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Optimization, design and control of a photovoltaic/wind turbine/battery system in Mediterranean climate conditions

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ABSTRACT

The goal of this study is to design and optimize a photovoltaic/wind turbine/batteries system. The application is made in the area of Bejaia (Algeria), a Mediterranean region where the solar and wind energy are extremely exploitable in this area due to its geographical location. The total incident energy approach was used to develop the device under consideration. To optimize power, the fuzzy logic control (FLC) is applied and to highlight the benefits of this maximum power point tracking (MPPT) strategy, it was compared to perturb and observe (P&O) method. A power management control has been applied. The findings from the three different days are displayed and analyzed to demonstrate the applicability of the suggested system. The examined system is assessed using the Homer software to demonstrate the best feasible integration of the several sources at the Bejaia location. There has been an increase in renewable power, which is one of the study's key novelty and objectives, so less stress on batteries in a PV/wind system. This is owing to the suggested accurate sizing procedure and to the FLC algorithm. The findings of the suggested study under various solar irradiation and wind speed velocity profiles are presented to demonstrate its applicability.

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1. INTRODUCTION

Electrical production by wind and photovoltaic is intermittent, which makes the power system more complicated. So, storage is important to fed power demand and by storing excess energy and generating energy when it is needed. It is obtained hybrid system more reliable and environmentally friendly [1]. To avoid these problems, a maximizing power approach is used. It is obtained a maximum load power despite variations in solar irradiation and wind speeds [2]-[7]. A great diversity of optimization methods has been adopted to track the photovoltaic panels and wind turbines powers [8]-[10]. The proposed strategy optimization is the fuzzy logic control (FLC) method and it is compared to perturb and observ (P&O) method. Power management strategies (PMS) are often used to control the load and the various power sources. Various methods have been proposed [11]-[30]. Some of them are synthesis of the most significant supervisory controls [11]-[20] and others in the two latest years are focused on a very precise method and defined systems [21]-[30].

In this paper, study on optimization, design, control and of a hybrid solar system with wind turbine and batteries is given. To determine the best design for the studied hybrid system, Homer pro software is applied. The suggested optimization strategy is based on FLC. The study's key features and goals can be summarized as a considerable increase in renewable power, so less stress on batteries in PV/wind system. This is due to the suggested accurate sizing approach and to the FLC algorithm. The studied system is described in section 2. Parameters identification is given in section 3. Measurements of weather conditions are given in section 4. Results of optimization methods and the power management control are discussed in section 5. Economic study using Homer pro software is presented in section 6 and at last the conclusion in section 7.

2. STUDIED SYSTEM DESCRIPTION

It is composed by a photovoltaic generator, a wind turbine, converters (DC/DC, DC/AC), batteries storage and a load Figure 1. To optimize power, the FLC is applied and to highlight the benefits of this maximum power point tracking (MPPT) strategy.

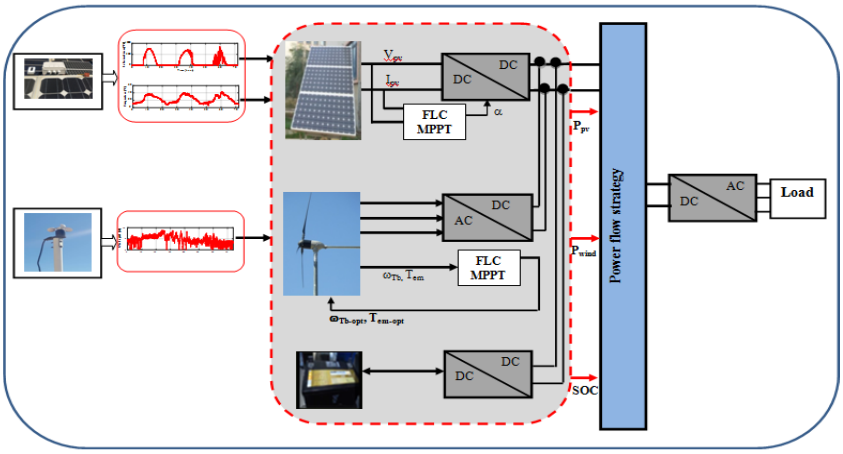


Figure 1. Studied system

3. PARAMETERS IDENTIFICATION

3.1. Wind turbine

A wind turbine and a permanent magnetic synchronous generator (PMSG) with a diode bridge rectifier compose the wind system. In the laboratory, it is proceeded the following tests Figure 2. The mechanical power can be written as [4].

$$P_{Tb} = \frac{1}{2}.C_p(\lambda).\rho.S.V_{wind}^3 \quad (1)$$

where ρ is air density (kg/m^3), S is section area (m²), V_{wind} is wind speed velocity (m/s).

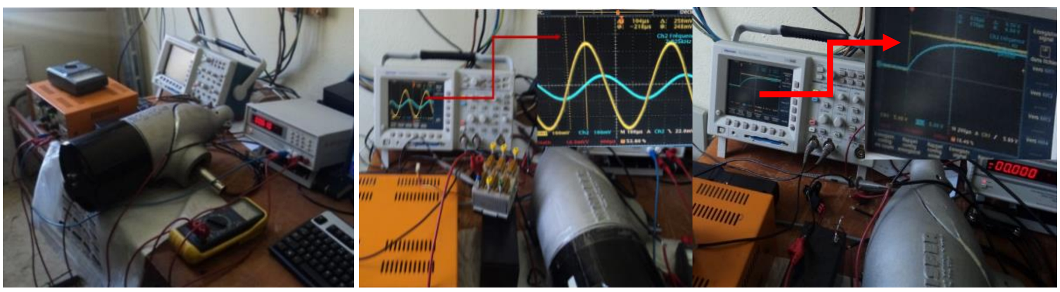


Figure 2. Wind turbine tests at the laboratory

The mechanical in (2) is [30]:

$$J\frac{d\omega_m}{dt} = T_m - T_e - f\omega_m \tag{2}$$

Te electromagnetic torque (N.m), J total inertia (kg/m²), T_m turbine's mechanical torque (N.m) and f viscous friction coefficient (N.m.s rad^{-1}). The electromagnetic torque generator T_e is [30]:

$$T_e = (\tfrac{3}{2})P(L_d - L_q)I_{sd}.I_{sq} + \Phi_f I_{sq} \tag{3}$$

3.2. Photovoltaic system

The used panels are 175 Wp and the current of single diode model is given by [2]:

$$I_{pv} = I_{ph} - I_0 \times \left[exp\left(\frac{q\times(V_{pv}+R_s\times I_{pv})}{A\times N_s\times K\times T_j}\right) - 1\right] - \frac{V_{pv}+R_s\times I_{pv}}{R_{sh}} \tag{4}$$

where $I_{ph}$is the photo-current (A), I_d the diode-current (A) and I_{Rsh} the shunt current (A).
The following test bench Figure 3 is used to establish electrical parameters for PV panels.

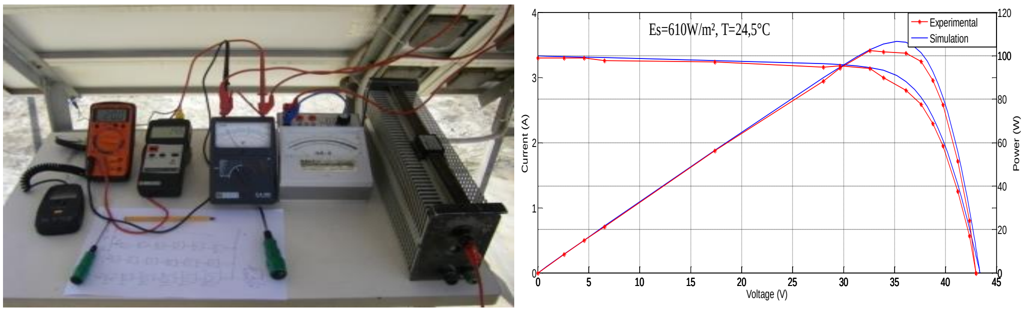


Figure 3. PV Experimental bench and electrical characteristics at E_s=610 W/m^2, T=24.5 °C

3.3. Battery system

As seen in Figure 4, this model is defined by a succession of electromotive forces that are set with a variable resistor. The battery voltage is represented as [6]:

$$V_{batt} = E_b - R_b.I_{batt} - K\int\left(\frac{I_{batt}}{Q}\right)dt \tag{5}$$

$$SOC = 1 - \frac{I_{batt}.t}{C_{batt}} \tag{6}$$

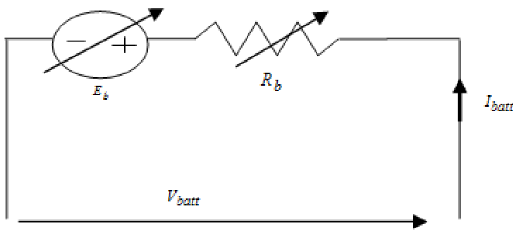


Figure 4. Lead acid battery model

4. MEASUREMENTS OF WEATHER CONDITIONS

Measurements of weather conditions were made for three different days Figures 5. The simulations are run in MATLAB using the measured solar irradiance in Figure 6(a), wind speeds profile in Figure 6(b) and ambient temperature in Figure 6(c).

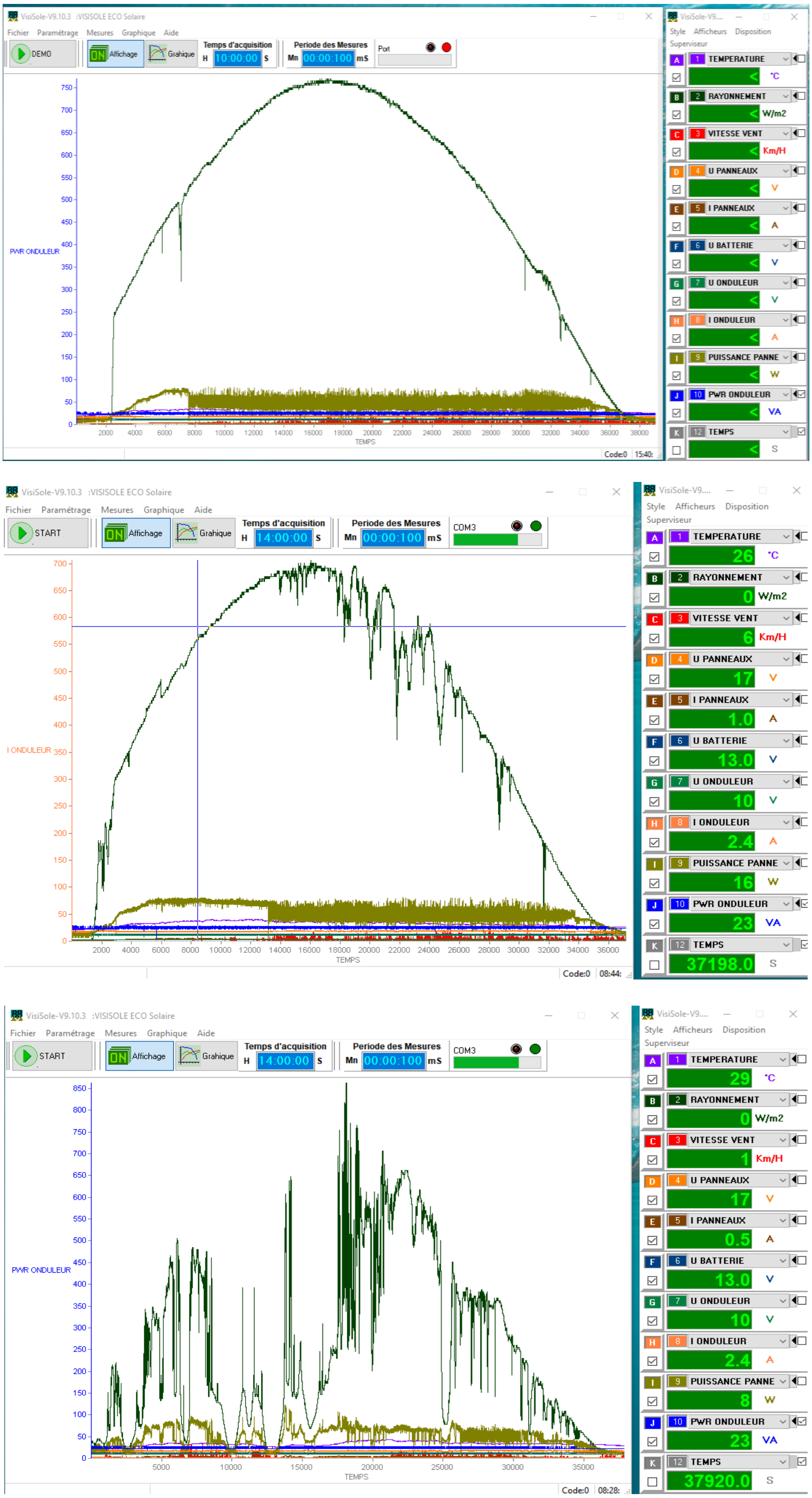
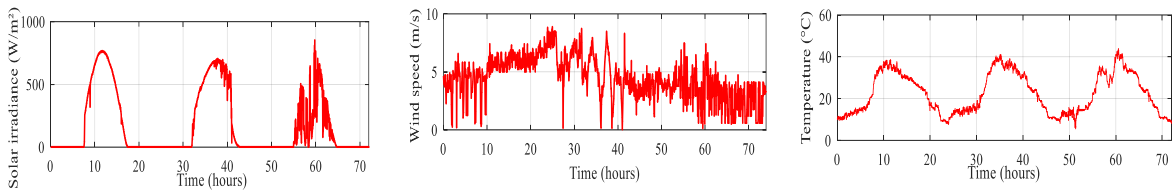


Figure 5. Measured solar irradiance and wind speeds profile during



(a) (b) (c)

Figure 6. Simulation measurements

5. RESULTS AND DISCUSSION

5.1. Optimization strategies

5.1.1. P&O strategy

P&O strategy is one of the most common used approaches [1]. Although very simple to use and requiring no prior knowledge of photovoltaic parameters, this increase oscillations at steady state. The algorithm is:

$$\Delta P_{pv} \rangle 0 \text{ and } \Delta V_{pv} \rangle 0 \text{ thus } \Delta P_{pv}/\Delta V_{pv} \rangle 0,\ D = D + \Delta D$$

$$\Delta P_{pv} \langle 0 \text{ and } \Delta V_{pv} \langle 0 \text{ thus } \Delta P_{pv}/\Delta V_{pv} \langle 0,\ D = D - \Delta D$$

$$\Delta P_{pv} = 0 \text{ and } \Delta V_{pv} = 0 \text{ thus} \Delta P_{pv}/\Delta V_{pv} = 0,\ \Delta D = 0,\ D = D$$

5.1.2. FLC method

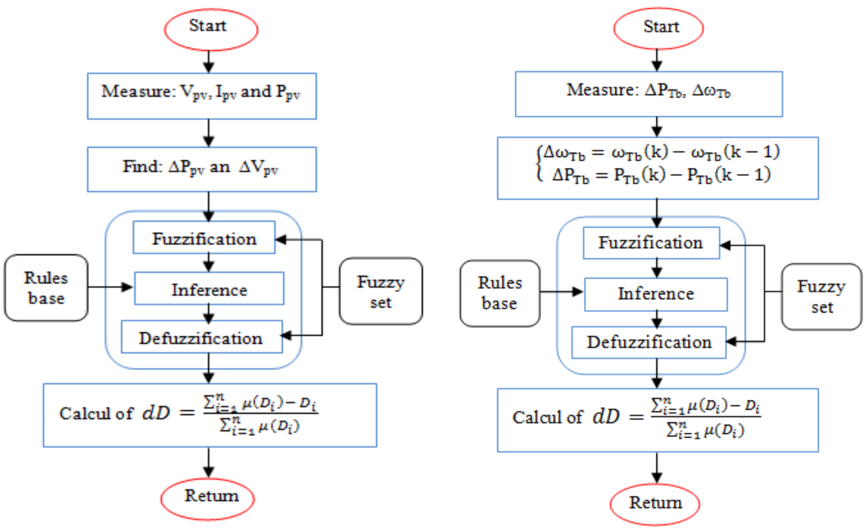
The two inputs to the controller system are the error and the change in error. For PV generators, it's flowchart is shown in Figure 7(a), and for wind generators, it's displayed in Figure 7(b). In PV generator:

$$\begin{cases} E(k) = \frac{P_{pv}(k+1) - P_{pv}(k)}{V_{pv}(k+1) - V_{pv}(k)} \\ CE(k) = E(k+1) - E(k) \end{cases} \tag{7}$$

In wind turbines, the regulations are based on changes in wind speed and power:

$$\begin{cases} \Delta\omega_{Tb} = \omega_{Tb}(k) - \omega_{Tb}(k-1) \\ \Delta P_{Tb} = P_{Tb}(k) - P_{Tb}(k-1) \\ \omega_{Tb-ref} = \omega_{Tb}(k-1) + \Delta\omega_{Tb}(k) \end{cases} \tag{8}$$

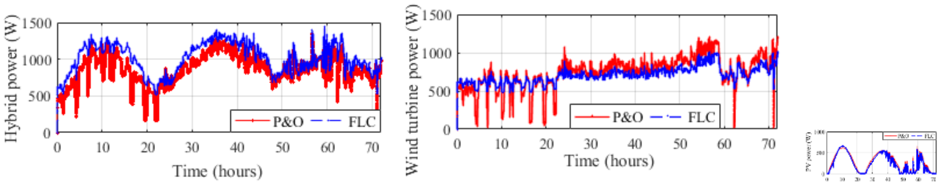
the output turbine power and its rotational speed are indicated by $P_{Tb}(k)$ and ω_{Tb} (k), respectively, and the instant of reference speed is designated by $\Delta\omega_{Tb,ref}(k)$.



(a) (b)

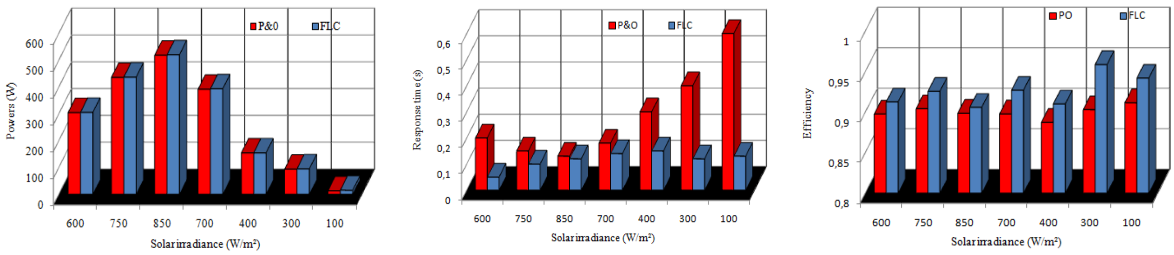
Figure 7. FLC flowchart (a) PV generator and (b) wind generator

It is observed in Figure 8(a) significant power gains in hybrid power up to 161 W due to the savings in wind Figure 8(b) and photovoltaic powers Figure 8(c) when FLC is used. Figures 9(a) to (c) and Figures 10(a) to (c) provide a comparison of the two methods' effectiveness, power consumption and response times. The FLC generates maximum power, less response time and best efficiency.



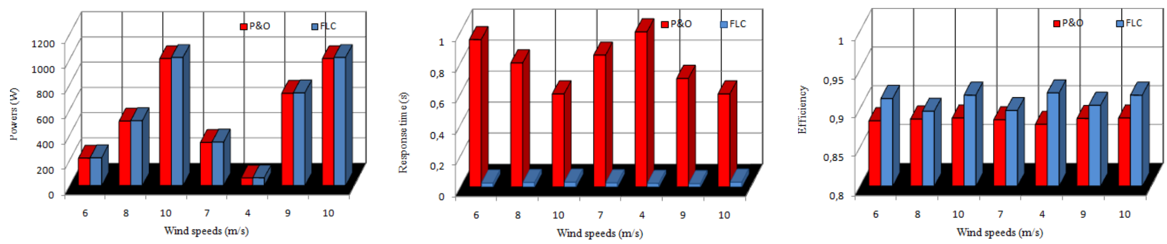
(a) (b) (c)

Figure 8. Obtained powers



(a) (b) (c)

Figure 9. Comparison performances for PV system



(a) (b) (c)

Figure 10. Comparison performances for wind turbine system

5.2. Power management control

The supervisory power approach is used to control the various powers. Our study is mainly based on previous works [11]-[14]. It is observed that the various sources have been effectively handled and that the batteries have experienced reduced stress Figure 11.

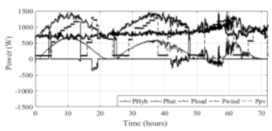


Figure 11. Different powers supplying the load using FLC strategy

6. ECONOMIC STUDY OF THE STUDIED SYSTEM

The Homer software [31] has been used to examine the system in order to prove the integration of the many sources at the Bejaia site. Figure 12 illustrates the hybrid system architecture. The load is of the residential AC type only. The daily energy use is 6.46 kWh, with a peak power consumption of 0.95 kW Figure 13. Table 1 shows the inputs of the various elements given to Homer pro.

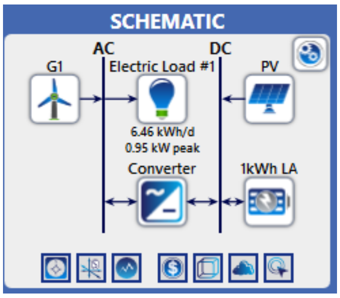


Figure 12. Configuration of the studied system

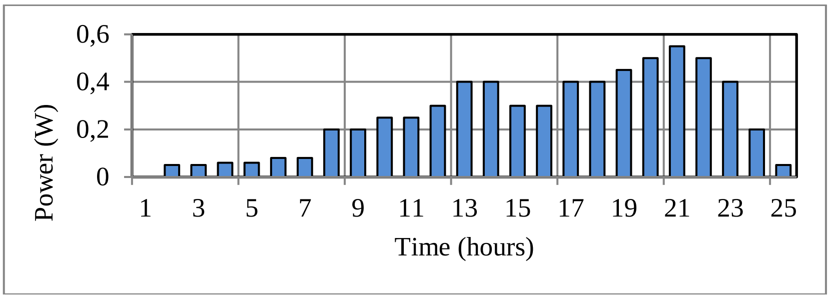
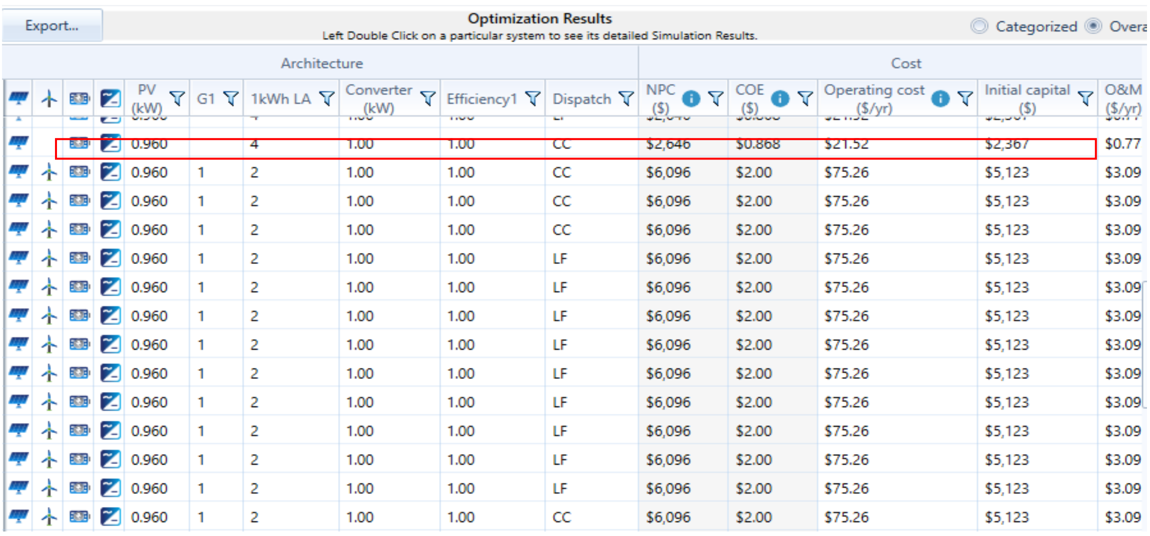


Figure 13. Hourly load profile by HOMER

Table 1. Different components inputs

Component	Capital cost ($)	O&M cost ($)	Replacement ($)	lifetime (years)
PV generator	143.83	10.00	143.83	25
Wind turbine	2876.68	30.00	1700.00	20
Batteries	60.37	0.00	60.37	10
Converter	400 .00	0.00	300.00	20

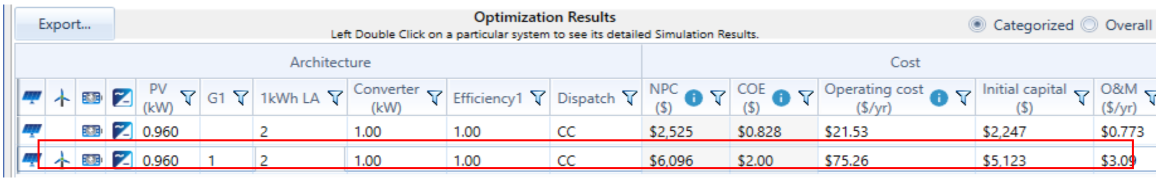
Some economic parameters have been considered. The cost of energy (COE) is an output variable that represents the price ($/kWh) of generated energy. The net present cost (NPC) is calculated by deducting the present value of all expenses from the present value of all earnings by the system over its lifespan. Figure 14 depicts the findings achieved after various simulations. The software proposed a better architecture in terms of cost, with NPC cost of $6096 Figure 15. The detailed operating costs is presented in Figure 16. Figure 17 shows the details of the system's annual electricity production and consumption. According to the findings, the photovoltaic installation has allowed us to cover 62.1% of a total of 6.46 kWh/year of the load need, while the wind source generates an important energy estimated at 1 kWh/year that covers the remaining 37.9% to satisfy the fully consumption and this during the whole year with a total of 2644 kWh/year as show in Table 2.



Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

PV (kW)	G1	1kWh LA	Converter (kW)	Efficiency1	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)
0.960		4	1.00	1.00	CC	$2,646	$0.868	$21.52	$2,367	$0.77
0.960	1	2	1.00	1.00	CC	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	CC	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	CC	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	LF	$6,096	$2.00	$75.26	$5,123	$3.09
0.960	1	2	1.00	1.00	CC	$6,096	$2.00	$75.26	$5,123	$3.09

Figure 14. Overall optimized result by HOMER



Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Export... | Categorized | Overall

Architecture						Cost				
PV (kW)	G1	1kWh LA	Converter (kW)	Efficiency1	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)
0.960		2	1.00	1.00	CC	$2,525	$0.828	$21.53	$2,247	$0.773
0.960	1	2	1.00	1.00	CC	$6,096	$2.00	$75.26	$5,123	$3.09

Figure 15. Proposed optimized architecture

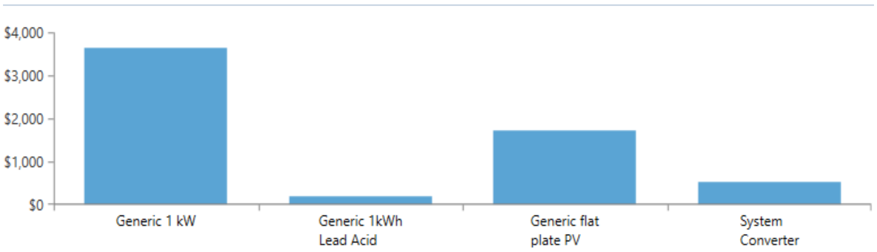


Figure 16. Categorized optimized result by HOMER

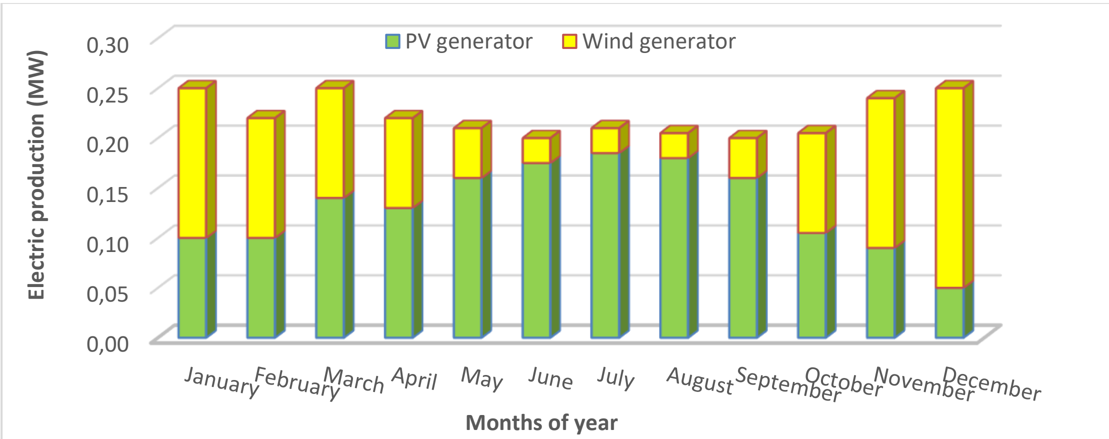


Figure 17. Monthly electric production from the system

Table 2. The fraction of photovoltaic/wind energy

Subsystem	Production (kWh/year)	Fraction (%)
PV array	1643	62.1
Wind turbine	1002	37.9
Total	2644	100

The consumption is 2360 kWh/year by the supplied AC load. The batteries store the extra energy generated by the two sources, as illustrated in Table 3. The photovoltaic and wind energy production can be represented in Figure 18. It is observed a low production from 0.26 kW to 0.46 kW, then it increases until it reaches 0.85 kW.

Table 3. Load energy consumption and excess electricity

Consumption	kWh/year	%
AC load	2360	100
Excess energy	284	12.03

The energy production is considerable by the wind turbine during winter and autumn seasons. It reaches the maximum value in January around 1 kW. The battery is an important component of this electrical system, it is used throughout the day, with its charge state ranging from 30% to 90% Figure 19.

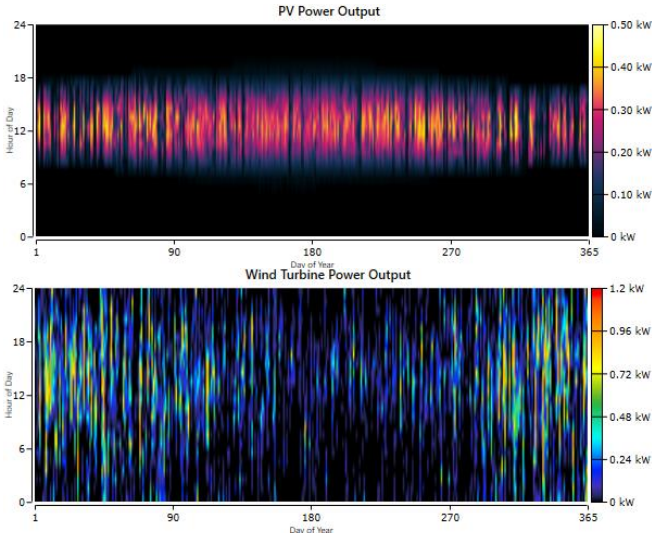


Figure 18. Distribution of photovoltaic and wind energy during a year

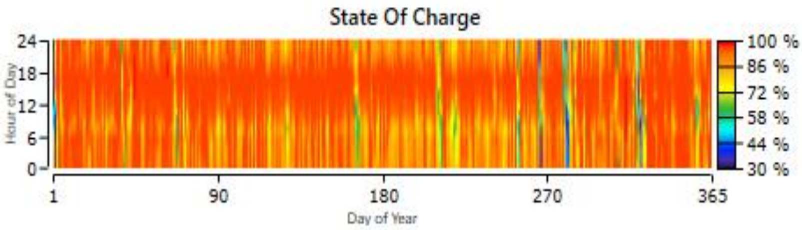


Figure 19. Battery state of charge during a year

7. CONCLUSION

The design, optimization, control, and feasibility of a solar system with a wind turbine with batteries are discussed in this study. An application has been made on three distinct days in the Bejaia area. Homer Po has presented the best solution based on calculations. Different findings have been compared and analyzed. It is noticed that the batteries have not been required too much due to correct sizing and gain saving in power by using FLC strategy and the power supervision method. Indeed, the gain in power allowed to change the priority of the tests of the proposed algorithm by using the batteries as much as possible and by charging them when it is possible with the power excess. It can be concluded that the different sources were managed in an optimal way in order to meet the load demand regardless weather variations. The findings are very promising and can be used to enhance PV/wind/battery installations' technological and economic efficiency in Bejaia area and around the Mediterranean region. In the future, it will be interesting to develop an application for water pumping in agriculture.

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