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Multi-Objective Optimal Control of Hybrid Energy System

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Abstract- This paper introduces a new method to configure renewable energy sources, using a smart technique selecting the best Hybrid Renewable Energy Systems (HRES), configuration and maximizing the output power as well as reducing the number of photovoltaic panels (PV), wind turbines (WT), and batteries. The demand profile is using the load steering based on the priority. Three types of loads have been considered: High priority load (HPL) that must be always supplied regardless of the meteorological condition of the site and the battery charge level, Medium priority load (MPL) supplied when the HPL is supplied and the battery is charged, and the Low priority load (LPL) feeds after the feeding of the MPL. The main objective of this methodology is to maximize the energy production, the reliability and minimize the environmental cost and the cost of the HES. This study is completed by a detailed economic method, studying the integrating feasibility of this method.

Keywords Hybrid system; smart grid; economic sizing; load priority; DPSP; energy management.

1. Introduction

The ever-increasing need of energy imposed the utilization of RES. Hybrid PV/WT/Battery storage (BS)/sector power systems are one important type of renewable energy power systems [1]. The integration of renewable energy sources with other energy sources and/or batteries presents a solution to satisfy the load demand.

1.1. Solar and wind

The renewable energy sources PV and WT are dependent on the climate, so the use of a back-up device is necessary. Therefore, the use of an individual source of renewable energy in the isolated site is unreliable [3], [4]. Moreover, wind system alone is unprofitable for some applications [5-8].

1.2. Solar, wind and battery storage

The hybrid system PV-WT with battery is very profitable for islands and remote areas compared to PV-battery, WT-battery, and PV-WT hybrid configurations [10], [11]. This has been verified with seven heuristic techniques optimization [12]. Other studies have shown that Photovoltaic, Wind and battery storage (PV-WT-BS) can satisfy the load demand in residential applications in rural and remote areas [9], [10], [13].

1.3. Solar, wind with other energy sources

In this association, the photovoltaic and the wind system are connected with other conventional energy sources and battery [30]. The use of battery is more cost-effective than totally relying on Diesel generator (DG) [14]. Therefore, the Photovoltaic, Wind, Diesel generator and battery storage HES is common in standalone applications [15]. Some studies proposed other combinations such as Photovoltaic, Wind turbine, Diesel generator, Fuel cell, Biomass and Hydrogen tank [16], [18] , Photovoltaic, Wind turbine, Diesel generator -hydro generator and battery [16], [17], Photovoltaic, Wind turbine, Diesel generator, Fuel cell, bio-diesel and battery [19]. Different techniques of optimization have been reported in the literature [2][32][34] such as dynamic programming [20], multi objective [21], graphical engineering [22], linear programming [23][33], metaheuristic method [24][25][31], probabilistic approach [26].

In this work, a smart method is introduced to select the best HRES and maximize power as well as reducing the total cost of this HRES. This method uses a class of hierarchical loads to get a smart consummation protocol ensuring highest reliability.

2. Sizing formulation

2.1. The photovoltaic panel energy model

The output power of PV model can be estimated considering the solar radiation, the area and the efficiency of the PV model [1]. The output power of the photovoltaic panel is calculated as follows:

$$P_{pv} = A_{pv}.I_r.\eta_{pv} \qquad (1)$$

Where A_{pv} is the area of panel (m2), I_r is the solar radiation on tilted surface (kW/ m2), and η_{pv} is the efficiency of PV model.

2.2. Wind energy subsystem model

The power of the wind turbine depends on the speed of the site; the equation 2 shows the output power of the turbine [27]:

$$P_{wg} = \begin{cases} 0 \ ; \ w_s(t) \le w_{cut-i} \text{ or } w_s(t) \ge w_{cut-o} \\ P_{r-WG}.\dfrac{w_s(t) - w_{cut-i}}{w_r - w_{cut-i}} \ ; \ w_{cut-i} < w_s(t) < w_r \\ P_{r-WG} \ ; \ w_r < w_s(t) < w_{cut-o} \end{cases} \qquad (2)$$

Where w_s is the wind speed (m/s), P_{r-WG} is the rated power of the wind turbine (Kw), w_{cut-i}, w_{cut-o} and w_r are respectively cut-in, cut-out, and rated speed of the wind generator (m/s).

2.3. Model of battery

Depending on PV, wind and load power demand, the state of charge (SOC) can be estimated by [28]:

Battery charging,

$$SOC(t) = SOC(t-1).(1-\mu) - \left[\frac{E_{HPL}(t)}{\eta_{inv}} - E_g(t)\right] \times \eta_{BC} \qquad (3)$$

Battery discharging,

$$SOC(t) = SOC(t-1).(1-\mu) - \left[\frac{E_{HPL}(t)}{\eta_{inv}} - E_g(t)\right] \qquad (4)$$

Where SOC(t) and SOC(t - 1) are respectively the states of charge of battery at the time t and t-1; μ is the rate of self-discharge; $E_g(t)$ is the energy generated by the HES; $E_L(t)$ is the power of the high priority load; η_{inv} and η_{BC} are respectively the efficiency of the inverter and the battery.

2.4. Deficiency of power supply probability

The deficiency of power supply probability (DPSP) is an important parameter in the design of the hybrid system. The DPSP is expressed as follows:

$$DPSP = \frac{\sum_{t=1}^{T}[P_L(t) - P_{wg}(t) - P_{pv}(t) - P_b(t)]}{\sum_{t=1}^{T} P_L(t)} \qquad (5)$$

Where, $P_b(t)$ is the power of battery and $P_L(t)$ is the power of the load.

2.5. Economic index

In this study, the life cycle cost (LCC) is calculated as follows [29]:

$$f_{LCC} = C_{pur} + C_{mai} + C_{rep} \qquad (6)$$

$$C_{pur} = C_{wt_p} \times N_{wt} + C_{pv_p} \times N_{pv} + C_{bp}N_b \qquad (7)$$

$$C_{mai} = C_{wt_m} \times N_{wt} \times T_{wt} + C_{pv_m} \times N_{pv} \times T_{pv} + C_{bm} \times N_b \times T_b \qquad (8)$$

$$C_{rep} = C_{wt_r} \times N_{wt} + C_{pv_r} \times N_{pr} + C_{br} \times N_{br} \qquad (9)$$

Where C_{wt_p}, C_{pv_p}, C_{bp} represent respectively the purchase cost of WT, PV and battery. C_{wt_m}, C_{pv_m}, C_{bm} represent the maintenance cost of WT, PV and batteries respectively. N_{wt}, N_{pv}, N_b represent the number of WT, PV and batteries respectively. T_{wt}, T_{pv}, T_b represent the life of WT, PV and battery. C_{wt_r}, C_{pv_r}, C_{br} represent the replacement cost of wind turbine, PV and battery.

3. The proposed methodology

The proposed method has been used to determine the optimal size of the HES components, it is based on the shifting of WT, PV and battery to meet the energy need with the lowest cost and the loss. This method has been divided into two phases: the control and the optimization algorithm for the hybrid energy system. The first step is the control of the energy balance of the hybrid system and it's summarized as follows:

If the power of the HES is greater than the PHPL, the battery will be charged. If the SOC get the SOC_{Max} the surplus of power will be fed the Medium priority load, then the surplus of power above the MPL needs will be used to feed the low priority loads. The unmet MPL and LPL will be reported to the moment of excess power generation.

The other step present a multi-objective optimization, the first maximize reliability of the hybrid energy system, the second minimize the HES cost and the third objective minimize the unmet MPL. This methodology has been simulated in MATLAB. The flowchart shown in the fig 1 illustrates the logic used in the proposed methodology:

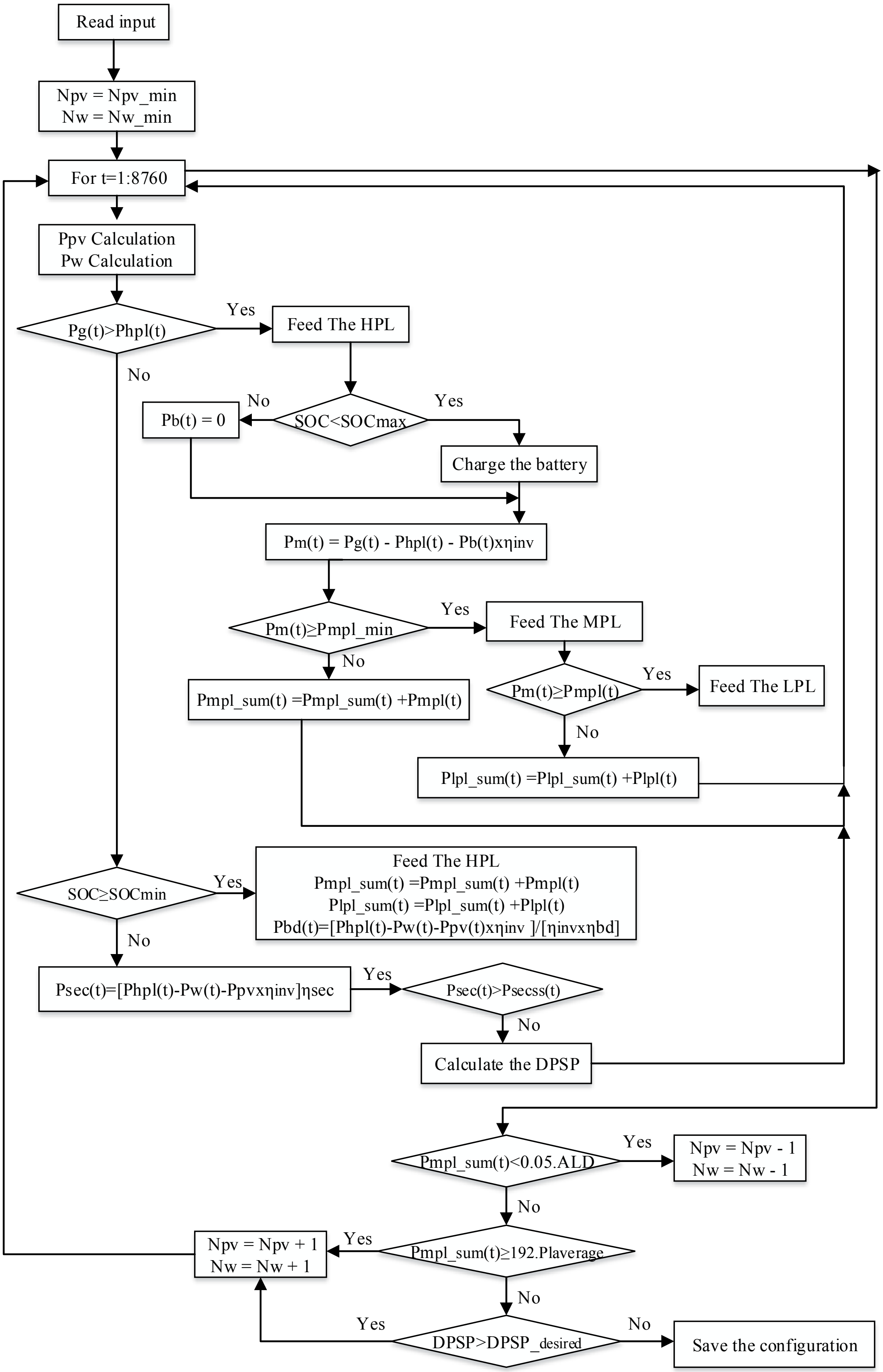


Fig 1. The organigram of the logic used in the program.

This method has been applied to optimize and analyse the size of a HES composed of PV/WT/Sector/ Battery in order to supply the residential households. The site selected for this study is named “GUEZNAIA” and located near Tangier (35°46′02″, 5°47′59″E). The load to be supplied with the hybrid system is anticipated as 25 KW. The characteristics of the HES component are listed in Table 1, the lifetime of the system has been chosen to be 30 years.

Table 1. The technical characteristics of the hybrid system

	Capital cost ($)	Replacement cost	Operation and maintenance cost	Life time (Years)	Number of replacement
PV	3090	3090	14	30	0
WIND	3000	3000	10	20	1
BATTERY	228	228	20	5	6

The simulations were executed by using hourly values of solar radiation, wind speed and temperature during the year 2017. The hourly solar radiation vary between 0 and 1054 W/m2 (Fig 2), the hourly wind speed vary between 0 and 13.2 m/s (Fig 3), and the temperature between 2.3 and 48.8 °C (Fig 4).

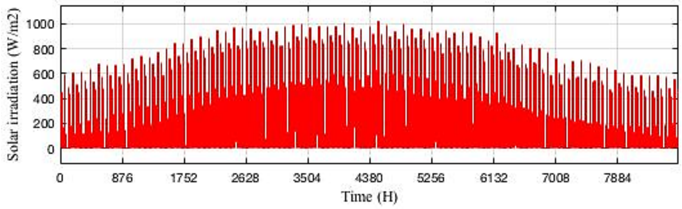


Fig 2. The site’s hourly solar irradiation.

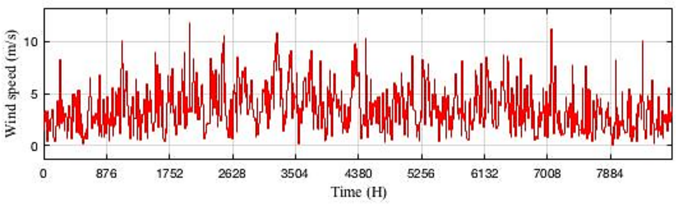


Fig 3. The site’s hourly wind speed.

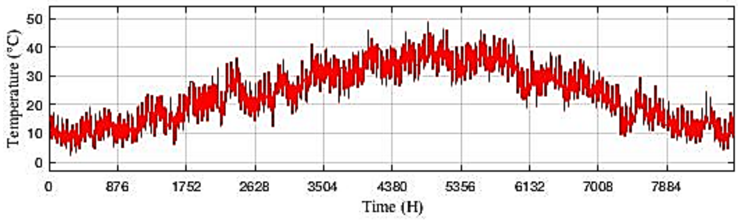


Fig 4. The site’s hourly temperature.

Real data of load’s power used in this project is equal to 25 KW; these loads have been divided into three categories: HPL, MPL, and LPL; the first type has been considered to be 70% of the total load, the second has been considered to be 20% and the last has been considered to be 10% loads. Fig 5 shows the values of the load profile.

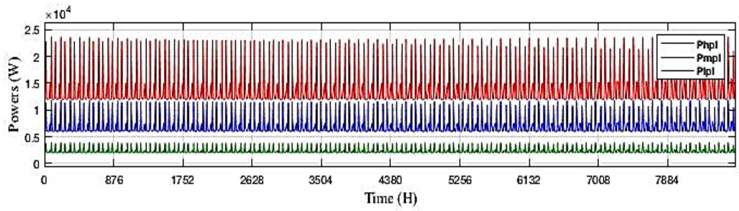
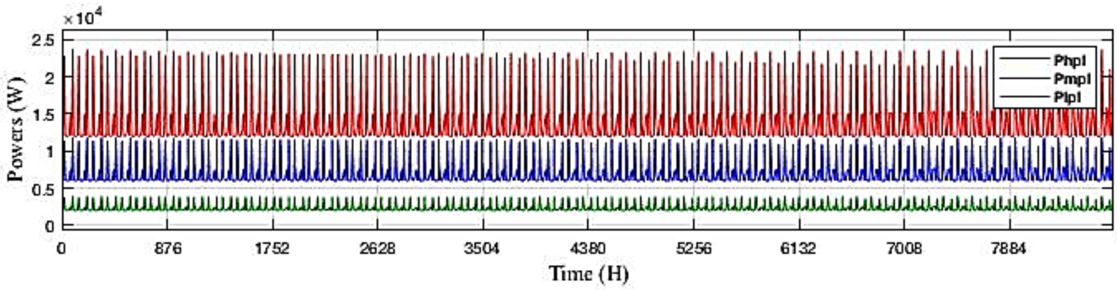
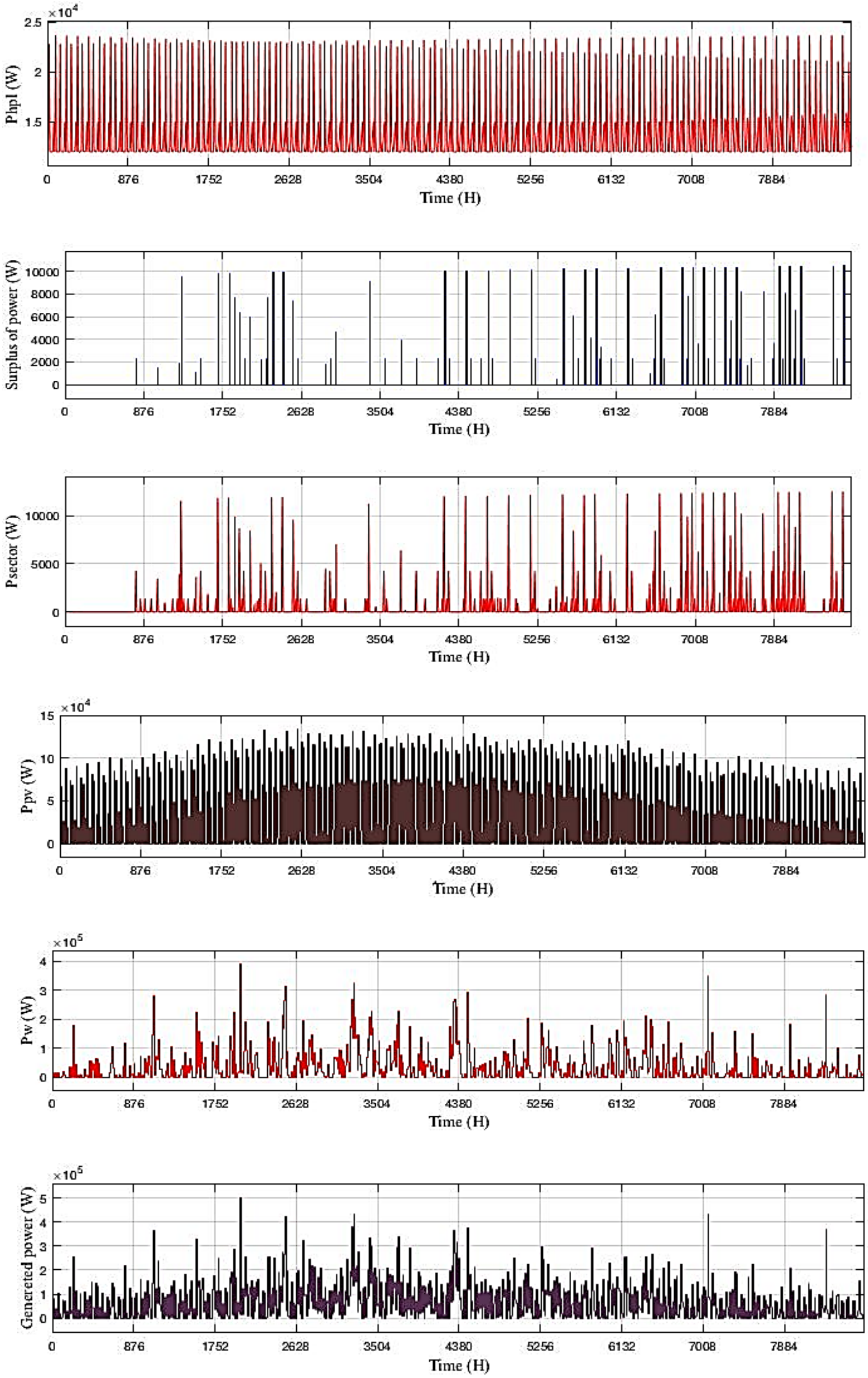


Fig 5. The load profile of the residential households.

This method determines the optimum sizes of the HES to satisfy the load demand of the residential household, based on the accumulated value of the unmet MPL (P_{mplsum}) and LPL (P_{lplsum}), the total dummy energy (E_{dummy}), DPSP and the minimum value of cost. For each hour, the program compares the HPL with the power generated by the system, then it decides the manner of charging and discharging batteries. Figure 6 shows the load’s hourly variation, the power of the high priority load demand, surplus of energy, power of: electric sector, solar panels, winds, hybrid system and battery, the accumulated unmet value of the MPL and LPL. As shown in the Figure 6, the HPL is always powered during the year. The principal objective of this methodology is to power the MPL and the LPL during the year, as presented in this figure the MPL and LPL feed efficiently during the year. In addition, the surplus of energy is negligible during the year as shown in Figure 7, where the power of sector is negligible than the power of the battery accumulator. By using the proposed methodology, we find that the optimal system’s cost is $ 26000, whereas the system’s cost without this methodology is $ 37 000. If the percentage of the High Priority Load is less, the cost of the system is less also.




Phpl (W)
Time (H)
Surplus of power (W)
Time (H)
Psector (W)
Time (H)
Ppv (W)
Time (H)
Pw (W)
Time (H)
Genereted power (W)
Time (H)

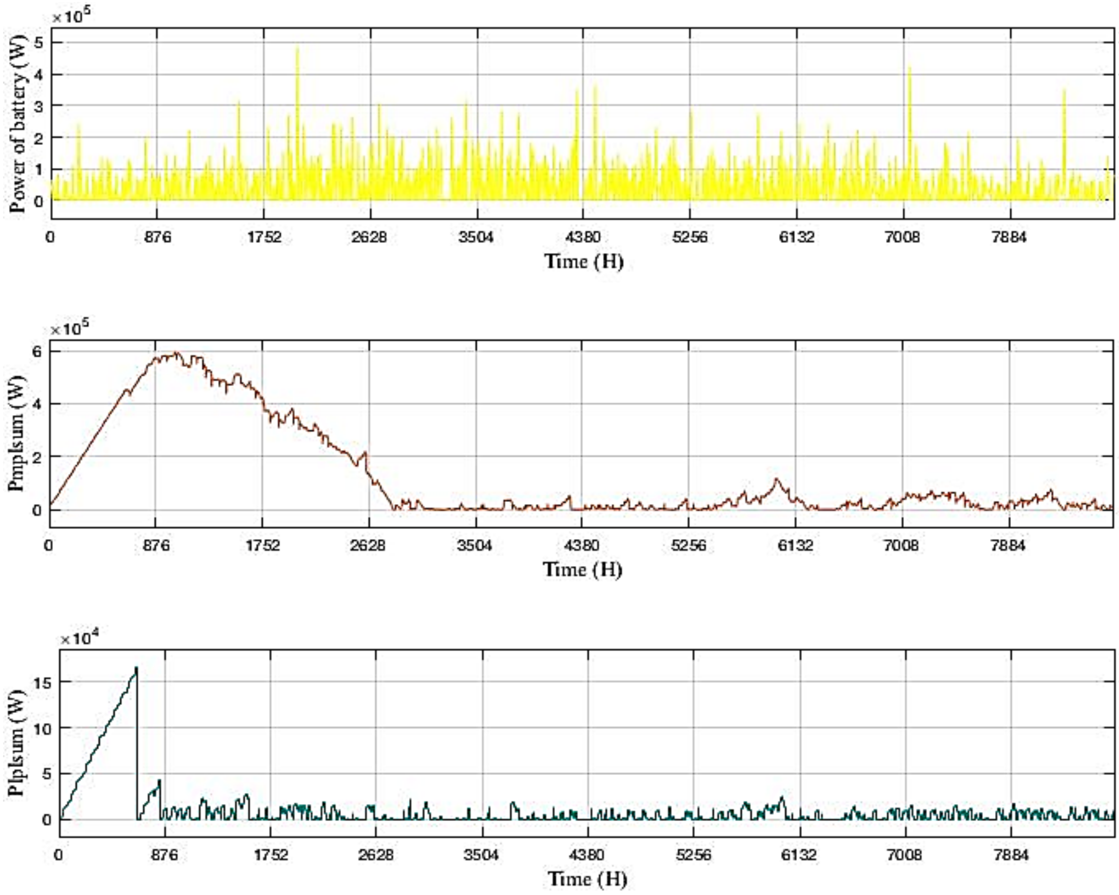


Fig 6. Performance of the hybrid system components through the year.

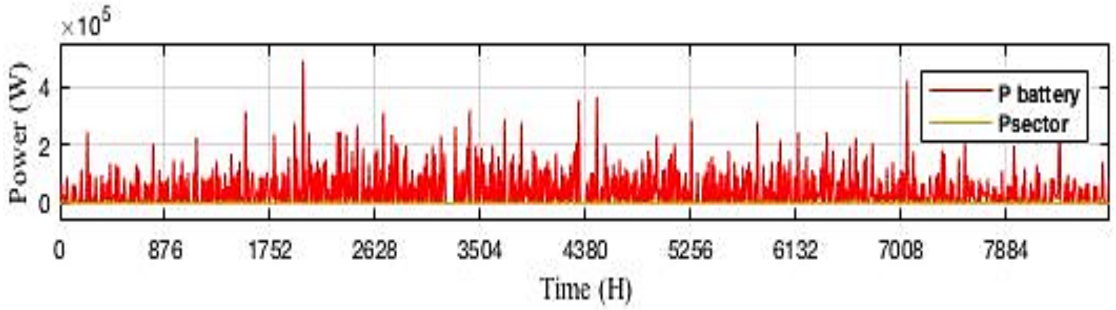


Fig 7. Power of battery and sector.

Conclusion

This paper has presented a technic to design and optimize the component number of PV, WT and Battery, connected to the electric sector. This method of optimization is based on dividing the loads into high, medium and low priorities. HPL must be always supplied with the energy generated by the HES or by the sector. The MPL will only be powered if the energy generated by the HES is greater than the power of the HPL and the state of charge is greater than the maximum of charge's state, and LPL will be energized if the medium priority load is powered. The methodology presented takes the power of the P_{mplsum}, P_{lplsum}, E_{dummy}, DPSP and the minimum value of cost to optimize the size of the HES. The lifetime of the project is considered 30 years. This method has been programmed with MATLAB. The results of simulation confirmed that dividing the loads into high priority load, medium priority load and low priority load optimize the size of the hybrid system and reduce the price of Kwh of energy.

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