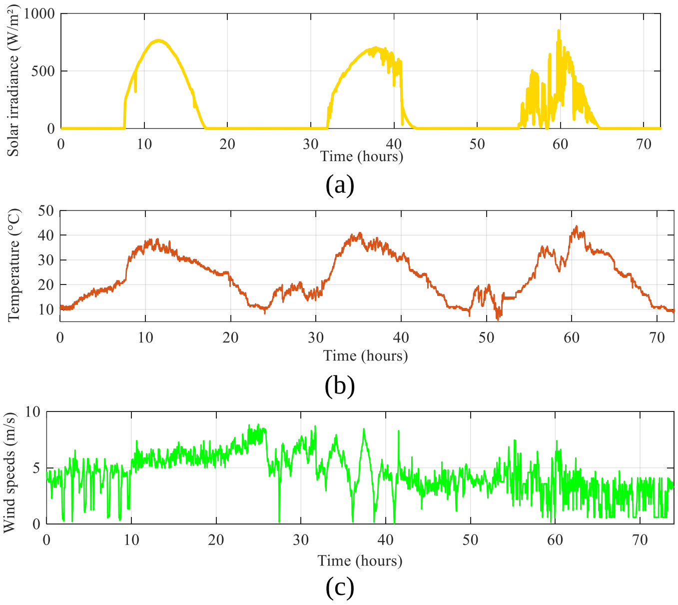


Figure 9. Solar irradiance, ambient temperature, and wind speeds during three different days (a) solar irradiance, (b) ambient temperature, and (c) wind speeds

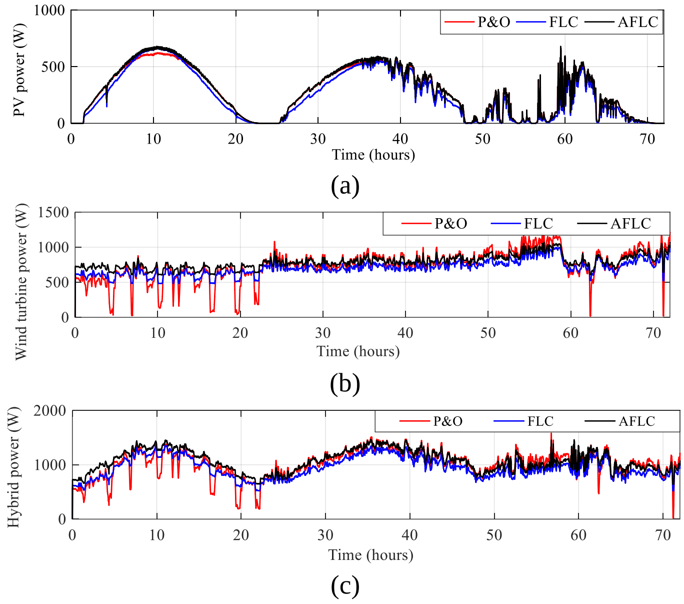


Figure. 10. Obtained powers during three different days (a) photovoltaic, (b) wind turbine, and (c) hybrid power (PV and wind)

5. PROPOSED POWER SUPERVISION SYSTEM

The analyzed system is an autonomous PV/Wind turbine with batteries using AFLC MPPT strategy. It has been controlled using a proposed power supervision method. There is always a comparison between load power and hybrid renewable power. When there is a power lack, the batteries, if fully charged, can supply the load alone or in compensation with other sources. It also charges batteries if there is an excess of power. For these, four switches (K_1, K_2, K_3, K_4) are used in the suggested power supervision system (Figure 11). The different switches operate as Table 4.

The load power is calculated as (5) [26].

$$P_{Load} = P_{PV} + P_{wind} \pm P_{Batt} \tag{5}$$

The battery state of charge (SOC) is a crucial component in evaluation of batteries to ensure a safe charging and discharging procedure. Estimating the SOC protects the battery from overcharging or deep discharging to extend their life. The battery SOC is within the following limits:

$$SOC_{min} \leq SOC \leq SOC_{max} \tag{6}$$

where: SOC_{max} and SOC_{min} are the maximum and minimum SOC values, respectively; with:

$$\begin{aligned} SOC_{min} &= 30\% \\ SOC_{max} &= 90\% \end{aligned} \tag{7}$$

The supervision proposed method can be represented [26]–[28] in the Figure 12.

Table 4. Different states of the switches

Switches states				Powers	SOC
K_1=1	K_2=0	K_3=0	K_4=0	$P_{hyb}=P_{Load}$	SOC
K_1=1	K_2=0	K_3=0	K_4=1	$P_{hyb}>P_{Load}$	$SOC>SOC_{max}$
K_1=1	K_2=1	K_3=0	K_4=0	$P_{hyb}>P_{Load,}$	$SOC<SOC_{max}$
K_1=1	K_2=0	K_3=1	K_4=0	$P_{hyb}<P_{Load,}$	$SOC>SOC_{min}$
K_1=0	K_2=1	K_3=0	K_4=0	$P_{hyb}<P_{Load}$	$SOC<SOC_{min}$
K_1=0	K_2=0	K_3=0	K_4=1	P_{Load}=0, P_{hyb}>0	$SOC \geq SOC_{max}$

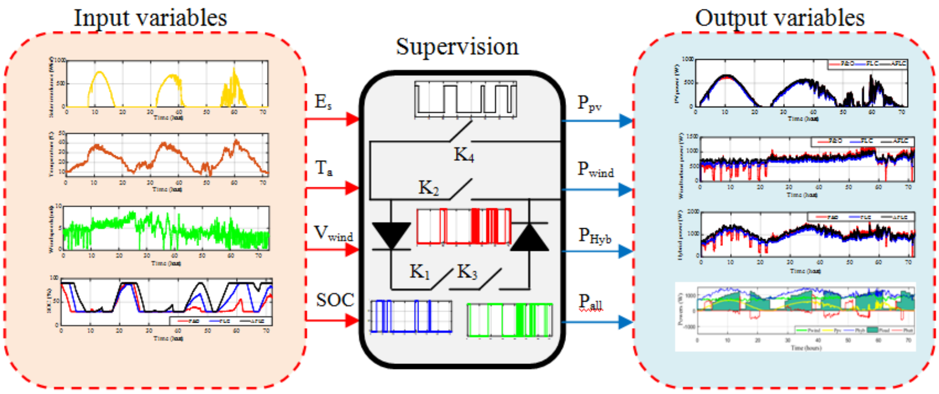


Figure 11. Proposed power supervision method

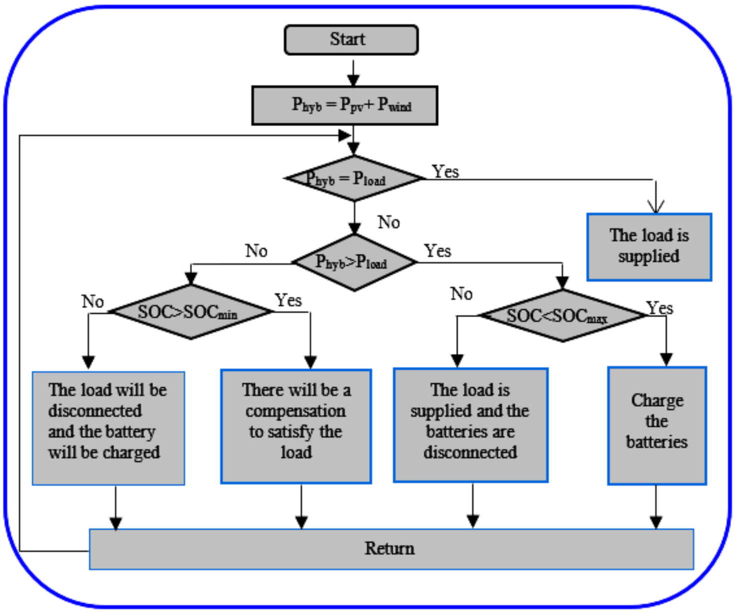


Figure 12. Flowchart for the suggested power supervision

6. RESULTS AND DISCUSSION

The different results of the battery are given below. Figure 12 shows that the battery voltage stays close to the reference voltage of 24 V. It is observed that the AFLC can maintain the battery's voltage around 24 V for a longer amount of time than the FLC and P&O techniques (Figure 13).

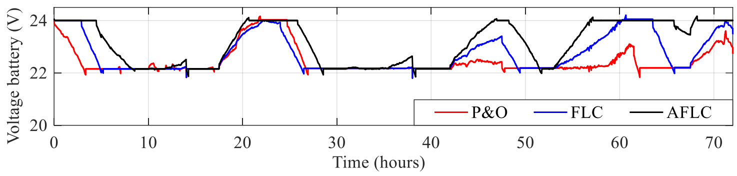


Figure 12. Battery voltage

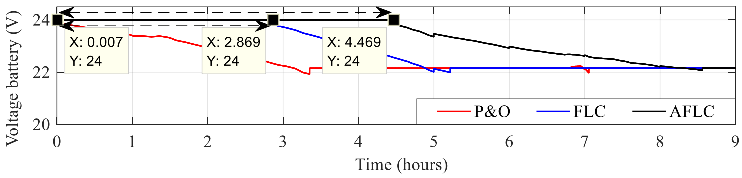


Figure 13. Zoom on battery's volage

A minimum value of 30% and a maximum value of 90% were controlled for the battery state of charge (Figure 14). With the help of this range of values, we can shield the batteries from deep discharges and overcharging, extending their lifespan. It is noticed that, unlike the FLC and P&O strategies, the AFLC can keep the battery's SOC at its maximum of 90% for a longer period of time (Figure 15). The different powers are illustrated in Figure 16.

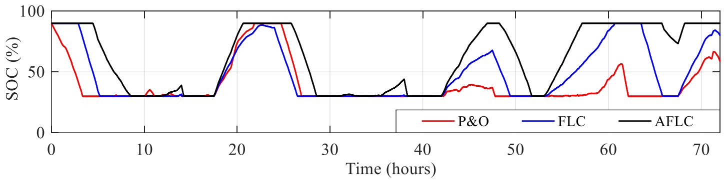


Figure 14. Battery state of charge

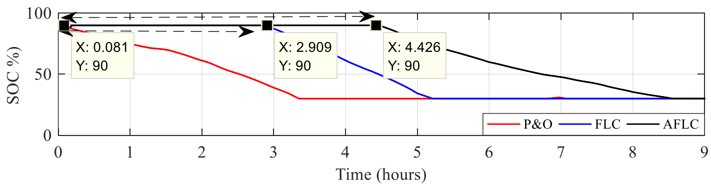


Figure 15. Zoom on battery state of charge

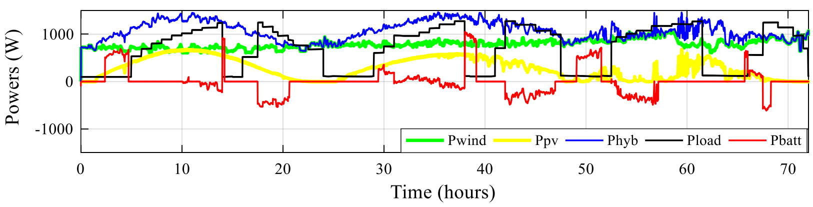


Figure 16. Different obtained powers

Three different zooms have been made on three different profile days (Figure 17). The first chosen day, it was a rather windy and cloudy day (in green color) and the solar irradiation was during some time intervals very low (in yellow color). Sometimes, the batteries charge (in red color) when solar irradiation and wind speeds are sufficient (zoom1), and during other times (zoom2), the batteries (in red color) feed the load in compensation mode with the wind and photovoltaic power. Also, it is noticed that the batteries were discharged (zoom3) because the hybrid power (in blue color) was less than the load power (in black color).

During the second chosen day, the solar irradiance and wind speeds were enough to supply the load, so the batteries were less solicited (in red color). The batteries where charged at first (zoom1), then compensated with PV and wind turbine power to fed the load (zoom2) and finally discharged (zoom3) when the load power exceeded than the hybrid power.

During the third chosen day, the batteries were first charged (zoom1), then stressed because the solar irradiance and wind speed were not very important (zoom2 ad zoom3). Photovoltaic, wind, and battery power in compensatory mode were used to satisfy the load. It can be concluded that during the three typical days, the load power was satisfied, because of the good sizing and in second part to the different sources power management by according to the power balance (15). It is obvious that the power discharge represents only a small quantity (negative parts in red color), which was expected in comparison with the results obtained previously where according to the AFLC MPPT method, the battery was less stressed.

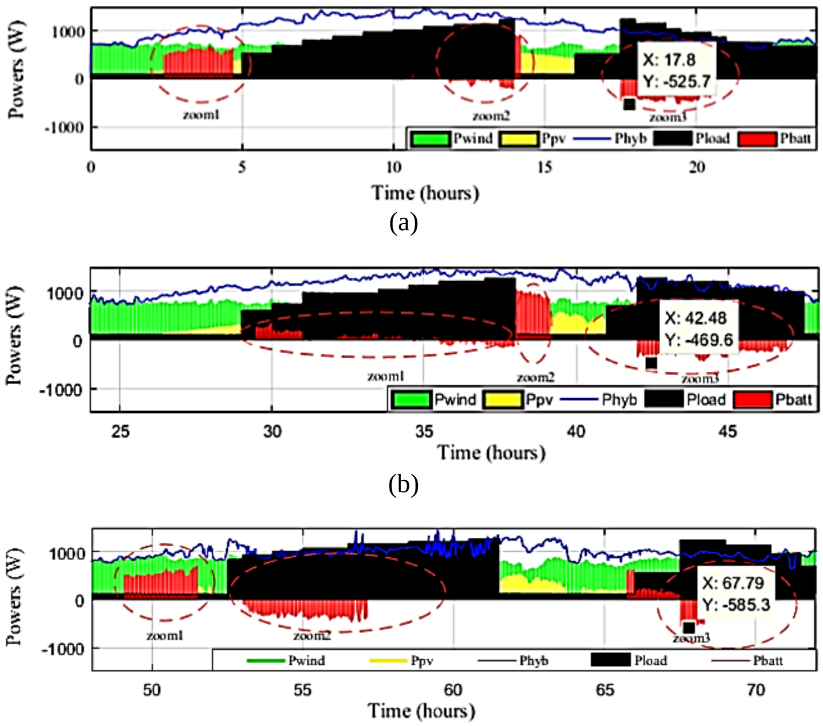


Figure.17. Zooms on powers during the three different days (a) day 1, (b) day 2, and (c) day 3

7. CONCLUSION

In this paper, a power supervision of a photovoltaic/wind turbine/batteries system using AFLC MPPT strategy has been presented. The most significant achievement of this paper is the reduction of the stress on the storage batteries in a multi-source system. This is as a result of the proposed accurate sizing methodology, the proposed AFLC MPPT algorithm, as well as the proposed power supervision. Additionally, the increased power allowed for a change in the suggested algorithm's test priority, which involves using the batteries as little as possible and charging them as needed. It may be concluded that the various sources were controlled in an ideal manner to meet the load requirement despite weather variations. Results obtained in simulation using MATLAB/Simulink. These findings confirm the effectiveness and feasibility of the suggested control technique at various days at the studied autonomous Mediterranean area. In perspective, it will be quite advantageous to develop a water pumping application.

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